Volume 1

ISBN 978-969-2201-10-0

ZOONOSIS

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ZOONOSIS

Volume 1

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ZOONOSIS (VOLUME 1) ISBN: 978-969-2201-10-0

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The Publisher

Book Specifications:

Total Chapters: 48

Total Pages: 669

Page Size: A4 (210mm × 297mm)

Book Weblink: https://uniquescientificpublishers.com/zoonosis-volume-1

Publisher: Unique Scientific Publishers (https://uniquescientificpublishers.com)

Editors: Ahrar Khan, Majeeda Rasheed and Rao Zahid Abbas

Editorial Assistants: Muhammad Adnan Sabir Mughal, Muhammad Ahmad, Munazza Aslam, Rida Asrar, Saba Mehnaz, Tayyaba Akhtar, Warda Qamar and Zohaib Saeed

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Published: December 31, 2023 Printed in Pakistan

PREFACE

The well-being of humans and animals is pretty much interdependent. It's impossible to ensure human health, without considering animal health and vice versa.

The need to enhance the collaboration between animal health workers and medical professionals, researchers and academicians has moved the editors to develop this publication. The book takes into account the major threats of animal and human health. This book provides the core concepts of Zoonosis with a critical focus on the key challenges and their effective management. The objective is to cover epidemiological interactions of various infectious diseases and their ecological implications as an emerging threat.

It is anticipated that this book would be of great use to a variety of readers. University students, graduates, practitioners, animal healthcare providers and health professionals would definitely find this book of great importance. The language of book has been intentionally kept easier for a non-technical person to grasp the concepts on interdependence of animal and human health. The editors wish to publish a series on the subject keeping in view the urgency to highlight these areas for awareness, research and development.

Editors

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VOLUME 1

A Didactic Approach to the Teaching-Learning of Zoonoses in Veterinary Public Health

01

José Antonio Romero López[1], José Juan Martínez Maya[1], Ada Nelly Martínez Villalobos[1] and Guadalupe Núñez Martínez[2]*

ABSTRACT

A relevant topic in medicine, essential for the training of professionals in the medical field, is public health. And under the context of One Health, the concept of zoonosis is particularly important. Thus, its approach must be based on a distinctive didactic, with a constructivist approach, which allows the student to comprehensively develop cognitive skills needed to reason about any situation in the environment, and to find solutions to needs and problems in it. It is imperative to apply student-centered educational strategies, without an excessive use of technology and always based on pedagogical principles. Therefore, it is essential to apply learning theories that guide these processes, such as the Theory of Meaningful Learning, based on the link between the student's previous and new knowledge; Connectivism, which considers elements for building learning and knowledge in technology-mediated environments; and Constructionism, which highlights the value of ICTs as mental construction tools that empower students and give them a leading and active role, providing them with the necessary resources, including tools such as ICTs. This should be supported by available resources such as repositories, books, videos, and blogs, as well as official or educational institution websites with related topics on education and communication platforms, which have grown in number in the wake of the pandemic and revolutionized the way such important topics as zoonoses are taught.

Keywords: Meaningful learning theory; Connectivism; Constructivism.

CITATION

López JAR, Maya JJM, Villalobos ANM and Martínez GN, 2023. A didactic approach to the teaching-learning of zoonoses in veterinary public health. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 1-9. https://doi.org/10.47278/book.zoon/2023.001

CHAPTER HISTORY Received: 08-April-2023 Revised: 28-May-2023 Accepted: 19-Aug-2023

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1. INTRODUCTION

1.1. PEDAGOGICAL MODELS: CONSTRUCTIVISM, CONNECTIVISM, AND CONSTRUCTIONISM

Teacher-centered teaching-learning methodologies have historically prevailed in all academic levels in the Mexican educational system. In these methodologies, the student is a passive entity, and his/her role is limited to the memorization and mechanical repetition of the information given by the teacher. In this model, priority is given to the contents to be "graded," without considering the needs and desires of the learner. According to Ayala et al. (2013), it is urgent to develop critical thinking skills that enable the learner to "propose solutions, the ability to solve new problems, the competence to obtain and evaluate sources of information". In this sense, it should be emphasized that the teacher is responsible for establishing a pedagogical relationship that encourages students to learn, that awakens their desire to know" (Barrón 2009).

Thus, teachers' work requires continuous reflection, analysis, and evaluation of their praxis, seeking to evolve in the opposite direction to its current situation; that is, to guide students within paradigms that allow them to be especially active learners, where emphasis is placed on understanding rather than memorization, and knowledge is built from experience. This reasoning calls for adjustments in the pedagogical and didactic models and in the teaching-learning processes, incorporating pedagogical theories, Information and Communication Technologies (ICT), and strengthening teacher training in ICT. It is considered "possible and perhaps necessary to hybridize face-to-face and non-face-to-face education" (Buendía 2020).

Higher education in particular should be supported by a distinctive didactic, which enables students to learn "with previous knowledge and experiences, motivations and diverse expectations regarding their personal project" (Moreno 2011). Authors such as Gutiérrez and Rada (2012) deem it viable to apply a constructivist approach, because the chronological age of university students allows the comprehensive development of cognitive faculties, which will be useful to reason about any situation arising from the environment, finding solutions to its needs and problems.

In this context, it is crucial to implement student-centered educational strategies, avoiding an excessive use of technology that is not based on pedagogical principles. This, according to Camacho and Alias (2019), implies modifying the role of the teacher, from a transmitter figure to a mediator of learning processes.

The not-so-new scenarios brought about by ICT-mediated learning environments must face several challenges, among which the following stand out: limited funding and budget for institutions, access of the user population to ICTs, inclusion of different population sectors in education, as well as the elaboration and development of content on an ad hoc basis, It is, therefore, essential not to lose sight of the pedagogy-ICT binomial, which has historically prevailed and will allow, on the one hand, the use and innovation of technology and, on the other hand, provide a basis for educational processes and bring them closer to different sectors of the population (Freixas 2015).

Given this scenario, it is essential to make use of learning theories to guide the teaching-learning processes and to support the direction and management of the educational act. It is essential for the student to develop adequate strategies aimed at meaningful learning, which will allow him/her to increase his/her metacognitive competences through a useful and critical knowledge. Particularly in the field of zoonoses, the professional in Veterinary Medicine (or in any health area) should not only fully understand the pathological interaction between animals and humans, either directly or indirectly, through the consumption of by-products, especially food, but should also interpret, evaluate, contrast, and even combine different criteria to classify zoonoses and, based on this, argue and, if appropriate, apply pertinent prevention, control, and eradication measures. This would enable the student to acquire, deploy, and apply the necessary competences for a better adaptation to a ever-changing context, in which public health, animal health, and environmental health interact.

1.2. THEORY OF MEANINGFUL LEARNING

A pillar of modern constructivism, proposed by David P. Ausubel and authors such as Joseph Novak and Helen Hanesian, the Theory of Meaningful Knowledge is based on the work of Vygotsky (Yepez 2011). This theory involves linking new knowledge with the student's previous knowledge, which requires the student to have a cognitive scaffolding based on skills, concepts, and experiences. According to Romero (2013), it is essential that the knowledge makes sense to the student, so the teacher must implement didactic strategies to show the information and contents in a congruent manner, incorporating and connecting the integrating concepts, thus facilitating their transfer and retention. Román and Diez (2000), cited by Osses and Jaramillo (2008), point out that, in meaningful learning, an individual assumes a favorable attitude that allows him/her to construct their own knowledge and gives it meaning based on the conceptual structure he/she already possesses. All this implies that the achievement of meaningful learning will depend on the fact that the proposed contents and materials are potentially significant and can be “anchored” in previous knowledge.

1.3. CONNECTIVISM

Developed by George Siemens, among its principles, Connectivism includes elements to construct learning and knowledge that occur in technology-mediated environments, and this construction has a strong implication in the design and management of such learning environments. This is consistent with what Garduño (2020) has expressed, arguing that learning processes in environments favored by technology face the challenge of giving meaning to the constructions, relationships, and patterns of information generated by both the teacher and the learner. Additionally, the theory establishes that teachers and students connect with each other to constitute “learning networks and communities, and these connections are generated through mixed environments, as well as the management of techno-pedagogical environments”.

1.4. CONSTRUCTIONISM

A final paradigm of support for this section is Seymour Papert’s Theory of Constructionism, which proposes that learning is constructed when the learner himself solves problems using previous knowledge as a tool for the foundation of new knowledge. And for this process to be effective, both the construction and the final product must be shared and explained (Papert 1982). Constructionism also highlights the value of ICT as “powerful tools for mental construction, for the development of complex thinking in students” (Vicario 2009), which empowers students and assigns them a leading and active role, making the necessary resources available to them, including tools like ICT.

The approaches described above make constructivism an ideal starting point for the teaching-learning processes, where the guiding and mediating function will be assumed by the teacher, working with the underlying elements of cooperative work of the learners.

2. INFORMATION AND COMMUNICATION TECHNOLOGIES (ICTS) AND THEIR APPLICATION IN DISTANCE LEARNING AND IN HYBRID MODELS

A major problem that health professionals face when trying to communicate their knowledge is a lack of pedagogical tools that allow them not only to convey information, but also to engage learners in the generation of their own knowledge. To achieve this, the health professional must have instruments in line with technological advances that allow him/her to propose new ideas.

According to Calandra et al. (2009), the practice of recording ideas to be consulted by others dates back to prehistoric times; perhaps the oldest examples could be found in cave paintings, the earliest evidence of Information and Communication Technologies (ICTs). In this need to transmit knowledge, many different supports have been used, such as constructions themselves with engravings, ideograms, and pictograms, or on portable or storable materials such as papyrus, parchment, or clay tablets.

Paper was a great invention, and its use spread throughout the world due to its ease of manufacture and practicality. The invention of the printing press allowed the systematic reproduction of documents, which made it possible to carry information to different places at the same time (Calandra et al. 2009).

Technological progress continued in the modern era, from the invention of the telegraph for sending short and punctual messages, with a very limited use in education. Subsequently, radio and television emerged, mass media for transmitting messages to a large population, which favored their massification and worldwide dissemination, especially after the design and launching of artificial satellites (Calandra et al. 2009). The first transmission was made on May 3, 1965, and worldwide on June 25, 1967, that is, just 56 years ago. Since then, the advance of ICTs has been impressive, particularly with the progress and massification of personal computers and the Internet, thanks to which we can now speak of an information society (IS).

ISs are groups of people characterized by communicating by means of digital media optimized to produce, store, and disseminate information. This paradigm has modified interpersonal relationships, production, education, and entertainment systems (Crovi 2002; Crovi 2005).

Any physical or virtual medium that stores data and codes in a transportable form and allows communication between human beings can be considered an ICT (Calandra 2009). Both concepts are relevant in higher education, and obviously in the subject of zoonoses, because integrating ICTs should be an additional resource for learning with an innovative approach, to implement Learning and Knowledge Technologies (LKTs) as a didactic means for learning and knowledge appropriation. This will make it possible to learn effectively through dynamics and practices supported by digital technology and will provide health professionals with a panorama that stimulates and promotes their ability to restructure reality and deliver innovative solutions to multiple problems (Valarezo and Santos 2019).

ICTs have enabled the development of social networks; groups with common interests are formed in these networks, which use them to keep abreast of new aspects or update information, taking an active stance to promote changes in their goals or paradigms. Thus, these platforms make it possible to address issues of common interest such as zoonoses or other public health aspects; this is known as Technologies for Empowerment and Participation (TEPs) (Valarezo and Santos 2019).

LKTs and TEPs should be integrated into innovative education approaches because they are not limited to a physical space, but it can be received anywhere (Valarezo and Santos 2019, Zambrano and Balladares 2017). The current technological development allows the dissemination of contents by using various educational resources in a individualized way, either through face-to-face, online, or distance learning. According to García (1999), distance learning is a reality that can offer good results thanks to the "evolution" of the means through which knowledge is transmitted. This began as a printed and unidirectional medium and evolved into teaching by correspondence, with greater interaction and a more creative use of the didactic materials available. The use of television programs in remote access areas was very common, and distance learning is now in an audiovisual stage, supported by information technology.

The COVID-19 pandemic forced many institutions to implement distance learning as a more flexible way of carrying out educational processes without the need to crowd people in closed spaces. Its great advantage is that it is supported by methodological and technological strategies that make possible to deliver content without the need to coincide in time and space, thus facilitating learning, while the educator remains present to address doubts and questions, either in real time or asynchronously. As a possible drawback, although this modality innovates positively with respect to the traditional models of knowledge sharing and learning, the learner must show greater independence and self-regulation, which does not always happen, as there is no prior training for it. In short, a great advantage is that a communication network can be established, in which everyone involved in the educational act enters into contact with the appropriate sector, from wherever and in an almost immediate and agile manner (Juca 2016).

To achieve this, it is necessary to implement "virtual campuses," spaces that offer the tools, services, and resources needed to work online. These resources include virtual classes, webinars, manuals and tutorials, digital library, and exercise sessions.

In short, education can and should change with the rise of ICTs, since the virtual environment becomes a bridge that connects with new educational approaches, to make information sharing better and more efficient. This makes it possible to raise a didactic proposal where the educator facilitates access to knowledge, and whoever receives the information can self-regulate their learning and develop academic skills (Juca 2016).

Not everything has to be black and white, and thus one option is to implement education in a hybrid model, combining elements of face-to-face and non-face-to-face education. It is possible to carry it out remotely and at different times (asynchronous), controlling the pace of the activities, in addition to carrying out face-to-face activities at the same time and space, with the support of the educator (synchronous). In this model, face-to-face and distance learning tools are used as required. For the results to be satisfactory, distance and face-to-face activities must be related to each other, thus reinforcing learning. Technology places learners at the center of the process.

It can be concluded that the hybrid model is a window that has expanded the space and time for learning, promoting cooperation and improving efficiency in the acquisition of knowledge, since it encourages active and meaningful learning. This model could be applied in courses or workshops with varied subjects, where a face-to-face event could receive distance support, with activities and reference materials for later review and analysis, or even feedback from the attendees to the rest of the group. Therefore, its application requires the participation of a teacher, who must be a good communicator and motivator, as well as a dynamic pedagogical designer, in order to incorporate ICTs appropriately.

3. ZOONOSES AND THEIR PROGRAMMATIC CONTENT IN VETERINARY EDUCATION

3.1. SELF-EDUCATION IS, I FIRMLY BELIEVE, THE ONLY KIND OF EDUCATION THERE IS. —I. ASIMOV

In general, the objectives of studying zoonoses in veterinary education are to analyze their global status by identifying the main risk factors, to discuss national and international morbidity statistics, and to understand international guidelines and standards. The teaching of zoonoses in the veterinary medicine and zootechnics program varies greatly: in some institutions it is dealt with in the last semesters, and the number of hours devoted to it can also vary from 1 to 4.

Zoonoses are not only discussed with an epidemiological approach but also those related to the host and the environment. Since epidemiology is the basis of preventive and social medicine, the student must be aware of the role he/she will play as a health professional. It is important that the integrative approach to include zoonoses that the bases of pathology, clinical medicine, statistics, microbiology, administration, planning, and other sciences. Therefore, the student must understand that the study of zoonoses is not a separate science, without practical application, but encompasses all diseases, communicable or not.

Understanding this can be easier if specific tools based on LKTs are available. To this end, we would like to propose some resources on the subject that can be applied, considering what we discussed above.

3.1. WEB RESOURCES ON ZOONOSES

3.1.1. BLOGS ON ZOONOSIS

According to Montilla (2015), this type of resources brings great benefits in the teaching and learning process. Among such benefits, the following stand out:

- They promote collaborative and autonomous learning.
- They favor a continuous evaluation and self-evaluation of the training and learning process.
- They provide evidence of student progress and feedback on the learning process.
- They allow the teacher to implement attractive and innovative methodological approaches.
- They develop literacy and communication skills.
- They facilitate access, assimilation, apprehension, and construction of knowledge.
- They are a suitable means of coordinating networked research projects, as they allow documentation to be organized.

An example of a blog on zoonosis can be found at the following link:
http://www.blogsanidadanimal.com/tag/zoonosis/

3.2. DISCUSSION FORUMS ON ZOONOSES

This type of tool can be very valuable in the debate and resolution of cases in the fields of epidemiology and preventive medicine, since they are spaces that allow the generation of reasoning around assertions (Veerman et al. 2000). In addition, they enable an equitable participation of students, while encouraging the analysis of different positions regarding a fact or a situation to resolve differences of opinion arising from a questioning.
The main characteristics of a virtual discussion forum are the following:

- Members can express themselves freely, which encourages plural and diverse participation.
- They allow recording, organizing, and labeling of contributions.
- They are informal spaces, but they are managed by a mediator.
- The subject is clear from the outset.
- They are asynchronous, which allows to rethink ideas without immediate pressure.
- They can be accessed at any time.

An example of a discussion forum on zoonoses where different institutions participate can be the following Instituto de Investigaciones Juridicas UNAM
Discussion forums, whether synchronous or asynchronous, are valuable resources that involve the application of different stages of critical thinking, from the construction and production of information, a continuous feedback between students and specialists in zoonosis, the resolution of doubts, and the application of exercises or practical problems that promote a proactive attitude in the participants for their analysis, resolution and argumentation, ultimately favoring the generation of knowledge.

3.3. WEBSITES WITH OFFICIAL INFORMATION ON ZOONOSES

The official national websites of each country, as well as some supranational ones (WHO/PAHO, OIRSA), provide updated information on different aspects of zoonoses. The teacher can obtain real-time information on the zoosanitary or public health situation.

3.3.1. WORLD ORGANIZATION FOR ANIMAL HEALTH (WHOA)

Formerly the Office International des Epizooties, is an organization whose mission is to ensure transparency of the animal health situation in the world. Thus, it provides up-to-date information on animal health and welfare (OIE, 2022). On its page one can find scientific information in the veterinary field, consult standards and various related publications. On the same page there is a link to the World Animal Health Information System (OIE-WAHIS). The page can be consulted at the following link: https://www.woah.org/en/home/

3.3.2. INTER-AMERICAN INSTITUTE FOR COOPERATION ON AGRICULTURE (IICA)

The site provides regional agricultural information, particularly on North and Central America and the Antilles. IICA consists of 34 member States and, according to its page, its mission is to "Stimulate, promote and support the efforts of the Member States to achieve their agricultural development and rural well-being through international technical cooperation of excellence" (IICA, 2018). The page shows the rural regions of interest and the changes they present over time, including any diseases that occur. In general, the site shows us the organization's work to prevent future diseases and report current ones: https://www.iica.int/es

3.3.3. CENTER FOR DISEASE CONTROL (CDC)

This U.S. institution provides information on human diseases and zoonoses and bioterrorism, among many other relevant topics. https://www.cdc.gov. Having resources where students can access updated information on zoonoses promotes the interpretation, analysis, evaluation and inference of such information, an essential skill in research. Therefore, the teacher-student binomial should have tools such as web pages with official information on important aspects of the subject, such as the description of zoonotic diseases of interest, for a better understanding of them, as well as quantitative data to evaluate their presentation and practice decision making.

4. THE CHALLENGES OF RAISING AWARENESS OF ZOONOSES IN A RURAL SETTING

Most zoonotic diseases are little known in the general population, who are usually unaware of their transmission mechanisms and their effects on humans and animals. This is a matter of concern especially in rural areas, where the risk of transmission of many zoonoses increases due mainly to poor personal hygiene caused by lack of services such as drinking water, lack of latrines or drainage, as well as certain habits, such as walking barefoot (particularly in children) and keeping a close contact with dogs, cats, or other pet species without deworming or vaccination, among other factors (Flores 2010).

Additional risk factors that contribute to the incidence and prevalence of these diseases have been reported in rural Mexico. These include environmental alterations, such as the clearing or burning of forests, with the consequent effect on ecological degradation; the movement of domestic animals and keeping wild animals as pets; settlements in jungle areas with the construction of houses with materials that favor the reproduction or habitat of vectors that can transmit diseases to humans; and the use of pesticides to eliminate these vectors, which favors their resistance (Margeli and Zulay 2020).

For this reason, it is essential that public health institutions responsible for the study and dissemination of information on these diseases adopt a comprehensive approach, considering the mechanisms of transmission, signs, and symptoms, as well as prevention and control measures. Nowadays there are many electronic means of information: academic sites and repositories, social networks, video transmission channels (such as Zoom, Skype and WebEx Meeting), in addition to the tools already mentioned (blogs, collaborative wikis, videos, podcasts, applications, and discussion forums). While it becomes difficult to use them in a rural environment, there is increasing access to them (Sánchez and Pinochet 2017), so it is important not to dismiss them.

It should also be considered that the economic conditions of the rural population often make it impossible to apply the information provided by the media or health professionals, either because of a lack of resources for its application or because people have other priorities, and animals tend to be put on the back burner. It has been reported that there is little interest among rural dwellers in informative meetings at health centers. However, health education for rural and urban populations should continue to be encouraged because of ongoing changes that alter the dynamics of both environments, including higher birth rates in rural areas, environmental conditions altered by climate change, growth of the global economy, industrialization, and increased interaction between people and animals, both for marketing and companionship purposes (Margeli and Zulay 2020).

It is essential to continue with the implementation of training plans and programs targeted at health personnel, with a "ONE HEALTH" approach, where the veterinarian is part of the multidisciplinary team in an institutional manner. The presence of a veterinarian would help to increase knowledge about zoonoses, especially for responsible pet and food animal ownership, the maintenance of an information and epidemiological surveillance system with laboratory diagnosis, and the participation of the community in the control of zoonoses, which have led to a large number of diseases and deaths (Dabanch 2003).

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Causal Factors and Epidemiological Analysis of the Main Bovine Zoonoses

02

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ABSTRACT

Even though cattle farming is a fundamental livestock activity in the production of food and the development of many countries, it is generating adverse effects on the environment and health. The invasion of natural ecosystems to expand breeding sites increases contact with wildlife and its pathogens, causing domestic animals to participate as potential reservoirs, which increases the risks of transmission of zoonotic diseases to humans. This condition highlights the relevance that animals have in both the origin and transmission of these diseases. The identification of causal factors, such as etiological agents, pathogenicity, environmental conditions in which they develop, transmission mechanisms, as well as risk factors for human and animal health, are decisive for generating intervention strategies.

From the epidemiological point of view, imbalances in the ecological triad etiological agent-host-environment are associated with natural changes in the environment, physical and chemical factors and the biological conditions of the pathogens that manifest under certain conditions, initiating the epidemiological chain, so the scope of each zoonosis will depend on environmental conditions, prevalence and incidence.

In the case of cattle, zoonoses can affect both productivity and public health, so adequate health management is essential, which includes primary prevention measures that guarantee the health of the animals by providing them with the necessary conditions of well-being and specific protection. Likewise, at a secondary level, early diagnosis and timely treatment of the disease, to promote the recovery of the animal and thereby reduce the risks of transmission to humans. The problem currently faced is the diversity of diseases and etiological agents that produce zoonotic diseases in cattle, highlighting bacterial, parasitic and viral zoonoses. Many of these diseases have a global distribution, such as brucellosis, anthrax, leptospirosis and tuberculosis, which are present in all five regions of the world. The current challenge, in addition to strengthening prevention and control measures, is to ensure that public, animal and environmental health function comprehensively.

Keywords: Cattle, ecological triad, Natural History of the Disease, epidemiological analysis, etiological agent, zoonoses

CITATION

García-Rubio VG and Ojeda-Carrasco JJ, 2023. Causal factors and epidemiological analysis of the main bovine zoonoses. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 10-23. https://doi.org/10.47278/book.zoon/2023.002

CHAPTER HISTORY Received: 22-Feb-2023 Revised: 3-April-2023 Accepted: 15-June-2023

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1. INTRODUCTION

Bovine farming is a fundamental activity for food production and development in many countries. As per report by FAO, the availability of beef increases by 5.9%, while its consumption by 20% until 2030 (OECD-FAO 2021). In 2021, the countries with the highest number of cattle were Brazil (224.6 million), India (193.2) and the United States (93.8). However, by 2022, the main producers of beef were the United States, Brazil, and China, with 12.8, 10.3 and 7.1 million metric tons, respectively (Orús 2023).
Although bovine production volumes make an important contribution to global food security, they are also having adverse effects on the environment and health. In addition to the factors inherent to climate change, the demographic explosion, migration, urbanization and the trade in animals increases the incidence of zoonoses that is associated with the modifications introduced to livestock production. The invasion of natural ecosystems to expand breeding sites increases contact with wildlife and its pathogens, causing domestic animals to participate as potential reservoirs and increasing the risks of disease transmission to humans (Morand et al. 2014).
Zoonoses represent important economic losses. Losses in the productivity and development of animals, abortions, premature deaths and disposal of animals unfit for human consumption, add to the expenditure of resources for animal health care. Likewise, they accentuate the risks for public health and animal health, especially when the measures applied are more oriented towards treatment than prevention and control. The importance given to zoonoses highlights the relevance of animals, both in the origin and in the transmission of diseases to humans (Rahman et al. 2020).

2. ZOONOSES FROM THE NATURAL HISTORY OF DISEASE

The growing emergence of zoonotic pathogens underscores the importance of advancing towards a greater understanding of the role of domestic animals as potential sources of disease. In the transmission of diseases, the interrelationships established between the environments, the etiological agent, animals and humans play a determining role. Zoonoses are no exception, as they have a series of characteristics that make their dissemination possible and make their control and eradication complex. The identification of causal factors, such as etiological agents, pathogenicity, environmental conditions, transmission mechanisms, as well as risk factors for human and animal health, are decisive for generating intervention strategies (Acero 2016).
The Natural History of Disease (NHD) allows us to know the natural behavior of a disease, from its origin and its evolution, without man's intervention. The risk factors in the health/disease patterns are those associated with the components of the ecological triad: etiological agent, host, and environment. It includes the periods a) Pre-pathogenic: the disease is not manifested, because the elements of the ecological triad are in balance; b) Pathogenic: there is a trigger that breaks this balance, starting the infection that can present sub clinically or clinically and c) Post-pathogenic: corresponds to the outcome of the disease (recovery, chronic state, sequelae or death) (Fajardo-Gutiérrez 2017).
From the epidemiological point of view, the most relevant period is the pre-pathogenic period. Imbalances in the ecological triad, in addition to being associated with natural changes in the environment (such as precipitation, floods, heat waves, high temperatures), are influenced by the action of chemical agents (pesticides, food additives, drugs). Physical (heat, mechanical force, radiation) and biological conditions of the pathogens that manifest under certain conditions (proliferation, changes in infectivity, degree of pathogenicity, ability to evade the host response), which marks the beginning of the epidemiological chain. The scope of each zoonoses depends on the specific environmental conditions, the prevalence (proportion of sick animals when evaluating the disease in the population) and the incidence (new cases). When these occur constantly in a geographical area, these are endemic. If their manifestation is transitory and affects a large number of animals, it is epizootics. These can even reach to greater magnitudes such as epidemics or pandemics (Rosales 2017; Briones et al. 2018; Baker et al. 2022).

Because bovine zoonoses can affect public health (due to the morbidity caused by the disease), as well as livestock productivity, proper sanitary management of bovines is essential through the application of preventive measures (Espejel 2020). In the pre-pathogenic period, primary prevention is oriented towards promoting animal health, including welfare conditions (adequate conditions of the facilities, access to water, adequate feeding, and adequate herd management), and specific protection (vaccination, deworming, pest control, and biosecurity measures) (Rosales 2017).

In the pathogenic period, the secondary level of prevention includes early diagnosis, in order to timely detect the infection and stop the chain of pathogen transmission before it spreads in the herd. The second measure is timely treatment, providing it from the beginning of the infection to increase its effectiveness; likewise, limit the damage to the animal as much as possible, to prevent it from becoming incapacitated or dying. Depending on the degree of progress, the bovine can recover from the infection; however, as a convalescent host it can remain as a carrier, for a determined or indefinite time. In the post-pathogenic period, tertiary level measures apply actions to seek the restoration of the animal, which depends on the disease, type of damage and purpose of production, which can conclude with the sacrifice of sick animals (Rosales 2017).

3. MAIN BOVINE ZOONOSES

During the pathogenic period of NHD, various etiological agents participate in the main bovine zoonoses. The majority (42%) are bacterial zoonoses, such as Anthrax, Tuberculosis, Brucellosis, Leptospirosis and *Escherichia coli* infections. Those caused by other agents include parasitic zoonoses (Cryptosporidiosis, Dermatophilosis), viral (Rabies), rickettsial (Q-Fever), protozoal (Giardiasis) and non-viral acellular pathogens (Bovine Spongiform Encephalopathy) (McDaniel et al. 2014; Rahman et al. 2020).

In recent decades, these zoonoses have shown a wide distribution in different regions of the world. Brucellosis, anthrax, leptospirosis and tuberculosis are present in the five regions of the world. Bovine Spongiform Encephalopathy in the Americas, Asia and Europe. Rabies and Q fever, in all regions except Oceania, while Vesicular Stomatitis only in the Americas. According to the data registered from 2005-2022 in the World Animal Health Information System (WAHIS), of the World Organization for Animal Health (WHO, created as OIE), the most important bovine zoonoses are Brucellosis (with 1,883,028 confirmed cases), Leptospirosis (923,236) and Tuberculosis (525,698), and Anthrax due to its level of lethality (20,054,380 dead animals) (WOAH 2023).

4. BOVINE BRUCELLOSIS

It is a highly virulent, chronic, infectious, and contagious bacterial zoonoses caused by *Brucella abortus*. It mainly affects reproduction. In females, it can cause abortions towards the last third of pregnancy and signs such as infertility, subclinical mastitis, anorexia, fever and depression. In males it produces epididymitis, testicular fibrosis, vesiculitis, orchitis and in some cases, permanent infertility (de Figueiredo et al. 2015). Infected pregnant females that do not miscarry remain with the calves as asymptomatic carriers (vertical transmission). Transmission in the herd occurs horizontally, through the conjunctival, oral, nasal, or genital routes, through direct contact with infected animals, and indirectly through contaminated materials, water, feed, and pasture. Between different herds, transmission usually occurs through the entry of infected animals, the use of shared pastures and water sources, especially in free-traffic breeding, and even by personnel working in different production units who do not observe control measures (Adesokan et al. 2013).

Humans can contract the disease through the digestive tract, by consuming contaminated milk and its unpasteurized derivatives, or raw or poorly cooked meat (Negrón et al. 2019). The greatest risks are associated with occupational and professional work, as for farm staff and veterinarians. Contagion can occur by conjunctival inoculation, respiratory route by inhalation of aerosols during the cleaning of the stables or the movement of livestock, or by direct contact with infected animals blood, urine, aborted products, or contaminated dust (Molineri et al. 2014).

5. LEPTOSPIROSIS

It is the second most important zoonosis transmitted by bovines and always present in breeding sites. Disease caused by the *Leptospira* bacterium. The *hardjo* and *pomona* serovars of *Leptospira interrogans* are the most frequent in cattle. Rodents are the reservoirs, while livestock and humans are incidental hosts. In times of heavy rain, its epidemic potential is high. The routes of entry to the animal are multiple, including the ocular, nasal, oral, genital mucous membranes or skin wounds. Upon entering, they move into the bloodstream from where they reach the tissues and organs. They multiply significantly in the convoluted tubules of the kidneys. Urine containing the bacteria contaminates water sources, feed, and pasture. Vaginal fluids and semen can present a bacterial load. In humid and warm conditions, they manage to survive outside the host for up to six months. In infected animals, it can cause infertility, abortion, nephritis, mastitis, anemia, hemoglobinuria, low weight of calves at birth and even cause the death of calves (Torres et al. 2018; Valverde-Latorre et al. 2021).
Humans can acquire the disease by direct contact, fomites, or environments contaminated with the urine of infected animals in contaminated lagoons or lakes. It usually develops asymptomatically. However, in severe cases multi-organ failure increases the mortality rates (Ramírez-García et al. 2019).

6. BOVINE TUBERCULOSIS

The etiological agent is the bacterium *Mycobacterium bovis*, with bovines being the definitive host. Other wild and domestic mammals may serve as incidental hosts. Infected animals shed the bacteria in milk, feces, respiratory secretions, and even in semen and vaginal fluids. Transmission can be through the air (aerosols), through skin wounds, or through the ingestion of contaminated milk (calves). Asymptomatic carrier animals contribute to the spread of the disease. The high tolerance of the pathogen to low temperatures and humid places increases the risks of contagion. The infection can remain dormant for years, entering its active form under stressful conditions or in physically compromised animals. Signs can take months to develop. When they manifest, the animal show weakness, fluctuating low fever, progressive emaciation and wet cough. In severe cases, the animal dies from acute respiratory complications (Olea-Polpeka et al. 2017; Hernández-Solís et al. 2019).
Zoonotic tuberculosis in humans can occur from exposure to aerosols, secretions, and primarily from the consumption of unpasteurized milk or dairy products and raw or undercooked meat (Scott et al. 2016).

7. ANTHRAX

It is a highly contagious infectious disease caused by *Bacillus anthracis*. This bacterium form spores that resist extreme environmental conditions, which allows them to remain viable and infective in the soil (reservoir) for a long time, as well as to survive pasteurization. A greater proliferation is associated in calcareous or alkaline soils. It mainly affects herbivorous wild animals, and to a lesser degree to domestic animals and humans. The bacteria capsule produces lethal toxins. The presence of spores in pastures and contaminated water sources are the main source of infection in cattle. In the super-acute course, the animals do not show obvious signs for days, but when they appear, death occurs within a few hours. The acute or fulminant form manifests itself two days after infection. The animal shows signs of depression, elevated temperature, heart and respiratory rate, and congested and hemorrhagic mucous membranes.

In both cases, bloody discharge from the nose, mouth, anus, and vulva is evident in the dead animal (Laverde et al. 2008; Shadomi et al. 2016).
It is a high-risk occupational disease for those who perform slaughtering, leather tanning, or handling contaminated wool. In humans, the disease can develop in the lungs by inhaling the spores (the most lethal form), through the skin, through a wound, or gastrointestinal by consuming raw or semi-raw meat from an infected animal (Guzmán-Terán et al. 2017).

8. Q-FEVER

The etiological agent is *Coxiella burnetii*, one of the most infectious agents known. The main reservoirs are domestic ruminants. The disease is seasonal, and occurs in females during the calving season. The bacterium has a selective tropism for the uterus and mammary glands. During pregnancy, it can cause abortion in some cases. The placenta, fetal membranes and fetuses (in abortions) from infected cows present a high infective load (Roca 2007). The main route of transmission is respiratory, through the inhalation of aerosols from calving waste (primary aerosols) or contaminated materials such as manure, bedding and other fomites (secondary). To a lesser degree, transmission can also occur orally through the consumption of contaminated food (de Rooij et al. 2016).
In humans, the highest risk is occupational, in people who carry out livestock activities and veterinarians by aerogenous route. The disease can also develop in humans from the consumption of contaminated milk. It presents a wide range of manifestations, ranging from mild infections that can be asymptomatic, to chronic and disabling clinical pictures, which can cause death in severe cases (Rabaza et al. 2022).

9. BOVINE SPONGIFORM ENCEPHALOPATHY

Until now, it is the only bovine zoonoses produced by prions (infectious abnormal proteins). It is a neurodegenerative disease, which is incurable and deadly. Animals acquire it in the first six months of life, by consuming feed formulated with contaminated meat and bone meal. The incubation period is long, generally more than 4 to 5 years. Specific risk materials (SRM) such as nervous tissues (brain, spinal cord) are responsible for transmission. The signs associated with the disease appear in cows of 5-6 years of age. These include weight loss, behavior changes, weakness, and progressive neurological deterioration. Prevention and control measures require the elimination of animals that show signs of the disease, as well as the confirmation of diagnosis with laboratory tests (Hernández et al. 2002).
In humans, the BSE variant is Juvenile Creutzfeldt-Jakob disease. It has its origin in the consumption of meat from infected cattle or that had contact with sick animals. It causes progressive neurological and psychiatric disorders, until death occurs due to cerebral or respiratory complications (García-Ortega et al. 2019).

10. PARALYTIC RABIES

It is a type of encephalitis caused by the RNA virus of the genus Lyssavirus. The disease is progressive and deadly, affecting all mammals. It attacks the host's central nervous system, causing brain death. The virus loses its infectious potential on exposure to light. Transmission occurs mainly in cattle through the bite of the hematophagous bat *Desmodus rotundus* (reservoir), or through contact of infected saliva with wounds, or the mucous membranes of the eyes, nose, and mouth. Neck flexion, hind limb paralysis and excessive salivation are unequivocal signs of the disease (Bárcenas-Reyes et al. 2015).

Transmission to people includes bites from sick animals or getting saliva into the eyes, nose, mouth, or wounds. The occupational risk is latent, especially in the traces when manipulating the brain. Consumption of unpasteurized infected milk can be another route of infection (NCEZID 2019).

11. GIARDIA INFECTIONS

It is a disease caused by the protozoan parasite of the genus *Giardia*, present in all vertebrates. Considered as the causal agent of a large number of cases of gastrointestinal diseases in animals and humans. In animals, it alters the functioning of the gastrointestinal tract, decreases the absorption of nutrients, and causes emaciation due to diarrhea, mainly in young animals. The flies of the Muscidae family that abound in manure heaps are the vectors of this protozoan (Abeywardena 2015). Dissemination is by cysts excreted in the feces, which contaminate food and water sources. Both animals with evidence of the disease and asymptomatic animals participate in an important way in this process. Once in the stomach, they disengage, releasing the trophozoites that multiply actively. As they descend towards the terminal portion of the digestive tract, they encyst again. After three days of infection, it is possible to observe the presence of cysts in the feces (Otero-Negrete et al. 2011).

In public health, these zoonoses is of great relevance throughout the world. Transmission is through fecal-oral route. The ingestion of the cyst with consuming water or food, or by putting contaminated fomites in the mouth. The highest prevalence and incidence occurs in unhealthy areas or with contaminated water. People who contract the infection have diarrheal symptoms of different intensity and their evolution usually depends on medical care. In severe cases, it can even lead to death (AMSE 2016).

12. CRYPTOSPORIDIOSIS

Infection caused by the protozoan parasite of the genus *Cryptosporidium*. It occurs ubiquitously with Giardia in diarrheal infections in animals. Despite the taxonomic differences, the form of transmission and mechanisms of action are very similar in animals. In *Cryptosporidium* the infective form are the oocysts. The joint action of these parasites represents a major public health problem, due to the high infectious potential and exposure. In livestock production, they cause significant losses due to the cost of treatments, the delay in the development of animals, and the deaths of newborn animals (Santin 2020).

13. *ESCHERICHIA COLI* INFECTIONS

This bacterium is part of microbiota of the digestive tract of ruminants and other mammals, including humans. However, there are serotypes that cause diarrheal-type diseases in calves. 15-20% of neonatal deaths are due to infections caused by this bacterium. *Escherichia coli* serotype O157:H7 is a zoonotic Shiga toxin-producing pathogen (STEC). It is located in the lymphoid tissue that joins the rectum with the anus, where it colonizes in cattle. This location allows a wide spread of the pathogen, through bovine feces (Lara-Duran et al. 2019).

STEC bacteria are included in the Verocytotoxin-producing *E. coli* (VTEC), responsible for hemolytic-uremic syndrome (HUS) in humans (Etcheverria et al. 2013). They are highly relevant foodborne pathogens in Foodborne Diseases. The sources of infection are diverse, including fruits and vegetables that have been in contact with contaminated feces; and contaminated raw or undercooked meat. Infections caused by STEC/VTEC include watery diarrhea, hemorrhagic colitis, renal failure, Thrombotic Thrombocytopenic Purpura (TTP) and Hemolytic Uremic Syndrome (HUS) (Rípodas et al. 2017).

14. EPIDEMIOLOGICAL ANALYSIS OF THE MAIN BOVINE ZOONOSES

Epidemiological information is crucial to understand the behavior of zoonoses, their effects on animal production and health and the possible risks to human health. Its indicators are the basis for defining intervention processes to prevent, control or eradicate them. Despite being the same livestock species, the scope of each zoonoses depends on the characteristics of the etiological agent, environmental conditions, contexts, and methods of breeding. Based on the information compiled by the WHOA, the analysis addresses different aspects related to the main bovine zoonoses (WOAH 2023).

Bovine brucellosis is the most prevalent zoonoses worldwide (Table 1). The Americas registers the highest number of susceptible animals with 49.2 million animals (Ma), which is 42.6% of the total cases reported worldwide. It corresponds to immunologically compromised animals, which have the necessary characteristics to develop the disease, when exposed to the etiological agent (Vargas and Galindo 2015).

As observed, there is no correspondence between the number of positive, eliminated, euthanized and dead cases. In addition to the subtotals by period, the analysis by region shows this condition more precisely: For Asia, the total number of positive cases is 405,943. If the eliminated (244,315), sacrificed (195,029) and dead (1,137,027) are added, the total amount goes to 1,576,371 (a difference of 1,170,428 compared to the positive cases). More than data errors, these differences show that the problem is much more complex in terms of prevalence and incidence. Likewise, in epidemiology, unless it is a follow-up, the data analysis cannot be linear. It is important to consider that, depending on the interaction with the etiological agent, the conditions of the animal and the environment, the course of the disease may be different in each animal (Rojas et al. 2021).

The highest frequencies registered by country show these differences at the regional level. In the number of susceptible animals, the highest value corresponds to Venezuela, for positive cases to Mexico and for dead animals to Turkey (Table 2).

In practice, unless there is systematic surveillance, in many cases when the cow miscarries in the last third of gestation, brucellosis appears as a probable cause. The disease is confirmed when laboratory tests are performed. There are infected, asymptomatic cows that do not abort, which contribute to the spread of the disease. In addition to the possible direct exposure to the placenta, which has a significant load of pathogen, bacteria contained in the milk increase the risk of contagion to humans. The undetected cases, the chronic carriers and the ignorance of the cause of death aggravate the real problem. In many places, the entities responsible for epidemiological surveillance violate the processes by leaving sick animals in free transit that spread the disease among herds, or by slaughtering without prior verification (McDaniel et al. 2014).

As part of these strategies, some countries have achieved excellent results by identifying and eliminating sick animals and receiving compensation to replace the animals. Although this measure has proven its effectiveness, the lack of economic resources is usually a determining factor, which is why it is applicable only in places of low prevalence. For this reason, many animals are destined for the sale of meat. Given the transmission mechanism of brucellosis, inadequate cooking of meat increases the risk of contagion in humans (Adesokan et al. 2013; Negrón et al. 2019).

In primary prevention, vaccination is the key to reduce the susceptibility of animals to contracting the disease. In the comparison of sub-periods, the increasing decrease in the number of immunized cattle in Africa is associated with the increase in susceptible animals. In the Americas, in the last sub-period, the significant increase in the number of vaccinated animals from 320,258 to 6.6 Ma reduced those susceptible from 22.1 to 3.2 Ma, showing the efficacy of immunization as a preventive measure (WOAH 2023).

Table 1: Epidemiological data on Brucellosis by world region (2005-2022)

Period	Region	New outbreaks	Animals Susceptible	Positive cases	Eliminated	Slaughtered for commercial purposes	Dead	Vaccinated
2005-2010	Africa	740	553,596	43,405	2,602	10,815	223	480,302
	Americas	8,259	23,899,771	588,022	5,704	121,257	806	424,500
	Asia	2,756	17,721,708	168,882	73,937	57,165	296,332	295,763
	Europe	2,271	12,271,959	128,543	57,085	97,846	837	373,921
	Oceania	4	12,127	123	0	116	7	0
	Subtotal	14,031	54,459,161	928,975	139,328	287,199	298,205	1,574,486
2011-2016	Africa	900	1,054,609	40,208	3,384	11,528	424	269,565
	Americas	5,362	22,117,982	224,766	4,986	70,985	12,182	320,258
	Asia	4,069	20,958,095	106,547	76,782	65,979	409,890	409,255
	Europe	1,140	5,817,708	100,564	20,861	76,273	114	377
	Oceania	20	84,003	1,291	0	920	1	521
	Subtotal	11,491	50,032,397	473,376	106,013	225,685	422,611	999,976
2017-2022	Africa	663	1,325,865	33,127	899	11,087	388	61,085
	Americas	5,907	3,223,236	252,530	10,593	57,702	1,051	6,616,890
	Asia	2,499	5,802,659	130,514	93,596	71,885	430,805	430,513
	Europe	707	787,949	64,425	1,429	62,152	203	1
	Oceania	7	41,780	81	0	75	0	0
	Subtotal	9,783	11,181,489	480,677	106,517	202,901	432,447	7,108,489
	Total	35,305	115,673,047	1,883,028	351,858	715,785	1,153,263	9,682,951

Susceptible animals: Animals that do not have specific immunity to the etiological agent.
Eliminated: Sick animals euthanized for elimination and replacement, as control measure.
Slaughtered for commercial purposes: Sick animals brought to the slaughterhouse for the sale of meat and offal.
Deaths: Animals reported to have died from the disease.
Source: Own elaboration based on the processing of data reported in WOAH (2023).

Table 2: Countries by region with the highest number of Brucellosis cases reported by indicator

Region	AC	ANIMALS SUSCEPTIBLE			POSITIVE CASES			DEAD ANIMALS		
Africa	37	Esuatini (506,916)	Uganda (501,755)	Mozambique (358,621)	South Africa (67,929)	Algeria (23,043)	Eritrea (5,755)	South Africa (538)	Zambia (187)	Mozambique (69)
Americas	21	Venezuela (22'100,445)	Mexico (14'085,318)	Bolivia (5'788,314)	Mexico (409,379)	Brazil (213,548)	Argentina (145,713)	Mexico (12,152)	Colombia (595)	Bolivia (430)
Asia	31	Azerbaijan (15'612,204)	Kyrgyzstan (9'637,809)	Armenia (7'546,538)	Korea (81,983)	Turkey (62,787)	Kyrgyzstan (59,269)	Turkey (276,004)	Syria (178,325)	Tajikistan (170,778)
Europe	17	Spain (16'649,591)	Italy (6'153,111)	Macedonia (1'151,028)	Russia (151,005)	Italy (73,705)	Spain (34,301)	Russia (770)	Greece (201)	Italy (169)
Oceania	1	Fiji (137,910)			Fiji (1,495)			Fiji (8)		

AC=Affected Countries (by region).
Source: Own elaboration based on the processing of data reported in WOAH (2023).

According to the data registered by the WOAH (2023), the second most prevalent zoonoses is Leptospirosis with 959,792 fewer cases than Brucellosis. It is noteworthy that for the period considered in the comparison (2005-2022), the records only include information up to 2011. Even so, they are greater than for those of Tuberculosis (Table 3).

The absence of data from 2012-2022 (even for 2023) cannot be interpreted as the disappearance of the disease. The main reason is that only in 2011 (without integrating Africa and Oceania), all the indicators increased with respect to the accumulated frequency registered for the previous 6-year period. The bias introduced by the lack of records in monitoring the behavior of the disease is important, especially considering the prevalence and impact it can have on human and animal health.
The report also includes birds, buffaloes, goats, deer, rabbits, equids, wildlife (unspecified species), cats, sheep, goats, dogs and pigs. In addition to showing the diversity of affected species, the global totals are useful to measure the impact of the disease. Suffice it to point out that the total number of outbreaks registered for bovines (2,402) represents only 12.74% of the 18,884. The same happens with the other indicators, when considering the different animal species affected by the disease. Of the total number of susceptible animals 47.53% and of the positive cases 85.52% correspond to bovines. This indicates that the spread of the disease can occur through contact with domestic and wild species, which increases the risks for humans (WOAH 2023). The diversity of wild and domestic species, for which the disease is registered, at least allow us to infer that it is zoonoses of great proportions.
Following the order of prevalence, despite of the fact that in public health tuberculosis before the SARS-CoV-2 (COVID-19) pandemic was the disease that caused the most deaths from a single infectious agent (*Mycobacterium*) worldwide, the WOAH records start from 2019 (Table 4).
This organization places the disease under control, although in 2018 it recognizes its presence in 82 countries. It is noted that although there have been important advances in the control of the disease; its persistence is associated with infection caused by wild animals. The registry integrates 39 animal species including 3 domestic (cattle, sheep and goats) and 36 wild animal species (WOAH 2023).
Alternative measures can contribute to the eradication of the disease in cattle. In Mexico, the control guide is the Official Mexican Standard NOM-031-ZOO-1995, which is the basis for the National Campaign against Bovine Tuberculosis (*Mycobacterium bovis*). This standard contemplates the tuberculin test for diagnosis. As a control measure, the positive reactors are eliminated (sacrifice). (Rojas et al. 2021). Different studies have suggested BCG vaccination as an alternative for the control of bovine tuberculosis (Buddle et al. 2018; Chandran et al. 2019; Marais et al. 2019). The difficulty is that immunization can lead to the identification of false positives in intradermal tuberculin tests. Its confirmation requires *M. bovis* antigens not expressed by BCG, which are not yet available (WOAH 2019).
Anthrax is the zoonoses with the highest levels of mortality. Despite of the fact that the prevalence is not comparable to that of brucellosis, the lethality of the etiological agent, together with the prevailing socio-economic conditions in each region are determining factors. According to the data, there are clear differences between the sub-periods. Between the first and second, all indicators are reduced (even vaccination). Africa is the region with the highest number of positive cases and dead animals, despite of the fact that it is also the region with the highest number of vaccinated animals (almost 100% of susceptible animals). The inferred effect is the reduction in the number of positive cases for the second period (78.2% reduction in prevalence). However, in the case of Asia, where the proportion of vaccinated animals is ten times higher than the reported susceptible animals, it is logical to assume a significant reduction in the number of positive cases for the following period. According to the data, the positive cases of the second period are equivalent to 88.4% of the previous period (reduction of 11.6%) (Table 5).
These comparisons show that care for zoonoses requires a comprehensive vision, which contemplates that, although it is the same etiological agent and the same species of host, the behavior of the disease depends on the condition of each animal, the environmental conditions and not only physical in which it is found, but also contextual (ecological triad). Despite the high lethality of *Bacillus anthracis*, the administration of timely treatment can prevent the death of the animal. In regions with insufficient budget, in addition to the inability to maintain vaccination schemes as preventive measures, there is also a lack of resources to provide the treatments, which increases the number of deaths, without neglecting the fact that the number of cattle heads is usually variable. Worldwide, the largest number of susceptible

animals is recorded by Ethiopia (15.9 Ma), the positive cases in the Ivory Coast (41,297) and the dead animals by Ethiopia (7.96 Ma) (WOAH 2023).

In the case of bovine rabies (Table 6), the Americas registers the highest number of vaccinated animals and it also reports the highest numbers of susceptible animals, positive cases, and dead animals. The world's main cattle producers i.e., Brazil and the United States are located in this region. The disease is present in 34 countries in Africa, 31 in Asia, 24 in the Americas and 21 in Europe. Oceania is a rabies free region. The largest number of susceptible animals is recorded by Paraguay (9.3 Ma) followed by the Philippines (5.1 Ma). For the positive and dead animals, Brazil (22.4 Ma and 22.3 Ma) and Russia (7.01 Ma and 7.01 Ma) have reported the highest number of cases (WOAH 2023).

Table 3: Epidemiological data on Leptospirosis by world region (2005-2011)

Period	Region	New outbreaks	Animals Susceptible	Positive cases	Eliminated	Slaughtered for commercial purposes	Dead	Vaccinated
2005-2010	Africa	2	35,018	28	0	0	1	0
	Americas	1,196	271,420	26,132	1	3	673	450
	Asia	238	1,001,787	858,880	16	14	915	105,024
	Europe	457	333,702	29,468	4,886	12	121	4,289
	Oceania	14	0	162	0	0	0	0
	Subtotal	1,907	1,641,927	914,670	4,903	29	1,710	109,763
2011	Americes	217	32,417	5,793	0	1	57	426
	Asia	19	14,258	44	0	0	12	0
	Europe	259	3,732	2,729	0	160	6	0
	Subtotal	495	50,407	8,566	0	161	75	426
	Total	2,402	1,692,334	923,236	4,903	190	1,785	110,189

Source: Own elaboration based on the processing of data reported in WOAH (2023).

Table 4: Epidemiological data on Bovine Tuberculosis by world region. (2019-2022)

Period	Region	New outbreaks	Animals Susceptible	Positive cases	Eliminated	Slaughtered for commercial purposes	Dead	Vaccinated
2019-2022	Africa	158	243,414	65,286	1,005	65,947	335	0
	Americas	1,508	715,879	129,210	3,614	120,417	123	0
	Asia	4,202	2,861,382	75,935	16,034	52,283	173	0
	Europe	2,544	10,723,412	254,326	20,511	264,171	39	0
	Oceania	34	300,644	941	0	2,097	0	0
	Total	8,446	14,844,731	525,698	41,164	504,915	670	0

Source: Own elaboration based on the processing of data reported in WOAH (2023).

15. IMPACT OF BOVINE ZOONOSES ON HUMAN HEALTH

Unlike the information available for animals, the information on human cases associated with human zoonoses is limited. In each region and country, the indicators are oriented towards the aspects that mostly affect the population as a basis for defining care and prevention strategies.

Table 8 shows the data registered by the European Center for Disease Control (ECDC) on bovine zoonoses of public health importance for the countries of the European Union (EU) and 3 countries (Iceland, Liechtenstein and Norway) of the European Economic Area (AEE). The accumulated data is from 2008 to 2021 and the incidences for 2020 for each disease (WOAH 2023).

The accumulated data show that the most prevalent zoonoses and the highest incidence is of Tuberculosis, with 9.72/100,000 population (9.50 according to World Bank figures). This data underlines the importance of this disease at global public health level.

Table 5: Anthrax epidemiological data by world region (2005-2022)

Period	Region	New outbreaks	Animals Susceptible	Positive cases	Eliminated	Slaughtered for commercial purposes	Dead	Vaccinated
2005-2010	Africa	314	7,202,734	71,192	12,146	24,576	7,212,517	7,199,819
	Americas	94	168,721	2,902	138	2,528	138,961	136,435
	Asia	163	376,714	6,246	538	4,238	3,869,334	3,865,098
	Europe	24	262,376	844	146	511	2,055,455	2,054,945
	Oceania	18	10,258	175	0	173	12,571	12,398
	Subtotal	612	8,020,803	81,359	12,968	32,026	13,288,838	13,268,695
2011-2016	Africa	178	6,461,533	15,573	923	12,250	2,665,645	2,653,900
	Americas	38	151,916	1,560	262	1,110	85,211	84,101
	Asia	200	414,504	5,524	1,396	4,551	1,213,357	1,209,418
	Europe	21	20,322	350	28	298	78,771	78,473
	Oceania	5	3,272	126	0	126	3,732	3,606
	Subtotal	443	7,051,547	23,133	2,609	18,335	4,046,716	4,029,498
2017-2022	Africa	72	6,194,779	9,036	370	8,066	1,498,498	1,490,476
	Americas	19	61,485	1,053	103	835	13,729	12,897
	Asia	106	476,284	5,439	477	4,993	1,238,832	1,233,938
	Europe	10	8,045	269	12	252	14,636	14,389
	Oceania	6	5,202	173	2	173	4,660	4,487
	Subtotal	213	6,745,795	15,970	964	14,319	2,770,355	2,756,187
	Totales	1,268	21,818,145	120,462	16,541	64,680	20,105,909	20,054,380

Source: Own elaboration based on the processing of data reported in WOAH (2023).

Table 6: Epidemiological data on Bovine Rabies by world region (Accumulated data 2005-2022)

Region	New outbreaks	Animals Susceptible	Positive cases	Eliminated	Slaughtered for commercial purposes	Dead	Vaccinated
Africa	854	2,224,074	12,387	3,757	318	8,019	256,241
Americas	795	11,366,676	41,773	1,294	266	40,151	180,464,692
Asia	1,309	13,404,954	19,375	3,499	165	15,615	824,997
Europe	8,817	9,803	12,566	812	23	11,711	182,863
Total	11,775	27,005,507	86,101	9,362	772	75,496	181,728,793

Source: Own elaboration based on the processing of data reported in WOAH (2023).

Table 7 shows the grouped data for Bovine Spongiform Encephalopathy and Q fever. In both cases, the largest positive cases correspond to Europe (WOAH 2023).

Based on the incidence report/100,000 people from the World Bank, for 2020 the worldwide incidence was 198.68. At the regional level, the incidence for Africa, Americas, Asia, Europe and Oceania was 192.07, 31.34, 124.52, 13.97 and 134.69, respectively (WB 2021). These figures show the differences that exist between regions, with the African region being the most affected. In many African countries, the low availability of economic resources means that factors such as poverty, inadequate nutrition, lack of water, overcrowding, lack of medical care, as well as drought conditions and other extreme weather events contribute to increase the problem of this disease. Despite the surveillance and implementation of coordinated strategies from different levels, it continues to be the zoonoses with the greatest global affectation.

16. CONCLUSIONS

It is undeniable that cattle raising has important contributions to food security, but it also brings negative effects. Its role in the transmission of zoonoses stands out, with worldwide effects on public and animal health. The available data on its incidence and prevalence are far from showing its real dimension. The data is partial, since it does not report the actual cases over the total population of each region. There are also deficiencies in notifications (mandatory for many of the zoonoses). In many cases,

Table 7: Epidemiological data on Bovine Spongiform Encephalopathy and Q fever by world region (Accumulated data 2005-2022)

Zoonoses	Region	New outbreaks	Animals Susceptible	Positive cases	Eliminated	Slaughtered for commercial purposes	Dead	Vaccinated
Bovine Spongiform Encephalopathy	Americas	26	27,101	28	540	277	10	0
	Asia	37	8	17	16	0	2	0
	Europe	165	1,838,577	1,320	20,137	1,125	157	0
	Total	228	1,865,686	1,365	20,693	1,402	169	0
Q-Fiver	Africa	9	8	8	0	0	0	0
	Americas	13	3,111	51	0	0	8	0
	Asia	942	8,353	196	0	0	14	0
	Europe	3,537	3,141,981	14,399	508	118	37	421
	Total	4,501	3,153,453	14,654	508	118	59	421

Source: Own elaboration based on the processing of data reported in WOAH (2023).

Table 8: Prevalence and incidence of zoonotic diseases in humans for the EU/EEA

	2008-2021					2020	
Zoonoses	NC_A (WAHIS)	NC_H (ECDC)	RC/C	HOSP	Deaths	RC/C	Incidence (N/100 000)
Anthrax	14	13	101	*	*	3	0.00
Brucellosis	10	26	6,052	1,384	12	134	0.03
Creutzfeldt-Jakob	19	5	24	*	*	0	0.00
Cryptosporidiosis	0	25	124,751	6,884	35	4,167	1.68
E. coli STEC/VTEC	*	31	106,941	32,928	237	4,824	1.59
Q-Fiber	17	26	13,951	*	*	528	0.12
Giardiasis	0	25	238,748	4,965	49	6,559	2.55
Leptospirosis	13	27	9,816	3,929	160	569	0.14
Rabies	1	9	22	*	*	0	0.00
Tuberculosis	14	31	826,039	*	*	5,032	9.72

NC=Number of Countries Affected (A_ Animals; H _ Humans); CR/C= Reported/Confirmed Cases; HOSP= Hospitalized
* No data Source: Own elaboration based on the processing of data reported by ECDC (2023) and WOAH (2023).

the epidemiological surveillance systems present deficiencies, which increases the risks. Control and prevention mechanisms should consider undiagnosed cases that are subclinical. In qualitative terms, the traditional view that zoonoses were typical problem of underdeveloped countries is unsustainable. The current worldwide distribution of bovine zoonoses and their effects on livestock productivity, public and animal health confirms this. Even though, it is in these countries where the impacts tend to be greater due to the lack of resources to face epidemiological surveillance, improve the health infrastructure and implement effective prevention programs. Countries with greater resources and infrastructure are not exempt from this problem. The distribution of etiological agents and the changing conditions associated with climate change are causing them to face new paths, due to the emergence of new diseases. The pending task is not only aimed at strengthening prevention and control measures, but also at seeking to ensure that public, animal and environmental health work in an integral manner.

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Potential Risks of Emerging and Reemerging Zoonoses

03

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ABSTACT

The global impact caused by diseases has had a predominant role throughout history, due to the loss of life, the economic implications and the social transformations produced at all times. Although at the beginning, the periods between one pandemic and another were very long, over the years this condition has changed. This is mainly due to the associated circumstances, initially wars, poverty, cultural practices, and deficiencies in health systems, created the ideal conditions for its manifestation. Currently, in addition to specific socioeconomic contexts, such as the demographic explosion, changes in land use, the invasion of natural habitats, changes in agricultural and livestock production, commercial exchange, international travel, hunting and consumption of wild animals, among other aspects, increase potential risk factors. Likewise, the emergence and re-emergence of zoonotic diseases are associated with the great evolutionary capacity of pathogens, which allows them to adapt to significant environmental changes, develop resistance to antimicrobials, diversify their hosts, and the appearance of new etiological agents or variants of existing ones and the increase in their harmful effects on health.

From the environmental aspect, the progressive alteration of natural habitats tends to break the balance in ecosystems, altering the population dynamics of the species that inhabit them, and promoting greater proximity of human beings to wild animals, natural reservoirs of many pathogens. Human disturbances to ecosystems due to excessive deforestation, establishment of monocultures, expansion of crop areas and livestock raising, increase in urbanization, among other factors, contribute significantly to increasing the risks of contracting zoonotic diseases. One of the main potential risks of zoonoses is the diversity of diseases and etiological agents involved. In addition to those already known, the evidence of the effects caused by hitherto unknown pathogens and their variants represents a potential problem for public health and animal health.

Keywords: Emergency, Re-emergence, Zoonotic diseases, Potential risks, Etiological agents.

CITATION

García-Rubio VG, Ojeda-Carrasco JJ, Espinosa-Ayala E, Hernández-García PA and Quiroz LDR, 2023. Potential risks of emerging and reemerging zoonoses. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 24-37. https://doi.org/10.47278/book.zoon/2023.003

CHAPTER HISTORY Received: 21-Feb-2023 Revised: 24-April-2023 Accepted: 10-Aug-2023

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1. INTRODUCTION

Throughout history, one of the great challenges that humanity has faced is the emergence of diseases. The degree of affectation they generate depends on the etiological agent of disease, their transmission mechanisms, and the scope of the disease with respect to its distribution. Some appear suddenly and localized in certain places (epidemic outbreaks). There are diseases in which the significant increase in the number of cases, along with their active and rapid spread in a given geographical area (epidemics), generating greater effects. In others, it is recurring and constant appearance or its chronic prevalence in certain areas or age groups (endemic) which increases the levels of vulnerability of the population that suffers from them. While in those with the greatest scope and affectation (pandemics), transmission occurs within the communities themselves, simultaneously reaching a wide distribution in different continents, regions and countries of the world (Hortal 2016).

Due to the global impact, diseases have played a preponderant role in history. These are important due to the loss of life, the economic implications and the social transformations. The first recorded epidemic was the plague, which in 571AC devastated the city of Constantinople and caused the fall of the Byzantine Empire. 775 years later (1346, XIV century), the Black Death presented the worst outbreak since its appearance. It is the first deadliest pandemic in history, due to the number of deaths it caused in Europe, Asia and North Africa. A disease of zoonotic origin caused by the bacterium *Yersinia pestis*, transmitted by the bite of infected fleas, and spread by rats (WHO 2018). Currently, it continues to present sporadic outbreaks in Madagascar, the Democratic Republic of the Congo, and Peru. Smallpox was a zoonosis that affected *Homo sapiens* since prehistoric times. Its greatest expansion occurred in the XVIII century, significantly decimating the population. For the eradication of this disease, vaccination was very important, registering its last case in 1977 (Álvarez 2020; Huguet 2022).

Subsequently, at the end of World War II, in 1918 the first case of Spanish Flu appeared. The advance of military troops, the devastation caused by the war and social vulnerability appear as the main causes of expansion of this pandemic. The death toll increased due to insufficient medical services. Nearly 40 years later (1957), the first case of Asian flu caused by the influenza A (H2N2) virus appeared, becoming a pandemic in less than a year, associated with nearly one million deaths. Ten years later (1968), a new pandemic appears with the Hong Kong Flu, with the H3N2 variant of the influenza A virus, causing nearly one million deaths (Crespo 2022). In 1981, the first records of Human Immunodeficiency Virus (HIV) cases appeared. Since its appearance, this disease has affected millions of people and caused a large number of deaths throughout the world. Due to its scope and effects, it is a current pandemic, which is currently underway. 42 years after its identification, advances allowed it to be a treatable chronic disease, but there is still no cure (Naniche 2018).

Recently, in 2019, the first case of the pandemic produced by a new coronavirus (SARS-CoV-2), of zoonotic origin, appeared in the City of Wuhan (China). To date, it has not been possible to specify the intermediary animal. From the genomic comparison with the bat coronavirus (initially identified as a carrier), only 96.2% identical sequence was obtained (Zapatero and Barba 2023). This emerging pandemic has wreaked havoc on public health, as well as economic and social impacts. Until June 2023, the disease registered 689.7 million positive cases and 6.06 million deaths worldwide (TRT 2023). In July 2022, the first case of monkey pox (re-emerging zoonosis) was reported. Due to its worldwide distribution (in 110 countries), it is considered as a pandemic. Until June 2023, it registered 84,430 cases (PAHO/WHO 2023).

2. DISEASES, POTENTIAL RISKS AND CONTEXTS

Although epidemics such as Bovine Spongiform Encephalopathy (BSE), Severe Acute Respiratory Syndrome (SARS), MERS-CoV (Middle East Respiratory Syndrome), Ebola,

Dengue, Malaria are not included in this historical preamble, which have affected animals and humans (Wen-Hung et al. 2021).
Initially, the periods between one pandemic and another were very long. Between the Plague and the Black Death, seven centuries passed. Subsequent pandemics reduced their temporality to almost half a century and the recent ones (COVID-19 and Monkey pox) to less than a year. The circumstances (contexts) in which they appeared, such as war, poverty, environmental conditions, cultural practices and deficiencies in health systems are determining factors. Some diseases have remained endemic for long periods (viruses) and others as controlled diseases. A relevant aspect is that in recent pandemics diseases are associated with the emergence of new etiological agents and their variants, mainly viruses. Likewise, most of them are zoonotic in which wild species are involved (UNEP/IRLI 2020).
The convergence of social, cultural, economic and environmental factors is decisive in the appearance of zoonoses. The demographic explosion, changes in land use, the invasion of natural habitats, changes in agricultural and livestock production, commercial exchange, international travel, hunting and consumption of wild animals increase the risk factors (UNEP/IRLI 2020). These circumstances introduce modifications in the local contexts, altering the balances between pathogens and hosts. As a result, the ecological plasticity of pathogens promotes the appearance of variants associated with physical and biological environmental changes, which translates into a greater diversification of reservoirs and hosts, and an increase in diseases (Ariza 2016; Lorenzo et al. 2017).
Under these conditions, the potential risks increase and with it, the probability of the re-emergence and emergence of diseases increases that affect the health of humans and animals. Thus, the etiological agent-host-environment interaction is decisive. The great capacity for evolution of pathogens allows them to adapt to significant environmental changes, develop resistance to antimicrobials, diversify their hosts and increase their harmful effects on health. Changes in environmental conditions make originally hidden zoonoses (mainly in tropical areas where there is a greater diversity of mammals) begin to manifest with different levels of scope. The deterioration of natural habitats due to the occurrence of extreme weather events causes the displacement of wild species, a reservoir of pathogens confined to certain habitats, favoring the spread of diseases to peri-urban and urban areas. Although not all of these zoonoses can become pandemics, the truth is that the vast majority of pandemics originate as zoonoses (Losa 2021).

3. ENVIRONMENTAL DAMAGE AND PATHOGENS

One of the main causes of the increase in diseases is environmental damage. The alteration of natural habitats breaks the balance in the ecosystems, alters the population dynamics of the species that inhabit them and promotes a greater proximity of the human being with wild animals that are natural reservoirs of many pathogens. Human disturbances to ecosystems due to immoderate deforestation, establishment of monocultures, expansion of cultivation areas and cattle raising and increase in urbanization contribute to increasing the risks of contracting diseases (Alonso et al. 2022).
In addition to the consequences faced by events associated with climate change, the most significant consequence of environmental damage is the loss of biodiversity. By reducing the number of species, the risk of new diseases increases due to the exposure of the remaining species to new pathogens. The low specificity of pathogens for non-human hosts, their high biological flexibility, capacities and resistance are leading to an increase in zoonoses (García-Rubio et al. 2023).
UN/IRLI (2020) warned about the significant increase in zoonoses. They estimated that around 60% of new diseases in humans have a zoonotic origin. While 75% of new diseases

are associated with this origin, which highlights the close relationship between diseases and ecosystem health. Climate change, the loss of ecosystems and their biodiversity will continue to cause the emergence of new pandemics. A determining factor to preserve the health of humans and animals is to conserve biodiversity (IPBES 2019).
In addition to the diversification of hosts, the risks of zoonoses increase due to the diversity of pathogen transmission routes and the dispersal capacities of some reservoirs. Although in zoonoses, the reservoirs can be all vertebrates, the mammals play a fundamental role in the maintenance, transmission and spread of pathogens. The progressive exposure to natural habitats and proximity to wild species is increasing the risks. The role of bats and rodents as reservoirs of emerging zoonotic viruses stands out. In the case of wild rodents, displacement to nearby rural areas is increasing direct contagion through feces, urine, or other excretions or through vector transmission. This causes domestic species to be exposed and the disease spreads from wild rodents to humans (Monsalve et al. 2009; Torres-Castro 2017).

4. CURRENT APPROACH TO EMERGING AND RE-EMERGING ZOONOSES

One of the main potential risks of zoonoses is the diversity of diseases and etiological agents involved. In addition to those that are already known, the evidence of the effects caused by unknown pathogens and their variants means a potential problem for public and animal health (Rebollo et al. 2021).
Of the 182 diseases integrated in the World Health Information System (WAHIS) of the World Organization for Animal Health, 62 (34.06%) are identified as zoonoses. 29 are caused by bacteria, 22 by viruses (3 by rotavirus and 1 by Coronavirus), 4 by parasites, 1 by prion, 4 by protozoa and 2 by Rickettsia (WHO 2023). According to the report on emerging diseases (reported for the first time in some locations) for the period 2005-2023, information is recorded for 17 different zoonoses. According to the regions considered by the WOAH, 7 different zoonoses are identified for Africa, the Americas and Europe, 10 for Asia and 3 for Oceania. The largest total number of localities with registration is Europe (40). The zoonoses with the highest frequency are SARS-CoV (33), West Nile fever (16) and Newcastle disease (11) (Table 1).

Table 1: Emerging zoonoses by WHO region (2005-2022)

ZOONOSES	AFRICA	AMERICAS	ASIA	EUROPE	OCEANIA	Total reports/ zoonoses
Anthrax	2		3	2		7
Brucellosis (*Brucella suis*)				1		1
Avian chlamydiosis			1		1	2
Japanese encephalitis					1	1
Equine encephalomyelitis		2				2
Foot and mouth disease	8		1			9
West Nile fever	2	2	1	11		16
Rift Valley fever	5					5
Q-Fever				2		2
Leishmaniosis		1	2		1	4
Glanders			3			3
Newcastle	1	2	1	7		11
Rabies	2	1	4			7
SARS-CoV in animals	2	9	6	16		33
Trypanosomiasis		2				2
Tularemia				1		1
Camel pox			1			1
Different zoonoses	7	7	10	7	3	98
Total reports/region	20	8	16	23	3	70

Source: Own elaboration based on the processing of information from WOAH (2023)

The SARS-CoV with reports for 2020-2022, is emerging worldwide. The rest of zoonoses have previous records in other locations. For each zoonoses, the number of sick animals depends on the number of specimens, the prevention, control and follow-up measures and the breeding conditions. As an example, the analysis of Anthrax allows us to show the regional differences that may occur. In the last two years, it appears as emerging zoonoses in two locations in Kyrgyzstan (2022 and 2023) and one in Kazakhstan (2023). 1 positive case and 500 dead animals registered from Kyrgyzstan in 2022. The analysis of the general behavior shows the impact generated by this disease (Table 2).

Table 2: Cases of anthrax in animals by world region (2005-2022)

REGIÓN	DOMESTIC									WILD	
	Cattle		Sheep		Goats		Equines				
	Cases +	Deaths	Cases +	Deaths	Cases +	Deaths	Cases +	Deaths	NAE	Cases +	Deaths
Africa	95,801	11,376,660	42,702	2,297,770	11,957	736,877	9,560	1,053,359	32	5,268	47,670
Americas	5,017	237,901	245	10,950	20	57,411	74	541	4	1,111	2,225
Asia	15,512	6,330,078	26,473	6,670,603	3,006	353,073	392	18,606	7	1,071	352,795
Europe	1,283	2,148,862	2,250	1,946,006	103	20,922	33	11,714	10	2,716	142,358
Oceania	474	20,963	1,470	51,155	1	1					
Totals	118,087	20,114,464	73,140	10,976,484	15,087	1,168,284	10,059	1,084,220	42*	10,166	545,048

NAE= Number of affected species: * Considered different species: Source: Own elaboration based on the processing of information from WOAH (2023)

The positive cases and deaths produced make it evident that despite the strategies promoted by international agencies, preventive measures such as vaccination and control measures implemented, the disease continues to be out of control. In addition to these indicators, the recent appearance of emerging zoonoses in new locations in three regions of the world (Africa, Asia and Europe) reflects the current situation. The registration of a greater number of deaths compared to the positive cases gives indications of the absence of a timely diagnosis. This situation represents a serious risk in transmission (WOAH 2023).

The implications in terms of risk are oriented towards the fact that this disease can expand its distribution and continue to affect animals and people. In terms of impact, the large economic losses generated by the death of animals have an equal impact on food security. The largest number of deaths (32’259,232) corresponds to livestock species such as cattle, sheep, and goats, which are the basis of food in many locations. The problem tends to worsen when it sells the meat of animals that suffer from or died of the disease. The consumption of contaminated meat is one of the routes of contagion to humans, due to improper cooking processes. The affectation in domestic species (89 deaths in dogs and 19 in domestic cats were excluded) and 42 species of wild animals shows the magnitude of the problem that is faced only with this zoonoses.

This is not exclusive to these zoonoses. According to estimates, domestic animals share an average of 19 zoonotic viruses with humans, while for wild species the average is 0.23. This relationship means that a large proportion of zoonotic diseases involve domestic animals, poultry, pigs, cattle and sheep, mainly (UNEP/IRLI 2020).

Whether they appear for the first time in a locality, their incidence and infectiousness increases, or they adopt new forms of transmission. Emerging zoonoses represent a potential risk, due to the problem involved in combating them and the effects they can cause on animal and human health. By 2020, in the European Union, 364,260 patients associated with 24 different zoonoses were registered. Of this total, 18,134 required hospitalizations, registering 465 deaths and the majority (168) due to listeriosis (Table 3).

When comparing the frequencies reported for some of these zoonoses in animals and humans in the European Union, some aspects stand out (Table 4). In terms of correspondence of information in WAHIS (WOAH 2023), not all zoonoses are included in the list of diseases. Of the 24 zoonoses identified in humans, only 9 have been reported in animals. Even considering that those transmitted by vectors, by direct contact with soil contaminated with the pathogen (tetanus), or by the consumption of contaminated food, bovine tuberculosis, for example, has no records for that year. For some zoonoses, the registries only report information up to 2011 (such as Leptospirosis).

Table 3: Cases of zoonoses in humans in the European Union (2020)

ZOONOSES	Positive cases	Hospitalized	No. of deaths
Anthrax	3	2	1
Botulism	80	29	0
Brucellosis	132	38	2
Campylobacteriosis	120,544	8,605	45
Crimean-Congo hemorrhagic fever	132	38	2
Zoonotic chlamydiosis	161,984	0	0
Cryptosporidiosis	3,674	192	0
Equinococcosis	544	44	0
Giardiasis	6,252	179	0
Hantavirus infection	1,640	301	16
Leptospirosis	569	239	6
Listeriosis	1,887	775	168
Lyme Disease	740	2	0
Q-Fever	528	0	0
Rabies	0	0	0
Salmonellosis	52,690	6,450	61
Tick-borne encephalitis	3,699	408	62
Tetanus	32	8	5
Toxoplasmosis	133	21	5
Trichinosis	117	16	0
Tuberculosis	3,380	103	79
Tularemia	678	0	0
STEC/VTEC Infection	4,489	673	13
West Nile fever	333	11	0
Totals	364,260	18,134	465

Source: Own elaboration based on ECDC data processing (2023)

Table 4: Comparison of the effects of zoonoses in animals and humans. (European Union, 2020)

ZOONOSES	HUMANS			ANIMALS			
	Positive cases	Hospitalized	Deaths	Positive cases	Eliminados	Sacrificados venta	para Deaths
Anthrax	3	2	1	7	1	1	6
Brucellosis	132	38	2	16,563	151	8,505	0
Zoonotic chlamydiosis	161,984	0	0	404	0	0	47
Q-Fever	528	0	0	1,665	1	1	14
Rabies	0	0	0	13	4	0	9
Salmonellosis	52,690	6,450	61	331	2	40	0
Trichinosis	117	16	0	1,091	128	78	0
Tularemia	678	0	0	211	0	0	49
West Nile fever	333	11	0	434	6	6	95
Totales	216,465	6,517	64	20,719	293	8,631	220

Source: Own elaboration based on data processing from ECDC (2023) and WOAH (2023)

Based on these data, they show the differential effects of zoonoses in animals and humans. Additionally, it reflects how the control of some diseases prevents contagion to humans, such as rabies. For Chlamydiosis, positive cases in humans significantly exceed that in animals. By way of transmission, a single bird (especially pigeons) may be spreading the disease to a larger number of people. In the case of salmonellosis, different domestic species are carriers of the bacteria, increasing the possibility of contamination of water and food sources due to deposit of their feces. The irrigation of vegetables with contaminated water, together with inadequate disinfection, expands the transmission of the disease together with the consumption of contaminated meat with poor cooking or contact with infected people and animals. Deaths are generally the consequence of profuse diarrhea, dehydration and toxemia (CFSPH 2005).

Despite the fact that WAHIS (WOAH 2023) integrates information on different diseases, the records are incomplete. There are diseases that are not included in the database and others that do not have recent records. This consideration is relevant to avoid false interpretations. In the first case, the absence of records do not imply the absence of the disease; and in the second, that only up to the reporting year (such as Listeriosis, which only has records up to 2011), is that the disease remained in force. The lack of information decreases the opportunities to implement preventive actions and timely care. In the case of humans, only the European Union has reports that integrate the behavior of different diseases, which enables greater control (ECDC 2023).

Although for many of the zoonoses reported as emerging in some localities, the history of the disease makes it possible to activate response mechanisms to control them. The risks increase exponentially when it comes to newly emerging diseases. As happened at the time with Ebola, which presented its first outbreak in 1976 in the Democratic Republic of the Congo (PAHO/WHO 2019). The appearance of Legionellosis in 1977 with the infection of those attending the 58th Convention of the American Legion (Ferrer 2022). The first cases of HIV were detected in 1981 in Los Angeles and New York in the early 1980s (Carrillo and Villegas 2004), and recently COVID-19 (TRT 2023).

As emerging zoonoses, COVID-19 pandemic has generated great health effects. For animals, records from 2020-2022 are available. They include 8 countries from the Americas (Argentina, Brazil, Canada, Chile, Colombia, Ecuador, the United States, Mexico and Uruguay), 1 from Africa (City of Johannesburg, South Africa), 4 from Asia (Hong Kong, Japan, Myanmar and Thailand), 5 from Europe (Bosnia and Herzegovina, Croatia, Finland, United Kingdom and Switzerland) and no reports for Oceania. Affected species include 22 wild and 2 domestic animals. Dogs with a higher number of cases (139) than cats (91). Mustelids register the highest number of cases (239). In the wild animals, white-tailed deer (48), tigers (29), lions (27), gorillas (13), and snow leopards (10) are important (WOAH 2023).

In humans, until June 2023, the total number of positive cases was 689,756,705, the number of deaths 6,067,072 (0.88%), recovered 620,405,865 (89.95%) and active 59,584,453 (8.64%) around the world (Table 5) (TRT 2023; WHO 2023).

Table 5: Accumulated records for COVID-19 at the regional level (Report as of June 30, 2023)

Region	Affected countries	Cases	Deaths	Recovered	Active cases
African	51	9,225,847	185,770	9,354,921	369,525
Americas	49	195,757,193	2,961,675	188,412,934	2,841,469
Southeast Asia	16	69,108,292	327,366	67,388,851	308,070
European	63	278,083,268	1,943,044	255,277,243	19,091,349
Eastern Mediterranean	20	21,455,914	332,140	19,795,968	1,337,679
Western Pacific	31	116,126,191	317,077	80,175,948	35,636,361
Totals	**230**	**689,756,705**	**6,067,072**	**620,405,865**	**59,584,453**

Source: Own elaboration based on the processing of data taken from WHO (2023) and TRT (2023)

The total of the percentage values is 99.46%, with a difference of 3,699,315. The comparison of the information reported for Mexico (TRT) and that registered by CentroGeo (2023) which shows the same number of cases (7,633,355), deaths (334,336) and recoveries (6,885,378); however, there are differences in the number of active cases 413,641 (TRT 2023) versus 3,558 (CentroGeo 2023), so it is inferred that the differences are associated with this indicator.

According to TRT (2023) worldwide, the United States (107,352,160) followed by India (44,994,407) and France (40,138,560), are the countries that have accumulated the highest number of cases since the start of the pandemic. Based on the WHO division, at the regional level the highest values correspond to the European Region (278.08 million), the Americas (195.76 million) and the Eastern Pacific (116.13 million). By regions, the countries with the highest number of cases include South Africa, Lebanon and Zambia from African Region, United States, Brazil and Argentina from Americas, India, Indonesia and North Korea from Southeast Asia, France, Germany and Italy from European Region, Iran, Iraq and Jordan from Eastern Mediterranean region and Japan, South Korea and Australia from Western Pacific region.

The behavior of the pandemic presents variations in different countries and regions. The registered deaths with respect to the number of cases in addition to the relationship between these two variables reflect other relevant aspects. The United States with the highest number of registered cases, and 1,168,485 deaths, only reaches a 1.09% mortality rate. In contrast, Aruba with 442 cases and 236 deaths has a mortality rate of 53.39%, recognized as the highest worldwide. However, a more specific appreciation of the impact of the pandemic derives from correlating the population data with the number of cases and deaths to reflect its real impact. The ten countries with the highest number of cases and the highest number of deaths are included (Table 6).

In official reports, the main indicator has been the number of cases reported, to which the number of deaths is associated. From the calculation of the percentage proportion of these two indicators, although the United States reports the highest number of cases, the highest percentage of deaths corresponds to Brazil (1.87%). The same happens with the countries with highest percentage of mortality, where the highest value corresponds to Ethiopia (7,574 cases) but the highest percentage to Aruba (53.39%) (TRT 2023).

To show the variations, the population data of 2020 (year in which the death report begins) is taken as a reference. Due to the number of cases, the most affected populations are South Korea with a population density of 515 inhabitants/km^2 (62.23%), France 124 inhabitants/km^2 (59.33%) and Germany 234 inhabitants/km^2 (46.21%). Regarding the countries with the highest percentage of mortality, both for the number of cases and for the number of registered deaths; the list is headed by Ethiopia. By direct relationship, the highest percentage corresponds to Aruba. When relating these indicators to the population, the highest percentage of affected population is for Bermuda (2.95%) with a population density of 1,201 inhabitant/km^2 (WB 2023).

As can be seen, demographic data paints a different picture. India in second place by the number of cases (44.9 million), reports 0.12% mortality. Although the affected population is 3.22%, it is necessary to consider that its total population is just over 1.396 million inhabitants, with a density of 428 inhabitant/km^2. This data shows that the differences in the behavior of zoonoses are associated with population characteristics, which as a risk factor in the transmission of zoonoses, are of great relevance (TRT 2023).

On the other hand, re-emerging diseases correspond to those apparently controlled, and which cease to represent a health problem. However, under certain conditions these sometimes reappear with more severe ranges than with which these started. Therefore, these diseases represent a serious health threat. Diseases such as dengue, yellow fever, cerebrospinal meningitis, cholera, are some examples of these type of diseases (Rebollo et al. 2021).

Table 6: Impact of COVID-19 on the number of cases and deaths vs. population reported in 2020

Countries	Cases	Death	% Mortality	Population 2020	Population Density Inhabitants/km^2	% of affected population
COUNTRIES WITH THE HIGHEST NUMBER OF CASES						
USA	107,352,160	1,168,485	1.09	331,257,000	34	32.41
India	44,994,407	53,191	0.12	1,396,387,127	428	3.22
France	40,138,560	167,642	0.42	67,656,682	124	59.33
Germany	38,428,685	174,352	0.45	83,155,031	234	46.21
Brazil	37,682,660	704,159	1.87	211,756,000	25	17.80
Japan	33,803,572	74,694	0.22	125,849,000	332	26.86
South Korea	32,256,154	35,071	0.11	51,836,000	515	62.23
Italy	25,897,801	190,868	0.74	59,236,213	195	43.72
United Kingdom	24,636,637	227,524	0.92	67,081,000	275	36.73
Russia	22,963,688	399,649	1.74	146,171,000	9	15.71
COUNTRIES WITH THE HIGHEST PERCENTAGE OF DEATHS						
Aruba	442	236	53.39	106,585	595	0.41
Liberia	809	295	36.46	5,058,000	47	0.02
Malawi	8,877	2,686	30.26	19,377,061	168	0.05
Namibia	17,131	4,091	23.88	2,504,000	3	0.68
Lesotho	3,479	723	20.78	2,254,100	75	0.15
Yemen	11,945	2,159	18.07	31,927,000	63	0.04
Cameroon	12,509	1,974	15.78	26,546,000	59	0.05
Ethiopia	50,092	7,574	15.12	99,700,000	90	0.05
Djibouti	1,569	189	12.05	988, 000	43	0.16
Bermuda	1,886	165	8.75	63,893	1,201	2.95

Source: Own elaboration based on the processing of data taken from Expansión (2023), TRT (2023) and WB (2023)

Biological factors such as the expansion in the distribution of pathogens, their variability and genetic adaptability, the diversification of reservoirs and the reproductive capacity of the vectors are determining factors. Those of an anthropogenic nature include the effects caused in the environment such as climate change and environmental deterioration. Those of a socio-economic type (poverty, marginalization, overpopulation) tend to harm populations in certain regions. In general, these involve problems of systems management and measures to prevent and control diseases. These include deficiencies in sanitary systems, water supply and sanitation, as well as epidemiological surveillance and vector control. The set of these biological, anthropogenic and socio-economic factors are the main causes of the reemergence of diseases (Arredondo and Amores 2009; Hortal 2016).

The effects of these diseases can be localized, manifesting as outbreaks or endemic in some locations, or generate greater impacts due to their wide distribution and affected species. As latent risks, it is unpredictable to determine a new occurrence of the disease. When they do, despite previous experience, control is often difficult in cases where epidemiological surveillance is inadequate, contributing to the global public health burden (Suberbiel et al. 2017).

Of the recent re-emerging zoonotic cases, monkey pox stands out to be an important landmark. A disease that was first detected in humans in 1970 in the Democratic Republic of the Congo (DRC) and spread to other African countries (Cameroon, Ivory Coast, Liberia, Nigeria and Sierra Leone). The total number of cases reported in that year was 48 (36 for the DRC). In 1980, the number of cases increased significantly in the DRC (343) and 14 more cases occurred in the Central African Republic, 4 cases in Gabon and 1 each in Ivory Coast and Cameroon. In 1990, the cases continued to increase with 511 for DRC and 9 for Gabon. In 2003, in addition to continuing the cases in African countries, there was an outbreak in the United States with 47

cases, the only report outside of Africa. In Africa, in some countries the cases have been significantly reduced (Bunge et al. 2022). According to the WOAH, this disease occurs mainly in the African rainforest, and can sometimes be present in other regions of the world. In WAHIS, there is only one record for 2014 in Cameroon, with 6 positive cases in chimpanzees. In 2022, the zoonoses occurs in a pig farm in Boende, Domaine locality in the Democratic Republic of the Congo, which affects 16 animals and causes the death of two piglets (WOAH 2022).
The current reemergence of these zoonoses is generating greater impacts, which led to the WHO declaring it an international public health emergency in July 2022. The first outbreaks occurred in Canada and the United States, and on the Iberian Peninsula, in Spain and Portugal. As of June 2023, 84,430 cases have accumulated in 110 countries around the world and 119 deaths in the Americas. The highest figures correspond to the United States (43), Mexico (30) and Peru (20). Table 7 shows the accumulated data of monkey pox disease by WHO regions (PAHO/WHO 2023).

Table 7: Cumulative cases of Monkey pox in humans by world regions according to the WHO (2022-2023).

Region	Affected countries	Countries without case reports	Cases	Deaths	Countries with the highest number of registered cases
African	12	37	1,770		Nigeria (843), Congo (675) and Ghana (127)
Americas	31	12	55,887	119	United States (30,324), Brazil (10,961) and Mexico (4,031)
Southeast Asia	6	5	201		Korea (117), Thailand (56) and India (22)
European	44	14	25,912		Spain (7,559), France (4,146) and United Kingdom (3753)
Eastern Mediterranean	10	13	63		Sudan (19), United Arab Emirates (16) and Saudi Arabia (8)
Western Pacific	7	21	597		China (194), Japan (158) and Australia (145)
Totals	110		84,430	119	

Source: Own elaboration based on the processing of data taken from PAHO/WHO (2023)

It is noteworthy that the number of cases significantly exceeds previous reports of these zoonoses. With this, the consideration of the WOAH of being a disease that occurs mainly in countries of the African continent, and occasionally in other regions, is no longer applicable. The evolution of zoonoses in different regions and the gradual increase in affected countries is alarming (PAHO/WHO 2023).

5. DETERMINANTS AND POTENTIAL RISKS FOR ZOONOSES

The data shown, especially on the effects caused by the COVID-10 emergency and the reemergence of monkey pox, lead to the inference that under current conditions, potential risks tend to increase. In addition to the high probability that new diseases will emerge, there is also the possibility that endemic diseases widen their distribution or those considered controlled and even eradicated, may reappear with effects that are more significant (Rebollo et al. 2021).
The reference to "current conditions" is not limited to increasingly deteriorating and changing environmental conditions. Although environmental deterioration, climate change and the loss of biodiversity stand as possible conditions for the emergence of new diseases, various factors are also contributing to this problem. In general, they range from those inherent to the pathogens themselves, their vectors and reservoirs, to those that are clearly anthropogenic (IPBES 2019).

The multiplicity of factors associated with the potential risks for the emergence and re-emergence of diseases (most of a zoonotic nature) make it impossible to list each one. However, the indication of the main factors and associated risks will allow us to infer the complexity of the problem (UNEP/IRLI 2020).

6. ENVIRONMENTAL FACTORS

- Environmental deterioration is causing significant alterations in 75% of the land surface, 66% in the ocean and the loss of 85% of wetlands, which increases the number of threatened plant and animal species (IPBES 2019).
- Alterations in ecosystems contribute to the displacement of wild reservoirs, causing contact with domestic species and the emergence of zoonoses (Keesing et al. 2010).
- The increase in deforestation benefits the propagation of vectors and the transmission of diseases (IPBES 2019).
- Alterations in natural cycles and environmental stability produced by climate change increase the risks of zoonotic overflows and the emergence of epidemics (Sánchez 2021).
- Global warming and changes in rainfall are promoting the expansion of the geographic range of vectors and the spread of diseases (Mora et al. 2022).
- Variations in temperature increase vector populations and favor the life cycles of pathogens (Alonso et al. 2022).
- The increase in the emission of greenhouse gases (GHG) is aggravating 58% of diseases in animals and humans (Mora et al. 2022).
- The fragmentation of forests and jungles displaces rodent predators (pathogen reservoirs) (IPBES 2019).
- The sustainability of the species is at risk, affecting not only ecosystem functions, but also promoting the spread of pathogens (IPBES 2019).
- The loss of biodiversity extends the risks for disease transmission (Keesing et al. 2010).
- High temperatures or extreme environmental conditions increase host immunosuppression, favoring the development of diseases (Sánchez 2021).

7. FACTORS ASSOCIATED WITH PATHOGENS

- About 80% of pathogens can affect more than one animal species (multi-host) (Gortázar et al. 2007).
- Zoonotic viruses express a high genetic evolution and formation of highly infectious lineages (Bunge et al. 2022)
- Current human influenza viruses tend to be increasingly pathogenic because of a complex evolution associated with the mixing of viruses in domestic animals, mainly birds and pigs (UNEP/IRLI 2020).
- Increased resistance to antimicrobials (Hortal 2016).
- Pathogens that spread via the respiratory route have fewer barriers to spread from one host to another (IPBES 2019).
- Indirect zoonoses such as Zika, yellow fever and West Nile fever (reemerging) are becoming endemic in different regions of the world, due to the capabilities developed by pathogens (UNEP/IRLI 2020).

8. HOSTS AND RESERVOIRS

- Biological communities are increasingly similar, which are increasing their vulnerability to zoonoses (IPBES 2019).

- A significant number of diseases are under control in domestic species, but remain dormant in wild reservoirs (Gortázar et al. 2007).
- There is a higher viral load in animals with greater resilience to environmental changes (Ariza 2016).
- The translocations of wild and domestic animals represent risk factors for the appearance of zoonoses (Gortázar et al. 2007).
- Domestic and wild peridomestic species can function as transmitters of diseases to humans (UNEP/IRLI 2020).
- Host susceptibility associated with health status, sex, age, nutritional status, exposure history, genetics and immunocompetence that is decisive in the evolution of the disease (Ariza 2016).

9. TRIGGERING HUMAN FACTORS

- Population growth favors the appearance of misery belts in the urban periphery, susceptible to a greater diffusion of existing diseases and the emergence of others (Cabezas-Sánchez 2015).
- Unsustainable use of natural resources due to changes in land use, urbanization, agricultural and extractive activities (IPBES 2019).
- Development problems including poverty, marginalization, scarcity of drinking water, political and food insecurity and high dependence on livestock and wild animals as resources for subsistence (Suberbiel et al. 2017).
- Unsustainable agricultural intensification (more animals, genetically homogeneous and equally susceptible populations) that increases the risks of zoonoses (Rebollo et al. 2021).
- International travel and commercial exchange of food. Diseases move around the world in times less than the incubation periods (Wen-Hung et al. 2021).
- Increased intrusion into natural habitats, leading to increased contact between wildlife, livestock, and humans (Wen-Hung et al. 2021).
- Increase in the use and exploitation of wild species, due to increase in the consumption of game meat, sport hunting, animal trade, decorative products and medicinal uses (Monsalve et al. 2009).
- Expansion of informal markets that sell wild animals for human consumption without regulation, as well as deficiencies in processing plants (Losa 2021).
- Modifications in food supply chains that generate cross contamination, traceability problems and an increase in foodborne diseases (Rebollo et al. 2021).

10. PROBLEMS IN THE MANAGEMENT OF HUMAN AND ANIMAL HEALTH

- Zoonotic diseases of wild animals are generally not included in monitoring programs, despite of the fact that 70% of human diseases come from these species (Ruiz et al. 2010).
- The trade in wild animals increases the possibilities for the evolution of pathogens and the spread of zoonoses (WOAH 2015).
- Deficiencies in the biosecurity of livestock production systems can favor the emergence of zoonotic variants. For example, in Rift Valley fever cattle have functioned as an amplifying host for the virus that originally circulated in vectors such as mosquitoes and in wild species and now operates as a zoonotic virus (IPBES 2019).
- Countries with deficient health systems and epidemiological surveillance are especially vulnerable to zoonoses (WOAH 2015).

- There is a significant number of neglected zoonoses, widely distributed in developing countries, which increases the vulnerability of the population to contract other types of diseases (Ramírez 2012).
- The demographic explosion, livestock overproduction and the increase in pests have reduced the populations of wild animals and increased the risks for domestic animals and humans to participate as incidental hosts (Losa 2021).
- Foodborne zoonoses with a high epidemiological burden and greater impact on vulnerable communities, increase neglected zoonoses (Ramírez 2012).
- Deficient epidemiological surveillance (Rebollo et al. 2021).

11. CONCLUSIONS

The diversity of factors associated with the emergence and reemergence of zoonoses leads to the recognition that the potential risks are diverse and complex. Reversing or at least mitigating many of them (such as climate change), is a complex task and perhaps for many, it is impossible to achieve. Recent experiences, particularly with COVID and monkey pox, show not only the vulnerability, but also the uncertainty in which we currently live. The deficiencies in controlling them, the inability to address them and impede their progress, the exponential growth of deaths and the costs that they have meant, underscore the importance of addressing this problem proactively rather than reactively. The recognition of the multiple interrelationships that exist between animals, humans and the environment is unavoidable to deal more effectively with this problem. The One Health strategy that is being promoted seeks to address these aspects in a comprehensive and transversal manner, as an alternative to face the health risks that are currently faced in order to propose efficient measures that guarantee a better future.

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Future Prospects of Zoonotic Health Threats: Their Risk Factors, Preventive and Control Measures

04

Muhammad Mobashar

ABSTRACT

Zoonotic diseases originate from microbes with natural transmission potential from livestock to public sector. The current prevalence of zoonotic diseases imposes vital intimidations to human health due to close contact with domestic or wild animals. These diseases are mainly spread from animals to humans directly or indirectly. Global climate changes, growing populations, shifting trend of rural towards urbanization, livestock transhumance and traveling are the key factors in emerging zoonotic diseases. In most developing countries such as India, Pakistan and Bangladesh, policies like public health interventions and mass vaccination of livestock are not much effective due to lack of collaborations among policies makers, livestock and public health centers for disease outbreak. Literature cited that there are almost 13 different zoonotic diseases which are very alarming to livestock community, growing animals population, public health and economy of country. In sub-continent, major portion of population belongs to poor community which depends on livestock farming for income source. To mitigate these emerging diseases, the aptitude of local and global circle needs a factual assessment for the global health safeguard. For supportable public health program for detection, prevention, and control of these diseases in the region, the present condition in the region triggers a clear-cut and coherent need. Public health approach is combination of a joint coordination procedure, mutual planning, joint application, community input, capacity building and joint monitoring. The strategic plan for control of zoonotic diseases needs the stakeholders to start and consolidate measures for integrating technical, social, political, policy and regulatory issues to improve their capacities sufficiently to lessen the public health hazard and economic impact. The application of a worthwhile strategy is the mode onward for mitigation of emerging and re-emerging zoonotic diseases in the region. Active mitigation program presents an opportunity for covering health risks of international relevancy and make the world safer from the novel pathogens.

Keywords: Emerging disease; Epidemiology; Mitigation program; Pathogens; Zoonoses

CITATION

Mobashar M, 2023. Future prospects of zoonotic health threats: their risk factors, preventive and control measures. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 38-53. https://doi.org/10.47278/book.zoon/2023.004

CHAPTER HISTORY Received: 06-April-2023 Revised: 28-April-2023 Accepted: 12-May-2023

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1. INTRODUCTION

Zoonotic diseases are produced by microbes having potential of transmission naturally from livestock to public sector. The current prevalence of zoonotic diseases imposes vital intimidations to human health, particularly those who live in impoverished areas and have close contact with domestic or wild animals (Yasmeen et al. 2022). These diseases are mainly spread from animals to humans directly or indirectly (Fig. 1). Global climate changes, growing populations, shifting trend of rural towards urbanization, livestock transhumance and traveling are the key factors in emerging zoonotic diseases (Rahman et al. 2020).
Several zoonotic diseases have been described in detail in Table 1. In most developing countries such as India, Pakistan and Bangladesh, policies like public health interventions and mass vaccination of livestock are not much effective due to lack of collaborations among policies makers for disease outbreak, livestock and public health centers. In general, it has been noticed that much more concentration is given on preventive and control measures with very little attention to transmission and control work plan (Narrod et al. 2012). According to a survey conducted by Grace et al. (2012), there are almost 13 different zoonotic diseases which are very alarming to livestock community, growing animal's population, public health and economy of country. In sub-continent, major portion of population belongs to poor community which depends on livestock farming for income source (Zia 2009). Improper survey, immense assessment, lack of investigation activities and diminutive field-diagnostic services have been the likely reasons of hindrance in declaring exact prevalence of zoonotic diseases and their pathogens in the region (Grace et al. 2012). In such circumstances, some wise approach should be followed to eradicate negative impacts of zoonotic diseases at their initial stages and their further propagation (Abbas et al. 2014). A vivid investigation of the situation generates different assumptions which should be evaluated. Originally, this chapter will explore possible avenues in depth for expected public health threats of zoonotic diseases in future, risk factors and their control measures.

1.1. EXPOSURE OF HUMANS TO ZOONOTIC EFFECTS

More than 200 different forms of zoonotic diseases have been documented, which have considerable disease share in human population (WHO 2020). About 75% of emerging diseases are of animal origin while 60% from human source (Mohammadpour et al. 2020). Literature indicates that 0.6 million deaths occur in human population in a year mainly due to Rabies, Avian flu and Rift Valley fever. These diseases have hazards on human and animal health sectors and consequently cause poor performance in livestock and or finally death, which thus influence the economy of farming community and country (Thormaehlen 2021). Worldwide, there are 13 important widespread zoonotic diseases in low and middle economy countries which annually cause 200 million disease cases and approximately 3 million deaths in human population (Rahman et al. 2020). Professionally human population can be exposed to hazard effects of zoonotic diseases via following means:

- Endemic zoonotic diseases are most prevalent in poor human population and cause billions of sickness and millions of mortalities every year. These diseases commonly include cysticercosis, brucellosis, bovine tuberculosis, leptospirosis, and foodborne disease.
- Epidemic diseases usually occur rarely, which are few in number such as anthrax, rabies, Rift Valley fever, and leishmaniasis however, they may also occur in susceptible populations under favorable factors like sickness, starvation, change in climate, flooding, and poor immune system. Their incidence shows a high degree of chronological and spatial unpredictability (Grace et al. 2021).
- Arising zoonotic diseases probably occur repeatedly in the area (Grace et al. 2021). According to literature, zoonotic diseases are attributed 2^{nd}-3^{rd} of all emerging diseases (Fong 2017). Around

335 cases of zoonotic diseases have been reported based on literature published from 1940 to 2004 (Haider et al. 2020).

- Currently zoonotic diseases are exclusively spread via human-to-human transmission. These diseases mainly include AIDS, pneumonia, malaria, measles, and dengue fever and their intensity can be compared with endemic zoonotic diseases (Grace et al. 2021).

1.2. CLASSIFICATION OF ZOONOTIC DISEASES

Zoonotic diseases are usually classified based on etiological agents, reservoir hosts and pathogen transmission cycle (Table 1).
Classification according to etiological agents includes different microorganisms (Table 1) which cause zoonotic diseases. Important bacterial, viral, parasitic, protozoal, fungal/mycotic rickettsial and chlamydial zoonotic diseases along with their hosts and main effects are described in Table 1.
Zoonotic diseases based on reservoir hosts are anthrapozoonoses, zooanthroponoses and amphixenoses. Anthrapozoonotic diseases mainly occur naturally in domestic and wild animals. Leptospirosis, Rift valley Fever and rabies are the major examples of anthrapozoones. Zooanthroponoses like tuberculosis and amoebias, spread usually from humans to animals. Amphixenoses transmit from human to animals and vice versa. Streptococcosis and staphylococcosis are grouped under amphixenoses.
Based on pathogen transmission cycle and epidemiology, zoonotic diseases are classified into orthozoonoses, cyclozoonoses, metazoonoses and saprozoonoses. Orthozoonoses propagate from diseased vertebrates to susceptible vertebrates either directly or indirectly. Brucellosis, rabies and trichinosis are its some important diseases. Spread of cyclozoonotic diseases need two or more host vertebrates for transmission of infectious agent. These diseases are subdivided into euzoonoses and non-obligatory. In euzoonoses, life cycle of agent does need human as a host for disease transmission. Taenia solium and taenia saginata are typical examples. In non-obligatory cyclozoonoses, transmission of disease and completion of life cycle of causing agent involve human as a host by accident. Hydatid disease and toxoplasmosis are examples. Spread of metazoonotic diseases needs two hosts: vertebrate and invertebrate for disease transmission. However, in invertebrate host, infectious agents may multiply, develop and remain dominant. Based on involvement of hosts, metazoonoses are further sub-divided into metazoonoses type I, II, III and IV. In metazoonoses type I, one host each from vertebrate and invertebrate is involved for transmission disease. This type includes yellow fever and plague. Type II needs three hosts, one host from vertebrate and two hosts from invertebrate for disease transmission such as Paragonimiasis disease. Metazoonoses type III also needs three hosts, two vertebrates and one invertebrate for agent transmission. Clonorchiasis is only one example of this disease. Metazoonoses type IV is transovarian transmission and its common example is tick borne encephalitis. Saprozoonotic diseases, in addition to vertebrate and invertebrate hosts necessitate substance site or reservoir such as plants, soil and some foods for completion of agent life cycle and transmission of disease. These diseases are sub-divided into saproanthrapozoonoses, saproamphixenoses *and* saprometanthrapozoonoses. Saproanthrapozoonoses require substance other than animal for transmission into humans. Cutaneous larva migrans and ancylostomiasis are its typical examples. Saproamphixenoses are equally shared in nature by man and animals. However, these are transmitted via non-animate substance. Major examples of this disease are histoplasmosis and fungal infections. For completion of life cycle of agent and transmission of saprometanthrapozoonoses, vertebrate and invertebrate hosts in addition to substance are required. Fascioliasis is the only one example of this disease.
Some important sources of transmission of zoonotic diseases are presented in Fig. 1 and 2 show people at more risk and most susceptible groups, respectively.

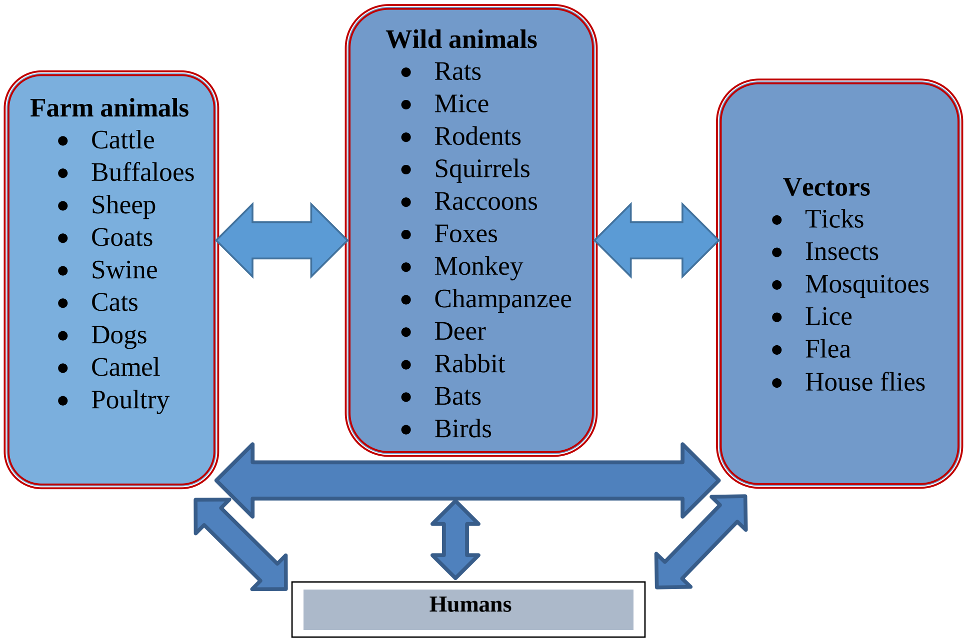

Fig. 1: Sources of zoonotic diseases transmission

1.3. ZOONOTIC DISEASES IN FRAME OF ENVIRONMENTAL DYNAMICS

Rising zoonotic diseases are by description in a flux process, which occur, multiply in host or geographically, or change. in pathogenicity, virulence, and or additional drivers are involved. Indeed, anthropogenic and environmental variations are essential zoonotic drivers which include deforestation agricultural encroachment, urban sprawl, climate change, and anthropogenic change like biodiversity loss (Anderson et al. 2004). Their mode of action is mostly through multifarious alleyways that are not well understood. This can be cleared from examples like, fragmentation, which can be due to, residential growth, which usually causes biodiversity loss; linked to Lyme disease risk (Allan et al. 2003).

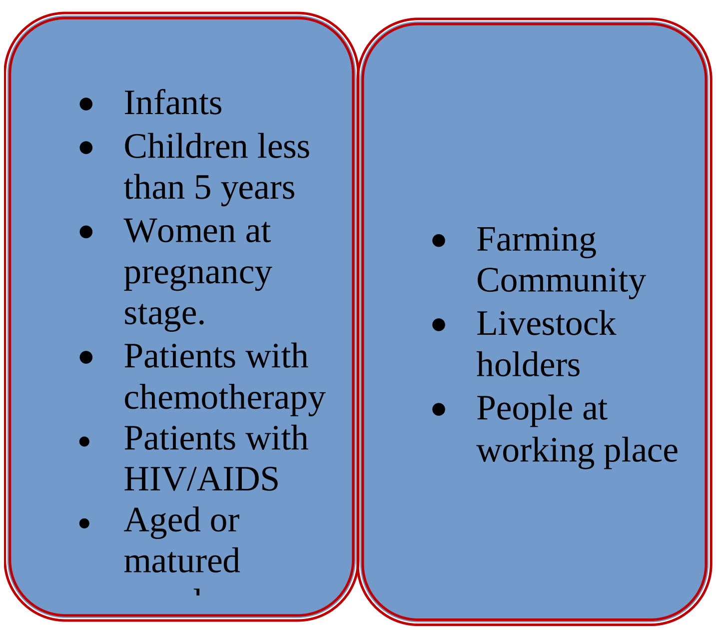

Fig. 2: People at more risk

Deforestation has increased quickly since the commencement of the 20th century. Though reforestation, has been accomplished in certain advanced nations, like the US and some zones of Europe, and up to 3% of global forests lose every year with maximum losses in tropical countries. Deforestation causes various ecosystem consequences such as it reduces habitat existing for wildlife creatures. It also alters the environmental frame, i.e. by segmenting habitats into little patches, separated by agricultural events. Deforestation and changes in land-use and human settlement patterns have caused higher prevalence of malaria and its vectors (Bauhoff and Buch 2020). Clearance of forests by road construction causes erosion and makes areas to be publically colonized (Caliskan 2013). Cleared lands and channels under roadways collect rainwater are favorable for malaria transmission- anopheline mosquitoes (Suwonkerd et al. 2013). Deforestation and water logging usually expose people and- animals to new pathogens in the area of bush meat hunting. Later, variations in land-use carry some of these pathogens and migrate them to increase the susceptibility of habitats and populations.

Fragmentation of wildlife habitat is unique anthropogenic land-use variation, changing host composition in an environment and basic microbial ecology. Little patches usually remained after fragmentation lessens target populations, by predators' destruction and an increase in the target mass. Slighter fragments in the forests of some developed belt like US have some animal predators and enhanced bulk of white-footed mice, which is a big reservoir for Lyme disease pathogen such as *Borrelia burgdorferi*, where people have higher risk of this disease. In habitats with less modification, alternative and less competent reservoirs diversity overcome diluting effect (Johnson and Thieltges 2010). Diluting effect is a buffering effect for risk of disease that is vanished during habitat fragmentation. Agriculture covers plenty of the world's productive land and consumes more than 2/3 (67%) of the world's fresh water (Tang et al. 2021). Increasing irrigation shrinks water supply for other purposes and therefore enhances breeding locations for disease vectors.

Growth in international trade of food has caused many disease outbreaks and the incidence of new agents. Import of strawberries, by US from Mexico, raspberries from, Guatemala, carrots, from Peru, and coconut milk, from Thailand has caused some outbreaks recently such as food-borne diseases in meat and vegetables. This accounts for more than 7 million sicknesses, 323,000 hospitalzations, and 5,100 causalities in US annually (CDC 2005) in the frame of essentiality of food security.

Some lesser health impacts on agricultural production coming from pathogen tolerance against antibiotics use in animal residues in groundwater from farm- run-off, and micro-dams for irrigation, in Ethiopia promoted in malaria up to seven folds (Gerald et al. 2009).

Modifications in natural resources and ecosystems are also causing agents for incidence of diseases. Human infringement on wildlife habitat may cause probability for occurrence of new and emergence of known communicable diseases (McLennan and Plumptre 2012). We take the example of rabies in animals, and has adapted, to, urban environment. Bats habitats: skunks, and raccoons, are the important breeds of dog and hunt human waste; and in several states, street dogs, are the main causing agent for infection in humans (Singh et al. 2001).

Climate Change in greenhouse warming forecast can cause cholera, malaria, dengue and leishmaniasis which are water and vector borne diseases, respectively, which are mainly determined by an increase in rainfall causing good conditions for vectors, intermediate and reservoir hosts (Campbell-Lendrum et al. 2015). Furthermore, a robust linkage occurs between El Niño-Southern Oscillation (ENSO) and prevalence of RVF, cholera and hantavirus (Anyamba et al. 2009). ENSO cycles are at extreme due to climate change, cause extensive and greater effect. Secondly, growth of vectors responsible for bluetongue and African Horse Sickness in Northern Europe will expose Europe to outbreak of these diseases (Wilson et al. 2009).

Table 1: Etiology, animal host, zoonoses and major organs and effects in human

Etiology	Animal host	Zoonosis	Organs/systems/ effects involved in humans	Type of microbe	References
Brucella abortus, Brucella melitensis, Brucella suis, Brucella canis,	Cattle, sheep, goats, pigs and dogs	Brucellosis	Poor appetite, Body weight loss, high fever in afternoon, pain in back and joints	Bacterial	(Hayoun et al. 2023)
Bacillus anthracis	Horses, ruminants (cattle, sheep and goats), wild animals (mink, bison, elks, white-tailed deer), pig and dogs	Anthrax	Skin, organs interlinked with respiratory system and gastro-intestinal tract	Bacterial	(WHO 2008)
Mycobacterium bovis, Mycobacterium caprae, Mycobacterium microti	Cattle, sheep, pigs, deer, wild boars, camels and bison	Tuberculosis	Lungs, bones (bone marrow) and nervous system	Bacterial	(Heemskerk et al. 2015)
Mycobacterium leprae	Mouse, rat, cat and monkey	Leprosy	Lesions in skin	Bacterial	(Truman et al. 2011)
Arcobacter butzleri, Arcobacter cryaerophilus, Arcobacter skirrowii	Cattle, sheep, swine and poultry	Arcobacter infections	Pain in abdominal, vomiting and fever	Bacterial	(Vandenberg et al. 2004)
Actinomyces bovis	Cattle, sheep, horses, pigs, dogs, and other mammals	Actinomycosis	Swelling of soft tissues, lymphatic nodes, skin, and abscess	Bacterial	(Valour et al. 2014)
Borrelia burgdorferi	Horses, dogs and cat	Lyme disease or Borreliosis	Fever, headache, rashes on skin or erythema migrans	Bacterial	(Radolf et al. 2021)
Campylobacter jejuni, Campylobacter coli	Cattle and sheep as main ruminants, poultry, swine, dogs, cats, mink and ferrets	Campylobacter enteritis	Enteric disorders like diarrhea, fever, stomach cramps, sometime nausea and vomiting	Bacterial	(Igwaren and Okoh 2019)
Corynobacterium ulcerans, Corynobacterium, Pseudotuberculosis	Cattle, dog and cat	Corynebacterium ulcerans and Corynebacterium pseudotuberculosis infections	Difficult breathing, heart rhythm problems, and even death may occur	Bacterial	(Dias et al. 2011)

E coli O157:H7	Cattle, sheep, pigs, deer, dogs, and poultry	Enterohemorrhagic Escherichia coli infections	Enteritis and Hemolytic–uremic syndrome (HUS)	Bacterial	(Fatima and Aziz 2023)
Helicobacter pullorum, Helicobacter suis	Poultry and pigs	Helicobacter infection	Peptic ulcer	Bacterial	Kusters et al. 2006)
Vibrio parahaemolyticus	Most common farm animals	Vibriosis	Enteritis	Bacterial	(Bell and Bott 2021)
Salmonella enterica, Salmonella bongor	Cattle, sheep, goat, horse, pigs, rabbits, cat, dog and chickens	Salmonellosis	Enteritis	Bacterial	(Grünberg 2020)
Pastuerella multocida	Cattle, buffaloes, sheep, goats, deer, poultry, pigs, cats and dogs,	Pasteurellosis	Fever, vomiting, diarrhea and gangrene	Bacterial	(Wilson and Ho 2013)
Influenza A virus Genus—Alphainfluenzavirus Family—Orthomyxoviridae	Ducks, chickens, turkeys, wild birds, dogs, cats pigs, whales, horses and, pinnipeds	Avian influenza	Flu, diarrhea, and pneumonia	Viral	(Capua and Alexander 2004)
Rabies virus, Genus—Lyssavirus Family—Rhabdoviridae	Dogs, wolves, cats, bats, monkey and cattle	Rabies	Affected nervous system/CNS	Viral	(Koury and Warrington 2023)
Paramyxovirus, Genus—Avilavirus Family—Paramyxoviridae	Poultry and wild birds	Newcastle disease (ND)	Conjunctivitis, loss of appetite, coughing, gasping, nasal discharge, watery eyes, bright green and diarrhea	Viral	(Alexander 2009)
Dengue virus Genus—Flavivirus Family—Flaviviridae	Monkeys and dogs	Dengue fever	High temperature, rashes and hemorrhages in skin hemorrhage, and depressed	Viral	(Hasan et al. 2016)
Hantavirus Genus—Orthohantavirus Family—Hantaviridae	Mice, rats, shrews, and moles, house mice, roof rats and Norway rats	Hantavirus Pulmonary Syndrome (HPS)	Breathing issues and affected lungs, fatigue, fever and muscle aches, dizziness, chills, nausea, vomiting, diarrhea, and abdominal pain.	Viral	(Moore and Griffen 2023)

Rift Valley fever virus Genus—Phlebovirus Family—Bunyaviridae	Buffaloes, cattle, sheep, goat and camels	Rift Valley fever (RVF)	Fever, muscle and joint pain, and headache	Viral	(Paweska 2014)
SARS coronavirus (SARS-CoV) Genus—Coronavirus Family—Coronaviridae	Bats, dogs, cats, ferrets, minks, tigers, and lions	Severe acute respiratory syndrome (SARS)	Fever, pain in muscle, respiratory disease and pneumonia	Viral	(Hodgens and Gupta 2023)
Monkeypox virus Genus—*Orthopoxvirus* Family—*Poxviridae*	Squirrels, Gambian poached rats, dormice and monkeys	Monkey pox	Skin with pox lesions and fever	Viral	(Moore et al. 2023)
Trichinella spp (nematode). e,g. *T. spiralis*	Pets (dogs and cats), pigs, mice and wild animals	Trichinosis	Vomiting, diarrhea, anorexia, pain in abdomen and myalgia	Parasitic	(Furhad and Buchari 2023)
Fasciola hepatica, Fasciola gigantica	Large and small ruminants	Fascioliasis	More bleeding, fever, nausea, inflamed liver, lesions/rashes on skin, and severe pain in abdomen	Parasitic	(Good and Scherback 2023)
Cryptococcus neoformans	Cattle, sheep, goats, horses, dogs and birds	Cryptococcosis	Issues in lungs, fever, nausea, and vomiting	Parasitic	(Del Poeta and Casadevall 2012)
Coccidioides immitis, Coccidioides posadasii	Dogs, farm animals, deer, horses and pigs,	Coccidioidomycosis	Coughing,low appetite, limping, enlarged joints, fever, diarrhea, abscesses, draining lesions), fever, and weight loss	Fungal/mycotic	(Dobos et al. 2021)
Sporothrix schenckii	Common pets (dogs and cats), horses, mules, ruminants (cows and goats), camels, swine, birds, rats and dolphins fish,	Sporotrichosis	Lesions ulcerate and discharge a serohemorrhagic exudate. lesions on head, nose and pinnae (cat), fever, listlessness, and depression and respiratory signs may occur	Fungal/mycotic	(Barros et al. 2010)
Cryptococcus neoformis	Common pets (cats and dogs), horse, ruminants, birds, and Other forest animals	Cryptococcosis	Inflamed membranes of brain and spinal cord, illness, fatigue, headache, neck rigorousness, photophobia, cough, nausea, and vomiting	Fungal/mycotic	(Chayakulkeeree and Perfect 2008)

Histoplasma capsulatum, var. capsulatum	Pets (cat, dogs), rabbits (bucks and does), and mice	Histoplasmosis	Mostly affected but no symptoms, sickness, cough, pain in chest, loss in body weight, infected liver cells, and disturbance in hematology	Fungal/mycotic	(Develoux et al. 2021)
Rickettsia prowazekii	Dogs, young ruminants, donkeys young camels	Louse-borne typhus, also called epidemic typhus	Increase fever, cephalalgia (headache), fast breathing, pain in body and muscle, rashes, cough, nervous system manifestations, nausea and vomiting	Rickettsial	(Ogrzewalska et al. 2017)
Orientia tsutsugamushi	Mice, rats, squirrels, prairie dogs, porcupines, beavers, guinea pigs, and hamsters	Scrub typhus	Pyrexia, dermatitis, body and muscle aches, increased rate of breathing, cough, and diarrhea	Rickettsial	(Rapsang and Bhattacharyya 2013)
Coxiella burnetti	Ruminants, pets mainly dogs and cats, poultry commonly chickens, and wildmammals	Q-Fever	High temperature and rashes on skin	Rickettsial	(Mostafavi et al. 2012)
Rickettsia rickettsia	Mice, rats, squirrels, dogs, guinea pigs, and hamsters	Tick borne typhus/rocky mountain spotted fever	High temperature, headache, rashes on skin, myalgia, abnormally decreased body weight, nausea, vomiting, pain in abdomen and eyes sensitivity to light	Rickettsial	(Graves and Stenos 2017)
Chlamydia felis, Chlamydia trachomatis	Very common in cats and mice	Chlamydia	Conjunctivitis, inflammation of urethra, cervix and pelvic, disturbed pregnancy, infertility, inflamed epididymis and arthritis	Chlamydial	(Bressan et al. 2021)
Chlamydia abortus	Cattle., horses, sheep, rabbits, pigs and, cats	Enzootic abortion	Typically characterized by abortion	Chlamydial	(Al-Ahmed and Salman 2020)
Trypanosoma brucei	Eland antelope, cattle, camels, and horses	African sleeping sickness	Increased fever, headache, nausea, vomiting, and development of erythematous (reddish) plaque	Protozoal	(Checchi and Barrett 2008)
Trypanosoma brucei	Antelopes, cattle, camels, and horses	Trypanosomiasis	Prolonged fever, headache, itching, swollen lymph nodes, swollen and enlarged liver and spleen, and disturbance in sleep	Protozoal	(Algehani et al. 2021)
Leishmania infantum	Bats, cats, dogs, and horses	Leishmaniasis	Lesions on skin, Swollen and enlarged liver and spleen, and wasting	Protozoal	(Mcgwire and Satoskar 2014)
Toxoplasma gondii	Swine, small ruminants including rabbits and Poultry birds	Toxoplasmosis	Swollen lymph glands, muscle aches and pains, headache, fever, inflammation of the lungs, heart muscle and eyes	Protozoal	(Dubey 2009)

Prion protein	Ruminants, mink, deer, and elks	Mad Cow Disease, also known as Bovine spongiform	Memory loss, changed personality, lack of coordination, unclear language, blindness, abnormal and shaking movements and brain and mobility loss.	Acellular non-viral pathogenic agents	(Setbon et al. 2005)

1.4. ECONOMIC IMPACT OF ZOONOTIC DISEASES

Generally, an increase in population, urbanization and per capita income results in increased utilization of animal feed source. This not only encourages livestock producers and other channels, but also expands and improves their businesses sector to fulfill consumer demand (ASL2050 2017a). In a business environment, which is being speedily changed, profits are often unreliable due to competitive, operational, legal and financial and other risk factors having greater impact on profitability of livestock industry. In such circumstances, some livestock farmers and enterprises are successful, and they will survive and expand business; while others relieve themselves from livestock industry due to failure. For the livestock business sector, the vital part for any administration is to implement some rules and regulations that make successful transformation of the sector in the future. If the government fails to consider the above keys, then it may cause degradation of grasslands, microbial water pollution, emission of greenhouse gas (CH_4), epidemics and zoonoses, which damage livestock industry and diminish wellbeing in society.

Zoonotic diseases targeting animal-human boarder are a major hazard for society by attack on livestock industry and therefore diminish human capital (Ari et al. 2022). This reduction in capital could be estimated by a zoonotic disease like avian influenza, during its peak, reduced chicken meat production, up to one third in China (Huang et al. 2017), and the 2009 swine flu pandemic, in Mexico infected over 100 million people with a death toll of about 20 000, (Nathason 2016).

The fiscal impact of the zoonotic diseases on livestock and public health sectors is determined by taking the sum of the losses (cost in US dollars):

- Loss of livestock
- Production loss due to infected livestock
- Loss of humans due to mortality (social cost)
- Number of morbid humans (social cost)

In cattle farming systems, a diseased animal will either be dead, be discarded, be slaughtered, or live with poor productivity at infected stage. Cost of animals' loss as well as cost of reduced production due to prevalence of disease in animal can be computed.

The cost of treatment (sick animals) is not usually considered because of negligible expenditure of farmers and veterinary services (CAHI 2015). So in such case, cost of animal loss is determined by sum of

- Number of dead animals multiplied by price of an adult animal at farm
- Number of condemned carcasses multiplied by price of an adult animal at farm.
- Number of carcasses from partially/not condemned animals multiplied by 30% discount in farm price of an adult animal
- Number of unborn calves (due to reduced fertility) multiplied by price of young animal at farm.

Cost of reduced production in survivors is estimated by taking sum of:

- Number of lactation periods loss (number of unborn calves/diseased and infertile females multiplied by milk yield per lactation
- Price of 1 lit milk in market

- Number of female infected and with no fertility loss multiplied by av. reduction in milk (lit) and market price of I liter milk.
- Number of survivors multiplied by av. dressed weight lost and market price of 1 kg beef.

In poultry farming systems, diseased birds may die, be culled or slaughtered, or suffer from reduced production (meat and or egg production). For some fatal diseases with high risk, the whole bird flock might be slaughtered precautionary and therefore such birds are not included in infected/diseased birds. In case of slaughtering, the birds can still be consumed, although they likely have not reached full slaughter weight. The treatment cost of sick birds is not considered due to the factors described above under cattle system while calculating economic losses.

Cost calculation of Loss of meat purpose birds is determined by taking sum of:

- Number of diseased killed multiplied by cost of live bird at farm
- Number of culled birds multiplied by cost of live bird at farm
- Number of slaughtered birds multiplied by price of live bird at farm.

Economic loss due to reduced egg production in surviving laying hens is quantified from number of surviving hens multiplied by reduction in eggs produced (number) and market price of egg.

By considering humans, transmission of zoonotic diseases from animals to humans occurs via direct and indirect contact, vectors and food consumption. Therefore, different groups of people face different risks of these diseases. To estimate the impact of morbidity and mortality of zoonotic diseases in public health sector, we have split the population at risk in three extensive groups (i) non-livestock holder and non-consumers of animal source foods (ii) non-livestock holders but consumers of animal source foods (iii) livestock holders and consumers of animal source foods. In such case, Economic loss in humans due to zoonotic diseases by taking sum of:

- Total number of survivors multiplied by number of working days lost and the daily weight measuring the severity of the disease and minimum wage/head/annum
- Total number of deaths multiplied by years of life lost

1.5. PREVENTION AND CONTROL MEASURES OF ZOONOTIC DISEASES

For minimizing the hazards of zoonoses in different sectors, the most suitable guidelines for the authorized bodies in that region are to develop plan for disease mitigation. The strategic plan should include the following considerations:

- Operative Structure Between Livestock and Human Health Sectors

To fight against sudden emerging of zoonotic disease, it is essential to establish strong coordination, between livestock and human health sectors. This alliance will enhance linkage, network and communication between public and organization sectors (Rahman et al. 2020). The task force developed from this collaboration can lead this practice towards building up strong agreement and partnerships through joint field investigation and share institutional resources for active mitigation measure at the animal–human level.

- Successful Investigation for Early Detection of Disease

Because of pool of emerging zoonoses in animals or/and in arthropods and difficulty in prediction exactly, investigation at the first sign of a new disease emergence in livestock is specifically important to detect disease threats (Meurens et al. 2021.

- Consolidation of Diagnostic Capacities for New Pathogens

Laboratory services should be strengthened with diagnostic potential be effective in detection of zoonotic disease in the region. Establishing laboratory networks inland and outland can enhance fast delivery of samples for timely analysis (Belay et al. 2017).

- Standardization in Case Management/Case Definition and Disease Mitigation

Health care facilities for disease threats should be ensured. An effective program with standard precautions for disease control should be exercised prior to disease occurrence. Most transmission through exposure to blood and body fluid can be prevented through standard precautionary measures before any zoonotic disease is recognized (Fesseha et al. 2022).

- Assimilating Management of Vector Mitigation

To optimize the use of resources for effective vector control, an integrated vector control management (IVM) strategy should be considered for all arthropod-borne viruses. This approach encourages interventions usage, either alone or in combination, which is based on confirmation and integrated management of mosquito's vectors. IVM is, therefore, most active effective stratagem for vector mitigation, responsible for transmission, of arthropod-borne viral hemorrhagic fever.

- Role of Social and Behavioral Interventions in Diminishing Transmission

The behavioral response of exposed populations determines the success or failure of interrupting the intermediate vertebrate hosts for most of the new zoonotic diseases. Awareness of the community's risk and, how this relate to intended behavior, socio- or psycho-cognitive factors need to be considered to plan appropriate social and behavioral interventions for disease threats (Vrba et al.2020).

- Evolving Epidemic Vigilance and Capacity Building for Novel Zoonotic Diseases

There should be a national plan including all key stakeholders. This plan should focus on distribution of zoonotic diseases in the region via, geographic information systems, other information technologies and risk assessment (Yasmeen et al. 2022). Also, identification of regions at high risk, improvement in investigation on human, animal and vectors and linkage of their data and then dissemination are very important in order to exchange important information on risks through well-established mechanism on a regular basis between these sectors.
Lastly, it is also important to monitor and evaluate the progress of this strategic plan for disease mitigation; officials should consider the following elements:

- Augmenting political commitment, national planning and coordination mechanisms
- Strengthening vigilance, surveillance and response
- Building national capacity and promoting research
- Improving regional and international cooperation and collaboration
- Linkage among health education, risk communication and social mobilization

1.6. USE OF ONE HEALTH APPROACH

For mitigation of zoonotic diseases, international organizations and researchers developed the liaison among public, livestock and environment sectors. This relationship is accepted and approved as a concept which is called "One Health Concept or Approach". This approach is designed to manage global health issues (Bidaisee and Macpherson 2014). One Health Approach inspires collaborations among different professionals like wildlife biologists, veterinarians, physicians, agriculturists, ecologists, microbiologists, epidemiologists, and biomedical engineers to warrant health for livestock, public and environment (One Health Commission 2020). In developing countries, this approach through control of zoonotic diseases has broad effects on poverty and food and health security. For preventing prevalence of zoonotic diseases, the partnerships of multi-sectors are intensively needed for maintaining surveillance among the human, animals, and environment. For control of zoonotic diseases, one health approach recommends (1) establishing "Zoonotic Disease Unit" for health security of above sectors (2) developing national plan for "Zoonotic Disease Unit"; (3) involving leadership from multi-sectors and relevant personnel to conduct zoonotic disease research; (4) implementing veterinary public health policies with collaborators from outlands and (5) reviewing

the zoonotic diseases on routine basis to address prevalence of diseases through surveillance, epidemiologically and laboratory tests (Pieracci et al. 2016).
In summary, the one health approach plays a vital role in addressing the prevalence and mitigation of zoonotic diseases among humans, animals, and environment sectors to make the globe free from intimidations of these diseases.

1.7. CONCLUSIONS AND FUTURE PERSPECTIVES

The region is now carried by effects of different zoonotic diseases. Therefore, these novel diseases occur as unexpected and unpredictable events. Secondly it has been observed that prevalence of any disease today could be a serious issue tomorrow for the globe and it appears to continue to provoke the resilience of National Health Authority and timely response. Similarly, to mitigate these emerging diseases, aptitude of local, and global circle will be a factual assessment -for the global health safeguard. In spite of global efforts to bridge the present gap in information related with the origination and transmission of several zoonotic diseases novel in the region, regional teamwork with greater focus would be required to safeguard, the public health. For supportable public health programme for detection, prevention and control of these diseases in the region, the present condition in the region regarding response to these diseases triggers a clear-cut and coherent need.
"Public Health" approach comprising a joint coordination procedure, mutual planning, joint application, community input, capacity building and joint monitoring and evaluation program, for livestock -human health sectors should be the basis for task-plan of team work for mitigation. This approach should also highlight following key areas, where public health approach is expected to make a difference:

- Sharing health resources between the medical and veterinary sectors
- Mitigating zoonotic diseases in animal reservoirs
- Quick identification and action against developing diseases.
- Prevention of epidemics and pandemics
- Generating awareness and value addition to health research and development.

The strategic plan also needs the stakeholders, to start and consolidate measures- for integrating technical, social, political, policy and regulatory issues to improve their capacities sufficiently to lessen the public health hazard and economic impact. The application of a worthwhile strategy is the mode onward for mitigation of emerging and re-emerging zoonotic diseases in the region. We suggest The Regional Main Power to consider and adopt the strategic guidelines described here. Active mitigation programs will present an opportunity for covering health risks of international relevancy and make the world safer from novel pathogens.

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Risk Assessment for Anthropogenic Socioecological Drivers of Zoonotic Diseases and Possible Controls

05

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ABSTRACT

Zoonotic diseases are reminder of devastating health situations all around the world. It is estimated that 6 out of 10 major zoonotic pathogenesis spill-over from host vectors to human. Densely populated anthropogenic societies are met with serious zoonotic outbreaks from several socioeconomical, geographical, ecological and climate changes drives. Some natural epidemiological drivers include anthropogenic swift transmission, linked with emergence and re-emergence that increase possible contact from wildlife-livestock to human populations. These drivers shape epidemic and pathogenesis situations globally. Such as rapid transmission of zoonotic diseases founding big challenges across the dense human vulnerable settlements. Therefore, it is needed to understand the anthropogenic socio-ecological drives and their interactions to managing prevention and control for public health in future. Although awareness of zoonotic diseases for health importance is strengthening, the knowledge about interactions among anthropogenic drivers are still poorly understood. As a result, socio-ecological vulnerabilities increase the chances for zoonotic outbreaks. In this study, we found several examples that how anthropogenic socio-ecological, biological and climate drivers influence the main cause of zoonotic diseases, driven by human behavior on ecosystems, mobilization, habitat encroachment, and development. Given the anthropogenic drivers nexus, we concluded that natural and anthropogenic drivers are intensely interlinked with zoonotic diseases outbreak.

Keywords: Zoonosis, anthropogenic drivers, ecological factors, control, socio-ecology.

CITATION

Sindhu L, Mangi SS, Akram M, Mangi HN, Song Y, Li L, Cui H, Guo W and Men X, 2023. Risk assessment for anthropogenic socioecological drivers of zoonotic diseases and possible controls. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 54-73. https://doi.org/10.47278/book.zoon/2023.005

CHAPTER HISTORY Received: 12-Feb-2023 Revised: 28-April-2023 Accepted: 12-July-2023

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1. INTRODUCTION

Zoonotic disease transmission is a current issue all over the world, most of human and wild type population are prone to be host for these pathogens from an unfavorable environment. These human-animal interfaces increase the chances for direct or indirect possible contact among various vectors, hosts, or infectious agents (carrier) (Soulsbury et al. 2015; Hassell et al. 2017). Zoonoses term coined by World Health Organization (WHO) from pathogenic or microbial infections acquired from wild type animals, threatening, and posing risk issues to public health (Daszak et al. 2007). Pathogens can switch from one host to another, resulting in different pathogenicity. This diverse nature reflected zoonosis that is influenced by anthropogenic drivers, such as socio-economic, climate, or urbanization, etc., (Fèvre et al. 2006).

Through rapid changes in anthropogenic demographics and geographical migration, resulted into the recruitment of persisting diseases in the system. For example, export-import transportation, migration and mobilization, globalization, urbanization, animal transportation. Some chemo applications on land as usage of agrochemicals, antimicrobial agents and insecticides also may trigger the chances for genetic drift and reassortment in pathogens. The emergence of disease is also influenced by climate drivers; temperature, humidity, drought, floods, rains, deforestation and wind, transportation may include goods exchange, travelling, animal transportation and marketing, meat consumption, and human-wild type interfacing. These risk drivers are proposed contributors and are more likely to be direct or indirect threats for emergence or re-emergences of any zoonosis outbreak (Jones et al. 2013).

The dispersion and causes of risks of the disease evolution has been under investigated since long (Woolhouse and Gowtage-Sequeria 2005). Several infections are hidden and insidious and perceived substantial host history in ecological niche. However, evolution of these alarming agents to public health is not one-way question. There are multifactorial set of anthropogenic driver involvement for the dispersion and emergence of zoonotic disease. Major circumstances such as regional farming of wild type animals, inappropriate hygienic conditions, supply chain of meat and nutritional goods, invasive agricultural applications, breeding of enormous animals may result to spread infections across the barrier (Combs et al. 2022).

Furthermore, the rapid growing demography of human population, increasing encroachment practices on natural lands or mobilization due to tourism provide risk opportunity for novel disease exposure (Gu et al. 2021). In zoonosis, the climate and environment drivers are serious issues of this century, re-emerging and expansion of disease vectors are promoted through compatible conditions. It is speculated that the next centuries will be more challenging to understand epidemiology of new pathogens in different regions (Rupasinghe et al. 2022).

Collective anthropogenic drivers can affect evolution, genetics, dispersion, and origin of the pathogens. This result into the rise of novel variants that could alter the fitness of ecological niche including human-wild type animal hosts dynamics (Bajpai and Watve 2022). These alterations are alarming to control pathogenic potential due to development and emergence of anthropogenic activities. Rising risks and symbiotic social vulnerability are obstacles to predict zoonotic diseases. Understanding about this question that how human, animal and host have different susceptibility for causative agent? Thus, both living in the same environment. Therefore, it is important to know the possible causative roots and their interactions that are involved for potential zoonotic diseases. It is possible to control the risk by assessing large scale habitat and anthropogenic fragmentation that increase after socio-ecological drivers (Ma et al. 2023).

Here, implementation of this study is to provide possible roots of the anthropogenic drivers with theoretical assessment method by summarizing climate, ecological modeling, risk assessments, vectors, prevention, and control of zoonotic dynamics. In this work, we provided co-occurrence network analysis to describe the strong and weak inter-links between the host and vector associations. Analysis of vector information can provide better understanding for microbial nature and host preferences. Anthropogenic drivers could be useful to predict the dispersion of zoonosis. Moreover, control and prevention are highlighting the present pathways to amend the new procedures and protocols in future. Taken all together, here we provided useful information that may help researchers to provide basics in zoonotic risk management systems.

2. ECOLOGY AND MODELING OF ZOONOTIC DISEASES

Ecological modelling is an alternative concept to predict distribution of species according to climate or environment by using different algorithms, mathematical modules, or geographical charts representations. It may vary according to preferences of data that cover climate data such as humidity, precipitation, and temperature. Some factors may represent this involvement with host and pathogens. Furthermore, soil, water type, depth, land area and mountains can also be included. Modelling may include species dispersion modelling, socio-ecological modelling, predictive habitat modelling, enviro-envelope modelling, and ecological niche modelling, etc. In the zoonotic disease system, some researchers use this concept with more simplifications as climate envelope or ecological niche, to elaborate the resistance of species that exist in the tolerable and confined range of geographical environment. These niches are inhabited by vectors, hosts, and pathogens (Peterson 2006).
The basic concept about ecological models was suggested by Urie Bronfenbren during 1970. Concept emphasizing that zoonotic disease is interlinked with human development that is influenced from upper level to lower level or individual to federal state level (Blaga et al. 2007). However, unlike climate factors, individual central circle is influenced by various factors, such as school, family, workplaces which create microsystem. This microsystem is surrounded by belief and knowledge of the person. In contrast, another concept is parallel knowing as exosystem can also be known as outer circle, including social network, government policy and regulation that constitutes informal structure (Robinson 2008). With passage of time, these levels have been revised and modified systematically. For example, individual and community, representing social cultural activities and outputs. Ecological, the institutions and states are policy makers with higher level that having great impact on the system. This model has gained attention by researchers since long to understand the epidemiology of the zoonosis and the treatments on different levels as shown in Table. 1.

Table 1: Socio-ecological categories and its characteristics

Category	Community	Characteristics
Centric	Individual / microsystem	Age, gender, economic status, education, knowledge, attitudes, behavior
Outer circle	Socio-cultural / Exosystem	conception on syndrome, severity and precautions, family, social networks, peers, cultural background
Middle circle	Ecological / Exosystem	Weather, tourism, outdoor activities
Upper circle	Policy / Exosystem	Collaborations, Health management, laws and regulations, federal health policies, health structures and safety

Some literature claimed that zoonotic diseases are independent of more than one species, therefore modelling systems can be ground as presence, absence, or data availability based on distribution dynamics. Modelling of zoonotic disease is a vector-host approach, as already discussed three approaches, it may differ among human and pathogen. For example, some zoonosis is similar with data approach and may act differently from human to human (Zeimes et al. 2012). Thus, comparison of exiting methods by applying any of model is important to consider host and vector species approaches (Pandit et al. 2022).

Generally, zoonosis is a complex model because of numerous factors involvements, such as human interactions, hosts, pathogen, and environment. In this situation, combined potential model (host-vector) can be used for both species distribution, however results and approaches may differ significantly due to mentioned influences of factors. Previous reporters collaborate the recorded data in points, they usually correlate unit organism, location and reported disease (Lambin et al. 2010; Zeimes et al. 2012). While others are investigating the availability of host and pathogen using independent variables (Hassell et al. 2021). Finally, all models follow different methods according to demographics, geographical area, and climatic factors to uncover the best model for zoonosis between host and pathogen.

3. RISK ASSESSMENT FOR ANTHROPOGENIC SOCIO-ECOLOGICAL DRIVERS OF ZOONOTIC DISEASES AND POSSIBLE CONTROLS

Zoonotic disease emergence is major threat for any country or region. Infections have negative impacts on human- wild type animals, crops, and livestock health all over the world (Fisher et al. 2012, Zhang et al. 2022). Zoonoses (Greek word: *Zoon*; animal, *Nosos*; illness) is the major infection that originate from natural environments and within populations (Doherty et al. 2021). The most of zoonosis is highly influenced by the activities of anthropogenic and sudden environmental changes since past decades. It is assumed that before spread of zoonosis, predicting infection emergence was one of the useful health approaches at global level (Zinsstag et al. 2011).

Accordingly, the triangle relationship between animals, humans, and environmental health has a significant role in the emergence and spread of various pathogenic infections (Thompson and Kutz 2019). Once Asia pacific strategy for emerging diseases (2010) released that about 60% of diseases are zoonotic that infect humans. Those related to zoonotic agents are exceeding than 70% those originated from wild type animals (Rahman et al. 2020). Additionally, it has been estimated that accounting for 61% of the zoonotic pathogens are from animal-human (Taylor et al. 2001). It is speculated that novel epidemic zoonosis in humans is a naturally driven source directly from animal origin or carrier animal. (Rahman et al. 2020). WHO (World Health Organization) also proposed the zoonotic diseases are directly linked from animal-human interface.

According to WHO, transmitted pathogenic infection or disease from the natural environment containing vertebrate animals-human or from human-animal sources are known as zoonotic disease. Sometimes, zoonoses is lethal to public health and results in increasing death ratio among deprived countries, due to poor health hygienic condition and improper medical facilities. At the world level, it has been observed that up most 13 major threatening zoonotic diseases have serious impact on poor workers of the low-middle income countries that dwell livestock or forest keepers. Annually, illness and death rate are accounting for 2.4 billion and 2.7 million after zoonosis affects the public health (Grace et al. 2012). Including livestock and animal health, decrease in production has also been noticed gradually, due to negative influences after zoonotic diseases. The anthropogenic intrusion after globalization in ecosystem have also altered the scenario of zoonotic disease, these alterations are disruptive, resulting in more emergence and dispersion of the zoonotic agent. Therefore, anthropogenic drivers play a key role for zoonotic pathogens among hosts (Quaresma et al. 2023).

3.1. ANTHROPOGENIC DRIVERS INFLUENCING ZOONOTIC PATHOGENESIS.

Anthropogenic drivers can be divided into behavioral and ecological categories. The behavioral anthropogenic strategy emphasizes how to deal with disease. It also includes the drivers which are involved in this zoonotic pathogenesis. The possible effect of anthropogenic behaviors with the relationship of disease can also be understood through network analysis (Fig. 1). This briefly described some major zoonotic diseases, for example, Brucellosis, Leptospirosis, Anthrax, Japanese encephalitis, Nipah virus, Canine/cystic echinococcosis, Campylobacteriosis, Rabies, Avian influenza, Hepatitis E, specific/ nonspecific, Tuberculosis and their interactions with general behavioral anthropogenic drivers. Besides, recently anthropogenic socio-ecological drivers have gained more attention due to anthropogenic activities that influence wildlife genetics and human risk health issues. Moreover, some zoonotic origins are land scale-pathogen interactions (Eisenberg et al. 2007), urbanization-animal health interactions (Mackenstedt et al. 2015) that emphasis the combined role of the urbanization and human activities for the zoonosis in cities. However, detailed surveillance of the anthropogenic driver interactions still needs to be investigated to improve the control of zoonosis in metropolitan and shallow economics cities. Though combined efforts required to work within effective collaborations, that often drive the single entity performances for prolong control. This can be organized between public health sectors, wild type animal experts or biologists, urban policy makers, local and health communities, researchers, hazard managements of the urban cities, etc. Multi-partnerships are the sincere solutions to adopt and mitigate serious zoonotic problems (Ramaswami et al. 2016).

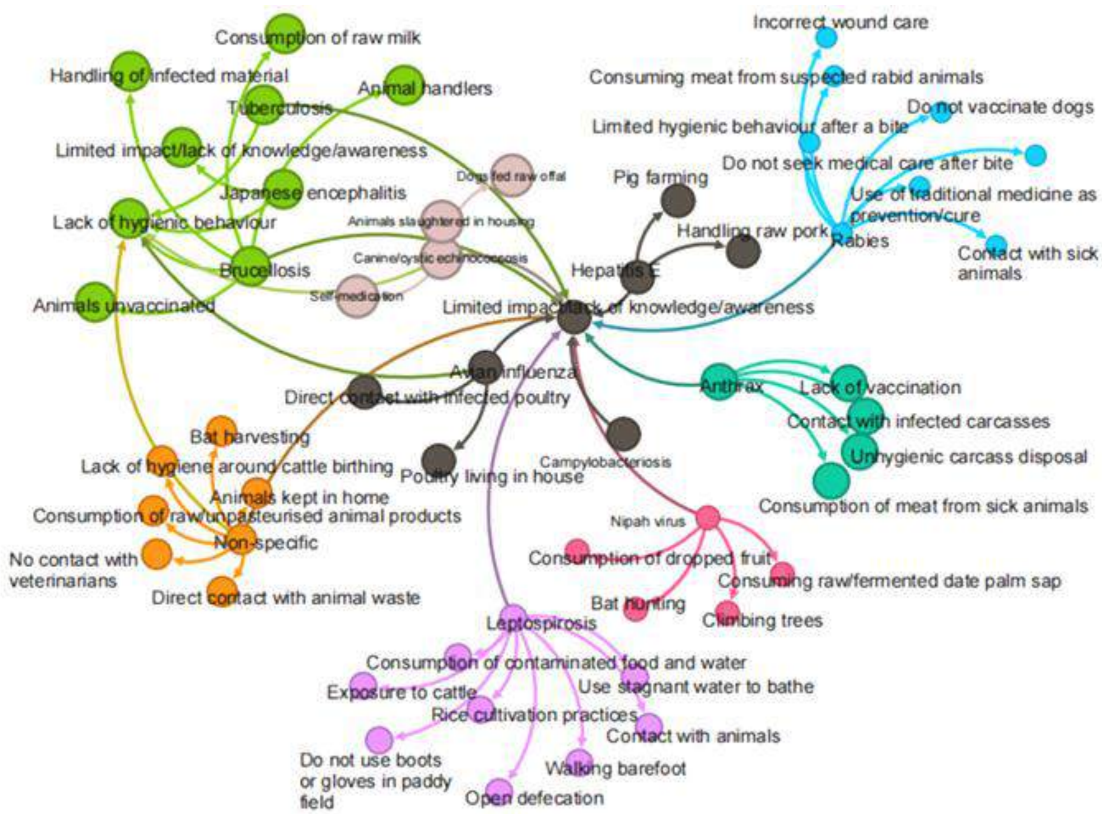

Fig. 1: Network modeling for behavioral anthropogenic vectors interactions with the major zoonotic diseases and their interrelationship.

In the endeavor, anthropogenic drivers are generally based on climate factors, tourism, deforestation, agricultural practices, mega-building construction, soil intensification, and urbanization. These drivers are escalated globally from time to time, manipulating the pathogen vectors in rapid transmission from one community to another, that is also supported by socioeconomic processes. These socio-economical drivers then increase the emergence rate of zoonoses from animal to human. Indeed, in 2020 various zoonotic epidemics changed the scenario of global researchers and public health concerns, such as Ebola outbreaks, SARS-CoV-2, Lassa fever, and many severe outbreaks seriously affect the economy, society's behavior, and public health. Due to past zoonotic outbreak experiences zoonotic diseases are being highlighted in the view of pandemics alertness (Gibb et al. 2020).

3.1.1. ZOONOTIC PATHOGENESIS

The pathogenesis of zoonotic disease could be considered as the series of processes to establish successful symptoms of disease after achieving transmission from animal to human. Thereby accidentally human became host for zoonotic agents. However, some zoonotic pathogens are reservoir in animals and humans at the same time. Pathogenesis can also be differentiated into a few stages such as entry route of transmission, increasing the progeny by replication, propagation of progeny into the targeted organ, then establishment of disease inside the respective organ. This pathogenesis by which an infectious agent acquired replication itself in human or animals solely depends on specific receptors (cell or organ) on the targeted organ, type of injury, immunity of the host, and remaining defensive factors. Later, after succession of entry and replication, pathogens have to outcome by termination of disease, persistence, or expectancy of the disease, change the host by transmission, or combination of these steps (Singh et al. 2017).

However, zoonotic infections and pathogenesis are not followed by series of infection, it differs from bacteria or virus. Some zoonotic diseases are following very complex mode of actions that have been acquired from nature. For example, yellow fever has zoonotic sylvatic cycle, that first starts into nonhuman primates then moved to urban cycle in human (Childs et al. 2019). Zika virus, similarly, followed sylvatic cycle in Africa region then urban cycles were emerged into Asian strains (Valentine et al. 2016). Common transmission of zoonoses is considered from animal to human, following random illness and epidemics. In rare instances, infectious agent is asymptomatic and circulating within population until it become opportunistic pathogen (Li et al. 2021).

The pathogenic process is dependable upon pathogenic agent and its pathogenicity potential or degree of pathogenicity, defined by capability to invade or damage cells or tissues of host and fertility rate (Singh et al. 2017). Number of Bacteria and virus mediate the pathogenicity/ virulence using host machinery and relevant factors which are genetically (DNA) under control by plasmids, chromosomes, bacteriophages etc. In addition, the persistence of chronic diseases is merely regulated by genes and their expressions. However, zoonotic pathogenesis still needs more efforts for understanding the direct mechanism, neither indirect nor subtle to open the bottle neck problem as basic model for particular infection.

3.1.2. ZOONOTIC VECTORS

One of the prominent anthropogenic ecological drivers is land cover. Understanding the association between land encroachment and diseases risk is mainly focused on favorable environment or habitats for vector and host reservoir interaction (Hassell et al. 2017). The interactions between infectious agent, vector and reservoir host are influenced by socio-ecological drivers (Fig. 2). These drivers are altered through climatic conditions and macro-economy for the development and dispersion of zoonosis. Vectors are potential tools to complete the transmission cycles in preferable environment or habitats, depending upon potential agent and host health, and the population of human residing in the infected areas. For some vectors water is a potential habitat to increase population within certain areas (Rocklöv et al. 2020).

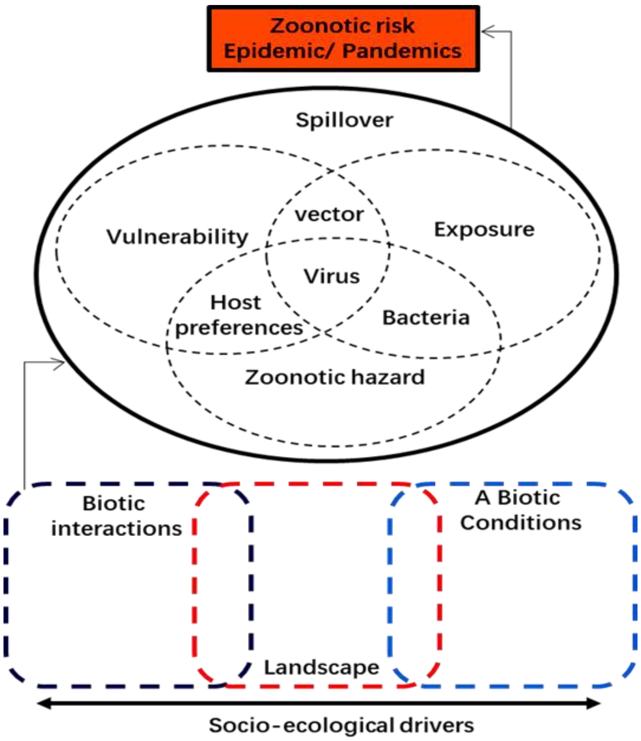

Fig. 2: Thematic flow highlighting the major relationship between zoonosis factors that how socio-ecological drives connected with spill over and zoonotic hazard, a foundation of component ultimately influencing the zoonotic risk.

It has been observed that prolonged water logging and water holding practices in rice fields increase the rate of contact between malaria vector and people (Linard et al. 2009). Floods, rainwater retention, poor drainage system managements have maximum abundances of mosquitoes, fleas and tick population that result in vector-borne zoonotic diseases. Connection rate between human habitat and vectors dynamics may not result in high level of risk outbreak if landscape is unfavorable. Vector-borne disease in the case of mosquitoes is important through special diffusion of time. Resultantly, landscape feature plays a major role to control such vector movements, such as at night, mostly female vectors are mobile and feeding on immobile livestock-animal and human. These flying vectors spread malaria, dengue, and typhoid causing agents from breeding sites to host. In general, arthropods like fleas, ticks and mosquitoes are often suggested as vectors; while animals that transmit zoonotic pathogens into human are also considered as vectors (Huang et al. 2019).

3.1.3. BACTERIA AND VIRUS RELATED ZOONOTICS

Bacteria and virus zoonosis both are endless topic with emergence and re-emergence of zoonotic diseases. Exceeding number of infectious agents and potential of pathogenesis may vary by means of transmission and epidemiology, including food borne and vector borne zoonosis. Transmission of bacteria can be done through different routes, such as it may occur from external skin injury (bites, scratches, and rashes) (Morrison and Grant 2001). Bacteria zoonosis can also spread through fecal oral route from animal foods or feces. Veterinary and farmer workers are at high risk due to wide exposure of zoonotic pathogens that can easily be dispersed through workers to other communities. Some vectors, contaminated soil and water management also contain the diversity of zoonotic agents. Most infections related to bacteria can be controlled by using antibiotics. However, re-emerged diseases that had been treated with improper (over usage or misuse) antibiotics, have developed resistance, and are at increasing public health risk all over the world (Laws and Thomas 2022).

Unlike bacteria zoonosis, virus zoonotic risk is different due to mode of replication and transmission. Trait-based analysis is often used to assess zoonotic virus agents (Wang and Crameri 2014; Binnicker and Matthew 2021). More research is required to address why and how questions for identification which based upon reservoir and viral type interactions (Heeney 2006). In terms of degree of virulence within population, mortality and morbidity rate may also vary due to severity of disease that is caused by potential agent. For example, Hantaan (HTNV), Corona, Japanese encephalitis, Rabies, and COVID-19 is associated with highest death ratio. So, predicting the conditions, such as longitudinal studies, epidemiology, and regional scale demography of the animal- wild type and human interface by which zoonosis occurs has significant role.

3.2. CHALLENGES FOR ASSESSING THE RISKS DRIVERS OF CLIMATE CHANGE

Anthropogenic driven vectors have created imbalance in the ecology and human relationship. Resulting climate crisis has emerged and is growing faster than expectations than previous predictions for 50 years (Ripple et al. 2022). Demography has been elevated almost 190% that accelerated visible changes in social environment (Collins et al. 2020). This indicated that the climate would change more than present conditions. The social environment is strongly coupled with increasing human population activities. Human migration from unfavorable to favorable environments from wetlands to dry lands may happen in future. Because sea levels are increasing gradually as compared with past decades (Bongaarts 2019).

The relationship between human-animal and vector interfaces with related communities are dynamically very complex (Fig. 3). Interactions among wild type-farm animals, vector habitat and human interface are strongly linked with seasonal changes and water management that are interconnected. Therefore, imbalance of one factor would influence the host. The trends by which spillover triggered potentially to human are usually crucial. For example, where and when zoonoses occur among people? What driving factors were common in that affected area? etc. The potential degree of pathogenesis of hazard also depends on anthropogenic drivers, such common practice is land encroachment; resulting disturbance in animals-vectors diversity from one place to other, hunting of wild type animals without proper dumping or improper handling and consuming meat, house management to keep clean environment, improper sanitations, and unfavorable weather conditions (Morris et al. 2020).

However, the realized zoonoses risk can be considered with vulnerability of infection, either at population or individual level. For example, proper health care, distance to access the health centers, nutrition (Bedford et al. 2019). The Eco-transitional affect by global warming give rise to temperature, therefore, geographical distribution of infectious agent and relevant vectors are swiftly brought in contact with animal or human (Wu et al. 2016). It has been observed that lack of thermostatic mechanisms in several pathogens and vectors are taking advantage of temperature fluctuations for successful zoonosis (Tazerji et al. 2022). Even systematic surveillance of emerging zoonotic disease and its relative influence was difficult to observe from natural and geographical perspectives (Shanbehzadeh et al. 2022).

Somehow, socioeconomic and ecology of the population is not similar after zoonotic incidence. Taken two examples of Ebola during 1976 and COVID-19 of the present time to understand this phenomenon. Ebola confirmed cases were only 25 and COVID-19 pandemic cases data is very huge, in both cases the spillover of small and large data is still difficult to conclude the involvements of risk drivers, and other factors by analyzing the anthropogenic data alone. Considering the anthropogenic and ecological framing of zoonosis such as mobility and population ratio of vectors-animals and humans may help to overcome such outbreaks and difficulties in natural system (Hosseini et al. 2017). Data information from host-animal and pathogen genetics, ecological landscapes, biogeographical areas and seasonal various can be used to assess the present and future zoonotic risks. To track vector traction and ecological process by using modelling methods can be used to improve understandings of zoonoses at narrow and broad levels (Gibb et al. 2020).

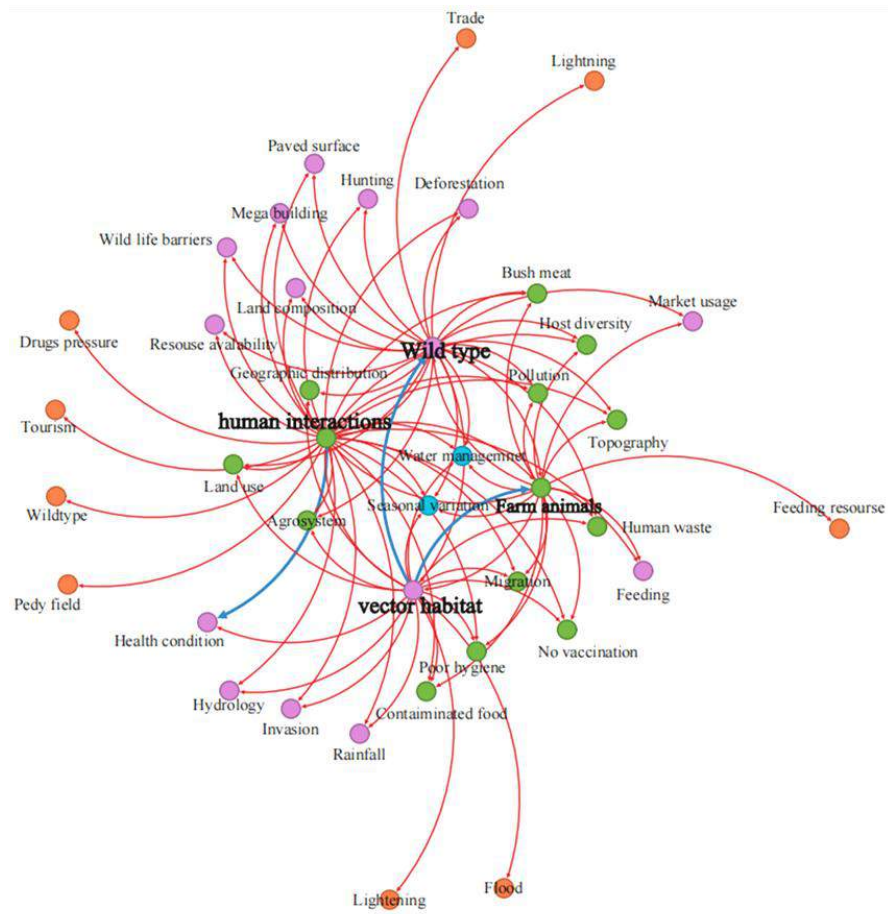

Fig. 3: Network modeling for anthropogenic drivers' interaction with the Human interface, Wild type, farm animals and vector habitat interrelationship. Different colors represent modularity class (37% - 5%), red lines indicate overall interactions and blue lines represent strong interaction.

3.2.1. ANTHROPOGENIC AGROECOSYSTEM

Agroecosystem is the study of agricultural management and natural resources for the evaluation of agricultural system (Liu et al. 2022). Researchers prioritize this field to analyze development activities by creating zones around agricultural fields. Information is collected by applying holistic systematic approach within the environment, to expose the key problems for their developments, research hypothesis, expansion, and programs. Most of analysis depends on retrieved secondary data that contains both socio-economical and bio-physical report information (Doherty et al. 2021; Winck et al. 2022). In zoonosis, we observe both examples such as bio-physical related major parameters which include water management, geology, infrastructures, soil physiochemistry, topography and covered area. While socio-economic data highlight the systems of agricultural land, agroforests, ethnicity, poverty issues, drugs or opium consumption and surrounded local markets (Bengochea et al. 2020).
This methodology can monitor collected information after conducted workshops and other rural tools. Anthropogenic agro-systems are interlinked with wild animals and other related diverse species that include feed crops or revive vegetation (pigs, livestock, poultry, rodents, dogs, or carnivores) and rely on prey or hunting (Winck et al. 2022). The cultivation and water systems

support the growth of airborne vectors. A collective agro-anthropogenic system creates a close interface on daily routine practice in different ways among domestic-wild type animals, human and vectors. Establishing the situations for zoonotic agents and rapid transmission (Plowright et al. 2017). Prevalent anthropogenic socio-economical activities out of agro-systems zones such as vendor, bush meat and vegetables selling in markets can modulate zoonotic outbreaks. Predicting zoonosis is hard and very challenging, as migration increases, including diversity of animals and vectors harboring various types of pathogens (some with vector or without vector). Once researchers identify the key risks related with zoonotic causative agents, assessment techniques can be implemented to evaluate the impact. Then after, assessment data information can help to modify existing solutions to control the potential risk in agroecosystem (Liu et al. 2022).

3.2.2. CATEGORICAL BIOTIC AND ABIOTIC FACTORS

In zoonoses, anthropogenic drivers reflected the spatial ecological landscape transformation leading to proximity of biotic and a biotic factor (Combs et al. 2022).

1.2.2.1 BIOTIC DRIVERS

Biotics can be defined as the interaction between different species (humans and vectors) and wild type animal communities, towards the abiotic factors and social behavior on landscape, that shape the zoonoses risk and pathogenicity. Thereby, zoonotic disease burden and animal-human interactions may directly affect. (Shaheen 2022). The identification and zoning of the zoonoses is conditional at understanding that which resources modify this zoonotic disease? How does inter/ intra animal-human interaction occur within diverse communities and infectious agent references? and how or which type of species are involved in the process of distribution and dynamics? Nowadays with technological advancement, we can define these questions by collecting data and modelling. The available biotic set of infectious agents include inhabitant vectors, animals and host that can be found locally. The way of usage of human, animal or vectors by pathogen is an important perspective in dispersion (Estrada-Peña 2014). These dynamic interactions between host and causative agent are generally decided by the responses of host immunity and then zoonotic outbreak on dispersal (Becker et al. 2018; Jo 2019).

1.2.2.2 A BIOTIC DRIVER

The anthropogenic alterations are significantly driven by the changes in landscape conditions. The elevated temperature, pollution, noise, radar, lights, hydrology, mega building structures, confined housing schemes, metal contaminations, wastage triggered the downstream impacts on animal-human-vectors interactions with associated zoonotic agent (Morris et al. 2020). The intensity of zoonoses also changed according to alterations in urban tradeoffs and impervious surfaces. For example, migration of birds towards attracted lights and their excretions containing pathogens fed by vectors disperse among urban areas (Brinkerhoff and Folsom-O'Keefe. 2011), noise and lights could invite arthropod vectors and insects (Combs et al. 2022), however, downstream molecular effects are currently unknown for zoonotic disease transformation (Igietseme et al. 2018).

3.2.3. ANTHROPOGENIC MOBILIZATION AND EPIDEMIC POTENTIALS

The mobilization and travelling of humans from one region to another determines the zoonotic disease dispersion and its pattern. Thus, control by limitations and prevention through certain restrictions, is done by countries (Keatts 2021). Epidemic potential corresponding with decrease

in the travelling activities of the epidemically most affected area. For example, H1N1 and COVID-19 outbreaks. The countries that successfully decline the ratio of infected patients using control measurement systems and policies, can control the epidemic situation. Therefore, appropriate, and feasible strategy for mobilization is necessary for international transportation and travelling from contributing areas, that can persist an epidemic situation for long time (Li et al. 2020).
Timely policy implication is required in the affected country of the zoonoses origin. For example, currently COVID-19 pandemic showed that the unlikely earlier precautions led to delayed in some strict regimes causing savior pandemic globally. Some seasonal effects should be taken into count to control mobilization of humans and implementation of computational data for the identification of zoonotic diseases (Mollentze et al. 2023). Generally, tourism increases annually with seasonal variations and novel infections also thrive within host/ vector. Thus, travel restrictions and novel outbreak analysis could be performed effectively in future to control novel zoonosis (Glidden et al. 2021).

3.2.4. ASSESSING THE RISKS OF ZOONOTIC RESURGENCE

After the burden of morbidity and mortality rate caused by zoonotic diseases, the resurgence of pathogenic infection has gained attention worldwide. Besides, epidemics and resurgence are very complex in nature and influenced by several factors that have been hardly identified as wild type-animals, human related drivers, pathogens, ecological and climate related drivers, etc., (Hassell et al. 2017; Liu et al. 2022). However, there is strong interaction with each other. Some anthropogenic related activities such as upgrading of lifestyle, tourism, hunting, or pet breeding, semi-raw cooked food consumption, industrialization, outdoor eating habits, agro-farming intensification, global trade, anthropogenic intrusions in natural ecosystems, across border migrations or immigration, etc., are uplifting resurgence risk as showed in Table. 2.
Climate related factors may include global warming, rise in sea levels, humidity level, seasonal variations, etc. External and internal factors help pathogens to adopt new variations genetically by drifting or shifting genetically. These alterations are persistence with change in environments and host (Combs et al. 2022). However, underlying mechanisms need to be revealed in future to understand the existing risk phenomenon. In addition, political conflicts and unsuccessful implementation of policies could increase the chances of outbreak. For example, large number of human involuntary/ illegal immigration in Balkan peninsula caused zoonotic outbreak, in Crimean-Congo, the hemorrhagic fever outbreak was observed including brucellosis, monkeypox and H5N1-avian influenza infect EU, Africa and USA, etc., (Cascio et al. 2011).
The climate change can result in resurgence of zoonotic disease, such as Sin Nombre virus (NSV) was noticed after heavy rainfall, making the population of rodents favorable and large population of the region suffered from hemorrhagic pulmonary syndrome (Klinkowski 1970). Likewise, according to UN (UN 2022) report recent flood disaster in Pakistan, especially Sindh province that large population is suffering from malaria and other zoonotic diseases, however, no novel zoonoses has observed yet in flood affected area but migration and mortality rates has increased. Therefore, quick health surveillance and implementation of effective policies should be taken in future to avoid such challenging zoonotic diseases.

3.3. ANTHROPOGENIC REVERSE TRANSMISSION OF ZOONOTIC DISEASES

Unlike zoonoses transmission from animal-vector to human host, Reverse zoonotic disease can be described as transmitted from human to animal-vector. This transmission from human to vector is particularly known as anthroponosis. In reverse zoonosis the host may shuffle, it could either be vector host or animal host. At global level, the largest reverse zoonoses have been observed and well-studied between human to swine (Messenger et al. 2014).

Table 2: Major zoonotic diseases of the Bacteria and Viruses in Humans

Pathogenic Agent	Anthropogenic activities	Pathogen	Reservoir/ vector	Symptoms	Disease/ infection
Bacteria	High-poor economical areas, consumption of contaminated food or water, close contact with infected animals	*Salmonella spp. (enterica or bongor)*	Farm animals, avian birds, dogs	Fever, Diarrhea (some time bloody), belly ache and cramps, may include, vomiting, headache and nausea	Salmonellosis
	Raw or semi cooked food consumption, drinking water/ food contamination, animal excretion, mobilization, invasion and urbanization	*Campylobacter fetus spp.* (*testudinum, fetus)*	Farm animals or livestock	Vaginal discharge, enteric disorder	Campylobacter fetus
	Consumption of contaminated meat, inhalation of anthrax from infected farm animals	*Bacillus anthracis*	Livestock animals, pigs, horse, deer, mink, elks, and bison	Shortness of breath, chest, neck discomfort, bloody cough, and meningitis	Anthrax
	Consumption of raw canned food, meat, keeping pets with poor hygienic condition	*Brucella spp. (abortus, melitensis, suis, canis)*	Farm animals, pigs, dogs, cats	Night sweat, weight loss, vaginal discharge, dry cough, and arthralgia	Brucellosis
	Deforestation, farming practices, contaminated meat consumption, water logging, Pedy fields	*Mycobacterium leprae*	Rats, mice, rodents, monkey, and pet animals	Nasal bleeding, skin lesions, and dermis thickness	Leprosy
	Poor framing practices, poor hygienic conditions, mobilization of infected animals from rural to urban cities	*Mycobacterium spp. (bovis, microti, caprae)*	Swine, cattle, deer, camels, bison, wild boars, and domestic mammalian animals	Chest pain, loss of appetite, prolong cough with mucous or blood, chills, and weight loss	Tuberculosis
	Consumption of raw or undercooked seafood, exposure of wounds to seawater	*Vibrio parahaemolyticus*	Fishes and farm animals	Enteritis	Vibriosis
	Contaminated water or food consumption, poor hygienic condition	*E coli* O157:H7	Avian birds, poultry, livestock animals and pigs	HUS (Hemolytic uremic syndrome) and enteritis	Enterohemorrhagic
	Urbanization, deforestation, and water logging	*Borrelia burgdorferi*	Tick bite	Arthritis, facial palsy, migrants, skin rashes	Lyme disease

	Close contact with infected animals, poor hygienic conditions, pooling of healthy animals with infected individual	*Bordetella bronchiseptica*	Nasal secretion of dogs, avians	Cough sneezing with watery discharge	Bordetellosis
	Consumption of raw salmon, seafood or fish and eggs	*Clostridium botulinum*	Fishes, salmon fish, dogs, horses, and cattle	Drooping eyes, dry mouth, and paralysis	Botulism
Virus	Direct interface with infected individual, poor medical and health condition	Rabies virus	Dogs, cats, monkey, wolves, jackals, skunks, horses, bats, and livestock	Salivation, fear, chills, hydrophobia, paralysis	Rabies
	Consumption of bush meat, mobilization of human and animals	Ebola virus	Green monkey, Gorilla, antelopes, apes, bats, and chimpanzees	Nausea, vomiting, diarrhea, organ failure, liver damage, hemorrhage, and weakness	Ebola
	Close contact with infected individual, poor medication, and hygienic conditions	Influenza A virus	Birds, poultry, livestock, and pigs	Rhinitis, cough, flu, weakness, sore throat	Avian influenza
	Consumption of bush meat, hunting, mobilization of animals, deforestation	SARS-CoV coronavirus	Wild animals, bats, dogs, cat family and minks	Flu-like symptoms, muscle pain, difficult breathing, night sweating, loss of appetite, headache, and weakness	Severe acute respiratory syndrome-SARS
	Interface with camels and meat consumptions	MERS-CoV virus	Camels, rodents, and sheep	Respiratory illness, cough, and shortness of breath	Middle east respiratory syndrome-MERS
	Poor water logging and fumigation	Flavivirus	Mosquitos	Pale eyes, aches, bleeding, chills, shock, nausea, confusion, and organ failure	Yellow fever
	Heavy rain, flood, poor drainage management, direct bite of vectors	West Nile virus	Reptiles, birds, and horses	Headache, stiff neck, coma, paralysis, and loss of consciousness	West Nile fever
	Flooded areas, water logging, rain, poor drainage management, direct bite of vectors	Dengue virus	Aedes species mosquitoes	Eye pain, vomiting, rashes, belly pain and tenderness	Dengue fever

	Consumption of contaminated food, meat, and poor hygienic condition	Hantavirus/ Sin Nombre hantavirus	Deer, white footed mouse and rats and moles	Fatigue, weakness, muscle aches and abdominal pain	Hantavirus Pulmonary syndrome-HPS
	Transgender sexual activities, drugs consumption, usage of contaminated utilities	Monkeypox virus	Monkey family, rats, squirrels, and wild type animals	Swollen lymph nodes, chills, and other respiratory symptoms	Monkey pox

After the outbreak of pH1N1, it was assumed of human origin, but also found in number of different animal species, such as aquatic animal seals (Goldstein et al. 2013), felines - the wild cat and canines - the canids (Messenger et al. 2014). It was reported that human influenza (IBV) was broadly observed in seals and considered as outbreak in seals (Osterhaus et al. 2000; Bodewes et al. 2013), indicating the possibility between human and phocid interface, such as fossils of phocid was recorded as twenty-four to thirty million years ago (Ma) may sustain reservoirs of IBV human origin (Nelson and Vincent 2015). Currently, the major existing reverse zoonotic disease that transmitted from human reservoir to animal host that caused by pathogens include, *Ascaris lumbricoides, Salmonella enterica Serovar Typhimurium, influenza A, B virus, Giardia duodenalis, Methicillin-resistant Staphylococcus aureus* (MRSA)*, Cryptosporidium parvum, and Campylobacter,* etc.
This indicates that animals and humans are infecting each other (Olayemi et al. 2020). This reverse zoonosis is not a direct relationship between human to animal transmission, but it could be transformed from animal to human then reverse back to animal.

3.3.1. EMERGENCE

The emergence and re-emergence are closely interconnected since the evolution of environmental changing and agricultural intensification nexus. The future of zoonoses and rate of emergence and re-emergence will also depend on these factors (White et al. 2020).
Emerging zoonotic disease is novel, newly emerged, or known previously but dispersion and spreading broadly in wide area of the landscape among host, animal, or vectors (El-Sayed and Kamel 2020). It has been evident that within last 70 years, about 250 zoonotic diseases has been upgraded as emergence or re-mergence zoonoses, the dispersion range of these diseases is around the world (Grace et al. 2012; Rahman et al. 2020). The dense population of humans and close contact with animals make it easier to make animal reservoir for zoonotic diseases (Woolhouse and Gowtage-Sequeria 2005).
Some parameters are involved for increasing pathogen population for zoonoses via direct interactions; such as socio-ecology behavior, vector species and their biology, adaptability of infectious agent, nature habitat, food hygienic condition, animal farm and livestock practices, meat production and uncooked consumption, deforest, rise in temperature, climate change by means of heavy rainfall, humidity, flood, drainage system, etc., (White et al. 2020). Changes in forest scenario and farming fields can alter the behavior of wild type animals that directly or indirectly encounter humans and later act as reservoir for zoonotic disease (Kjær and Schauber 2022). Temperate and water contamination give rise to water borne diseases such as Cholera; transmission occurs after consuming contaminated water. Population of the Cholera pathogen rises with increase in temperature of water (Asadgol et al. 2019).

3.3.2. RE-EMERGENCE

The re-emergence of zoonoses is a serious public health concern because most pathogens acquired adaptability and dispersion with animal or human migration. Lyme disease and West

Nile fever have been counting this health concern for a long time (Downs et al. 2019). Vectors playing active role in the re-emergence due to wide range of host target, while some hosts are non-active reservoir for such pathogenesis, these differences were observed among birds that act as low preferences for pathogens than that of human reservoir. This ecological diversity highlights the pathogenicity of zoonotic re-emergence. For example, West Nile fever in USA (Pauli 2004).
Another re-emergence noticed in North America after forest fragmentation, resulted in elevation of white-footed mouse population, a potential carrier for *Borrelia burgdorferi* zoonotic agent that caused Lyme zoonotic disease in human. In Brazil, re-emergence of Chagas disease - the American trypanosomiasis, caused by *Trypanosoma cruzi* was attributed by tick vector (Jones et al. 2013). Malaria is a major re-emerging disease in developed countries due to poor water management, floods, and close contact of hosts with mosquito vector. Overall, emergence or re-emergence is not a new concept for zoonotic diseases, emergence of zoonotic diseases from animals to human has been increased gradually, such as MERS - Middle East respiratory syndrome, Ebola, avian influenza, severe acute respiratory syndrome - SARS and so on. The disturbance in ecological niche will end in the existence of these zoonoses time by time (El-Sayed and Kamel 2020).

3.4. CONTROL AND PREVENTION

To understand the importance of control and prevention against zoonotic diseases, including direct or indirect, reverse, neglected, emergence, re-emergence, and several others, requiring different strategies. Most of general and effective actions may include recognition, data processing and sharing, key networks collaboration, accessible and developed structure for zoonotic diagnosis, trainings and awareness, social media and communication, information transfer, national and international involvements (Dong and Soong 2021). Some actions should be neglected or avoided such as conflicts between nations and civilians, instability beyond territory and political war, vector-host poor surveillance or measurements (Naicker 2011).
Every nation or country at state level may take active actions to provide some general facilities for better control. It includes vaccinations, health centers with effective treatment facilities, demography control, cattle farms and livestock health investigation and clean environment, restriction of animal movements, diagnostic centers, drainage system for water management, safe and proper disposable of infectious materials from laboratories, local clinics, and hospitals, etc. Some anthropogenic behavior issues need to be changed, that the negligence towards existing diseases because of preventable and less effective non-contagious specially under developing countries (Narrod et al. 2012).
Prevention is important to avoid infected individual by self-medications or prior to diagnosis, leaving behind recommended medication without consent a doctor, which may increase the resistance chances in the causative agent of zoonotic disease. Quick report to health center if zoonotic disease observed in animal-human species. Cleaning and hygiene, proper medication, exercise, and balanced diet, reporting and guidance near health center if zoonotic case observed in neighborhood. Isolation from social activities and proper care of infected one, washing hands, timely garbage disposable, sanitation and hygienic of living places (Dafale et al. 2020).
Besides, natural and anthropogenic factors directly or indirectly influence in controlling zoonoses. In the natural environment, climate factors have obvious dominated role in dispersion of the zoonoses (Rocklöv et al. 2020). In addition, characteristics of pathogen and adaptation within area of origin should be compared with another region. Meanwhile responses of animal behavior necessarily should be considered. Due to rapid adaptational behavior of some zoonotic pathogens, emergence of novel variant such as Chikungunya disease was the result of A336V

mutant variant. This disease dispersed by vector (*A. albopictus* mosquitoes). Another example of anthropogenic driven antibiotic usage triggered resistance, such as in Madagascar, the Salmonella species acquired resistance known as Multidrug-resistance *Yersinia pestis* was the result of using selective antibiotic pressure. For control and prevention, it is needed to understand both natural and anthropogenic perspective for better outcomes.

3.4.1. RISK ASSESSMENT AND SURVEILLANCE

Finding the potential vector or host that harbors pathogenic agents is the crucial step for zoonotic risk assessment (Wille et al. 2021). The risk assessment became challenging due to unfolding the current information from latest database access. This could result in prolonged or delaying identification or assessment of the novel infectious agent, unless epidemic situation is faced by the most of population. We can just assume the existing information gap from this example, most of researchers using ICTV (International Committee on Taxonomy of Viruses) or different database platform that also solely rely on similar information that provided by ICTV database. According to Wille et al. (2021) study, the three animal data sets were lower that has been ratified by ICTV in 2020 as compared with viral data information from similar hosts in genomic studies that was performed provisionally (Mollentze and Streicker 2020). It suggested that relying on only one database could be outdated to assess novel or new strains. Therefore, using different approaches are necessary to verify results.

The trained morphology differentiation, mode of action in existing ecology, and the sequencing or phylogenetic analysis could improve the analysis of pathogenic and potential degree of that infectious agent in the reservoir. Moreover, data assessment could be interpreted by using pathogenic agent interaction with different host species range using network connections to predict vulnerable zoonotic diseases (Johnson et al. 2020). It is known that transmission root of zoonotic agents is not similar but may vary according to the pathogenicity of host or reservoir. This difference in root of transmission and pathogenicity make it difficult\ for assessment. Therefore, understanding the value of surveillance programs is essential for pathogenic control. It is an integral part of zoonotic disease control program, as it provides massive database information from practical practices that is mainly focused on effectiveness by removing most emotions and opinions than that of evidence (Loh et al. 2015).

Currently, outbreaks after COVID-19, SARS, H1N1, MERS, Ebola, etc., have made the surveillance program as tool of early control managements against zoonotic emerging diseases. Surveillance program may set the crucial steps to achieve the goals, such as evaluation (biosecurity and infection effectiveness), monitoring (patient routine check-up and procedures), establishment of data (period of data and hypothesis testing), determining the data gathering processing, etc. Risk assessment and surveillance programs are critical and efficient data tools for possible control management of zoonotic infections (Doherty et al. 2021).

3.4.2. MONITORING AND MITIGATION

The pandemic events have re-focused on socio-ecological factors and the behavior of animals and humans in zoonoses and spillover (Keatts 2021). Considering the mitigation strategies, the one health approach is the tool of interactions between ecological sectors, animal-human health. However, this approach is not commonly used at the ground level, but medical field experts, environmental researchers, veterinary specialists utilized knowledge and then transferred to grassroots to construct effective strategies. Other groups of researchers are mainly focused on monitoring the lifestyle of wild type and protection, conducting experimental testing in laboratories, engagement of diseases in reservoirs and host, treatment response and preventions, etc. The flow of information by monitoring the possible factors of zoonotic disease and mitigation of retrieved knowledge to control the zoonotic disease is a collaborative work (Christopher and Marry 2015).

3.4.3. PREDICTION OF EPIDEMIC POTENTIALS

The Host-pathogen association has evolved under natural selection circumstances during evolution. However, cross species transmission and ecological variations arose several human infections. The existing challenging part is predicting the potential effectiveness of newly emerging diseases. In other words, prediction is assumption of host range that is targeted by similar infectious agent. For example, coronaviruses have large number of host choices therefore, infections have great impact at world level (Hiscott et al. 2020). Analysis of new microbes and viruses could be receptor specific of the reservoir, that help in meta-profiling at genetic level and construction of target specific drugs (Rodriguez-Morales et al. 2020). Meta data modeling also enables researchers to predict the range of infection within population. However, prediction for viruses is still a more sensitive issue and challenging due to shifting genetics and rapid variations from one host to another (Mollentze et al. 2023).

4. CONCLUSION

To understand the possible interactions between vector-host and pathogenic agent; how anthropogenic drivers influenced zoonotic infections and what are the current strategies of the zoonoses. Current situation of vectors, human-animal behavior with pathogen agent and relevant factors for possible spillover of zoonotic disease; was studied. Our work illustrates the scientific challenges and complexity of disease in transmission. The patterns were highlighted to overview the anthropogenic dynamics, biotic, a-biotic factors, emergence, and risk assessment. The control for zoonotic diseases and scientific obstacles to handle the outbreak systems were also mentioned. Overall, this study provides the basic understanding of the socioecology and human-animal status for the zoonoses.

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Zoonotic Diseases: Emerging Threats to Public Health and Livestock Production

06

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ABSTRACT

Zoonoses are diseases that transmit between humans and animals. The three types include endemic, epidemic, and emerging/re-emerging. Endemic diseases are common and affect many people and animals. Epidemic diseases occur sporadically. Emerging/re-emerging diseases are new or expanding rapidly in incidence or geographic range. This study investigates the intricate relationships between people, animals, and the environment, and the ongoing threat to human health posed by zoonotic illnesses. The research examines the factors leading to the emergence, spread, and global impact of these diseases. These include globalization, habitat degradation, climate change, increased human-animal contact, and antibiotic resistance. Early detection and treatment of infections are hindered by the fast development and adaptability of pathogens. Effective response plans require international collaboration and multidisciplinary approaches. To prevent future outbreaks, it is crucial to understand the ecological, socioeconomic, and environmental factors that contribute to zoonotic diseases. This chapter discusses various zoonotic diseases, their causes, transmission mechanisms, and prevention practices. It emphasizes the importance of international collaboration and multidisciplinary methods in reducing the risks of emerging zoonotic illnesses and safeguarding global public health.

Keywords: Antibiotic resistance, climate change, ecosystem change, habitat degradation, one health, pandemic, zoonotic disease

CITATION

Raza A, Ahmad S, Ahmad M, Abedin MZ, Channo A, Subhan A, Beig MM, Irshad Z, Mujahid U and Khan AK, 2023. Zoonotic Diseases: Emerging Threats to Public Health and Livestock Production. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 74-88. https://doi.org/10.47278/book.zoon/2023.006

CHAPTER HISTORY Received: 21-May-2023 Revised: 20-June-2023 Accepted: 28-July-2023

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1. INTRODUCTION

Zoonosis accounts for approximately two-thirds of human infections and roughly three-quarters of newly emerging and re-emerging human diseases (Ear 2012). Some of the emerging diseases that have gotten much attention from the media and, in the case of pandemic influenza A H1N1 and avian influenza, many resources include West Nile virus, Bovine Spongiform Encephalopathy (BSE), SARS, and Nipah virus (Lashley 2006). A complex interplay of various factors influences the rise of new infectious diseases. These include population growth, changes in dietary habits, agricultural practices, commercial activities, and land use alterations, such as rapid urbanization, deforestation, and encroachment on wildlife habitats (Bousfield and Brown 2011).
Moreover, certain historical zoonotic diseases like anthrax, rabies, brucellosis, zoonotic trypanosomiasis, bovine tuberculosis, and disorders related to tapeworm infections are re-emerging and becoming more prevalent. This resurgence can be attributed to several interconnected reasons, one of which is the transmission of pathogens from wild animals to domestic animals (Elelu et al. 2019; Rahman et al. 2020).
With the increasing complexity of food chains and various systems involved in food production and preparation, the importance of food-borne zoonotic diseases like Salmonella, Escherichia coli, and Campylobacter infections, all associated with livestock production and processing, is growing (Abebe et al. 2020). However, this is expected to impact pathogen diversity, range, distribution, and potential morbidity (Ali and Alsayeqh 2022). The exact influence of climate change on this intricate interplay of factors remains uncertain.
These findings elicit two critical questions. Why do these problems keep getting worse and worse? And how should we control and manage them? We also offer a conceptual framework for an analytical approach that may be used to direct research into so-called one-health concerns and guide legislation. We emphasize the significant transformations in livestock systems and how they impact infectious diseases. To achieve optimal health outcomes for humans, animals, and the environment, various disciplines must collaborate across local, national, and international borders. One-health's integrated approach represents the initiative to address these interconnected health challenges (Coker et al. 2011).
The interconnectedness of wildlife, people, domestic animals, and the environment is crucial in maintaining and spreading infectious diseases (Thompson and Polley 2014). For a long time, wildlife has been singled out as the main culprit for the emergence of zoonotic illnesses in humans, though this accusation may not be entirely fair (Blancou et al. 2005). In recent times, the fields of medicine, veterinary medicine, and wildlife science have come to understand that the transmission of diseases is more intricate and not strictly one-sided. The distribution of species and the ecological interactions between humans, animals, and habitats are drastically changing due to anthropogenically altered landscapes and climate change (Thompson 2013). At a rate unmatched in history, purposeful and accidental globalization is simultaneously spreading organisms throughout the globe. These changes risk human health, wildlife, and

animal production systems (Thompson and Kutz 2019). Fig. 1 shows the zoonotic transfer of the pathogens.

The science of wildlife parasitology has developed into a considerably more complicated discipline due to increased knowledge of the significance of parasites as evolutionary drivers and determinants of population health. Previously, it was primarily concerned with classical parasitology, taxonomy, and case studies. A deeper understanding of the parasitological interactions between people and animals has been gained thanks to increased disease monitoring in wildlife, advanced disease ecology modeling, and the widespread use of genetic technologies. Findings support the idea that wildlife may not always be the source of zoonoses and frequently become the unwitting victims of interspecies parasite transmission, spill-back, or reverse zoonotic (zooanthroponotic) transmission (Lloyd-Smith et al. 2009). These findings show a much higher diversity of parasites than was previously believed.

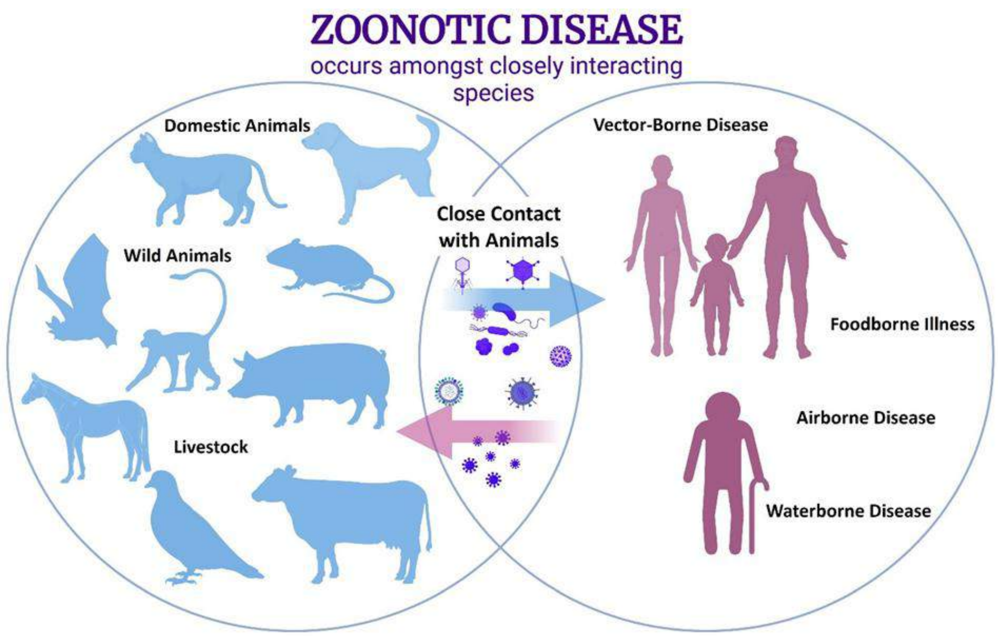

Fig. 1: Zoonotic transfer of pathogens occurs when close contact encourages species-jumping transmission between animals such as domestics, wildlife, or livestock—and humans. This transmission can be in the form of vector intermediates, ingestion of contaminated food or drinks, or the inhalation of droplets. (Esposito et al. 2022).

2. EMERGING ZOONOTIC DISEASES

2.1. BACTERIAL ZOONOSES

There are several methods through which bacterial zoonotic infections can be transmitted from animals to people (Cantas and Suer 2014). Zoonotic bacteria from food animals can infect humans through direct fecal-oral routes, contaminated animal products, improper food handling, and inadequate cooking (Ali and Alsayeqh 2022; Logue et al. 2017; Roe and Pillai 2003). Animal health professionals (veterinarians) and farmers are more likely to come into contact with some zoonotic infections, contract them, and perhaps spread them to others. In soil and water contaminated with manure, there is a wide variety of zoonotic bacteria, which raises the risk of zoonotic infections and expands the pool of resistance genes available for the transmission of bacteria responsible for human diseases (Polley et al. 2022; Schauss et al. 2009).

Bacterial infections are zoonotic diseases that can resurface even after being considered eliminated or controlled. Another worldwide public health issue that is getting worse is the emergence of antimicrobial resistance from excessive or improper use of antibiotics. These illnesses have a detrimental effect on international trade, travel, and the economy. Antibiotic-resistant zoonotic bacterial infections are particularly relevant for at-risk populations in most industrialized countries, including the young, aged, pregnant women, and impaired immune systems (Acha and Szyfres 2001). In the past, bacterial zoonotic diseases such as bovine TB, the bubonic plague, and glanders caused millions of human deaths before hygiene regulations, vaccinations, and antibiotics were introduced. Today, there is a global rise in the prevalence and importance of several bacterial zoonoses. To ensure the most effective preventive measures for public health, many developing nations are investing more resources in enhancing the screening of animal products and bacterial reservoirs or vectors (Blancou et al. 2005).

The detection of newly developing zoonotic illnesses has risen due to advancements in monitoring and diagnostics. Here, changes in our way of life and increased animal interactions have exacerbated or brought back several bacterial illnesses. Recent research indicates that the risk of contracting bacterial zoonotic diseases is higher than ever (Messenger et al. 2014). This is likely due to increased interactions with adopted small animals that have become part of households and are treated like family members. On the other hand, in our modern globalized world, intensified animal farms play a significant role in the food supply, making them primary sources of food-borne bacterial zoonotic diseases (Logue et al. 2017; Roe and Pillai 2003; Zambori et al. 2013).

People with close contact with many animals, such as farmers, slaughterhouse workers, zoo/pet store employees, and veterinarians, are more susceptible to zoonotic diseases. The zoonoses that household pets can spread pose a threat to the general public as well. Humans are frequently exposed to zoonotic bacterial illnesses through animal bites and scratches. Pit bull breeds, malamutes, chows, rottweilers, huskies, German shepherds, and wolf hybrids are only a few of the dog breeds that have been identified for their role in stopping dog bite assaults (Cantas and Suer 2014). In the USA, nearly half of the zoonotic diseases resulting from dog bites were caused by pit bull breeds, which are 3 times more common than German shepherds. Healthy dogs and cats carry hundreds of harmful bacteria, including Pasteurella sp, in their oral cavities. Overall, only 20% of dog bites lead to infections, while cat bites result in infections about 60% of the time (Bula-Rudas and Olcott 2018).

A cat bite carries a ten times greater chance of contracting *Pasteurella multocida* infection than a dog bite. Bite wounds infected with *P. multocida* typically develop within 8 hours (Morgan, 2005; Morgan and Palmer, 2007). Human infections from animal bites or scratches are thought to occur in about 20% of cases (Zambori et al. 2013). Human pet bite diseases are reported to include bacteria like the animals' oral microbiota. *P. multocida* (50%), *Staphylococcus sp* (46%), together with alpha-hemolytic *Streptococcus sp* (46%), *Neisseria sp* (32%), and *Corynebacterium sp* (12%), typically dominate infections in dog bite wounds. However, *Fusobacterium nucleatum* (16%), *Propionibacterium acnes* (14%), *Prevotella heparinolytica* (14%), *Peptostreptococcus anaerobius* (8%), and *Prevotella intermedia* (8%), and are also isolated from infected wounds (Morgan and Palmer 2007).

In people who have been bitten, the bacteria causing the infection often differ from the normal bacteria found on human skin or other environmental germs (Abrahamian and Goldstein 2011; Morgan and Palmer 2007).

An infection develops 8 to 24 hours after an animal assault, with varying degrees of discomfort at the injured site. Pus-containing discharge, which can occasionally smell bad, may come after the cellulitis. Patients with immune suppression, diabetes, or liver disease are particularly vulnerable to developing life-threatening illnesses due to animal bites. Patients could have bacteremia in certain circumstances and perish away more quickly (Zambori et al. 2013). Bites that penetrate near the joints and bones can lead to conditions like septic arthritis and osteomyelitis. To comprehend the chronicity of human wounds, it is crucial to understand how dental plaque biofilm develops in dogs' mouths (Kirketerp et al. 2011; Zambori et al. 2013).

In individuals, a clinical illness known as cat-scratch disease has been documented for over a century. But *Bartonella henselae*, the etiological agent that caused cat scratches and bites, wasn't discovered until 1992 (Stechenberg 2011). Bartonellosis can also be brought on by touching cat saliva on open sores or sclera. The earliest warning signs of a cat scratch are papules and pustules at the injury site. A persistent, non-healing wound, infrequent fever, weakened local lymphatic drainage, and abscession are possible disease-progression symptoms. The most at-risk groups are cat owners and veterinarians (Cantas and Suer 2014). Most of the time, individuals with weakened immune systems require comprehensive medical care. Otherwise, granulomatous conjunctivitis, osteomyelitis, and encephalopathy might manifest (Slater 2000).

Since the beginning of time, people and horses have had a strong association for recreational, athletic, and professional purposes. Over the past ten years, the number of horses per person in Europe has remained steady. Sweden has the most horses per person in the EU, whereas Germany and Great Britain have the most significant horse populations. In Europe, 3-5% of horse bite wounds are thought to be infectious (Cantas and Suer 2014). Horse bites are believed to make up as much as 20% of all animal bites in Turkey and come in second behind dog bites (70%) in frequency (Emet et al. 2009).

In contrast to small animal bites, most horse assaults may result in more severe muscular injury. Horse bites on humans have produced a variety of aerobic and anaerobic microbes often dominated by *Actinobacillus lignieresii* (Abrahamian and Goldstein 2011). E. coli and Bacteroides species have also been found in human illnesses with unpleasant odors and pus discharge from horse bites (Rycroft and Garside 2000).

Escherichia coli, Salmonella sp., *Shigella sp., Leptospira sp.,* and *Campylobacter sp.,* which cause infectious diarrhea in companion animals, can also spread to people via the fecal-oral route. Estimating the spread of these pervasive microbes is challenging. Nevertheless, it is widely recognized that these bacteria can exist in many healthy animals and persist long in their feces (Ahmad et al. 2023). In 2009, human cases of campylobacteriosis ranked as the most reported zoonotic bacterial infections among EU members (Lahuerta et al. 2011). They can induce gastroenteritis (vomiting and diarrhea), headaches, depression, and occasionally even death like many other entero-pathogens can. Feeding pets, a raw food diet dramatically increases the chance that humans may become infected with gastrointestinal diseases and zoonotic bacterial enteropathogens (Cantas and Suer 2014).

Companion birds, also known as songbirds (such as finches, canaries, and sparrows) and Psittaciformes (such as parakeets, parrots, budgerigars, and love birds), are pretty common in Europe and are potential zoonotic disease vectors (Evans 2011). Some of them, such as chlamydophilosis (Vanrompay et al. 2007), campylobacteriosis (Wedderkopp et al. 2003), and salmonellosis (Carlson et al. 2011), may have a significant effect on human health. Birds' respiratory systems are home to the intracellular bacterium *Chlamydia psittaci,* which causes parrot fever (chlamydophilosis). The primary method of transmission to humans is by inhalation of the dander, dust, and nasal secretions of infected birds (Circella et al. 2011). Infected people may suffer moderate to severe flu-like symptoms, which might lead to a false-positive influenza diagnosis (Evans 2011).

In Europe, there are now more than 200 million animals raised for food on farms (including cattle, pigs, sheep, goats, and chickens). Farm animals are reservoirs for various zoonotic infections that affect humans (Wells et al. 2001; Lahuerta et al. 2011). However, each year, a significant number of pharmaceuticals are used around the globe to produce enough food to support a fast-

expanding global population (Carvalho 2017). Farm animals worldwide consume a staggering 8 million kilograms of antibiotics yearly, while only one million kilograms are used annually in human medicine. Shockingly, 70% of the antibiotics used in animals are for non-therapeutic purposes such as growth promotion, a practice banned in the EU since January 2006. Additionally, some antibiotics are used for disease prevention in animals (Done et al. 2015).
Mycobacterium bovis (M. bovis), the cause of bovine TB, has been recognized globally. The infection's prevalence has significantly decreased due to decades of disease management activities. However, the USA continues to record hundreds of new cases of human TB (Miller and Sweeney 2013). The European badger in the United Kingdom (De la Rua-Domenech 2006), the elk in Canada (Wobeser 2009), and the white-tailed deer in the USA are three examples of wildlife where *M. bovis* has spread. Experience in Europe and the USA has demonstrated that *M. bovis* may be confined in cattle, but eradication is impossible once it has done so (O'Brien et al. 2006).

2.2. VIRAL ZOONOTIC DISEASE

According to the World Health Organization and most infectious disease specialists, wildlife is increasingly considered the primary source of zoonotic diseases that might cause the next human pandemic. While specific zoonoses originating in wildlife, such as rabies and avian influenza, are well documented, others have only recently arisen or been connected to animal reservoir species. The latter is exemplified by the Ebola virus, which was recently related to African cave-dwelling bats after decades of investigation. Like the SARS coronavirus, which killed over 800 people worldwide and cost over $60 billion, the SARS virus first appeared in civets and bats before spreading to humans in the wet markets and eateries of southern China (Leroy et al. 2005; Li et al. 2005). Middle East respiratory syndrome (MERS), which has recently emerged, serves as a reminder that while we must remain vigilant against known pathogens with pandemic potential, the next deadly pandemic could result from a zoonotic agent that is currently unknown or from one of the thousands of genetically identified agents with unknown pathogenic potential (Zaki et al. 2012).
There are several ways that zoonotic viruses might spread. They are "direct" or "indirect" contact (such as the rabies virus), "nosocomial" (such as the Ebola virus), "aerosol transmission" (such as the SARS coronavirus), "vertical" (in utero) (such as the Zika virus) and "vector- or arthropod-borne" (such as the yellow fever virus and the West Nile virus). All continents, save for maybe Antarctica, experience the spread of viral zoonotic diseases. Some can be discovered all over the world in various ecological environments. Others are confined to a small number of ecological and geographical focuses. Despite the number of zoonotic disease viruses in the hundreds, the significance of many of these viruses is unknown (Reed 2018).
Emerging infection outbreaks have occurred often since the turn of the century. Adenovirus, Middle East Respiratory Syndrome (MERS), Ebola Virus Disease (EVD), Coronavirus Disease 2019 (COVID-19), Monkeypox (MPOX), Lassa Virus (LASV), and Zika virus are only a few of the illnesses that are mainly brought on by animals (Manirambona et al. 2022; Alarcon-Valdes et al. 2022; Ahmad et al. 2023). These illnesses used to be known to harm animals, but today, they also affect people. We believe that important contributing causes to the origin and spread of viral zoonotic diseases include human activities, land use, livestock management practices, as well as the effects of climate change. We may lessen the danger of further epidemics and enhance public health by addressing these underlying causes (Haruna et al. 2023).
In December 2019, Wuhan, China, reported the first human case of COVID-19. Following the virus's global spread, almost 6.6 million people have died, and over 650 million COVID-19 infections have been confirmed (WHO 2022). The World Health Organization (WHO) labeled it a worldwide pandemic on the 20th of March 2020. This illness also worsens the health of those who

already have coexisting diseases and interrupts socioeconomic activity, leading to economic downturns, the loss of employment, and other sources of income. Another epidemic of the monkeypox virus appeared and expanded rapidly while the COVID-19 pandemic was still causing devastation. As of the 22nd of December 2022, there were around 83,434 confirmed cases and 110 fatalities worldwide, according to the Centers for Disease Control and Prevention. Surprisingly, most instances occur in regions where the illness has never seen an outbreak. Similar to how deaths from monkeypox have also happened in non-endemic areas (CDC 2022). As a result, the WHO deemed it a Public Health Emergency of International Concern (PHEIC) on the 23rd of July, 2022.

On 17th of July 2022, Ghana announced an outbreak of the zoonotic illness *Langya henipavirus* (LayV), linked to the Marburg and Nipah viruses and other zoonotic diseases of public health significance. EVD and the Marburg virus illness are connected. The EVD outbreak from 2013 to 2016 was the worst in recorded history, with most infections occurring in Guinea, Liberia, and Sierra Leone (WHO 2014). There are no particular therapies or vaccinations to help contain these viruses, even though they are unpredictable and have a high potential for epidemics. In addition to their strain on health systems, they alarmingly have a high case-fatality ratio (WHO 2014). Therefore, it is essential to address the causes of the overflow of these diseases as they continue to cross international borders and diseases that were formerly regional become global.

According to Alimi et al. (2021), the reasons that hasten the introduction of these illnesses include increased human-animal contact brought on by fast urbanization, the degradation of natural habitats, wildlife hunting, livestock raising, climate change, domestication of animals, and shifting ecosystems. Nipah virus (NiV) has been linked to many ailments. For instance, it may result in mild to severe encephalitis. Infecting people's respiratory systems and animals might lead to deadly infections. NiV can be spread between individuals and humans by bats or domestic animals (Ghareeb and Sultan 2021).

3. PARASITIC ZOONOTIC DISEASE

3.1. ZOONOTIC DISEASES CAUSED BY CESTODES, NEMATODES, AND TREMATODES:

3.1.1. CESTODES ZOONOSES

It is possible to define cestode zoonoses as "those cestode diseases which are naturally transmitted between (other) vertebrate animals and man." The Taeniidae family of zoonotic cestodes is of utmost significance in the developing world. For *Echinococcus granulosus*, most food-producing animals, including cattle, buffalo, sheep, goats, pigs, and several other mammals, serve as intermediate hosts (Xiao et al. 2013). Accidental ingestion of eggs secreted by Echinococcus species in the feces of the specific carnivorous host/animal might result in human infection (Dhaliwal et al. 2013). Taeniasis is a genuine zoonotic infection (Euzoonoses) in which humans serve as the definitive/final hosts.

In contrast, pigs and cattle serve as intermediate hosts for *Taenia solium* and *Taenia saginata*, respectively (Hemphill and Lundström-Stadelmann 2021). More than 100 human cases of coenurosis, a rare zoonosis, have been documented worldwide. Parasites like *Spirometra mansoni* and *Diphyllobothrium latum* are other significant cestodes (Dhaliwal et al. 2013). Epidemiological patterns of diphyllobothriasis have been recorded in different parts of the world. *Dipylidium caninum*, a parasite, can infect domestic dogs, cats, some wild predators, and on rare occasions, people. Sparganosis is an uncommon cestode zoonosis that can affect humans (Conboy 2009). The parasite has been discovered worldwide but is most frequently encountered in eastern Asia. Important cestodes, including *T. solium, E. granulosus*, and *D. latum,* are spread by food and water (Dorny et al. 2009).

3.1.2. NEMATODES ZOONOSES

Endemic angiostrongylosis is present in South Asia, the Pacific Islands, Australia, China, and the Caribbean Islands. At the same time, zoonotic ascariasis caused by *Ascarissuum* has been widely documented in North America and certain European nations. Raccoons' intestinal roundworm *Baylisascaris procyonis* has been linked to severe neurologic illness in humans (Roepstorff et al. 2011; Ahmad et al. 2023). Cutaneous larva migrans (CLM) in humans may result from the subcutaneous migration of animal hookworms. A zoonosis that is significant for public health is gnathostomiasis. Except for the deserts, most regions of the world have documented cases of trichinellosis. Non-industrialized nations must provide safe food and water to prevent and manage these illnesses (Otranto and Deplazes 2019). *Ancylostoma, Baylisascaris, Capillaria, Uncinaria, Strongyloides, Toxocara, Trichinella*, as well as arthropod vectors including *Dirofilaria spp., Onchocerca spp.,* and *Thelazia spp*. provides a danger of transmitting zoonotic nematodes from wild predators to people through food, water, and soil (Otranto and Deplazes 2019).

3.1.3. TREMATODES ZOONOSES

Several neglected trematode zoonotic infections are now thought to be severe human illnesses. Cercarial dermatitis results from the invasion of human skin by avian *schistosome cercariae*. The two main heterophyids that can transmit zoonotic diseases are *Metagonimusyokogawai* and *Heterophesheterophes*. Pigs appear to be the only proper natural host of the human disease-causing parasite Gastrodiscushominis. Fasciolosis affects animals mainly; however, 42 nations have also documented humans (Alba et al. 2021). Fasciolopsisbuski is a common parasite in several Southeast Asian countries. *Dicrocoelium dendriticum*-infected ants accidentally eaten by humans might make them sick. *Clonorchis sinensis* is East Asia's most significant fish-borne zoonoses among all liver flukes. Human fascioliasis is now categorized as a plant/food-borne trematode infection among zoonotic parasitic illnesses, with a greater frequency observed in agricultural communities in low-income countries (Mera y Sierra et al. 2011; Soliman 2008). The *Fasciola hepatica, Fasciola gigantica, Faciolopsis buski* (family Fasciolidae), *Watsonius watsoni, Gastrodiscoides hominis* (family Gastrodiscidae), and *Fischoederius elongatus* (family Paramphistomidae) are among the plant- and food-borne trematodes. The liver is infected with *Fasciola hepatica* and *F. gigantica* (Carrique-Mas and Bryant 2013).

3.1.4. FUNGAL ZOONOSES

Zoonotic fungi can pose serious public health risks and spread naturally between animals and people. Several mycoses linked to zoonotic transmission are among the most prevalent fungal infections globally. However, it is noteworthy that several fungal infections with zoonotic potential have yet to receive enough attention in global public health initiatives, resulting in inadequate attention to their preventative tactics (Seyedmousavi et al. 2015). Fungi infections linked to zoonotic and saprozoic transmission represent a significant public health issue (Akritidis 2011). Some of these infections are among the most prevalent fungal disorders, including histoplasmosis (Bonifaz et al. 2011), sporotrichosis (Barros et al. 2011; Yegneswaran et al. 2009), and dermatophytosis (Moretti et al. 2013). In this regard, it is noteworthy that several zoonotic-potential fungal infections have yet to receive enough attention from worldwide public health initiatives, resulting in a lack of focus on preventative measures. Mycotic infectious agents can be either true pathogens or opportunists from an evolutionary point of view (Köhler et al. 2017). From the same perspective, pathogens can be divided into obligatory pathogens (having host-to-host transmission) and environmental pathogens (having a saprobic but infectious phase in the environment). Infected tissue may develop invasive systemic environmental pathogenic fungus forms, such as Coccidioides' spherule or Histoplasma's intracellular yeast (Bonifaz et al. 2011). Almost all fungi can survive for long periods in their environment, but diseases have an evolutionary advantage since they can employ vertebrate hosts as a vector for a portion of their life cycle. Humans are often only a secondary host for the fungus, with other animals serving as its primary target (Seyedmousavi et al. 2015).

3.1.5. PROTOZOAL ZOONOSES

A developing zoonotic protozoan illness called cryptosporidiosis has been found in both human and animal populations worldwide. The primary method of transmission is through the consumption of tainted food and water, and the illness is external in origin. In ambient water, where they can live for months, Cryptosporidium oocysts are numerous and spreading. It favors the epithelial cells present in the digestive tracts of various hosts (Pal et al. 2016). Several countries have had outbreaks worldwide due to waterborne transmission through drinking water or swimming pools. The illness may appear sporadic or widespread. Both immune-competent and immune-compromised persons have contracted the sickness (Pal et al. 2021).

A developing ciliated protozoan parasite of zoonotic significance called *Balantidium coli* (*B. coli*) causes the illness balantidiasis in a wide range of host animals, including swine, camels, ruminants, equines, and even humans. Due to ideal geo-climatic circumstances for the establishment and survival of the parasite, this illness has a worldwide distribution with high incidence rates in tropical and sub-tropical parts of the world (Ponce-Gordo and García-Rodríguez 2021). Pigs and other animals are the principal reservoir hosts for this disease; humans often become infected by consuming contaminated food or water. The afflicted animal displays anorexia, dehydration, excessive watery stool, and stunted development as clinical indicators (Ahmed et al. 2020).

3.1.6. RICKETTSIAL ZOONOSES

Globally, *Rickettsia felis,* an obligate intracellular microorganism, is becoming more widely acknowledged as the cause of human rickettsial illness (Brown and Macaluso 2016). There is currently no agreement on the pathogen's vertebrate reservoirs, which is essential for the continued existence of this agent in nature. The bite of an infected vector transmits the agent, the *Ctenocephalides felis* cat flea (Ng-Nguyen et al. 2020). As a re-emerging zoonosis of public health significance, epidemic typhus is brought on by the bioterrorist *Rickettsia prowazekii*. Millions of people died from epidemic typhus in previous ages in various regions of the world. The illness, spread by contaminated body louse feces, causes large outbreaks in congested and filthy populations. Several nations, including Burundi, have reported epidemic typhus outbreaks by louse bites—Uganda and the African countries of Ethiopia, Nigeria, Peru, and Rwanda. The main clinical symptoms of the illness include rash, headache, and fever. Test results must confirm the clinical diagnosis and must be distinguished from other diseases that cause febrile fever (Pal and Dave 2019).

3.1.7. MYCOPLASMA ZOONOSES

Infections in vertebrates that don't cause hemotropic mycoplasmas cause any symptoms. Some species, including *Mycoplasma haemofelis* in felines, *Mycoplasma haemomuris* in rodents, *Mycoplasma ovis* in caprines, and *Mycoplasma suis* in swine, can also produce moderate to putatively deadly hemolytic anemia (Neimark et al. 2001). Finally, many bats have hemotropic mycoplasmas (Volokhov et al. 2017). Hemotropic mycoplasmas, hitherto considered to be exclusive to animals, were first recognized to be human infections in the United States in 1972 (Jelani G et al. 2023). Hemobartonella-like forms were observed in the blood of patients with systemic lupus erythematosus.

4. FACTORS CONTRIBUTE TO THE EMERGENCE OF ZOONOSES

The establishment of zoonotic illnesses can be caused by various reasons (Walsh et al. 2020). Growing human and animal populations are frequently linked to increased infectious disease agent spread, making them apparent risk factors for new zoonotic risks. The relationships between viruses and their hosts, including the reservoir in a multi-host system, rely significantly on the environment they inhabit, and this environment is undergoing rapid changes. It must be emphasized that zoonoses always originate through a multifactorial process (Kosoy 2013). Changes in agricultural and trading techniques, human behavior, the distribution of animal vectors, and the genetics of the microbes and their hosts can all be a part of this process.

Assessing and comprehending the implications of these modifications on the dynamics between harmful microorganisms and their respective hosts, as well as among hosts and other animal populations such as cattle, wildlife, and humans, holds paramount significance. This comprehension will prove invaluable in formulating mitigation plans and expediting efficient responses to emerging scenarios. The pivotal role of these interactions in the resurgence of zoonotic diseases further underscores the necessity for diligent examination and proactive measures.

When the first infected person, known as the index case, spreads the infectious agent to multiple others, an illness can quickly escalate into an epidemic within a human community. To comprehend why certain viruses are more dangerous than others, it might be beneficial to conduct immunological research that examines the quantitative and qualitative variations in the balance between hosts and viruses in animal reservoirs. In local settings, places with frequent human-to-animal contact and heightened transmission risks include wet markets and slaughterhouses, which are vital for providing daily food supplies to billions of people. We observe shifting agricultural techniques or shifting farm management in various parts of the world. This encompasses agricultural modernization, especially in emerging nations, and continuous agrarian intensification in the West for more efficient output. Alongside the intensified agricultural practices, the alteration of habitats for grazing and cropping can significantly impact biodiversity and trigger the re-emergence of infectious diseases (Keesing et al. 2010). These agricultural factors play a pivotal role, yielding diverse outcomes by facilitating interactions between various wildlife species and leading to the cohabitation of wildlife and livestock, thereby creating opportunities for new pathogens to spread among vulnerable and unsuspecting species (Greger 2007).

Furthermore, the global air travel network has emerged as a conduit for the rapid dissemination of diseases across continents, exemplified by the occurrences of SARS-CoV in 2003 and, most recently, SARS-CoV-2. The movement of reservoir hosts and vectors through commerce and international travel can expedite the spread of infections (Morse et al. 2012). As human activities encroach further into virus-endemic regions, the incidence of illnesses caused by vector-borne viruses may increase, along with potential animal infections. Consuming bush meat is a typical traditional practice and dietary source in many countries. However, trading and handling live animals in marketplaces where different species are close can increase the risk of infection transmission (Greatorex et al. 2016). These activities have been linked to the initial transmission of SARS-CoV from a Chiroptera reservoir to amplifying hosts, including masked palm civets (Pagumalarvata). Additionally, according to Li et al. (2020) and Andersen et al. (2020), the transmission of SARS-CoV-2 from the animal reservoir to the human population may have been facilitated in 2019 through a wildlife market.

The life cycles of vectors, reservoirs, and pathogens are influenced by various intricate environmental processes, making them susceptible to the impacts of climate change and weather variations (Zinsstag et al. 2018). Changes to the temperature and environment may significantly affect the range of insect vectors. For instance, a virus previously isolated to one location may spread to another place with naïve populations of both animals and people. Climate change may bring prolonged droughts or heavy downpours, which might spread more mosquitoes. In urban areas, mosquitoes can spread more extensively because of factors like water storage facilities, swimming pools, and the transportation of old tires. As their vectors colonize new environments, zoonotic viruses like West Nile (WNV) and Rift Valley fever (RVFV) are increasingly spreading in many countries. Additionally, climate change can accelerate the release of specific pathogens from frozen soils in the northern regions, including the bacteria *Bacillus anthracis*. For more information on this, you can refer to the section on the bacteria *Bacillus anthracis* (Huber et al. 2020).

Several animal species, including rodents and bats, can carry numerous infections affecting human and veterinary health. Several species can multiply quickly to large populations, which might lead to unforeseen circumstances with substantial disease transmission risks. Environmental alterations, such as urbanization and climate change, significantly impact rodent populations (Bengis et al. 2004).

Wildlife is the primary reservoir and, frequently, the spreading factor for many new zoonotic illnesses (Yon et al. 2019). Some diseases spread to humans through direct contact or by the mediation of vectors. Still, actual pathogen transfer is uncommon, and human-to-human transmission keeps the illness within the community. Viruses can freely transmit between wild and domesticated animals, and commercial animal transportation can contribute to the spread of wild zoonoses (Bengis et al. 2004). Hotspots where zoonotic agents can be transmitted from animals to humans, include places or activities where people often interact with wildlife, such as bush-meat hunting, wet markets, deforestation zones, and bird migratory routes. The significant losses of wildlife habitat and changes in land usage have further increased the potential for transmission between wildlife, cattle, and humans. Human activity has altered more than 77% of the land (excluding Antarctica) and 87% of the water (Allan et al. 2017; Watson et al. 2018). Changes in the remaining high biodiversity regions in Africa, Asia, Central America, and South America can significantly increase interactions between livestock and wildlife species and promote the occurrence of (re)emerging diseases.

Apart from wild animals, pets, and cattle, urban fauna can also act as reservoirs for zoonotic diseases. In Western countries, it is estimated that over 60% of families have pets. Many urban areas have more stray and partially domesticated dogs than usual. As populations grow, urbanize, and become more affluent, livestock is one of the fastest-expanding agricultural subsectors in emerging nations (FAO 2020).

5. CONCLUSION

Zoonotic diseases are a major public health threat, and they are becoming increasingly prevalent. This is due to several factors, including changes in land use, agricultural practices, and human behavior. Zoonotic diseases can cause a wide range of illnesses, from mild to severe, and they can even be fatal. Many things can be done to prevent the spread of zoonotic diseases. These include routinely improving sanitation and hygiene practices in surrounding areas, vaccinating animals against zoonotic diseases, following proper and timely vaccination schedules, and educating the public about zoonotic diseases. The emergence of new zoonotic diseases is a serious threat to global health. However, by preventing the spread of these diseases, we can help protect ourselves and our loved ones.

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The Next Pandemic: A Comprehensive Look into Zoonotic Emerging Threats

07

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ABSTRACT

Zoonotic diseases, infections transmitted between animals and humans, encompass a diverse range of pathogens, including viruses, bacteria, parasites, and fungi, leading to conditions ranging from common colds to severe infections like Ebola. The emergence of zoonotic diseases, particularly those considered as emerging infectious diseases, presents a significant global health threat. Some well-known examples include Salmonellosis, Lyme disease, Rabies, COVID-19, Ebola, and Nipah virus. Factors driving the emergence of these diseases are complex, involving deforestation, livestock movements, and climate change. The impact of zoonotic diseases on society is multifaceted, disrupting social order, causing livestock losses, and instigating psychological distress. Moreover, these diseases pose a substantial economic burden, with notable examples such as the economic losses incurred during the 2009 H1N1 influenza pandemic and the 2015 Ebola outbreak. Vulnerable populations are disproportionately affected, necessitating equitable access to healthcare and resources. Mitigating the socioeconomic consequences of zoonotic disease outbreaks requires investment in early warning systems, robust healthcare infrastructure, resilient economic policies, risk communication, and extensive research. Furthermore, a sustained interdisciplinary approach and international cooperation are crucial for effective surveillance, prevention, and control measures. As zoonotic diseases continue to evolve, addressing these challenges is imperative to safeguard global health and well-being.

Keywords: Zoonotic diseases, Emerging infectious diseases, Global health, Socioeconomic consequences, Interdisciplinary collaboration

CITATION

Nadeem S, Tahir SB, Ahmad M, Aslam A, Farooq M, Hussain Q, Majid H, Usman M and Maqsood H, 2023. The next pandemic: a comprehensive look into zoonotic emerging threats. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 89-103. https://doi.org/10.47278/book.zoon/2023.007

CHAPTER HISTORY Received: 23-March-2023 Revised: 20-May-2023 Accepted: 21-July-2023

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1. INTRODUCTION

Diseases that can be spread from animals to people are called zoonotic. Viruses, bacteria, parasites, and fungi are only some pathogens that can cause these conditions. From the ordinary cold to fatal infections like Ebola, zoonotic diseases cover a broad spectrum of severity (Ahmed et al. 2020). All around the world, people are falling victim to a growing number of infectious diseases known as emerging infectious diseases. Many new infectious diseases are zoonotic or can be transmitted from animals to humans. However, novel viruses that have never infected humans can potentially produce emerging infectious illnesses (Anwar et al. 2019).
Some of the most common zoonotic and emerging diseases discussed forward. Salmonellosis is a foodborne illness caused by Salmonella bacteria (Shafique et al. 2019). It can be found in raw or undercooked poultry, eggs, meat, and dairy products. Lyme disease is a tick-borne illness caused by the bacterium *Borrelia burgdorferi*. It can cause various symptoms, including fever, headache, fatigue, and a characteristic rash. Rabies is a deadly virus transmitted through an infected animal's bite (Ashraf and Khan 2017). COVID-19 is a respiratory illness caused by the SARS-CoV-2 virus. It emerged in December 2019 and has since spread to over 200 countries, causing a global pandemic. Ebola is a deadly virus that is transmitted through contact with the blood or body fluids of an infected person or animal. It emerged in West Africa in 2014 and caused an outbreak that killed over 11,000 people (Baig et al. 2019).
The Nipah virus can cause severe respiratory illness or encephalitis (brain inflammation). It emerged in Malaysia in 1999 and has since caused outbreaks in other countries, including Bangladesh and India (Azam et al. 2016). The causes of emerging zoonotic diseases are complex and multifactorial. However, some of the most important factors include:
Deforestation can bring humans and animals closer, increasing the risk of transmission of zoonotic diseases. Livestock can lead to the spread of zoonotic diseases through the movement of animals and their products. Climate change can alter the distribution of animal hosts and pathogens, making diseases more likely to emerge in new areas. The emergence of zoonotic diseases seriously threatens global health (Ali et al. 2017). However, several things can be done to reduce the risk of outbreaks. Improving sanitation and hygiene can help prevent zoonotic disease from contact with contaminated water or food. Vaccinating animals against zoonotic diseases can help to protect humans from infection. Monitoring animal populations of zoonotic illnesses can help to identify and contain outbreaks early (Shabbir et al. 2015).
The emergence of zoonotic diseases is a complex issue, but it can be addressed through a combination of prevention and control measures. By working together, we can reduce the risk of these diseases and protect human health (CDC 2021).

2. ZOONOTIC DISEASES AS A GLOBAL HEALTH THREAT

Zoonotic diseases are a major global health threat. They are responsible for millions of deaths each year, and they can cause significant economic and social disruption. Some of the most well-known zoonotic diseases include COVID-19, a respiratory illness caused by the SARS-CoV-2 virus. It emerged in December 2019 and has since spread to over 200 countries, causing a global pandemic (Baig et al. 2019). EBOLA is a deadly virus that is transmitted through contact with the blood or body fluids of an infected person or animal. It emerged in West Africa in 2014 and caused an outbreak that killed over 11,000 people (Baig et al. 2019). NIPAH VIRUS is a virus that can cause severe respiratory illness or encephalitis (brain inflammation). It emerged in Malaysia in 1999 and has since caused outbreaks in other countries, including Bangladesh and India (Daszak et al. 2001). Zoonotic diseases can cause high death tolls. For example, the COVID-19 pandemic has caused over 6 million deaths worldwide. Moreover, the Lassa virus causes 1-3 million infections annually (Ahmad et al. 2023).

2.5. ECONOMIC DISRUPTION

Zoonotic diseases can cause significant economic trouble. For example, the COVID-19 pandemic has caused trillions of dollars in financial losses.

2.6. SOCIAL DISRUPTION

Zoonotic diseases can cause social trouble. For example, the COVID-19 pandemic has led to widespread lockdowns and travel restrictions.
In addition to the direct costs of zoonotic diseases, they can also have indirect costs. For example, zoonotic diseases can lead to decreased productivity, as people who are sick are unable to work. They can also lead to increased healthcare costs, as ill people must be treated (Feng and Xiao 2011). The risk of zoonotic diseases is increasing for several reasons. These include:

2.7. INCREASED CONTACT BETWEEN HUMANS AND ANIMALS

This is due to factors such as deforestation, urbanization, and the growth of the livestock industry (Khan and Baig 2015).

2.8. CLIMATE CHANGES

These changes can create new opportunities for pathogens to spread and cause disease.

2.9. GLOBALIZATION

This has led to increased travel and trade, which can facilitate the spread of zoonotic diseases. The good news is that several things can be done to prevent and control zoonotic diseases. These include:

2.10. IMPROVING SANITATION AND HYGIENE

This can help prevent zoonotic disease spread through contact with contaminated water or food.

2.11. VACCINATING ANIMALS AGAINST ZOONOTIC DISEASES

This can help to protect humans from infection.

2.12. MONITORING ANIMAL POPULATIONS FOR ZOONOTIC DISEASES

This can help to identify and contain outbreaks early.

2.13. CHANGING HUMAN BEHAVIOR

This can help to reduce the risk of exposure to zoonotic diseases. For example, people can avoid contact with wild animals and cook meat thoroughly. By taking these steps, we can reduce the risk of zoonotic diseases and protect human health.

3. AN OVERVIEW OF THE HISTORY OF ZOONOTIC DISEASES

Zoonotic diseases, also known as zoonosis, have been an integral part of human history, shaping societies and leaving indelible marks on public health. These diseases are caused by infectious agents that can be transmitted between animals and humans. By investigating the historical trajectory of zoonotic diseases, we can gain valuable insights into the complex interplay between humans, animals, and the environment, allowing us to better understand the challenges zoonotic outbreaks pose (Khaliq et al. 2015).

4. ANCIENT CIVILIZATIONS AND EARLY ZOONOTIC DISEASES

Zoonotic diseases have afflicted humans since the dawn of civilization. Ancient texts and archaeological findings provide evidence of zoonosis, such as anthrax, brucellosis, and tuberculosis in early human populations. Diseases were more easily spread in agricultural civilizations because of the close closeness of humans and domesticated animals. In the 14th century, for instance, the bacteria *Yersinia pestis* appeared and caused one of the deadliest pandemics in human history: the Black Death (bubonic plague) (Malik et al. 2019).

5. EXPLORATION, COLONIZATION, AND THE SPREAD OF ZOONOTIC DISEASES

The Age of Exploration and subsequent colonization brought Europeans into contact with unfamiliar ecosystems, diverse wildlife, and novel pathogens. This encounter between old and new worlds facilitated the transmission of zoonosis such as smallpox, measles, influenza, and yellow fever to indigenous populations, leading to devastating epidemics. The introduction of European livestock to newly colonized regions also resulted in the transmission of diseases, including bovine tuberculosis and brucellosis (Mian and Malik 2018).

6. MODERN CHALLENGES AND THE ONE HEALTH APPROACH

In the modern era, zoonotic diseases continue to pose significant challenges to global health security. Deforestation, wildlife trade, and the risk of zoonotic spillover events are growing due to climate change and intensive animal rearing. Recent epidemics of zoonotic illnesses like Ebola and Middle East respiratory syndrome (MERS), as well as the ongoing COVID-19 pandemic caused by the SARS-CoV-2 virus, emphasize the need to act quickly (Mirza and Khan 2017).

In recent years, the threat posed by infections that can jump from animals to humans has been brought to attention by the introduction and global spread of zoonotic illnesses. COVID-19, Ebola virus disease (EVD), Middle East respiratory syndrome (MERS), highly pathogenic avian influenza (HPAI), severe acute respiratory syndrome (SARS), and Bovine Spongiform Encephalopathy (BSE) are six of the most prominent new zoonotic illnesses discussed in this chapter. By examining their symptoms, transmission routes, prevention strategies, and impact on global health, we can gain insights into the complex nature of these diseases and the challenges they present (Mirza and Khan 2017).

7. COVID-19

The SARS-CoV-2 virus, which produced COVID-19, surfaced in late 2019. It rapidly spread throughout the world. Loss of taste and smell, weariness, and a high body temperature are common symptoms. The virus is often communicated through a person's cough, sneeze, or spoken words. Effective prevention measures include vaccination, mask-wearing, frequent hand hygiene, and maintaining physical distancing. The impact of COVID-19 on global health has been profound, leading to millions of infections, widespread economic disruption, and unprecedented strain on healthcare systems (Nisar and Khan 2020).

8. EBOLA VIRUS DISEASE

Fever, exhaustion, muscle discomfort, headache, and bleeding are just a few of the symptoms of Ebola virus disease (EVD). Transmission from diseased animals typically occurs through bodily fluids or tissues, especially blood, often non-human primates, or human-to-human transmission via direct contact with bodily fluids. Prevention efforts focus on early detection, isolation of cases, contact tracing, safe burial practices, and public health education (Nisar and Khan 2020). EVD outbreaks have had a devastating impact on affected communities, causing high mortality rates and straining healthcare resources.

9. MIDDLE EAST RESPIRATORY SYNDROME

The MERS-CoV virus causes MERS and presents with symptoms such as fever, cough, and shortness of breath, often progressing to severe respiratory illness. Dromedary camels are the primary reservoir, and human transmission occurs through close contact with infected animals or through human-to-human transmission in healthcare settings. Preventive measures include hygiene practices, avoiding close contact with camels, and rapid identification and isolation of cases. Although MERS has a lower global impact compared to other zoonotic diseases, sporadic outbreaks have raised concerns due to its high case fatality rate (Rehman et al. 2018).

10. HIGHLY PATHOGENIC AVIAN INFLUENZA

Highly pathogenic avian influenza (HPAI) refers to viruses primarily affecting birds, but certain strains can be transmitted to humans. Symptoms range from mild respiratory illness to severe respiratory distress, with high mortality rates. Direct contact with infected birds or their secretions, as well as handling contaminated surfaces, are common modes of transmission. Prevention includes strict biosecurity measures in poultry farms, early detection, culling of infected animals, and public health surveillance. HPAI outbreaks have led to significant economic losses in the poultry industry and sporadic human infections, raising concerns about potential pandemics (Lee et al. 2021).

11. SEVERE ACUTE RESPIRATORY SYNDROME

The SARS-CoV virus causes SARS. The virus spreads through close person-to-person contact and respiratory droplets. Strict infection control measures, including isolation of cases, contact tracing, and hygiene practices, are crucial for prevention. The impact of the 2002-2003 SARS outbreaks was significant, with widespread transmission across multiple countries, high mortality rates, and economic disruptions (Hui and Zumla 2019).

12. BOVINE SPONGIFORM ENCEPHALOPATHY

BSE, also known as "mad cow disease," is a neurodegenerative disease affecting cattle. In humans, it manifests as a variant of Creutzfeldt-Jakob disease (vCJD), characterized by progressive neurological symptoms. Transmission occurs through the consumption of contaminated beef products from infected animals. Measures such as feed bans, surveillance, and culling of affected animals have been implemented to prevent the spread of BSE. While the impact of vCJD on global health has been relatively limited, the disease has had significant economic consequences for the livestock industry and generated public health concerns.
Understanding the symptoms, transmission routes, prevention strategies, and global health impact of these emerging zoonotic diseases is crucial for effective disease control, outbreak response, and public health preparedness. Continued research, surveillance, and international collaboration are essential for mitigating the risks associated with these diseases and preventing future outbreaks (Kumagai et al. 2019).

13. THE FACTORS DRIVING THE EMERGENCE OF ZOONOTIC DISEASES

Zoonotic diseases are diseases that can be transmitted from animals to humans. They are a major global health threat and are becoming increasingly common. Several factors are driving the emergence of zoonotic diseases, including:

13.1. DEFORESTATION

Deforestation brings humans and animals closer, increasing the risk of transmission of zoonotic diseases. When forests are cleared, animals are forced to move into new areas, which can bring them into contact with humans. This can lead to the spread of diseases that are carried by animals, such as Ebola and HIV/AIDS. (Sultana and Shafique 2020).

13.2. CLIMATE CHANGE

Climate change is also a factor in the emergence of zoonotic diseases. As the climate changes, it can create new habitats for animals that carry diseases. This can spread diseases to new areas that may not have been previously present. For example, climate change is thought to have played a role in the emergence of the Zika virus, which is spread by mosquitoes. (Yousaf et al. 2014).

13.3. INCREASED HUMAN-ANIMAL CONTACT

Increased human-animal contact is another factor driving the emergence of zoonotic diseases. This is due to several factors, including the growth of the livestock industry, the increasing popularity of exotic pets, and the rise of ecotourism. When humans come into close contact with

animals, they are more likely to be exposed to diseases that those animals carry. For example, the SARS outbreak 2003 was thought to have been caused by a virus that originated in bats. (Zaidi and Ahmed 2019)
It is essential to be aware of the risks of zoonotic diseases and to take steps to protect yourself from infection. These steps include:

13.4. COOKING MEAT THOROUGHLY

This will kill any pathogens that may be present in the meat.

13.5. WASHING YOUR HANDS FREQUENTLY

This will help to prevent the spread of germs.

13.6. AVOIDING CONTACT WITH WILD ANIMALS

This will reduce your risk of exposure to zoonotic diseases.

13.7. GETTING VACCINATED

There are vaccines available for some zoonotic diseases, such as rabies and yellow fever.
By taking these steps, you can help to protect yourself from zoonotic diseases and stay healthy.

13.8. FACTORS DRIVING THE EMERGENCE OF ZOONOTIC DISEASES

The factors driving the emergence of Zoonotic diseases are:

14. DEFORESTATION

Deforestation is the clearing of forests for human use. This can negatively impact the environment, including losing biodiversity, releasing greenhouse gases, and soil erosion. It can also increase the risk of zoonotic diseases.
When forests are cleared, animals are forced to move into new areas. This can bring them into contact with humans, who may not be familiar with these animals' diseases. For example, the Ebola virus is thought to have originated in bats, which are found in tropical forests. When forests are cleared, bats may be forced to move into new areas, where they may come into contact with humans (Zia et al. 2019).

14. CLIMATE CHANGE

Scientists refer to long-term shifts in the typical weather patterns that characterize Earth's local, regional, and global climates when discussing climate change. A wide variety of impacts can be attributed to these alterations. Changes in the statistical distribution of weather patterns that persist over time scales ranging from decades to millions of years are what we mean when discussing climate change. Whether this means more or less intense weather events on average or a shift in the distribution of weather around the average is unclear (Abbasi and Khan 2018).
Climate change is also a factor in the emergence of zoonotic diseases. As the climate changes, it can create new habitats for animals that carry diseases. This can spread diseases to new

areas that may not have been previously present. For example, climate change is thought to have played a role in the emergence of the Zika virus, which is spread by mosquitoes.

15. INCREASED HUMAN-ANIMAL CONTACT

Increased human-animal contact is another factor driving the emergence of zoonotic diseases. This is due to many factors, including the growth of the livestock industry, the increasing popularity of exotic pets, and the rise of ecotourism. When humans come into close contact with animals, they are more likely to be exposed to diseases that those animals carry. For example, the SARS outbreak 2003 was thought to have been caused by a virus that originated in bats (Shabbir et al. 2015).

16. STRATEGIES THAT CAN BE USED TO MITIGATE THE RISK OF ZOONOTIC DISEASE OUTBREAKS:

Surveillance and early detection:

This is essential for identifying and responding to zoonotic disease outbreaks early. Surveillance systems should monitor animal and human health and environmental factors that could contribute to disease transmission (Ahmed et al. 2020).

16.1. ANIMAL VACCINATION

Vaccinating animals against zoonotic diseases can help protect them from infection and reduce the risk of transmission to humans.

16.2. VECTOR CONTROL

Vectors are animals that transmit diseases from one host to another. Controlling vectors, such as mosquitoes, ticks, and rodents, can help prevent the spread of zoonotic disease.

16.3. BIOSECURITY

Biosecurity measures help to prevent the introduction and spread of diseases in farms, food processing plants, and other settings where animals and humans come into contact. These measures include good sanitation practices, quarantine procedures, and the use of personal protective equipment.

16.4. RISK COMMUNICATION

Communicating effectively with the public about zoonotic diseases can help to raise awareness of the risks and how to prevent them. This can be done through education campaigns, social media, and other channels.

16.5. RESEARCH

Research is essential for understanding zoonotic diseases' causes, transmission, and prevention. This research can lead to the development new vaccines, treatments, and control strategies.

These are just some strategies that can be used to mitigate the risk of zoonotic disease outbreaks. By implementing these strategies, we can help to protect human health and prevent the spread of these devastating diseases. In addition to the strategies listed above, several other factors can contribute to mitigating zoonotic disease outbreaks. These include:

16.6. SUSTAINABLE DEVELOPMENT

Sustainable development practices can help to reduce the risk of zoonotic disease outbreaks by reducing deforestation, improving sanitation, and providing access to clean water.

16.7. CLIMATE CHANGE

Climate change is a significant threat to global health, and it is also a factor that can contribute to the emergence of zoonotic diseases. By mitigating climate change, we can help to reduce the risk of zoonotic disease outbreaks.

16.8. INTERNATIONAL COOPERATION

International cooperation is essential for the prevention and control of zoonotic diseases. This cooperation can take the form of sharing information, coordinating responses to outbreaks, and developing new technologies (US DHHS 2018). By taking these steps, we can help to mitigate the risk of zoonotic disease outbreaks and protect human health.

The impact of zoonotic diseases on society can be far-reaching. They can lead to illness outbreaks, which can disrupt social order and cause widespread fear. They can also lead to the death of livestock, which can have a devastating impact on rural communities. In addition, zoonotic diseases can have a psychological effect on individuals and communities, as they can lead to feelings of anxiety, isolation, and fear (Pal 2018).

Here are some of the ways that zoonotic diseases can impact society:

16.9. DISRUPTION OF SOCIAL ORDER

Zoonotic disease outbreaks can disrupt social order in many ways. They can lead to quarantines and travel restrictions, isolating communities and disrupting businesses. They can also lead to panic and fear, which can make it difficult to maintain order.

16.10. LOSS OF LIVESTOCK

Zoonotic diseases can also lead to the loss of livestock. This can devastate rural communities, as livestock is often a significant source of income and food. In some cases, the loss of livestock can lead to food insecurity and malnutrition.

16.11. PSYCHOLOGICAL IMPACT

Zoonotic diseases can also have a psychological effect on individuals and communities. They can lead to feelings of anxiety, isolation, and fear. This can be especially true in communities affected by previous outbreaks. In addition to these direct impacts, zoonotic diseases can also have some indirect effects on society. For example, they can:

16.12. INCREASE HEALTHCARE COSTS

Zoonotic diseases can increase healthcare costs by requiring the treatment of infected individuals. They can also increase the cost of research and development of new vaccines and medicines.

16.13. DISRUPT TRADE

Zoonotic diseases can disrupt trade by restricting the movement of animals or animal products. This can harm the economy, leading to lost revenue and jobs.

16.14. DAMAGE THE REPUTATION OF THE AGRICULTURAL SECTOR

Zoonotic diseases can damage the reputation of the agricultural industry, as consumers may become wary of consuming animal products. This can lead to decreased demand for animal products, harming the economy.
One of the most immediate socioeconomic consequences of a zoonotic disease outbreak is a disruption in healthcare systems. When a new disease emerges, it can take time for scientists to understand how it is transmitted and how to treat it. This can lead to shortages of medical supplies, as well as a strain on healthcare workers (Ahmad and Khan 2017).
In addition to the direct impact on healthcare systems, zoonotic disease outbreaks can also have a ripple effect on other sectors of the economy. For example, if a disease outbreak leads to a decline in tourism, this can negatively impact businesses that rely on tourism revenue. Another necessary socioeconomic consequence of zoonotic disease outbreaks is the loss of livelihoods. When people are sick, they are unable to work. This can lead to financial hardship for individuals and families and a decline in economic productivity.
In some cases, zoonotic disease outbreaks can even lead to economic downturns. Due to the outbreak, businesses may be forced to close or reduce their operations. This can have a knock-on effect on other companies, as well as the broader economy. The socioeconomic consequences of zoonotic disease outbreaks can be severe. It is essential to be aware of these consequences and take steps to mitigate them. Some specific examples of the socioeconomic implications of zoonotic disease outbreaks include:

1. The 2009 H1N1 influenza pandemic caused an estimated $1.4 trillion in economic losses worldwide.
2. The 2003 SARS outbreak in China led to a decline in tourism, which cost the country an estimated $20 billion.
3. The 2015 Ebola outbreak in West Africa caused an estimated $32.6 billion in economic losses.
4. These are just a few examples of how zoonotic disease outbreaks can significantly impact the economy. It is essential to be aware of these risks and take steps to mitigate them (Khan and Anwar 2018).

17. WHAT CAN BE DONE TO MITIGATE THE SOCIOECONOMIC CONSEQUENCES OF ZOONOTIC DISEASE OUTBREAKS?

Many things can be done to mitigate the socioeconomic consequences of zoonotic disease outbreaks. These include:
Investing in early warning systems and surveillance networks will help to identify and contain outbreaks early before they have a chance to spread and cause widespread economic damage. Building robust healthcare systems will ensure that people have access to the care they need when they are sick, regardless of their ability to pay. Developing economic policies that are resilient to shocks will help to protect businesses and individuals from the financial impact of outbreaks. Raising awareness of the risks of zoonotic diseases will allow people to take steps to protect themselves and their families from infection. By taking these steps, we can help reduce

the socioeconomic impact of zoonotic disease outbreaks and protect the health and well-being of people worldwide (WHO 2016).

18. IMPACT OF ZOONOTIC DISEASES ON VULNERABLE POPULATIONS

Zoonotic diseases can have a disproportionate impact on vulnerable populations. This is because these populations are more likely to be exposed to animals that carry zoonotic diseases, and they are also more likely to have weakened immune systems. As a result, they are more likely to get sick from zoonotic diseases, and they are also more likely to die from these diseases (Zinsstag et al. 2011).

19. EQUITABLE ACCESS TO HEALTHCARE AND RESOURCES

To protect vulnerable populations from zoonotic diseases, it is vital to ensure that they have equitable access to healthcare and resources. This includes access to preventive measures, such as vaccination, and access to treatment for people who get sick. It is also essential to address the underlying factors that make vulnerable populations more susceptible to zoonotic diseases, such as poverty and lack of access to clean water and sanitation (Sheikh and Khan 2021).

20. THE FUTURE OF ZOONOTIC DISEASES

Zoonotic diseases, or diseases that can spread between animals and humans are a major global health threat. In recent years, there have been a growing number of zoonotic disease outbreaks, including SARS, MERS, Ebola, and COVID-19. These outbreaks have caused significant human suffering and economic loss.
A number of factors are contributing to the increasing number of zoonotic disease outbreaks. These factors include:

20.1. DEFORESTATION AND HABITAT DESTRUCTION

This brings humans closer contact with wildlife, which increases the risk of cross-species transmission of diseases.

20.2. INCREASED INTERNATIONAL TRAVEL AND TRADE

This is facilitating the spread of diseases around the world.

20.3. CLIMATE CHANGE

This is creating new conditions that favor the spread of some diseases.
The Importance of Sustained Research, Surveillance, and Prevention Efforts
The increasing number of zoonotic disease outbreaks indicates that we must do more to prevent these diseases from emerging and spreading. There are a number of things that can be done to address this challenge, including:

20.4. SUSTAINED RESEARCH

We need to continue investing in research to understand better the causes, transmission, and prevention of zoonotic diseases.

20.5. SURVEILLANCE

We must improve our surveillance systems to detect and track zoonotic diseases better.

20.6. PREVENTION

We must implement effective prevention measures like vaccination, hygiene, and sanitation.
In addition to the above, here are some other specific research, surveillance, and prevention efforts that could be made to address the future of zoonotic diseases:

20.7. DEVELOP NEW DIAGNOSTIC TOOLS

We must develop more sensitive and specific diagnostic tools to detect zoonotic diseases better.

20.8. IMPROVE VACCINE DEVELOPMENT

We must improve our ability to develop and produce effective vaccines against zoonotic diseases.

20.9. STRENGTHEN PUBLIC HEALTH INFRASTRUCTURE

We must strengthen public health infrastructure in developing countries to better detect and respond to zoonotic disease outbreaks.

20.10. EDUCATE THE PUBLIC

We need to educate the public about the risks of zoonotic diseases and how to prevent them.

21. THE POTENTIAL FOR INTERDISCIPLINARY COLLABORATIONS

Zoonotic diseases are complex and require a multidisciplinary approach to understand and control. This means that researchers from various fields, including veterinary medicine, epidemiology, ecology, and public health, must work together to address this challenge (Sheikh and Khan 2021).

22. THE NEED FOR INTERDISCIPLINARY COLLABORATION

There are several reasons why interdisciplinary collaborations are essential to combating zoonotic diseases. First, zoonotic diseases are often caused by complex interactions between humans, animals, and the environment. Researchers need to deeply understand all three of these areas to develop effective prevention and control measures.
Second, zoonotic diseases can emerge and spread rapidly. This means that researchers need to be able to share information and collaborate quickly and effectively. Interdisciplinary collaborations can help to facilitate this sharing of knowledge and cooperation.
Finally, zoonotic diseases can have a significant impact on human health and well-being. It is crucial to develop effective prevention and control measures as quickly as possible. Interdisciplinary collaborations can help to accelerate the development of these measures.

There are many successful interdisciplinary collaborations in zoonotic disease research, for example, the One Health approach. This approach brings together experts from human, animal, and environmental health to address the complex challenges of zoonotic diseases.
Another example is the Global Virome Project. This project is a global effort to catalog the viruses that can infect humans, animals, and the environment. This information will be used to identify new zoonotic threats and develop more effective prevention and control measures.

23. THE IMPORTANCE OF INTERNATIONAL COOPERATION

Zoonotic diseases do not respect national borders. This means that international cooperation is essential to preventing the spread of these diseases. By working together, countries can share information, resources, and expertise. This can help to ensure that outbreaks are detected and responded to quickly and effectively.
There are several examples of successful international cooperation in zoonotic disease control, for example, the World Health Organization's (WHO) Global Strategy for the Prevention and Control of Zoonotic Diseases. This strategy outlines several actions countries can take to reduce the risk of zoonotic disease outbreaks. Another example is the Coalition for Epidemic Preparedness Innovations (CEPI). This organization funds research and development of vaccines against emerging infectious diseases, including zoonotic diseases (Bhatti and Khan 2016).

24. CONCLUSION

Zoonotic diseases are those that can be transmitted from animals to humans. Bacteria, viruses, parasites, or fungi can cause them. Vulnerable populations are those that are at increased risk of contracting zoonotic diseases. These populations include people who live close to animals, people who work with animals, people with weakened immune systems, and people who live in poverty. Zoonotic diseases can have a disproportionate impact on vulnerable populations. This is because these populations are more likely to be exposed to animals that carry zoonotic diseases, and they are also more likely to have weakened immune systems. As a result, they are more likely to get sick from zoonotic diseases, and they are also more likely to die from these diseases (Khan et al.2019)
There is an urgent need for proactive measures to address the growing threat of zoonotic diseases. These measures should include:

- ✓ Increased surveillance of animal and human populations for zoonotic diseases
- ✓ Development of new vaccines and treatments for zoonotic diseases
- ✓ Improved sanitation and hygiene practices
- ✓ Increased education about zoonotic diseases

The growing threat of zoonotic diseases is a serious public health concern. Proactive measures are urgently needed to protect vulnerable populations and prevent the spread of these diseases.

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Emerging Threats to Regional Public Health Posed by Zoonoses

08

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ABSTRACT

Zoonoses, diseases transmitted between animals and humans, present a growing menace to regional public health. The emergence of new zoonotic diseases poses significant challenges, as globalization, climate change, and increased human-animal interaction amplify the risks of spillover events. The intricate interplay between pathogens, animal hosts, and human populations creates a dynamic landscape of emerging threats that demand vigilant surveillance and proactive public health measures. The encroachment of human activities into natural habitats, coupled with the intensification of agriculture and wildlife trade, facilitates the transmission of zoonotic agents. Notable examples include the transmission of the H5N1 avian influenza virus from birds to humans and the spillover of the Ebola virus from wildlife to humans. These instances underscore the vulnerability of regions to novel and potentially devastating zoonotic outbreaks. Climate change further exacerbates the situation, influencing the distribution of vector-borne diseases and altering the habitats of reservoir hosts. This climate-driven shift contributes to the geographical expansion of diseases like Lyme disease and West Nile virus, challenging established public health infrastructures. Addressing the emerging threats of zoonoses necessitates a multidisciplinary approach. Robust surveillance systems, collaboration between human and animal health sectors, and international cooperation are imperative for timely detection, containment, and mitigation. Strengthening the resilience of regional public health systems to adapt to evolving zoonotic challenges is essential in safeguarding communities from the complex and interconnected web of emerging infectious diseases.

Keywords: Avian influenza, Ebola virus, Lyme disease, Public health, Zoonoses

CITATION

Ijaz S, Tariq S, Khan R, Saleem M, Jamil S, Bhatti Mfe, Rizvi Sbh, Saleem M, Liaqat C, Fatima N and Rehman A, 2023. Emerging threats to Regional Public Health posed by Zoonoses. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 104-114. https://doi.org/10.47278/book.zoon/2023.008

CHAPTER HISTORY Received: 25-Jan-2023 Revised: 16-May-2023 Accepted: 25-June-2023

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1. INTRODUCTION

1.1. IMPORTANCE AND PURPOSE

Zoonotic diseases are those illnesses and diseases that are inadvertently transfer from vertebrate animals to humans. There are three categories: endemic zoonoses, which is widespread and affect both humans and animals, epidemic zoonoses, which has sporadic temporal and spatial distribution, and emerging and re-emerging zoonoses, which are either newly discovered in a population or were present in the past but are now spreading rapidly both geographically and in terms of incidence. Rift Valley fever, SARS, pandemic influenza H1N1 2009, Yellow fever, Avian Influenza (H5N1) and (H7N9), West Nile virus, and the Middle East respiratory syndrome coronavirus (MERS-CoV) are examples of the latter, as reported in recent months (Malik et al. 2013).

A tendency in these zoonotic illnesses is the regular unexpected occurrence and global distribution of novel ailments from animals, particularly viruses. Because of their propensity for epidemic spread, high case fatality rate, and lack of treatments or vaccinations (with the peculiarity of the yellow plague vaccine) to stop the transmission of most of these zoonotic diseases, the diseases are also a worry for world health. Emerging zoonoses in one country could perhaps pose a threat to the security of global health because of how interconnected the world is becoming. In the end, however, zoonoses is important not just because they are so widespread but also because it causes morbidity and mortality, a significant burden on health systems, and—most importantly—significant economic losses to the countries by loss in tourism, decreased animal trade, and human economic opportunities because of the loss of livestock (Markoff et al. 2013).

According to approximation, zoonoses generates roughly 1000 million cases of infections and 10 million of mortalities every year throughout the planet. Zoonotic diseases make up to 60% of recently reported infectious ailments in the whole world. Over 30 new human infections have been discovered in the past three decades, 75% of which have animal origins (Jones et al. 2008). In the WHO's Eastern Mediterranean Region, the threat posed by new zoonoses to public health is increasing. Emerging zoonotic diseases have been recorded from 18 of the region's 22 countries during the past 20 years, frequently with explosive outbreaks and significant deaths that have never been seen (Malik et al. 2013).

In any other WHO region, the up-to-date emergence of MERS-CoV is a template of how these infections can emerge at any interval because they come from animals, are frequently brought on by new viruses, and are only disclosed when epidemics occur. Because of its high population density, enhanced capacity of global business, counting cross-border bulk population and animals' movement within adjacent states, the WHO Eastern Mediterranean Area is still particularly vulnerable to zoonotic infections (Chinikar et al. 2012).

Globalization, travel abroad for business, tourism, or religious purposes, and varying levels of health systems' capacity to early detect epidemics have all been identified as significant risk factors for the emergence and rapid international spread of infectious diseases with zoonotic origin. This is because the region continues to be at the crossroads of repeated outbreaks of emerging infectious diseases. Animal-human interface countries' varying levels of surveillance and response capacity have often made these outbreaks adverse. Owing to their capacity for rapid global escalation because of enhanced marketing and international association, including trans-boundary movement of livestock, these zoonotic infections are also a concern for the protection of the universal health system. The emergence of zoonoses also has an economic impact on travel, the trading of animals, and the loss of employment prospects for people owing to the loss of livestock (Hartzell et al. 2007).

Thus, zoonotic illnesses have the potential to have a catastrophic effect, with serious economic repercussions for the countries due to loss of trade, tourism, and consumer confidence. Just to use SARS as an illustration of how zoonosis can negatively affect a nation's economy, it cost the global economy more than USD 50 billion in medical costs and lost revenue due to the tourism industry's precipitous collapse. Another illustration is the fact that each household in Kenya lost an average of US$500 during the RVF outbreak due to reduced productivity and the high expense of the disease's containment.

This chapter will focus on:

(i) Growing public health risks of imminent zoonotic diseases in the sector

(ii) Challenges in prevention of these diseases

(iii) Enhancing a strategic way for anticipating, diagnosing, and eliminating these diseases through a consolidated and associative access between the animal and human health sections.

2. CURRENT SITUATION ALL OVER THE REGION

In the WHO's Eastern Mediterranean Region, the precise magnitude of the zoonotic disease burden is unknown. Despite the fact that endemic zoonotic diseases like brucellosis, anthrax, and rabies have not been eradicated from the states, the zone endures to see both intermittent and epidemic outbreaks of emergent zoonotic infections. Recent outbreaks of West Nile fever in Tunisia (EpiSouth 2012), Chikungunya in Yemen (Malik et al. 2014), Yellow fever in Sudan (Markoff et al. 2013), and Q fever in Afghanistan (Aronson 2008), Iraq (Leung-Shea et al. 2006) have all been reported in the region. Numerous arboviruses and filoviruses are found in the area. Despite the fact that seasonal outbreaks of Crimean-Congo hemorrhagic fever (CCHF) occasionally occur in Pakistan (Mofleh et al. 2013), Afghanistan (Mofleh et al. 2012), Iran (Chinikar et al. 2012), and hospital-acquired plagues of the illness have been documented in the region in recent years in Iraq (Athar MN et al. 2002), the United Arab Emirates and Sudan (Onyango et al. 2007). The persistent risk of viral hemorrhagic fevers exists in the area. The only viral hemorrhagic fever in the area that is caused by a filovirus was the Ebola Hemorrhagic Fever in Sudan in 2004 (Onyango et al. 2004). The quick geographic spread of Rift Valley fever, native to sub-Saharan Africa, to Yemen WHO (2000), Saudi Arabia (Madani et al. 2003) and Sudan is a typical illustration of developing zoonoses in the area.

Human-being ailments have been documented in Djibouti, Iraq, Pakistan, and Egypt as the extremely virulent avian influenza broaden quickly through the Eastern Mediterranean Region in 2006. Numerous countries disclosed experiencing huge epizootics. With a modest level of transmission all year long, the avian influenza is currently thought to be well-established in Egypt. All of the nations in the region were impacted by the influenza A (H1N1) of swine origin in 2009. The region has also seen the emergence of other zoonotic illnesses that are uncommon but nonetheless have substantial morbidity rates. These comprise Plague (Cabanel et al. 2013), Sandfly fever, and monkey pox (Formenty et al. 2010) The Alkhurma virus serves as an example of how recently developing diseases of zoonotic origin also reside in this area. A mankind disease with a novel coronavirus (MERS-Cove) appeared in the area in 2012 (Malik M et al. 2012) which quickly brought attention to this new virus on a worldwide scale. This incident served as a reminder to the zone that appearing zoonosis can happen anywhere at any time and that no state is unsusceptible to the hazards of these illnesses. MERS-Cove has so far afflicted the following nations in the region: Egypt, Iran, Jordan, Kuwait, Lebanon, Oman, Qatar, Tunisia, United Arab Emirates, and Yemen.

These illnesses pose a threat to every nation in the area, and cross-border outbreaks are common. However, the countries in the zone are probably most at risk because they are regularly troubled by difficult emergency situations and are often noted for failing to address the appearance of new diseases or the re-occurrence of old infections properly (Onyango et al. 2004).

Ineffective zoonoses control programs, a lack of agreement on the roles and responsibilities of each region, and the less importance given to zoonotic infections are all cited as major contributing agents to the region's high burden of zoonotic infections and their frequent emergence, frequently with explosive outbreaks. A number of disease-amplifying factors, like as population shifts, disjointed healthcare systems, inadequate laboratory diagnostic capabilities, and interruption of normal epidemiological assistances in calamity-affected nations, have also greatly impacted the rise of new zoonotic ailments in the sector.

3. IMPORTANCE OF ZOONOTIC DISEASES

A tendency in these zoonotic illnesses is the extended unexpected disclosure and worldwide circulation of unusual diseases from animals, particularly viruses. As a result of their high mortality cases, propensity for scourge spread, and scarcity of approachable therapies and vaccines for the most of these zoonotic infections, the illnesses are also a worry for world health (excluding yellow fever vaccine). Imminent zoonoses in any region could perhaps put the reliability of universal health at risk because of how interconnected the world is becoming. In the end, however, zoonoses is important because it is so widespread as well as it causes ailments and death, excess baggage on healthcare organizations, and remarkable financial damage to the society through lost opportunities for travel and animal trade and for the people through the loss of livestock (Mofleh et al. 2013).

Because of low trade, exploration, and consumer trust, zoonotic illnesses can have a disastrous effect and have serious economic repercussions for the countries. Just as an illustration of how zoonosis can negatively affect a nation's economy, the 2003 appearance of SARS put a value on worldwide financial system over US 50 thousand million dollar in cost of health care and income losses due to the unexpected shutdown of the tourism industry. Another illustration is the loss of US$500 per household during the RVF outbreak in Kenya because of decreased production and the high expense of the disease's containment (Cabanel et al. 2013).

4. CHALLENGES IN MANAGING ZOONOTIC INFECTIONS

The unrivalled fluctuation of humans, livestock, and objects beyond intercontinental borders arise owe to globalization has contributed to the zoonotic infection pandemic. Many zoonotic diseases are cross-border illnesses; they pass over frontiers from their point of dawning and have a severe economic influence on dealings, bargaining, globetrotting, and confidence belt.

Most zoonotic infection outbreaks have been documented in distant locations, which makes it difficult or impossible in some cases to reach these populations with public health services. Owing to challenges in expanding squads for field inquiry, absence of pertinent and secure specimen lading mechanisms, insufficiency of requisite laboratory distinctive apparatus on the spot or intra-state, and inadequate dimensions of the countries to plan, disperse, and enforce suitable precautions in such environment as well as to detect the progression of protective measures in geologically disseminated areas, the disclosure and diagnosis of the ailment have been significantly delayed. Therefore, there is a need to invest in bolstering territory-wide upsurge scrutiny and feedback capabilities in the states that are habitually afflicted by the infections to detect these disease threats (Formenty et al. 2010).

Countless vigorous germs that are producing new zoonotic ailments in human being were first found in animals (particularly wildlife) or in items made from animals. Understanding these infections' extra-human reservoirs is still crucial for comprehending the public health and prospective preventative actions for these zoonotic infections.

Additionally, there is insufficient translucency when it comes to promptly informing WHO or any other international organization tasked with investigating and taking appropriate action to ensure the security of global health. Medical authorities in these nations frequently contest the presence of cases in humans, composing it challenging for the organizations that comprehend the health surveillance, course of the sickness, and the best ways to control it in various contexts.

Lack of effective cooperation linking the livestock and human being wellness programs underneath the "One Health" approach, which combines the humans and the animal medical management sectors and merges the livestock and humans' disease surveillance or response system, is the main obstacle in controlling zoonotic diseases in livestock, permitting preliminary eruption exposure, and averting deadland transmission (Mofleh et al. 2013).

Infirm monitoring and coverage organizations and inadequate laboratory function fin diagnosing newly developing zoonotic diseases like SARS, Ebola, Marburg, and novel influenza strains are among the additional difficulties associated with preventing and controlling zoonotic diseases in Member States. Most nations have a low capacity for local response because of a lack of awareness, inadequate resources, and poor quality and quantity of human resources. Among the major industries, there are not many formal mechanisms for collaboration. Because of the difficulty in gathering reliable information from the ground up and the poor coordination between the Ministries of Health and Agriculture, it is laborious to collect exact and up-to-date facts and descriptions on zoonotic infections (Veterinary Services). Additionally, the Region lacks effective zoonotic disease health education and community participation. Additionally, there is little harmonization across the many regulatory frameworks for public health. There is little to no research on recently discovered diseases. In conclusion, the primary difficulties are:

4.1. ORGANIZATIONAL

(i) Insufficient knowledge of the burden, trend, and hazards of zoonotic illnesses.
(ii) Low degree of strategy and opinion-formers' awareness of the dangerous characters of the infection.
(iii) A lack of competent labor and resources for zoonotic disease control.
(iv) Insufficiency of clarity of the states to account for the appearance or incident of zoonotic infection due to fright of consequences.
(v) Fragility or astray of alliance and participation, joining the agriculture, community health, veterinary, and wildlife zones.
(vi) Disappointing cooperation and association to tackle measures to sustain the forestalling and standard programmed of zoonosis.
(vii) Presence of other competing health priorities frequently taking precedence.
(viii) The absence of communication between the departments of surveillance, clinical services, and laboratory services within the healthcare industry.
(ix) The deterioration of health infrastructure, particularly in nations with complicated problems.

4.2. DIAGNOSIS AND DETECTION

Absence of integration between the human and veterinary sections prevents the sharing of observational and lab inspection records from public health sectors. Infirm infection monitoring systems as well as insufficient identifying capabilities make it difficult to find zoonotic infections.

(i) Challenges in doing field research in remote locations, where the majority of developing zoonotic outbreaks take place.

(ii) The countries' weak cross-border cooperation, surveillance, and information sharing.

(iii) Insufficient participation of the community in the zoonosis management programmed.

4.3. CONTROL AND INTERRUPTION OF TRANSMISSION

(i) Nations' inability to design, organize, and carry out effective preventive techniques.

(ii) An inflated likelihood that some recently discovered zoonoses would spread by nosocomial sources in healthcare settings.

(iii) Inadequate implementation of stringent hurdle fostering and necessary disease prevention methods in healthcare facilities.

(iv) Inadequate or inappropriate vector control efforts.

(v) Lack of knowledge of high-risk behaviors, such as cultural and social elements that are linked to the risk of spreading new zoonoses in the community.

(vi) Inadequate or missing evidence supporting some epidemiological control interventions.

5. CURRENT STRATEGIES FOR CONTROL OF ZOONOTIC INFECTIONS

There is little consistency between the sectors of animal and human health in the existing approaches to zoonotic disease prevention and control. Additionally, there are no plans in place globally for the inhibition and management of newly approaching zoonotic ailments. No concentrated attempts have been made in the area to design some scheme for handling and prevention of zoonotic infections and related community well-being hazards because of a lack of resources and a suitable policy response (Hassan et al. 2011). The Regional Office's efforts to promote zoonotic disease control remain marginal despite the threats that new zoonotic pathogens pose to public health. Although efforts to control zoonotic infections are far from sufficient, two Provincial Cabinet decisions.

(i) EM/RC54/R.4 Viable challenges of viral hemorrhagic fevers in the Eastern Mediterranean Region: an appeal for operation.

(ii) EM/RC58/R.4 (D) Dengue: Command for critical interruptions for a quickly broaden imminent infection—have embellished on the issue.

Specified the size and scope of the issue and the changing community fitness concerns linked to zoonotic ailments, it may be count for a standard transfer and modifications to the course of action, WHO wishes to approach the impending hazard to the well-being of the world and its regions.

6. VITAL INDICATIONS FOR PREVENTION OF ZOONOTIC DISEASES

Extremely suitable control for the Zonal Office would be to create a planned structure for control and elimination of zoonotic infections in the area with a perspective of diminishing the well-being, social, and commercial effects of zoonosis in the nations of the land. This is because zoonotic diseases are becoming increasingly important in the region. The following strategic methods will be among the most crucial and significant technical aspects that will need to be considered:

6.1. CREATING PRODUCTIVE PARTNERSHIPS BETWEEN THE DOMAINS OF LIVESTOCK AND HUMAN-BEING HEALTH

Since it is challenging to foresee wherever the next zoonotic illness would appear, it is crucial that veterinarian and public health professionals work closely together. This cross-sectoral partnership aims to improve communication between people and between organizations (Hassan et al. 2011). This practice of actively promoting collaboration between the two sectors through routine scientific information exchange can be led by an inter-agency taskforce. With a planned skeleton of alliances and reconciliation for the one health idea, the labor strength can also direct cooperative discipline research and participate in organizational assets. Effective preventative and anti-dumping measures at the human-animal interaction would be enhanced by doing this.

6.2. INCREASING SURVEILLANCE TO RECOGNIZE INFECTIOUS HAZARDS EARLIER IN HUMAN-BEING

Investigation at the first sign of an emerging ailment in livestock that can cross genus barriers is especially vital to early identify any infection hazards from zoonosis because the majority of imminent infections have causative agents in animals or in invertebrates, and the presence of such ailments in individuals can frequently not be accurately anticipated. Prompt collection and investigation of animal infection data that can intersect breed hurdles, the incorporation of infection monitoring systems across the humans and livestock fitness sections is essential. Syndromic surveillance systems may also be useful for real-time threat detection and can speed up necessary mitigation and preventative activities.

6.3. INCREASING THE LABORATORY'S ABILITY TO DETECT NEW PATHOGENS

When one can find a standard and collaborative delivery etiquettes for exchanging research monitoring facts and figures between the sectors of humans and livestock health instantaneously, diagnostic facilities would be more effective in the initial detection of any zoonotic infection. Furthermore, a technique for sharing research exploring information beyond the preventive medicine business is mandatory, especially among the clinical assistances and infection monitoring sections. The establishment of lab web chains both inside and outward of the countries will speed up the transfer and shipment of specimen for instant recognition of capable zoonosis hazards.

6.4. INCREASING INFECTION PREVENTION AND CASE MANAGEMENT

Prior to the introduction of a disease, an infection prevention and control programmed should be put in place, with the usual precautions serving as a crucial component, to guarantee that healthcare institutions are ready to manage risks from zoonotic illnesses. Regardless of their suspected or confirmed infectious state, all patients should get the same care and treatment. Standard precautions, if consistently followed, would help stop most of the transmission by contact with blood and bodily fluids before any zoonotic diseases of unknown origin are identified (Onyango et al. 2004). The practice of an analytic resolution blueprint for critically inflamed ailment with a susceptible case interpretation may be beneficial for untimely diagnosis of any suspicious specimen owing to the scientific demonstration of many of the appearing zoonotic infections are frequently difficult to discriminate, leading to confusion and misidentified by healthcare specialist. By using such step-by-step diagram, one can help direct prompt treatment possibilities and set off compact actions for additional diagnostic testing and investigation. The accomplishment of this scientific computational system requires coaching of health-maintenance workers in disease prevention and case control operations, as well as pre-position of tactical necessities.

6.5. INCLUDING MANAGEMENT OF VECTOR PROHIBITION

For all the viruses that belong to phylum-Arthropoda, an integrated vector control management (IVM) scheme ought to be taken into consideration as the same technique of resource escalation for coherent vector management. The IVM strategy prescribes the utilization of various interventions, either solely or reciprocally that are selected established on indigenous education about the vectors, diseases, and infection determinants. On the basis of corroboration and consolidated handling of mosquito immediate hosts, inclusive of rodents. IVM might be the most productive technique for management of rodents and carriers that participate in the escalation of specified viruses that cause hemorrhagic fever (Formenty et al. 2010). To determine the spatial and temporal diffusion of the carrier species, countries must first map the vectors in detail, including their breeding grounds. Intending preventive efforts for multiplying sites during the periods between the epidemics may benefit from this information. The aim of carrier control methods should be to lessen mature mosquito inhabitants' probable reproducing areas or their interconnections with people beyond levels that would support an outbreak. Establishing a spotter location for parasite monitoring in sites with high carrier aggregation, unified it with health surveillance and viral scrutiny systems, and reporting on atypical clumps of critical delirious ailment, a sudden increase in carrier density, or an unanticipated segregation of a unique zoonotic germs can all help to gather useful information. Such details can aid in understanding the predicted, current, or changing risk.

6.6. REDUCING TRANSMISSION THROUGH BEHAVIORAL AND SOCIAL CHANGES

For most emerging zoonoses, especially those involving median mammal hosts, the efficacy or negligence of faltering the transference chain will rely on the significance of the behavioral response of the exposed public. The commune's risk approach and how this correlate with real or intentional attitude, social, lunatic and reasonable components that distinguish the manifested population's nature, and intellectual features that effect the protecting elements and acceptability of cohesion to such defensive behavior will ought to be taken into consideration when designing appropriate social and behavioral interventions for threats from specific diseases.

6.7. BUILDING EMERGENCY RESPONSE AND PREPAREDNESS CAPABILITIES FOR NEW ZOONOSES

The chief strategy should begin with the formation of a governmental scheme with involvement from entire momentous collaborators. The scheme should consider utilize earth science data organizations and other statistics techniques to design an absolute danger evaluation and plan the geological dissemination of zoonotic infections that are exist in the countries (Malik et al. 2012). Areas that are vulnerable to the spread of zoonoses should also be identified. To assure that main facts and figures on hazards is routinely disclosed between the companions through a well-compatible structure, human-being, livestock, and carrier scrutiny ought to be strengthened and, if possible, integrated with details and dividend. Pre-allocation of strategic necessities (investigation kits, personal protective equipment, etc.), modelling of admissible standard and calibers to evaluate the achievement of retaliation movements, and public guidance operations pointed at diminishing danger revelation should all be comprised in the plan. The basics to a prosperous infestation preparedness and counter scheme ought to be the installation of a multi-disciplinary integrating team to encourage collaboration and incorporation between all associates and to escort, conduct, and contribute compulsion reaction procedures during an epidemic.

Finally, to track the strategy framework's execution throughout time, it will be necessary to provide the right monitoring and evaluation instruments and indicators (Aradaib et al. 2011). The following factors must be considered by the countries when creating their own programmed for the control and management of imminent zoonotic infections:

6.8. STRENGTHENING CIVIL DEDICATION, STATE DESIGNING, AND CORRELATION TECHNIQUES

It would be necessary to develop policies for fostering efficacious cross-regional cooperation connecting the humans and livestock health sections through improved sectoral coordination, joint planning, and increased sectoral communication.

6.9. STRENGTHENING PREPAREDNESS, SURVEILLANCE, AND REACTION

This includes cooperative surveillance operations at the animal-human interface, enhancing laboratory diagnostic capabilities, and developing multi-sectoral preparedness and response strategies for controlling zoonotic illnesses. Designing schemes for governmental dimensions building for zoonotic disease preventive and eradication programs, including creating a firm research base for novel methods for prevention of zoonosis in the nation.

6.10. ENCOURAGING RESEARCH

6.10.1. IMPROVING REGIONAL AND GLOBAL COOPERATION AND COLLABORATION

Reducing the dangers of zoonotic diseases to the public's health will necessitate a commitment and intensive cooperation and collaboration from all parties in pursuit of a shared vision, objective, and purpose. This must be considered in the suggested strategy framework.

6.11. HEALTH ADVOCACY, HAZARD REPORTING, AND COMMUNAL FULL-TIME TRAINING

Regulations on the efficient utilization of risk conveying and society involvement in addressing the epidemiological hazard associated with the initiation of zoonotic infections would require to be implemented in the countries (Onyango et al. 2004).

7. CONCLUSION AND FUTURE APPROACHES

Following the discovery of MERS-CoV, the area is now becoming a growing priority for global health. The impact of numerous newly developing zoonotic infections has been felt in the area. Our modern time has demonstrated us that dynamic zoonotic infections are unpredictable and unplanned phenomenon. Another lesson is that certain disease outbreaks that happens currently allover in the world could create problems for the whole globe tomorrow. The resilience and responsiveness of the governmental well-being authorities to react quickly will pursue to be assessed by these impending diseases. Global health security will also be put to the test by how well regional and global communities can work together to fight these diseases that cut across national borders.

A lot more zonal correlation would be needed to protect the public's fitness from all sorts of zoonotic illnesses, even while worldwide efforts should continue to adjacent the knowledge intervals associated to the inception and transmission of many zoonotic infections, nearly all are distinctive in origin. Constituting a viable epidemiological programmed for the identification, prohibition, and elimination of new zoonotic ailments in the state is imperative given the current circumstances in the area regarding the global and national response to MERS-CoV.

The "One Health" approach, that demands a common correlation procedure, mutual designing, collective administration, communal involvement, amplitude establishment, and joint monitoring and assessment framework joining the humans and livestock health divisions, should present as the premise for any strategic framework for the control of zoonosis. The "one Health" strategy also call attention to 5 crucial areas where it is most apparently to have an impression. These include:

(i) Pooling health resources between the veterinary and medical fields
(ii) Preventing the spread of zoonotic diseases among animal reservoirs
(iii) Identifying emerging diseases early and responding to them
(iv) Preventing epidemics and pandemics
(v) Developing new knowledge and enhancing health research and development (Cabanel et al. 2013)

To reinforce their abilities to turn down the community well-being concern completely and lucrative influence obtrude on their people and animals by zoonosis, the Member States will also be required by the strategy to inaugurate and integrate scales that incorporate technical, social, political, strategically, and administrative controversies. The best course of action for the prevention and control of newly developing and re-occurring zoonotic ailments in the WHO Eastern Mediterranean Region is the execution of a workable strategy. The strategic directions outlined in this paper are invited for consideration and adoption by the Regional Committee. As stated in the International Health Regulations (2005), effective control of emerging zoonoses will provide a chance to lessen the global well-being risks linked with zoonotic illnesses and molding the globe into less vulnerable to recently spreading and reappearing pathogens.

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Zoonoses in Sheep and Risk Factors

09

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ABSTRACT

The progressive growth of sheep farming on a global scale, although it has an important contribution to development, subsistence and food security, also implies risks for human health. The high propensity of sheep to suffer from diseases associated with a variety of etiological agents underlines the importance of recognizing and addressing the risk factors of zoonotic diseases associated with this livestock species. The emergence and re-emergence of zoonotic diseases and the expansion of their distribution worldwide highlights that in addition to the biological risk factors, related to the susceptibility of sheep, as carriers or reservoirs of different diseases, the rapid evolution and diversification of some etiological agents, changes in the environment and various anthropogenic factors are being determining factors. The current climatic conditions associated with climate change tend to generate variations that favor the adaptation and diversification of pathogens, as well as the multiplication of vectors, which accentuates the problem. Aspects such as the type and size of the herd, the production and grazing system, the coexistence of different livestock and domestic species such as dogs and cats, the introduction of non-certified animals, overcrowding, the sanitary conditions associated with the accumulation of feces and fomites, are contributing to the spread of zoonotic diseases. In the case of humans, interaction with domestic and wild animals, non-compliance with biosafety measures in the management of animals and their waste, as well as sanitary deficiencies in food consumption, increase the risks of dissemination of zoonoses. The geographical distribution of zoonoses is expanding in different regions of the world; in addition to climatic variations, socioeconomic conditions, productive breeding practices and sheep production volumes are being determining factors. The behavior of each zoonosis in each region is variable, since it depends on the convergence of various factors. The fact that for the same zoonosis there are different definitive and incidental hosts is increasing the risk of transmission of these diseases. In addition to this, deficiencies in epidemiological surveillance, animal health controls and prevention measures tend to exacerbate this problem.

Keywords: Sheep, Zoonotic diseases, Risk factors, Production practices, Transmission routes

CITATION

Ojeda-Carrasco JJ, García-Rubio VG, Espinosa-Ayala E, Hernández-García PA and Márquez-Molina O, 2023. Zoonoses in sheep and risk factors. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 115-133. https://doi.org/10.47278/book.zoon/2023.009

CHAPTER HISTORY Received: 14-March-2023 Revised: 20-July-2023 Accepted: 17-Aug-2023

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1. INTRODUCTION

For many populations in the world, sheep farming represents a livestock activity that benefits communities by contributing to subsistence and food security. The progressive growth of sheep farming on a global scale, although it supports these essential aspects for the development and well-being of societies, also highlights the importance of promoting production processes that reduce the associated negative effects. One of the most important is to guarantee the health of the animals, in order to minimize the development of zoonotic diseases that affect the health of humans. The high propensity of sheep to suffer various diseases, associated with a diversity of etiological agents that include viruses, bacteria, rickettsia, protozoa and different types of parasites, underlines the importance of recognizing and addressing the risk factors associated with this type of disease (Ojeda et al. 2022).

The alterations produced by these diseases in animals have serious economic repercussions due to the decrease in productivity. The delay in growth, weight loss, the presentation of abortions and death, generate important losses in production. In health, the ease and speed with which they spread tends to affect the health of the herd, extending their effects to human health, given the diversity of transmission routes to which they are associated (Vega-Pla et al. 2022).

The emergence and re-emergence of zoonotic diseases and the expansion of their distribution in different regions of the world, from originally endemic areas, is part of the current problem. In addition to the biological risk factors, related to the susceptibility of sheep, as carriers or reservoirs of different diseases, the rapid evolution and diversification of some etiological agents (especially viruses), the changes generated in the environment are being decisive. In addition to this, anthropogenic factors such as the population explosion, the increase in interactions with wild animals, the increase in the global mobilization of people, the trafficking of exotic species and commercial diversification, which includes animals, frozen and processed foods, are making important contributions in this regard (PAHO/WHO 2018).

2. WORLD SHEEP POPULATION

Worldwide, the raising of small ruminants is becoming a livestock activity of great importance both economically, as well as for food security and the development of countries. From 2005 to 2020 (Table 1), the highest growth rate is reported in goats among livestock species such as sheep, goats, cattle and pigs. The second place corresponds to sheep, which reach a percentage growth of 14.38% for this period.

Table 1: Percentage growth from 2005 to 2020 by livestock species

	Number of heads		Growth rate	Percentage of growth
Species	2005	2020		
Sheep	110,707,630	126,613,454	0.0014	14.38
Goats	85,057,090	112,810,624	0.0033	32.63
Cattle	908,669,878	982,004,053	0.0008	8.07
Pigs	223,856,534	235,113,946	0.0005	5.03

Source: World data. Elaboration based on data obtained from FAOSTAT (2022)

For sheep, despite the global growth in this period, only Africa (46.01%) and Asia (22.05%) report an increase in their populations at the regional level (Table 2; Fig. 1). For the Americas, Europe and Oceania, the number of sheep has decreased, more significantly in Oceania (-36.46%).

At the sub regional level (Table 3) in 2020, East Asia reported the highest number of sheep heads (20,333,148). For this sub-region, the largest volume is for China, with 17.31 Million head of sheep, followed by Mongolia (3,004) and Korea (17,100). In the second place, West Africa is located with 12,583,753 Million head of sheep (Mhs), placing Nigeria (4.77 Mhs), Mali (2.01) and Niger (1.37) as the contributing countries. In the Americas, of the total value (8,573,865), 76.15% corresponds to South America, with contributions from Brazil (2.06 Mhs), Argentina (1.45) and Peru (1.19). In the case of Europe, according to the total number of heads, it is located in Northern Europe. The largest contributors to this sub region are Norway (22,466), Sweden (50,115) and Iceland (40,072). However, at the regional level, the countries with the highest number of sheep heads are the United Kingdom (6,879 Mhs) from Western Europe, the Russian Federation (2,065) from Eastern Europe and Spain (1,543) from Southern Europe.

Table 2: Five-year growth of the sheep population (Comparison of the Rate and Percentage of growth between 2005 and 2020)

	Number of heads				2005-2020	
Region	2005	2010	2015	2020	Growth rate	Percentage of growth
Africa	28,648,543	32,293,630	36,195,455	41,830,381	0.0046	46.01
Americas	9,349,045	9,161,025	8,475,230	8,573,865	-0.0008	-8.29
Asia	44,853,746	45,610,887	50,761,802	54,742,389	0.0022	22.05
Europe	13,754,353	13,013,244	13,084,305	12,506,887	-0.0009	-9.07
Oceania	14,101,944	10,066,912	10,006,193	8,959,933	-0.0036	-36.46
	110,707,630	110,145,698	118,522,984	126,613,454	0.0014	14.38

Source: Own elaboration based on data obtained from FAOSTAT (2022)

Table 3: Sheep population by sub region (2018-2020)

Sub region	2018	2019	2020
East Africa	9,283,456	10,981,046	11,154,784
Central Africa	3,971,187	4,238,062	4,525,771
North Africa	10,830,676	10,770,075	11,069,863
Southern Africa	2,603,487	2,538,006	2,496,210
West Africa	11,920,836	12,325,190	12,583,753
Regional total	38,609,641	40,852,378	41,830,381
North America	914,160	908,670	899,370
Central America	932,610	935,655	938,085
Caribbean	206,173	210,604	207,301
South America	6,317,921	6,519,417	6,529,109
Regional total	8,370,863	8,574,346	8,573,865
Central Asia	5,719,572	5,828,712	5,987,514
Eastern Asia	19,212,546	19,594,146	20,333,148
South Asia	15,917,093	15,976,052	16,262,849
Southeast Asia	1,917,832	1,943,631	1,959,068
Western Asia	9,283,478	9,617,458	10,199,811
Regional total	52,050,521	52,959,998	54,742,389
Eastern Europe	3,732,344	3,603,849	3,557,181
Northern Europe	4,171,816	4,133,509	4,035,855
Southern Europe	3,992,947	3,918,717	3,877,686
Western Europe	1,033,736	1,029,174	1,036,165
Regional total	12,930,843	12,685,249	12,506,887
Australia	7,006,732	6,575,541	6,352,937
Fiji	2,770	3,165	3,074
New Zealand	2,729,575	2,682,185	2,602,894
Papua New Guinea	754	758	763
Regional total	9,739,830	9,261,649	8,959,667

Source: Own elaboration based on data obtained from FAOSTAT (2022)

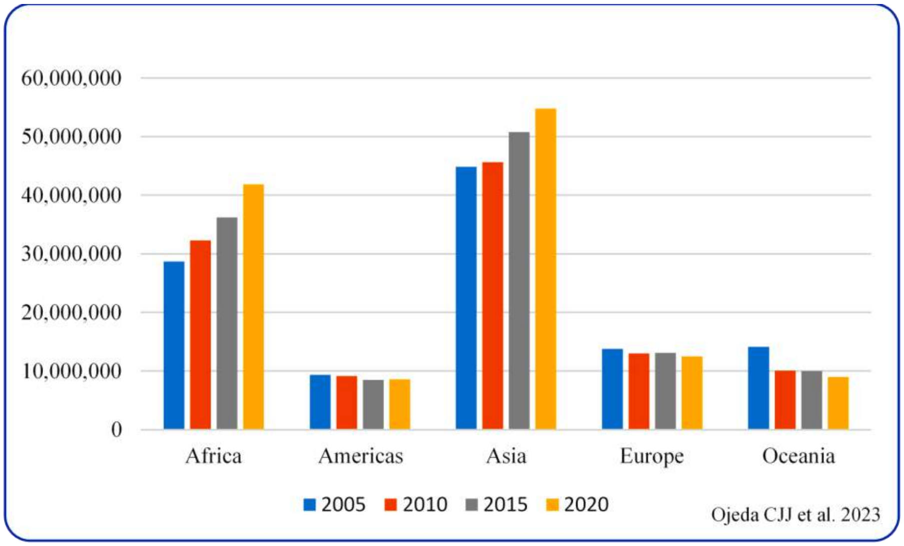

Fig. 1: Five-year growth of the sheep population by regions of the world: **Source:** Own elaboration based on data obtained from FAOSTAT (2022).

3. ZOONOTIC DISEASES IN SHEEP

From the productive point of view, sheep have great advantages for their rearing. Its great adaptability to different environments, the ease of its extensive production, the high level of use of food resources and its efficient forage transformation capacity to produce a greater amount of meat, among other aspects, stand out. However, it is also one of the species most susceptible to various diseases (Moreno and Grajales 2017). This is due to the variety of etiological agents that affect this species.

Among the main zoonotic diseases in sheep, 19 are of bacterial origin, 15 parasitic and 5 viral. Of the bacterial zoonoses, due to their prevalence, distribution and effects, Chlamydiosis (enzootic abortion), anthrax (Anthrax), Leptospirosis and Campylobacteriosis are of significance. Among those of parasitic origin, Echinococcosis, among viral diseases Paralytic Rabies and Rift Valley Fever, and among those of protozoa, Toxoplasmosis are most important (Ojeda et al. 2022). Table 4 shows the etiological agents related to the main ovine zoonoses and the effects they cause in animals and humans.

4. MAIN RISK FACTORS ASSOCIATED WITH OVINE ZOONOSES

Undoubtedly, one of the main risk factors for ovine zoonoses is their great diversity. Table 4 includes those with the highest incidence in sheep and humans. Along with bacterial diseases, parasitic zoonotic diseases are the most diverse and common, generating greater impacts on the productivity and health of sheep, such as Haemoncosis, caused by *Haemonchus contortus*. Of the parasitic zoonoses, only one out of 15 is included in Table 4 (Ojeda et al. 2022).

This diversity is directly associated with etiological agents. Its inherent biological characteristics, the resistance to survive in the external environment, its infective capacities, its adaptability to different hosts, among others, potentiate the risks. A preponderant factor is the different routes of transmission (Table 5). Contact with sick animals, body fluids, wounds, abortion products, trans placental transmission, during childbirth or lactation, as well as the consumption of forage and food, contaminated water or soil, fomites and aerosols, are some of the dissemination routes for these diseases (Sempere et al. 2019).

The interrelation established between etiological agents, animals, humans and the environment is a determinant of risk factors. In animals, their own conditions influence such as the productive and physiological state, age, origin, the use of antimicrobial and anti-parasitic treatments, their

susceptibility. Likewise, aspects such as the type and size of the herd, the production and grazing system, the coexistence of different livestock and domestic species such as dogs and cats, the introduction of non-certified animals, overcrowding, sanitary conditions associated with the accumulation of feces and fomites, mainly. In the case of humans, interaction with domestic and wild animals, non-observance of biosafety measures in handling animals and their waste, as well as sanitary deficiencies in food consumption, increase the risks of spreading zoonoses (Jiménez-Martín et al. 2015; Rizzo et al. 2016; Palomares et al. 2019).
The risks increase under current climatic conditions, which tend to generate important climatic variations and new microclimates, which favor the adaptation and diversification of pathogens, as well as the multiplication of vectors (Wu et al.2016).

Table 4: Main ovine zoonoses

Zoonotic diseases	Aetiological agent(s)	Effects		References
		Animals	Humans	
Anthrax	*Bacillus anthracis*	Fever Rumination stops Excitement then depression Breathing difficulties Incoordination Seizures Sudden death Incomplete hardening of the carcass after death Bloody discharges from natural body orifices Swelling in different parts of the body	*Skin form:* *Appearance of sores that* become ulcers with a black center Gastrointestinal form: Fever Nausea bloody diarrhea loss of appetite *Respiratory form:* Sore throat Cough Weakness breathing difficulties	Perret et al. 2001 Palomares et al. 2019 Ojeda et al. 2022
Black leg	*Clostridium chauvoei*	Emphysematous muscle inflammation Necrosis (gangrene) Incoordination Edematous swellings on the hip, shoulder, loin, chest and neck Deaths	Localized infection in superficial wounds Foul-smelling serous exudates Myonecrosis Cellulitis Myositis	Cesar 2010 Bush et al. 2021
Botulism	*Clostridium botulinum*	Anorexy Weakening with ataxia Incoordination of previous members Decreased muscle tone Chewing and swallowing problems Anuria Intestinal and ruminal hypotonia Dehydration Progressive paralysis Death	Nausea Threw up Abdominal pain Progressive head-to-limb paralysis respiratory distress Death (without timely care)	Cesar 2010 Uzal 2013 Ojeda et al. 2022

Brucellosis	*Brucella ovis* *Brucella melitensis* *Brucella abortus*	Depression Weight loss Diarrhea In females: Late abortion Lesions in the fetal membranes Retained placenta Mastitis In males: Epididymitis Orchitis Injuries to the scrotum and tunica vaginalis Reduced motility and sperm concentration	Some asymptomatic Fever Weakness Arthritis Hepatic injury Weight loss Abortion	Leite-Browning et al. 2019 WHO 2020b Ojeda et al. 2022
Campylobacteriosis	*Campylobacter fetus* subesp. *intestinalis* *Campylobacter jejuni*	Inflammation of fetal membranes (placentitis) Abortion in the last month of pregnancy Stillbirths Birth of weak pups that die after birth Postpartum metritis	Intestinal inflammation Diarrhea Abdominal pain Fever Nausea Threw up Seizures Meningitis	Gutiérrez et al 2008 López de Armentia et al. 2017 Ojeda et al. 2022
Caseous Lymphadenitis	*Corynebacterium pseudotuberculosis (*antes *Corynebacterium ovis)*	Progressive Anorexy Decrease in meat and milk production Reproductive disorders Skin form: External purulent abscesses, behind the ears, under the jaws, neck, shoulder, hind flank, scrotal sac, and udder. gut shape: Visceral lymph node abscesses Abscesses in liver, lungs and kidneys	Painful skin wounds with purulent exudate and necrotic tissue	Martínez-Hernández et al 2019 Valle et al. 2021
Chlamydiosis (enzootic abortion)	*Chlamydophila abortus* (antes *Clamydia psittaci*)	Epididymitis Encephalomyelitis Enteritis Pneumonia Conjunctivitis Respiratory disease Infertility In pregnant females: Endometrial ulceration Retained placenta Weakening of placenta Abortion (last third of pregnancy) Stillbirths Birth of weak pups	Conjunctivitis Pneumonia Abortions Flu-like signs (fever, chills, joint pain)	Leite-Browning et al. 2019 Palomares et al. 2019 Ojeda et al. 2022

Coenurosis	*Taenia multiceps*	*Coenorus cerebralis* (Cystic vesicle of *T. multiceps*) Depression Ataxia Incoordination Paresis Episodes of excitement Sudden collapse Tremors Blindness Comatose states	Cysts (Cenuri) in: *Central Nervous System* Increased intracranial pressure Loss of consciousness Focal neurological deficits *Subcutaneous tissues* Painful fluctuating nodules *Eye muscles* Vision impairments	Valladares-Carranza et al. 2016 Leite-Browning et al. 2019 Ojeda et al. 2022
Contagious ecthyma	*Parapoxvirus/Poxvirus*	Skin lift Vesicles that form encrustations on the lips, oral cavity, ears, vulva, scrotum, udder, and feet	Painful sores on the hands	Leite-Browning et al. 2019 Ojeda et al. 2022
Dermatophilosis	*Dermatophilus congolensis*	Exudative-proliferative dermatitis Hyperkeratosis	Pustules on arms and hands Ulcerations on the skin	García et al. 2020
Foot and mouth disease	Aftovirus de la familia Picornaviridae	Fever Blisters on tongue, lips, mouth, udders and between hooves Decrease in milk production Abortions In lambs, death from heart failure	Vesicular lesions Fever Runny nose Cut body Articulations pain	WOAH 2021 Ojeda et al. 2022
Echinococcosis	*Echinococcus granulosus*	Fluid and masses in the abdomen Hepatomegaly and abdominal enlargement Breathing difficulties	Pain in the liver region inflammation of the abdomen Sputum with blood Cough Jaundice Hemoptysis	Gottstein and Beldi 2017 Tercero y Olalla 2008
Hemorrhagic sepsis	*Manheimia multocida* *M. haemolytica*	Pyrexia Congestion of the mucous membranes Dehydration Hollow eyes Nervous breakdown Weakness Cough Dyspnea Hyperpnoea muscle tremors Nasal and ocular discharge from serous discharges Anorexy reduced rumination Pleuritis Emission of frothy fluids from the mouth in the terminal phase	Cellulitis with or without abscesses Fever Dyspnea Pleuritic pain Spontaneous bacterial peritonitis Secondary peritonitis due to perforation of viscera Intra-abdominal abscesses Less frequent: Endocarditis Eye infections Genital and urinary tract infections Meningitis	CFSPH 2009b Pinto 2016 Cueto y Pascual 2018

Leptospirosis	*Leptospira interrogans* *Leptospira* spp.	Stillbirths Premature births Abortions Anemia Jaundice Hepatic injury	Some asymptomatic High fever Headache Shaking chills Myalgia Threw up Jaundice Meningitis In severe cases, death	Luna et al. 2019 Leite-Browning et al. 2019
Listeriosis	*Listeria monocytogenes*	Abortion Depression Fever Anorexy Reduction in milk production they walk in circles Seizures Facial paralysis Death	Fever Headache and abdominal Pain Muscle contracture Nausea Vomiting Myalgia Miscarriage or premature birth Newborns with health problems	Leite-Browning et al. 2019 Ojeda et al. 2022
Mycoplasmosis	*Mycoplasma ovis*	Persistent intravascular infections Submandibular edema Hemolytic anemia Hemoglobinuria Jaundice Less meat production Infertility Death in severe cases	Pyrexia Moderate chronic neutropenia Acute hemolysis	Aguirre et al 2009 Martínez-Hernández et al. 2019
Ovine Encephalomyelitis	Virus louping ill de la familia *Flavivirus*	Initial febrile viremic stage Depression Anorexy Encephalitis Muscle tremors and/or stiffness Incoordination Ataxia Hypersensitivity Salivation Nervous Nibbling Movement "in jumps" Death in animals with neurological signs	Fever Headache Articulations pain Meningoencephalitis Neurological signs of paralysis Fever inducing bleeding	Andersen et al. 2019 CFSPH 2009a
Q-Fever	*Coxiella burnetiid*	Abortions Stillbirths Prenatal depression Antepartum anorexia Reproductive disorders	High fever Headache and myalgia Chills and sweating Dry cough Vomiting Diarrhea Pain in abdomen and chest Hepatitis	Rizo et al. 2016 Leite-Browning et al. 2019

Paratuberculosis	*Mycobacterium avium* subsp. *paratuberculosis* (MAP)	Irreversible weakening Inflammation and disorders in the intestinal tract Inflammation of the mesenteric lymph nodes Progressive weight loss Profuse diarrhea Pasty stools Intermandibular edema Reduction in milk production Death	Serious local infections Tissue detachment Chronic synovitis Tendinitis	CFSPH 2007 Santillán-Flores et al. 2021
Salmonellosis	*Salmonella abortus ovis*	Placentitis at the cotyledon level Possible abortion in the second half of pregnancy With abortion, females can develop metritis and peritonitis. Infertility in females Birth of septicemic and weak pups Necrotic foci in the liver and lungs In pups lung infections and diarrhea Death in severe cases	Inflammation of the gastrointestinal tract Diarrhea Threw up Nausea Headache Muscle contractures Myalgia	Gutiérrez et al. 2008 Contreras-Soto et al. 2019
Staphylococcus disease	*Staphylococcus* spp.	Mastitis Milk coagulation Presence of blood, pus and lumps of casein in the milk Drop in milk production	Skin infections Endocarditis Pneumonia Osteomyelitis	Esnal y Extramina 2019 Martínez-Hernández et al. 2019 Ojeda et al. 2022
Tuberculosis	*Mycobacterium tuberculosis* Complex (MTC)	Immunosuppression Encapsulated gaseous lesions Lesion in mesenteric lymph nodes (large and prominent) Loss of appetite and weight Dyspnea and intermittent dry cough Signs of low-grade pneumonia Diarrhea	Severe coughing up blood or sputum Chest pain Weakness or fatigue Loss of appetite Weight loss Shaking chills Fever Night sweats	Muñoz et al. 2012 Muños-Mendoza et al. 2015 Gelalcha et al 2019
Toxoplasmosis	*Toxoplasma gondii*	Embryonic or fetal death or late Abortion Fetal mummification Stillbirths Loss of successive pregnancies	Abortions Infected newborns with eye and brain damage Swollen lymph nodes Muscle pains brain and organic damage Vision problems or blindness	Diakoua et al 2013 Leite-Browning et al. 2019

In 2020, worldwide sheep inventory reported 126,613,454 head. Of this total, 49.29% is concentrated in 14 countries (Fig. 2). The largest producer is China with 17,309,553 heads (13.67% of world production), followed by India with 6,809,976 heads (5.38%) and Australia with 6,352,937 heads (5.02%) (FAOSTAT, 2022).

Table 5: Routes of transmission of the main ovine zoonoses

ZOONOSES	ANIMALS										HUMANS										REFERENCES
	Acquisition				Vertical		Horizontal				C	A	M	F	Oral (Food)					V	
	CF	A	S	V	IU	P	BF	BP	H	I					C	MP	L	D	A		
BACTERIAL																					
Anthrax	■								■	■	■	■			■						Perret et al. 2001; Martínez-Hernández et al. 2019
Botulisms	■		■						■						■	■	■	■			Cesar 2010; Uzal 2013; Ojeda et al. 2022
Brucellosis	■	■			■	■	■	■		■	■	■	■	■	■		■	■			Leite-Browning et al 2019; WHO 2020b; Ojeda et al. 2022
Campylobacteriosis	■	■					■	■			■				■	■			■		Gutiérrez et al. 2008; López de Armentia et al. 2017; Ojeda et al. 2022
Black leg	■										■				■	■					Cesar 2010; Bush et al. 2021
Chlamydiosis	■	■			■		■	■		■	■			■							Palomares et al. 2019; Ojeda et al. 2022
Dermatophilosis			■	■					■		■										García et al. 2020
Staphylococcus disease			■						■		■			■							Esnal y Extramina 2019; Martínez-Hernández et al. 2019
Q-Fever	■			■			■	■			■										Rizo et al. 2016; Leite-Browning et al 2019
Leptospirosis	■	■	■				■	■	■		■										Leite-Browning et al 2019, EFSA/ECDC
Caseous lymphadenitis	■								■		■				■		■				Martínez-Hernández et al. 2019; Valle et al. 2021; Rodríguez et al. 2021

Listeriosis	Leite-Browning et al 2019; Ojeda et al. 2022
Mycoplasmosis	Aguirre et al. 2009, Martínez-Hernández et al. 2019
Paratuberculosis	CFSPH 2007; Santillán-Flores et al. 2021
Salmonellosis	Gutiérrez et al. 2008; Conteras-Soto et al. 2019
Hemorrhagic sepsis	CFSPH 2009b; Pinto 2016; Cueto y Pascual 2018
Tuberculosis	Muñoz et al 2012; Gelalcha et al. 2019
VIRAL	
Contagious ecthyma	Leite-Browning et al 2019; Ojeda et al. 2022
Ovine encephalomyelitis	CFSPH 2009a; Andersen et al. 2019
Vesicular stomatitis	Leite-Browning et al 2019; Palomares et al. 2019
Foot and mouth disease	Gutiérrez et al. 2008, WOAH 2021
PARASITIC	
Coenurosis	Valladares-Carranza et al. 2016
Echinococcosis	Tercero y Olalla 2008; Gottstein and Beldi 2017; Ojeda et al. 2022
by PROTOZOA	
Cryptosporidiosis	Leite-Browning et al 2019; Ojeda et al. 2022

Toxoplasmosis	Diakoua et al. 2013, Jiménez-Martin et al 2015

ANIMALS. Acquisition: CF=Contaminated food, A=Contaminated water sources, S=Contaminated soil, V=Vectors. Vertical: UI=Intrauterine, P= during childbirth. Horizontal: BF=Body fluids, BP= Contact with birth products, H=Wounds, I=Inhalation/Aerogen: HUMANS. C= Direct contact with infected animals, placenta and/or aborted fetuses, A=Aerogenous route (Aerosols), M= Manipulation of meat or viscera, F=Fomites. Oral: C=Contaminated meat, MP=Meat products, L=Contaminated milk, D=Contaminated dairy products. A= Contaminated water, V=Vector transmission.

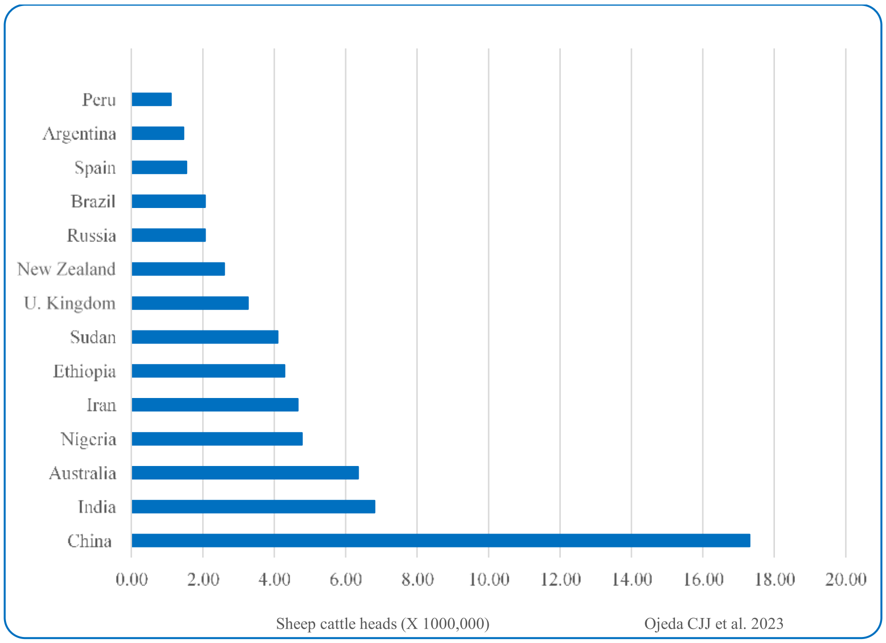

Fig. 2: Main sheep producing countries in 2020: **Source:** Own elaboration based on data obtained from FAOSTAT (2022)

5. WORLD INDICATORS OF THE MAIN OVINE ZOONOSES

The World Health Information System (WHAIS) of the World Organization for Animal Health (WOAH) records data for 14 different zoonoses associated with sheep (WOAH 2023). For 11 zoonoses, the cases for mixed herds (sheep and goats) have also been reported (Table 6). In the case of brucellosis, figures are presented separately for *Brucella abortus*, *B. melitensis* and *B. suis*.

There are differences between the numbers of susceptible animals, positive cases and deaths, of sheep compared to mixed herds. For the 16 zoonotic diseases that are registered, in mixed flocks a greater number of susceptible animals reported (10.6 million) compared to 7.3 million in sheep. In sheep, the highest frequencies correspond to zoonotic taeniasis (61.8%) and foot and mouth disease (14.7%), and for mixed flocks, brucellosis (due to B. melitensis) with 61.7% and foot and mouth disease (22.3%). For six of the zoonoses, susceptibility is greater in mixed flocks than in sheep flocks, including anthrax, brucellosis, foot and mouth disease, tuberculosis and rabies. However, in general the number of positive cases is much lower in mixed flocks (1.6%) than in sheep (14.2%). Proportionally to the number of susceptible animals, positive cases for brucellosis are 3.27% in sheep versus 1.43% in mixed flocks, in foot-and-mouth disease 9.01% vs. 2.42% and in tuberculosis 6.72% vs. 1.80%, respectively. With some exceptions, the relationship is inverse as in hemorrhagic sepsis (4.55% vs 15.97%). In general, sheep-only flocks are more susceptible to disease development (Rizzo et al. 2016; Palomares et al. 2019).

Table 6: Accumulated data, total per year and percentage per world region of the main ovine zoonoses (2018-2022) registered in WOAH

ZOONOSES		SUSC	Cases	Deaths	2018	2019	2020	2021	2022	AF	AM	AS	EU	OC
SHEEP														
Anthrax		300,656	28,341	28,189	1,128	26,105	469	390	249	91.86		6.13	0.18	1.83
Brucellosis	*B. abortus*	5,672	545	3	189	69	277	4	6	54.31	39.08	6.61		
	B. melitensis	792,113	25,935	521	4,656	4,790	3,917	6,315	6,257	2.79		86.62	10.59	
	B. suis	0	1	0		1							100	
Encephalitis		16	6	0	1	1	2		2			50.00	50.00	
Zoonotic taeniasis		4,489,645	865,487	5	171,126	188,448	190,336	225,618	89,959	76.82	20.49		2.69	
Foot and mouth disease		1,068,214	96,224	6,096	13,886	6,667	4,795	65,924	4,952	10.23		89.77		
Hemorrhagic septicemia		67,894	3,086	2,251	2,699	387				79.29		20.71		
Tuberculosis		119	8	0		8					87.50		12.50	
C. pleuropneumonia		250	47	32	47					100				
Paratuberculosis		190,454	3,080	305	97	901	38	1,448	596	57.31	1.98	37.18	3.54	
Q-Fever		166,163	4,589	175	18	1,245	605	1,116	1,605	13.07	0.04	77.56	9.33	
Salmonellosis		61,211	1,750	137	492	992	113	142	11	0.86		37.94	61.20	
Rabies		90,742	1,261	680	349	331	313	216	52	60.82	6.82	32.36		
Rift Valley Fever		34,802	707	384	389	77	69	172		100				
West Nile Fever		0	4	0		4				100				
MIXED HERDS (SHEEP AND GOATS)														
Anthrax		1,236,704	6,113	4,729	2,094	3,608	253	158		37.35		62.65		
Bruc.	*B. abortus*	26,122	1,492	0		1,484	8			1.74	98.26			
	B. melitensis	6,514,810	93,064	608	35,265	26,762	11,003	14,964	5,070	0.52		70.16	29.32	
Zoonotic taeniasis		165,423	1,147	79	534	419	172	22		4.71		95.03	0.26	
Foot and mouth disease		2,352,224	56,850	6,389	13,362	6,008	14,041	12,834	10,605	26.49		73.51		
Hemorrhagic septicemia		6,767	1,081	351	1,069	12				32.38		67.62		
Tuberculosis		39,982	720	0		256	12	45	406	35.69	58.19		6.11	
Paratuberculosis		13,973	1,009	269	17	24	424	141	403			68.09	31.91	

Q-Fever	30,531	1,732	131	26	214	72	600	820		38.91	61.09
Salmonellosis	20,532	1,367	127	849	0	246	250	22		63.06	36.94
Rabies	113,506	463	361	115	216	100	29	3	12.31	87.69	
Rift Valley Fever	37,947	326	104	139	181	6			100		

SUSC= Susceptible. AF= Africa, AM=Americas, AS=Asia, EU=Europe, OC=Oceania
Source: Own elaboration based on the processing of data registered in WOAH (2023).

An important factor is the geographic distribution of zoonoses. The environmental conditions that prevail, the socioeconomic conditions and the productive practices of breeding in each region, are usually determining factors. As observed, from 2018-2022 in sheep the highest number of zoonoses (considering in all cases Brucellosis as one, regardless of the *Brucella* species) occurs in Africa (11), followed by Asia (9), Europe (8), Americas (7) and Oceania (1). For mixed herds, in Asia and Africa (8), Europe (6) and Americas (2). Among other aspects, it stands out that, both in Asia and in Africa, they raise sheep and mixed flocks mainly by transhumance, which contributes to the spread of zoonoses. In contrast, there are four zoonoses reported for a region. Brucellosis caused by *Brucella suis*, with the only case for Spain. The 47 cases of contagious pleuropneumonia for Chad in Africa. Rift Valley fever is present in sheep and mixed herds in 12 African countries where the highest cumulative prevalences reported for South Africa (335), Senegal (246) and Madagascar (154). Four positive cases of West Nile fever has been reported in 2019 for South Africa (WOAH 2023).

In Asia and Africa, in addition to the mentioned factors, the volume of production also determines the diversity of zoonoses. As noted above, the main producers worldwide are located in Asia and Africa. Of the 2020 world sheep inventory, Asia contributes 43.24%, Africa 33.04%, Europe 9.88%, Oceania 7.08% and the Americas 6.77%. However, this relationship between production volume and zoonoses does not necessarily have a directly proportional relationship, that is, as the volume increases, the number of zoonoses increases. The condition that occurs in Asia and Africa does not happen the same when comparing the Americas with Oceania. For 2020, the sheep inventory in the Americas was 8,573,865 heads vs. 8,959,933 in Oceania, with 7 and 1 zoonoses in sheep, respectively.

This indicates that the causality of zoonoses at the regional level is multifactorial. Climatic conditions, infrastructure, nutrition and welfare of animals, epidemiological surveillance, among many other factors, intervene. The figures show that the behavior of each zoonosis in each region is variable, due to the association with these factors. In some, despite international measures to promote its prevention and control, adverse conditions can interfere with these purposes, such as Anthrax, which had a significant increase in cases between 2018 and 2019, going from 1,128 to 26,105 cases. In others, such as zoonotic taeniasis caused by *Echinococcus granulosus*, which experienced sustained growth from 2018-2021, in 2022 the number of cases dropped to about a third of the previous year. Others present fluctuations that make their future behavior unpredictable. In the same way, between one year and another the number of zoonoses registered is variable.

Even when this information provides elements to infer the dimension of the problem associated with ovine zoonoses, it only does so partially. In principle, because WHAIS does not integrate data for other zoonoses of great importance. The records do not include bacterial diseases such as Campylobacteriosis, Chlamydiosis (enzootic abortion), Leptospirosis and Listeriosis, among others, or viral such as ovine encephalomyelitis. As well as those caused by protozoa such as Coccidiosis, Cryptosporidiosis and Toxoplasmosis. Additionally, the figures represent a sample of the regional sheep inventory. For example, for Africa in 2020 the inventory is

41,830,381 heads of sheep, the number of susceptible animals is 55,956, which is equivalent to 0.13% of the inventory. Although it is possible to consider that not all animals are in a condition of susceptibility, this percentage represents only a small part of the real problem for this disease.

Added to the real impact that these zoonoses have on animals are the effects on human health. Sheep zoonoses that affect public health mostly include those transmitted by food, associated with the consumption of meat or meat products, milk and its derivatives, with deficient cooking or pasteurization processes. Among these are Campylobacteriosis, Salmonellosis, Yersiniosis, Escherichia coli infections (STEC infections), Listeriosis, Trichinosis, among others. Other zoonoses, due to direct contact with infected animals, such as tularemia, a disease present in different animal species, but to which sheep are particularly susceptible (CFSPH 2019). Alternatively, by other routes of transmission such as aerosols, fomites contaminated with feces or urine, contact with the birth products of a sick animal, or through vectors, which increases the risk of contracting them.

Due to their routes of transmission, some occur more frequently in people related to the care and attention of animals. However, those that represent a greater risk are Foodborne Diseases. In most cases, the effects on public health are precisely unknown, due to the lack of systematized records. The referents appear in isolation through estimates, reports on specific outbreaks or general information provided by the World Health Organization. This organization refers, for example, that Campylobacteriosis in humans is associated with the consumption of contaminated food, such as meat, milk and its derivatives (WHO 2020). In the case of Listeriosis, it has been found that cold cuts (meat pies and other sausages) and soft cheeses made with contaminated products served as high-risk foods (WHO 2018). For this zoonosis, the CDC (2017) estimates that annually 1,600 people contract the disease and that about 260 (16.25%) die from it. In Spain, in 2019, 254 people were affected, four deaths and six abortions caused by the disease. In 2020, the number of cases increased to 1,900, of which 817 (43%) required hospitalization, with a mortality rate of 13%, which implies that 1:8 people died from the disease (Lurueña 2022). In 2022, 16 cases were reported in 6 states of the American Union (7 in New York), 81.25% required hospitalization and 1 died (CDC 2023).

Of the different health instances, only the European Food Safety Authority and the European Center for Disease Prevention and Control annually record information on cases of zoonoses that occur in the European Union. For 2021 (Table 7), they report 14 zoonoses in which sheep are involved (EFSA/ECDC 2022).

Of the 14 zoonoses, 11 are systematically reported and three (Yersiniosis, West Nile Fever and Toxoplasmosis) are only monitored based on the epidemiological situation that occurs. Based on the incidence and notification rate (N/1000 000 population), the most important are Campylobacteriosis and Salmonellosis. By the number of deaths, Listeriosis and Salmonellosis. Most of the reported cases correspond to infections acquired within the European Union. The report of cases acquired outside the EU indicates that one of the risk factors is associated with global movements that have increased significantly in recent years. Comparison with reported data shows that the number of cases has increased by 10 zoonoses, with the largest increase for *Escherichia coli* STEC infections. A reduction is only shown in cases of Echinococcosis (Zoonotic Taeniasis), Q-Fever, Trichinosis and West Nile Fever.

Table 8 shows the contrast between the number of cases and deaths reported in humans and animals. Until now, information systems do not have records that allow us to know the real scope of zoonotic diseases, in principle due to the lack of systematization of reports from humans in the world. Additionally, because not all zoonoses are integrated into the WHAIS registry. In this case, the ECDC (2022) reports 14 zoonoses in humans for the European Union and WHAIS (WOAH 2023) only includes five of these. Campylobacteriosis,

Table 7: Cases of zoonoses in humans in the European Union for 2021 based on data registered in EFSA/ECDC

Zoonoses	CASES	HOSP	DEATHS	NR	FC	ACQUIRED IN: In EU	Outside EU	Country unknown	Changes compared to 2020 in %
Campylobacteriosis	127,840	45,121	26	41.1	249	81,311	704	45,825	2.10
Salmonellosis	60,050	11,785	71	15.7	773	43,720	925	15,405	14.30
Yersiniosis (*)	6,789	1,564	0	1.9	248	3,478	18	3,293	11.80
E. coli STEC Infections	6,084	2,133	18	2.1	31	4,355	117	1,612	36.90
Listeriosis	2,183	956	196	0.49	23	1,484	2	697	14.10
Tularemia	876	221	2	0.2		715	160	1	33
Equinococcosis	529	121	0	0.15	0	128	81	320	-7.50
Q-Fever	460	0	4	0.11		359	3	98	-12.00
Brucellosis	162	60	0	0.03	1	76	21	65	0.03
Tuberculosis	111	0	0	0.03	0	55	47	9	12.40
Trichinosis	77	26	0	0.02	1	29	2	46	-32.50
Rabies	0	0	0	0	0	0	0	0	0
West Nile Fever(*)	158	70	21	0.04		153	5	0	-57
Toxoplasmosis (*)	133	98	0	0.02	95	124	7	2	1.80

HOSP= Hospitalized, NR= Notification rate N/1000, 000 population, FC Foodborne cases
(*) Zoonoses monitored based on the epidemiological situation
Source: Own elaboration based on the processing of data registered in EFSA/ECDC (2022).

Table 8: Comparison of reported cases and deaths, for animals and humans in the European Union (2021)

ZOONOSES	Animals		Humans		Countries (Highest reported cases)			
	Cases	Deaths	Cases	Deaths	Animals	No.	Humans	No.
Campylobacteriosis	*	*	127,840	26			Germany	47,912
							Czech Republic	16,305
							Slovakia	6,099
Salmonellosis	126	0	60,050	71	Italy	67	Czech Republic	10,032
					Spain	43	France	9,315
					Romania	16	Germany	8,144
Yersiniosis	*	*	6,789	0			Germany	1,912
							France	1,451
							Czech Republic	456
E. coli STEC Infections	*	*	6,084	18			Germany	1,635
							Denmark	927
							Ireland	878
Listeriosis	*	*	2,183	196			Germany	560
							France	435
							Italy	241
Tularemia	N/R	N/R	876	2			Sweden	292
							France	143
							Germany	113
Echinococcosis	1,350	0	529	0	Spain	1,349	Germany	152
					Hungry	1	Bulgaria	89
							Austria	42
Q-Fever	192	0	460	4	Spain	145	Spain	149
					Germany	39	Germany	99
					Hungry	7	France	92
Brucellosis (*B. melitensis*)	65	0	162	0	Spain	54	Italy	32
					Italy	11	Spain	25
							Greece	24
Tuberculosis	N/R	N/R	111	0			Germany	42
							Spain	32

							Italy	12
Trichinosis	N/R	N/R	77	26			Bulgaria	29
							Croatia	17
							Austria	10
Rabies	0	0	0	0				
West Nile Fever	N/R	N/R	158	21			Italy	65
							Greece	59
							Romania	7
Toxoplasmosis	*	*	133	98			France	110
							Germany	14
							Poland	9
Paratuberculosis	37	0	N/R	N/R	Spain	29		
					Germany	8		
Totals	1,770	0	205,452	462				

*= Not included in the WHAIS database. S/R= No data record in WHAIS or EFSA for that year: **Source:** Own elaboration based on the processing of data registered in EFSA/ECDC (2022) and WOAH (2023).

Yersiniosis, *E. coli*/STEC infections, Listeriosis and Toxoplasmosis are not on the list of diseases in the WHAIS information system. It stands out that the first three are the most prevalent in humans and that there is no information to associate the corresponding animal species. For another four, although the disease is on the list, there are no recorded data for 2021 or the species. In sheep, Tularemia registers 32 positive cases and zero deaths (2005-2007), all for Bulgaria. Rabies 139 cases, 45 deaths (2005-2016) with distribution in 5 countries (Bulgaria, Croatia, Latvia, Poland and Romania). Tuberculosis associated with the *Mycobacterium tuberculosis* complex and Trichinosis report 3 and 56 cases, respectively for pigs and wild boars (2007-2019), none for sheep. As for West Nile Fever, the cases reported in sheep are for Africa and Canada (WOAH 2023).
The absence of data in both categories for some zoonoses makes a 1:1 comparison impossible. For cases that meet this condition, the prevalence reported in humans are higher than in animals, except for brucellosis. The controls established in the EU have made it possible to significantly reduce the cases of this zoonosis and even eradicate it in some countries (EFSA/ECDC 2022). In the list of countries with the highest incidence, there is not necessarily a direct correspondence between the number of cases between animals and humans. For example, for Salmonellosis, positive cases in sheep include Italy with 67 (3,768 in humans), Spain with 43 (3,912) and Romania with 16 (518). However, in humans, the highest incidences correspond to the Czech Republic (10,032 cases), France (9,315) and Germany (8,144). In Echinococcosis, cases in sheep are only reported for Spain (1,349 cases in animals vs. 33 in humans) and Hungary. The proportions are for Spain and Hungary (1 vs 7). The highest incidences are for Germany (152), Bulgaria (89) and Austria (42). In these cases, the disease may be associated with infections outside the EU, or that the pathogens came from other domestic or wild animal species.
According to the EFSA/ECDC reports (2022), of the 27 countries that make up the European Union, 15 (55.6%) show effects on public health due to the report of zoonoses. Based on the incidence and diversity of zoonotic diseases in humans, Germany stands out with 10, France (6), Italy (4) and Spain and the Czech Republic, both with 3 zoonoses. These data allow us to infer the impact generated by zoonoses on human health in different regions of the world. The complexity of the risk factors is that they are not unidirectional and that in many cases they tend to be convergent, which tends to exacerbate the problems faced.

6. CONCLUSIONS

Sheep farming is a livestock activity that is gaining strength throughout the world. Its contributions to food security, economy and development contrast with the effects on animal and human health.

This is mainly due to the diversity of factors that increase the risks of these diseases occurring. The changing environmental conditions associated with climate change are propitious for originally endemic diseases to expand their distribution. The population increase, the greater contact with wild species, the increase in international transit, commercial exchange and changes in lifestyles, which include the consumption of processed foods, among other factors, are increasing these risks alarmingly.

The fact that for the same zoonosis there are different definitive and incidental hosts, which include both domestic and wild species, is increasing the risk of transmission of these diseases. In addition to this, deficiencies in epidemiological surveillance, in animal health controls and prevention measures, tend to exacerbate this problem. Although the food needs of human populations require an increase in food production, deficiencies in biosecurity and animal welfare measures in animal husbandry, as well as inadequate handling during slaughter and food processing, they are violating this objective. In addition to the economic impact due to the losses generated by the low productive performance or death of animals, as well as the costs of veterinary care, zoonoses violate food safety. The impact on the availability and safety of food seriously jeopardizes human health and the future development of populations.

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Zoonotic Respiratory Diseases: Historic Impact & Emerging Threats

10

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ABSTRACT

Zoonotic respiratory illnesses have played a significant role in shaping human history and continue to pose global health challenges by crossing over from animals to humans. This abstract investigates the historical significance of diseases and the current dangers they pose, with a focus on specific examples and their consequences. Throughout history, respiratory pandemics that have caused widespread devastation have been triggered by infectious agents originating from various animal sources. The 1918 Spanish Flu, which originated from an H1N1 influenza A virus with mixed avian and swine origins, serves as a notable illustration of the effects of zoonotic respiratory illnesses. Tuberculosis, caused by a bacterial infection, has demonstrated the ability to cross from cattle to humans, showing zoonotic potential with Mycobacterium bovis. New dangers in the current world consist of illnesses such as MERS and Avian Influenza. MERS, which is caused by a type of coronavirus, has been connected to dromedary camels, emphasizing the ongoing danger of animals passing diseases to humans. Constantly looming threats, avian flu variants such as H5N1 and H7N9 originate from wild birds as their natural hosts. The effects of zoonotic respiratory diseases are displayed through the COVID-19 pandemic, which is a result of the SARS-CoV-2 virus. Bats are thought to be the original source of the virus, and it is likely passed on to other animals before reaching humans. Confronting these difficulties requires a comprehensive and collaborative strategy. The integration of human, animal, and environmental health is essential for effective surveillance and mitigation strategies, known as the One Health approach. Effective collaboration on a global scale, sharing of data, and comprehending the factors involved in the transmission of zoonotic diseases are essential for preventing and managing these illnesses. In light of continued challenges with respiratory diseases that can be transmitted from animals to humans, it is essential to take a proactive and multidisciplinary approach to safeguard human health from these changing dangers.

Keyword: Zoonotic Respiratory Diseases; Historic Impact; Emerging Threats; Pandemics; One Health Approach

CITATION

Waseem M, Iftikhar A, Anwar H, Nausheen R, Saleem S, Batool F and Bibi A, 2023. Zoonotic respiratory diseases: historic impact & emerging threats. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 134-155. https://doi.org/10.47278/book.zoon/2023.010

CHAPTER HISTORY Received: 04-Feb-2023 Revised: 15-April-2023 Accepted: 20-May-2023

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INTRODUCTION

Zoonotic respiratory diseases are illnesses caused by microorganisms found in animals that can be transferred to humans via the respiratory system. Due to their potential to produce pandemics and global health catastrophes, such as COVID-19, these diseases have escalated in significance recently. The transmission of these diseases is often facilitated by modern transportation systems, cross-border trade, and increased human encroachment into natural habitats, leading to massive contact with wildlife (Chomel 2014, McFarlane 2015, Hassell et al. 2021). Various pathogens, including viruses, bacteria, and fungi, are responsible for causing zoonotic respiratory diseases. COVID-19, SARS, MERS, and avian influenza are the most common zoonotic respiratory diseases. The COVID-19-causing SARS-CoV-2 virus is assumed to have emerged in bats and spread to humans, potentially via an intermediate animal host. Similarly, coronaviruses causing SARS and MERS are also thought to have originated from bats and spread to humans via the carriers like civets and camels, respectively (Contini et al. 2020). The influenza viruses that cause bird flu, also known identified as avian influenza, are mostly found in birds. Humans can get the disease by coming into contact with infected domestic or wild birds (Peiris et al. 2016).

Many routes exist for spreading zoonotic respiratory disorders, including physical contact with sick animals or their waste, intake of infected animal products, and inhaling particles carrying the pathogen. For instance, when an infected individual talks, sneezes or cough, COVID-19 spreads by respiratory droplets. Another person may inhale these droplets and become infected. Some zoonotic respiratory diseases can also spread by touching contaminated surfaces like door handles or utensils or touching bodily secretions from contaminated persons or animals (Karesh and Noble 2009, Rehman et al. 2009). Zoonotic respiratory diseases can present with a range of symptoms, although they typically involve fever, irritable throat, cough, body pains and difficulty breathing. In certain situations, the disease can escalate to more chronic disorders, such as acute respiratory distress syndrome (ARDS), pneumonia, and even death. Early diagnosis and treatment are vital in preventing the spread of zoonotic respiratory diseases and minimizing the severity of symptoms. Treatment options may include antiviral medications, antibiotics, and supportive care to manage symptoms. Vaccines may also be available for certain zoonotic respiratory diseases, such as avian influenza (Warwick and Corning 2013, Rahman et al. 2020). The summary of various respiratory zoonotic diseases is enlisted in Table 1.

Prevention measures for zoonotic respiratory diseases include avoiding contact with infected animals, practicing good hygiene such as hand washing and wearing masks, and following food safety guidelines when handling animal products. To prevent the spread of these diseases, public health officials may take measures like imposing travel restrictions or implementing quarantine protocols. Ongoing surveillance and research into these illnesses are vital to comprehend their origins, pattern of transmission and possible treatment (Bender and Shulman 2004, Rahman et al. 2020, Ziarati et al. 2022). Zoonotic respiratory diseases impose a major threat to global public health and require a collaborative, multidisciplinary approach to prevention and treatment. Early identification, quick intervention, and continuous surveillance and research work are all part of the effort to prevent and manage these illnesses. More investment in public health infrastructure and research, as well as a better knowledge of the processes that contribute to the genesis and spread of zoonotic infection, are necessary to avoid future outbreaks and preserve public health (Nantima et al. 2019, Milbank and Vira 2022).

2. HISTORICAL PERSPECTIVE OF ZOONOTIC RESPIRATORY DISEASES

Zoonotic Respiratory illnesses have caused some of the most catastrophic global pandemics in history, leading to a crucial impact on mortality rates worldwide. With an estimated one-third of the planet's population affected and at least 50 million documented deaths, the 1918 influenza outbreak ranks

Table 1: Summary of Zoonotic Respiratory Diseases: Causative Agent, Animal-Host Species, Mortality Rate, and Global Prevalence.

Disease	Causative Agent	Animal-Host Specie	Mortality Rate	Global Prevalence
Anthrax	*Bacillus anthracis bacterium* (Omodo et al. 2023)	Cattle, sheep, goats (Omodo et al. 2023)	45-80% (Stratilo et al. 2020)	Africa: (Romero-Alvarez et al. 2020) Asia: (Sushma et al. 2021) Europe: (Sushma et al. 2021) Middle East: (Doganay and Metan 2009) North America: (Jernigan et al. 2002)
Avian influenza	*Influenza A virus* (Mosaad et al. 2023)	Chickens Turkeys Wild waterfowls (Mosaad et al. 2023)	60% (Camphuysen et al. 2022)	Asia: (Sims et al. 2005) Europe: (Atkinson et al. 2006) Africa: (Brown 2010) North America: (Pasick et al. 2012)
Bovine tuberculosis	*Mycobacterium bovis bacterium* (Abrantes and Vieira-Pinto 2023)	Cattle animals (sheep, goats) Domesticated animals (cats, dogs) Wild animals (deer, bison, badger) (Kasir et al. 2023)	16% (Nakayiza, Walekhwa et al. 2022)	Africa: (Ayele et al. 2004) Europe: (Yahyaoui-Azami et al. 2017) North America: (Yahyaoui-Azami et al. 2017) South America: (Arnot and Michel 2020)
Brucellosis	*Brucella bacterium* (Jokar et al. 2023)	Cattle animals (sheep, goats, pigs, cows) Domesticated animals (dogs) (Jokar et al. 2023)	<5% (services 2004)	Africa: (Ducrotoy et al. 2017) Asia: (Thimm 2013) Middle East: (Musallam et al. 2016) Central & South-east Europe: (Taleski et al. 2002)
Camelpox	*Camelpox virus* (Gieryńska et al. 2023)	Camels (Gieryńska et al. 2023)	28% (Jezek et al. 1983)	Middle East: (Balamurugan et al. 2013) North Africa: (Zhugunissov et al. 2021) Central Asia: (Afonso et al. 2002) South Asia: (Venkatesan et al. 2018) East Africa: (Kriz 1982)
Hantavirus pulmonary syndrome	*Hantavirus* (Sundar et al. 2023)	Rats Mice (Avižinienė et al. 2023)	30-40% (Thorp et al. 2023)	North and South America: (Hjelle and Glass 2000) Europe: (Vaheri et al. 2013) Asia: (Kruger et al. 2015) Africa: (Witkowski et al. 2014)
Hendra virus infection	*Hendra virus* (Tomori and Oluwayelu 2023)	Horses Flying foxes (fruit bats) (Wang et al. 2023)	50-100% (Marsh and Wang 2012)	Australia: (Field et al. 2010)
Middle east respiratory syndrome	*MERS coronavirus (MERS-CoV)* (Azhar et al. 2019)	Camels (Azhar et al. 2019)	20% (Park et al. 2018)	Middle East: (Memish et al. 2014) Europe: (Zumla et al. 2015) Asia: (Hui et al. 2015) South Korea: (Cowling et al. 2015)
Monkeypox	*Monkeypox virus* (McCollum and Damon 2014)	Rats Monkeys (El Eid et al. 2022)	1-10% (Parker and Buller 2013)	Central & West Africa: (Pastula and Tyler 2022)
Nipah virus infection	*Nipah virus* (Shariff 2019)	Flying foxes (fruit bats) Pigs (Soman et al. 2020)	40-90% (Alam 2022)	South East Asia: (Hossain et al. 2008)

Pasteurellosis	*Pasteurella multocida bacterium* (Register and Brockmeier 2019)	Cattle animals (sheep, goat) Domesticated animals (cat, dog) Wild animals (rabbits, rodents) (Mohamed and Abdelsalam 2008)	<10% (Reinsch et al. 2008)	North America: (Snyder and Credille 2020) Asia: (Brickell et al. 1998) Europe: (Magariños et al. 1996) Africa: (Miller 2001)
Plague	*Yersinia pestis* (Kool and Weinstein 2005)	Rats Mice Squirrels (Smiley 2008)	≥90% (Pechous et al. 2016)	Central Asia: (Tsuzuki et al. 2017) Africa: (Duncan and Scott 2005) Europe: (Bramanti et al. 2019)
Psittacosis	*Chlamydia psittaci* (Stewardson and Grayson 2010)	Parrots Cockatiels Parakeets Pigeons Poultry (Jorgensen 1997)	<1% (Chu et al. 2019)	North and South America: (Chu et al. 2019) Asia: (Matsui et al. 2008) Australia: (Elliot 2001) Europe: (Rehn et al. 2013)
Q fever	*Coxiella burnetii bacterium* (Woldehiwet 2004)	Cattle animals (sheep, goats) (Hirschmann 2019)	1-2% (Parker et al. 2006)	Australia: (Sloan-Gardner et al. 2017) Europe: (Georgiev et al. 2013)
Severe acute respiratory syndrome	*SARS coronavirus (SARS-CoV)* (Lam et al. 2003)	Bats Civet cats (da Costa et al. 2020)	10% (Anderson et al. 2004)	Asia: (Curley and Thomas 2004) Europe: (Worobey et al. 2020) Australia: (Rockett et al. 2020) North America: (Worobey et al. 2020) South America: (Poterico and Mestanza 2020) South Africa: (Pulliam et al. 2022)
Swine flu	*Influenza A virus* (Perez-Padilla et al. 2009)	Pigs (Parmar et al. 2011)	2-20% (Singh and Sood 2012)	North America: (Sinha 2009) East & South-east Asia: (Trevennec et al. 2011) Europe: (Klemm et al. 2016) Africa: (Butler 2009) Australia: (Webb and Seppelt 2009)
Pneumonic tularemia	*Francisella tularensis Bacterium* (Reed et al. 2011)	Domesticated animals (cats, dogs) Wild animals (rabbits, rodents, squirrels, beavers) (Matyas et al. 2007)	30% (Penn and Edwards 2019)	North America: (Matyas et al. 2007) Europe: (Maurin and Gyuranecz 2016) Asia: (Matyas et al. 2007)

among the worst pandemics in history. The source of the 1918 influenza virus is unclear, although it is hypothesized to have been patented in birds before spreading to humans, potentially through a middle host like pigs. The 1918 influenza affected many young adults, with an estimated 99% of deaths occurring in people under 65. The severity of the pandemic worsened by the close living conditions of soldiers in World War I, which facilitated the speedy spread of the disease (Morens and Fauci 2007, Short et al. 2018). The Severe Acute Respiratory Syndrome (SARS-2003) outbreak resulted in a considerable upsurge in mortality. The virus, alleged to started in bats and spread to people through civet cats in China, is to blame for the SARS pandemic. The outbreak resulted in 8,096 confirmed cases and a total of 774 deaths in 26 countries, with a mortality rate of approximately 10% (Matus et al. 2023, McGarity-Palmer et al. 2023). Similarly, the 2012 Middle East Respiratory Syndrome (MERS) pandemic had a mortality impact. The coronavirus that causes MERS; originated from camels before infecting humans. The outbreak resulted in 2,494 cases and 858 deaths across 27 countries, with a mortality rate of approximately 34% (Alsaadi et al. 2023, Mohapatra et al. 2023). Recently, the COVID-19 pandemic has been having a significant impact on mortality rates over the world. As of March 2023, there were around 590 million confirmed illnesses and nearly 14 million fatalities worldwide. Before infecting humans, the coronavirus that causes COVID-19 was first appeared in bats, maybe via an intermediary host like pangolins. The mortality rate of COVID-19 varies depending on age, underlying health conditions, and access to medical care. Overall, the estimated global mortality rate is approximately 2%, with higher rates among older adults and those with underlying health conditions (Haruna et al. 2023, Qureshi et al. 2023).

Studying zoonotic respiratory diseases is an imperative study of literature because of the increasing risk posed by these types of infections. With the increase in human activities that bring people and animals into closer contact, such as deforestation, urbanization, and wildlife trade, the risk of diseases jumping from animals to humans is more substantial than ever. Zoonotic respiratory infections, especially avian influenza, MERS, and SARS, are potent to cause devastating outbreaks and pandemics, as evidenced by the current COVID-19 pandemic. By investigating zoonotic respiratory diseases at the animal-human interface, we can better understand the transmission mechanisms, risk factors, and prevention strategies for these diseases, ultimately helping to reduce their impact on human and animal health. This chapter also incorporates policies and practices that aim to promote more sustainable and responsible interfaces between humans and animals, thus mitigating the threats of future zoonotic disease outbreaks.

2.1. ANTHRAX

Anthrax is a disease that affects animals but can potentially infect people. It is caused by the bacteria *Bacillus anthracis*. Meanwhile, the disease is typically contracted by contact with diseased animals, their waste products or soil polluted with the bacteria's spores and is classified as a zoonotic illness. Bacillus anthracis produces spores that can remain viable in the environment and animal products for many years. The spores can live in hostile conditions because of their excellent heat, chemical, and radiation resistance (Omodo et al. 2023). Anthrax contracts by inhaling, ingesting, or exposure to the spores. Anthrax spreads to people through contact with diseased animals or animal yields, including meat, hides, and wool. Inhalation anthrax can occur when spores are inhaled, usually from contaminated animal products or soil. Cutaneous anthrax can occur when spores enter through a cut or abrasion in the skin. Gastrointestinal anthrax can occur when spores are ingested, usually through contaminated meat (Chanda et al. 2023). Flu-like symptoms, including fever, muscle cramps and fatigue are typical symptoms of inhalation anthrax, followed by respiratory distress and shock. A raised, itchy lump that turns into a pain-free ulcer, encircled by a black region of dead tissue, resulted from cutaneous anthrax. Gastrointestinal anthrax can induce nausea, abdominal pain, vomiting and bloody diarrhea (Pradhan and karanth 2023).

Anthrax significantly impacted human history and was responsible for several deadly outbreaks. One of the most well-known outbreaks occurred in the late 19th century in Scotland, where a herd of sheep caused the death of several hundred people. More recently, in 2001, an epidemic in the US, believed to be a bioterrorism attack, resulted in 22 cases and 5 deaths (Parker Jr 2023). The utilization of anthrax as a bioweapon by terrorist organizations or rogue nations, which results in widespread disease and fear, is one of the biggest concerns. The likelihood of a bioterrorism assault might rise, resulting from the development of artificial genetic and biological engineering that could make it simpler to manufacture and alter more deadly or drug-resistant anthrax strains. Antibiotic resistance is a different danger that makes treating anthrax infections more difficult. In areas with weak veterinary and public health infrastructure, natural epidemics can happen when people come in contact with diseased animals or their products. The spread of infectious illnesses can mitigate by tracking and researching anthrax, creating new vaccinations and treatments, upgrading the infrastructure of public health and fostering more international collaboration (Doganay and Demiraslan 2015).

2.2. AVIAN INFLUENZA (BIRD FLU)

Influenza A causes avian influenza is a viral pathogen. The disease is commonly referred to as bird flu as it affects birds. It is infectious and it can rarely transfer to people resulting in fatal respiratory infections (Mosaad et al. 2023). Avian influenza is an illness caused by *Influenza A* strain that mainly infects birds. Avian influenza viruses have different subtypes, with the H5N1 genotype being the most well-known for having the ability to sicken humans severely (Qureshi et al.). Direct contact with diseased birds, their excrement, or ambient surfaces contaminated with the virus can result in the human transmission of avian influenza. The virus can also be contracted through the consumption of undercooked or raw infected poultry products, such as eggs or meat (Ntakiyisumba et al. 2023, Saifur et al. 2023). The symptoms of avian influenza in humans can vary, but typically include cough, fever, irritable throat, body aches and in severe cases respiratory distress, pneumonia, and even death. The severity of the symptoms can depend on the age and overall health of the individual (Debnath et al. 2023).
Historically, avian influenza has instigated several deadly outbreaks in birds and humans. In 1997, one of the most widely recognized avian influenza outbreaks happened in Hong Kong, infecting 18 individuals with the H5N1 subtype and resulting in six fatalities. Since then, there have been numerous additional outbreaks of avian influenza, with the H5N1 and H7N9 subtypes causing the most distress due to their potential to cause severe illness in humans. Avian influenza continues to represent a hazard to both humans and animals. The possibility that the virus would mutate and spread quickly amongst people, causing a global pandemic, is one of the key threats (Shi et al. 2023). The virus's ability to spread to domestic poultry and other animals due to its persistence in wild bird populations is another danger. Moreover, infections may become difficult to cure if the virus develops resistance to antiviral drugs. The likelihood of the virus spreading to new areas is further increased by the continued commerce and travel of live animals and their byproducts worldwide. Firm monitoring and early warning systems, enhancing biosecurity precautions, raising public awareness, and investing in the development of efficient vaccines and antiviral drugs are all essential for reducing these new dangers (Palese 2004, Watanabe et al. 2012).

2.3. BOVINE TUBERCULOSIS

Bovine tuberculosis, also known as TB or cattle TB, is a chronic bacterial infection primarily affecting cattle, but can also infect other domesticated animals and wildlife. It may also be transmitted to others by eating contaminated food or having close contact with sick animals, which can result in life-threatening respiratory conditions (Abrantes and Viera-Pinto 2023). The bacterial agent that causes bovine TB is *Mycobacterium bovis*. The bacteria primarily affects the lungs and can spread to other organs of the infected animal, leading to chronic illness (Kasir et al. 2023). Transmission of the bacterium typically occurs through direct contact with sick animals or by the intake of infected food and water. Humans can contract bovine tuberculosis through inhalation of airborne bacteria or consuming contaminated meat and dairy products (Collard 2023). The symptoms of bovine tuberculosis in cattle can vary but typically include chronic cough, loss of weight and decreased milk production. The symptoms in people might range from moderate respiratory disorders to severe pneumonia (Ramanujam and Palaniyandi 2023).

Bovine tuberculosis has had a significant impact on human history, causing a high mortality rate during the industrial revolution in Europe and parts of North America due to the consumption of contaminated milk. In the early 20th century, bovine tuberculosis was considered a significant public health threat, leading to the development of control programs aimed at eradicating the disease in livestock (Perea et al. 2023). The main concern is the infection growing among cow herds, which might result in large financial losses for the agriculture sector. Furthermore, there is fear that consuming infected animal products might spread bovine TB to people and cause life-threatening sickness. Another serious hazard is the development of drug-resistant strains of the bacteria that causes bovine TB because they make treatment more challenging. Controlling the illness is further made difficult by the disease's transmission between animals and cattle, especially in regions where both species interact closely. Implementing efficient control and preventative measures, such as routine testing and the killing of diseased animals, immunization programs, and public awareness campaigns on the responsible handling and use of animal products is crucial to addressing these rising dangers (Olea-Popelka et al. 2004, De la Rua-Domenech et al. 2006, Miller and Sweeny 2010).

2.4. BRUCELLOSIS

The genus *Brucella* is the source of the bacterial illness known as brucellosis. Although it mostly affects cattle including cows, sheep, and goats, it may also infect people by contact with infected animals or eating infected food, which can result in a fatal sickness (Jokar et al. 2023). The Brucella bacterium, which mostly affects livestock's reproductive system, is the cause of brucellosis. Four Brucella species may infect people: *B. suis, B. canis, B. melitensis, and B. abortus* (Rangel-Ortega et al. 2023). Direct contact with infected animals, eating unpasteurized meat and dairy or undercooked food can all spread brucellosis to people. It can also be spread via inhaling contaminated air or accidental exposure to contaminated materials, such as laboratory samples (Koyun et al. 2023). The symptoms of brucellosis in humans can vary but typically include fever, fatigue, joint pain, muscle aches, and headache. It can cause long-term effects including arthritis, cardiac issues, and chronic weariness in extreme situations (Koyun et al. 2023).

The public's health was significantly impacted by brucellosis throughout history. In the early 20th century, it was a leading cause of occupational disease among abattoir workers and farmers. The development of effective vaccination programs and control measures has significantly reduced the incidence of brucellosis in developed countries (Al Zahrani et al. 2023). There are various new risks posed by Brucella to human and animal health. The main concern is that people will get the illness from infected animals like cattle, goats, and sheep and then pass it on to themselves by consuming the animal products. The rise of Brucella strains that are resistant to medications is another major concern since it makes the illness more challenging to cure (Ducrotoy et al. 2014). The likelihood of the illness spreading to new areas is further increased by the worldwide movement of people and animals. However, because Brucella can spread widely and generate concern, its potential as a bioweapon is an increasing problem. Implementing efficient control and prevention measures, such as routine screening and elimination of infected animals, vaccination campaigns, public awareness campaigns on safe practices and consumption of animal products, and monitoring drug resistance patterns in Brucella strains, is crucial to combat these emerging threats (Olsen et al. 2018, Harpreet et al. 2019).

2.5. CAMELPOX

A virus called *Camelpox* affects humans, but camels are the central targets. The Orthopoxvirus genus of viruses, which causes camelpox, is most common in the Middle East, Central Asia, and North Africa, where camel herding is common (Gieryńska et al. 2023). This disease is related to other diseases such as cowpox and smallpox (Anuradha et al. 2023, Sepehrinezhad et al. 2023). Continuous contact with diseased camels, eating raw meat or milk that has been tainted and inhalation of infected aerosols are all ways that the disease can be passed from camels to people. In addition, camelpox can also be transmitted through exposure to contaminated materials such as bedding or equipment, or insect bites. In humans, camelpox usually manifests as a mild, self-limiting disease, with symptoms including fever, rash, and vesicular lesions on the skin. Camelpox has the potential to root severe ailments in humans, with complications that may include pneumonia, meningitis, and septicemia (Thakur et al. 2023).

There is inadequate information available regarding the historical impermanence angle of camelpox in humans. However, outbreaks of camelpox have been reported in regions where camel husbandry is prevalent, with sporadic cases occurring among people who come into contact with infected camels or contaminated materials (Gieryńska et al. 2023). To summarize, the present rising threat status of camelpox is unknown. While not currently seen as a serious hazard to public health, constant monitoring and control are required due to the virus's propensity for breakouts and its future use in bioterrorism. Camelpox is classified as a moderate danger to public health and safety by the World Health Organization. To combat this potential hazard, regular monitoring of camel habitats, vaccination programs, and public education campaigns on managing and consuming animal products are critical measures in lowering the risks connected with camelpox. In tackling new hazards posed by infectious illnesses like camelpox, it is critical to stay alarmed and proactive (Balamurugan et al. 2013, Dahiya et al. 2016).

2.6. HANTAVIRUS PULMONARY SYNDROME

Hantavirus pulmonary syndrome (HPS) is a respiratory disorder that is rare but serious and is caused by exposure to *Hantavirus*. Hantavirus pulmonary syndrome was first identified in the US in 1993, and since then, it has been reported in several other countries in the Americas (Sundar et al. 2023). Hantaviruses can be identified in the faeces, saliva, and urine of infected rodents like deer mice and rice rats, which are responsible for causing the syndrome (Avižinienė et al. 2023). Infected rodents or their droppings are the main sources of disease transmission to people. Direct engagement with a sick person's body fluids or blood can potentially spread the virus but this is very rare (Alshammari 2023). Symptoms of HPS typically include fever, muscle aches, and fatigue, followed by coughing and breathlessness. In some cases, the disease can progress rapidly to severe respiratory distress and can be fatal in up to 40% of cases (Pattiyakumbura et al. 2023).

There have been several outbreaks in the Americas since HPS was originally discovered in 1993, with the majority of cases being reported in the US. With a fatality rate between 30% and 40%, HPS has always had a high mortality outlook (Fullerton et al. 2023). Public health is still threatened by the disease, particularly in areas where rodents harbour the virus. The danger of HPS outbreaks may potentially rise due to the introduction of new virus strains or modifications in the behavior of rodent populations. The existing COVID-19 pandemic has also highlighted the potential for newly developing infectious illnesses to spread quickly and result in severe morbidity and mortality. To counter this possible hazard, continuing rodent population tracking, public education campaigns on proper rodent handling and sanitation, and research into vaccinations and therapies are necessary. It is critical to stay alert and antagonistic in dealing with emerging and re-emerging infectious disease risks such as HPS (Barui et al. 2022).

2.7. HENDRA VIRUS INFECTION

The *Hendra virus* is responsible for causing a rare and fatal zoonotic illness known as Hendra virus infection. The virus was first identified in 1994 in Australia and has since been responsible for a small number of human and equine deaths. The *Measles virus* and the *Mumps virus* are both members of the family Paramyxoviridae, which contains the virus (Tomori and Oluwayelu 2023). The virus is believed to be primarily transferred to humans through nearby contact with sick horses, which are considered to be the natural host for the virus. It is thought that flying foxes, a type of fruit bat, serve as the reservoir for the virus, and can transmit it to horses through contact with their urine or other bodily fluids. It is thought that exposure to body fluids from infected animals, such as saliva, nasal secretions, or blood, can cause the Hendra virus to spread from horses to people. The spread of the virus is extremely rare from one person to another (Wang et al. 2023). Symptoms of Hendra virus infection are alike to those of other respiratory illnesses and may comprise fever, headache, muscle aches, and coughing. Patients may encounter progressively severe symptoms as the illness worsens, including organ failure, encephalitis, and pneumonia (Becker et al. 2023, Wang et al. 2023).

Since the first outbreak of the Hendra virus in 1994, few cases of the disease were reported in Australia. The historical mortality perspective for Hendra virus infection is relatively high, with a mortality rate of approximately 50%. Moreover, the equine industry can suffer significant economic losses due to the disease, as infected horses may need to be put down to avoid further transmission of the virus. Taking necessary precautions to prevent exposure to the Hendra virus is crucial, especially for those who work with horses or in areas with fruit bats. Wearing protective clothing and practicing good hygiene can help minimize the risk of infection (Becker et al. 2023, Sachan et al. 2023).

2.8. MIDDLE EAST RESPIRATORY SYNDROME (MERS)

The highly contagious viral respiratory disorder termed Middle East respiratory syndrome (MERS) is primarily caused by the *Middle east respiratory syndrome coronavirus* (MERS-CoV). Since the virus was initially discovered in Saudi Arabia in 2012, numerous other nations, mostly in the Middle East, have reported many cases of this disease (Azhar et al. 2019). Humans can get the virus by getting into continuous contact with sick animals or by breathing in respiratory secretions from infected individuals. The virus is believed to have its origins in bats and is transmitted to humans primarily through camels. MERS can also spread through human-to-human transmission, particularly among individuals who have close contact with infected individuals, such as healthcare workers who are attending to MERS patients (Control and Prevention 2016). Fever, breathlessness and cough are the major symptoms which can progress to severe respiratory illness, pneumonia, and even death. MERS is thought to have a death rate of about 35% and those who have underlying conditions including diabetes, chronic lung disease, and immunosuppression are more susceptible to dying from it (Control and Prevention 2014).

Since its emergence in 2012, several episodes of MERS have been recorded, primarily in the Middle East, but also other regions such as South Korea. South Korea experienced the greatest MERS epidemic outside of the Middle East in 2015, where over 180 cases were reported, resulting in 36 fatalities (Kim and Kim 2018, Salamatbakhsh et al. 2019). MERS remains an emerging infectious disease with potential hazards, although there is no confirmed active outbreak. One of the major problems is the disease's lack of effective treatment, with no specialized antiviral medicine available. The virus's ability to spread is also a concern, as MERS-CoV is conveyed through intimate contact with infected people or their respiratory secretions. Moreover, camels are thought to be the virus's principal reservoir, and continuing surveillance of the virus in animals is required to understand the danger of transmission to humans. Lastly, MERS-CoV, like other viruses, can modify and adapt to new hosts, which might affect how the virus spreads and the degree of sickness it causes. To address the rising hazards associated with MERS, continuing research, surveillance, and planning are required (Lee and Hsueh 2020).

2.9. MONKEYPOX

Monkeypox is a viral disease that is relatively rare and mostly affects primates and people living in Central and West Africa. Monkeypox is induced by the *Monkeypox virus*, which is closely linked to the virus that causes smallpox (McCollum and Damon 2014). Direct exposure to infected animals or their body fluids, including blood, faeces, and respiratory secretions, is the main way in which the virus is transferred. Continuous exposure or nearby contact with infected body secretions can lead to transmission of the virus in the human population. The respiratory droplets from an infected person can also transmit the disease to others (El Eid et al. 2022). Monkeypox symptoms are comparable to smallpox symptoms but less severe. The disease usually begins with a fever, headache, muscle aches, and exhaustion, followed by skin irritation involving the whole body. Lesions progress to become fluid-filled and then scab over and fall off after a few weeks (Kannan et al. 2022).

Monkeypox is a rare disease, and outbreaks are infrequent. In 1958, the emergence of a pox-like disease was reported in monkeys that were being used for research, leading to the identification of what is now known as monkeypox. Later, in 1970, the disease was identified in humans. However, since 2003, there have been several outbreaks in Central and West African countries, including Nigeria, the Democratic Republic of Congo, and Cameroon. In the United States, there have been a few isolated cases of people who have travelled from Africa or had close contact with infected animals. The fatality rate from monkeypox ranges from 1% to 10%, with younger age groups being more frequently affected (Parker and Buller 2013). Monkeypoxis is a growing concern to people due to a variety of circumstances. When humans continue to intrude on natural ecosystems and come into touch with animals harbouring the virus, the chance of transmission from animals to humans grows. Recent outbreaks of monkeypox in other regions of Africa have also extended beyond their initial locations, and there is a danger of human-to-human transmission, particularly in hospital settings. Furthermore, the lack of a particular treatment or vaccination for monkeypox might make it difficult to control outbreaks and manage individual patients. As a result, more study and monitoring are required to better understand and manage the hazards associated with monkeypox, as well as to generate effective strategies to prevent the virus's spread (Modgil et al., Wani and Kumar 2022).

2.10. NIPAH VIRUS INFECTION

The zoonotic disease, *Nipah virus* (NiV) can have serious effects on both human and animal nervous systems and respiratory systems. The virus was discovered in 1998 after an encephalitis and respiratory sickness outbreak among Malaysian pig farmers and employees at slaughterhouses. The virus is named after the Malaysian town of Sungai Nipah, where the first epidemic occurred (Nor et al. 2000, Shariff 2019). The virus naturally infects fruit bats of the Pteropodidae family, sometimes referred to as flying foxes. Humans can contract the virus by coming into touch with infected bats, eating contaminated fruits, or drinking raw date palm sap. Person-to-person transmission can also occur, particularly in healthcare settings (Soman et al. 2020). NiV infection in humans can cause symptoms that vary from

mild or moderate respiratory disease to severe encephalitis with convulsions and coma. In some cases, neurological symptoms such as dizziness, confusion, and disorientation may precede respiratory symptoms (Hossain et al. 2008).
Since the first outbreak in Malaysia, there have been several more outbreaks of the NiV infection in both India and Bangladesh, with the majority of infections occurring in rural areas where bats and infected date palm sap are common (Hossain et al. 2008, Plowright et al. 2019). Mortality rates vary depending on the outbreak and population affected and ranges from 40-90%. NiV infection has no particular therapy or vaccination. Although it is largely spread by animals to humans, the Nipah virus continues to pose a serious threat to human health. Throughout the years, there have been various outbreaks in South and Southeast Asia, with the most recent taking place in India in 2018. As humans continue to expand their populations and encroach upon natural habitats, there is an increased likelihood of exposure to the virus. Furthermore, the Nipah virus can cause severe illness in humans, including encephalitis and respiratory illness, making it a public health concern, highlighting the need for continued surveillance and preparedness to address this emerging threat (Alam 2022).

2.11. PASTEURELLOSIS

Pasteurellosis is a bacterial infection caused by the *Pasteurella multocida* bacterium. The most common way to contract the infection is through animal bites, especially from dogs and cats, but also from other animals such as rabbits, rodents, and farm animals (Register and Brockmeier 2019). Pasteurellosis is more common in individuals who work with animals, such as veterinarians, animal handlers, and farmers. The bacteria move in the body through a skin incision or wound caused by an animal bite or scratch. In some cases, it can also be transmitted through respiratory droplets when an infected animal sneezes or coughs. Symptoms caused by the bacteria vary based on the strength of the infection and the person's immune response. Common symptoms include swelling, redness, and pain at the site of the bite or scratch, fever, chills, swollen lymph nodes, and difficulty breathing (Mohamed and Abdelsalam 2008).
Historically, pasteurellosis has been documented as a significant public health concern in individuals who work with animals, particularly those who handle cats and dogs. In the United States, it is assessed that about 10-15% of all domestic animal bites are caused by Pasteurella species (Toranzo et al. 1991). In severe cases, pasteurellosis can lead to sepsis, meningitis, and other life-threatening complications (George et al. 2008). Pasteurellosis is an uncommon but rapidly spreading bacterial illness with devastating repercussions for human health. The rising abundance of domestic animals in human civilization has raised the potential of microbial exposure, notably through dog and cat bites and scratches. Pasteurellosis poses a substantial public health problem due to limited treatment options and the rise of antibiotic-resistant bacteria. As human connections with domestic animals grow, it is critical to emphasize continuous research, surveillance, and preventative strategies to minimize the prevalence of this disease and improve outcomes for individuals who are affected. By increasing public knowledge of this rising issue, we can fight to reduce the risk of Pasteurellosis and ensure a healthier future for both humans and animals (Wilson and Ho 2013).

2.12. PLAGUE

The bacterium *Yersinia pestis* causes respiratory plague, a severe and possibly lethal contagious disease. This disease is primarily associated with bubonic and septicemic plagues, but it can also manifest as a respiratory illness, known as pneumonic plague (Kool and Weinstein 2005). Respiratory plague is the dangerous infectious form of the illness, since it may be passed from person to person via the air, resulting in extensive outbreaks. The bacterium is primarily found in rodents and their fleas, which serve as the primary reservoirs for the disease (Smiley 2008). When infected fleas bite humans, they can transmit the bacterium, leading to a bubonic or septicemic plague. Inhaling aerosolized droplets or dust infected with Y. pestis can also cause respiratory plague. The disease can also spread through direct exposure to infected body fluids, such as blood or pus, or by touching contaminated surfaces (Kool and Weinstein 2005). The symptoms of respiratory plague usually appear within 1-3 days of exposure and include headache, chills, fever weakness, cough, chest pain, and breathlessness. The illness can rapidly progress, leading to severe pneumonia, septic shock, and death if left untreated. Pneumonic plague is often fatal if not treated promptly, with a mortality rate of 90% or higher (Pechous et al. 2016).

Many pandemics throughout history, notably the 14th-century “Black Death”, which killed an estimated 25 million people in Europe, have been attributed to the respiratory plague. Pneumonic plague cases have recently been recorded in several international locations, including China, Mongolia, and also the Democratic Republic of the Congo. In 2017, a pneumonic plague outbreak in Madagascar resulted in over 2,300 cases and more than 200 deaths (Duncan and Scott 2005, Tsuzuki et al. 2017). Plague is a serious increasing danger to human health due to a variety of variables, including the growth of antibiotic-resistant strains, changes in global climatic patterns and human behaviour, and the possibility for purposeful release as a bioweapon. Continuous efforts to improve monitoring and readiness, find novel treatment options, and raise knowledge of the disease's risk factors are critical to reducing the danger of a broad epidemic. With potentially serious repercussions, prioritizing research and public health measures to ensure that we are prepared to confront this rising issue and safeguard the health and safety of people globally (Ditchburn and Hodgkins 2019).

2.13. PSITTACOSIS

Psittacosis, often known as parrot fever, is a respiratory condition brought on by the *Chlamydia psittaci* bacteria. The disease can affect both humans and birds, particularly parrots, pigeons, and doves, which serve as reservoir hosts (Stewardson and Grayson 2010). Transmission occurs through inhalation of the bacterium from infected bird faeces, feathers, and respiratory secretions. Individuals who are regularly in contact with birds, such as those who work in pet stores and poultry facilities, and those that are passionate about birds are more likely to become infected (Jorgensen 1997). Psittacosis can cause a range of symptoms in humans, varying in severity from mild to severe, including chills, fever, cough, headache, muscle aches and breathlessness. The infection can lead to pneumonia and even death in extreme circumstances. Psittacosis is often underdiagnosed, as it can mimic symptoms of other respiratory illnesses (Branley et al. 2014).

Historically, psittacosis outbreaks have been reported in various countries, including the United States, Japan and Australia. One notable outbreak occurred in 1929 when hundreds of people in the United States became sick after attending a parrot show (Ramsay 2003). Although uncommon, psittacosis represents a rising hazard to human health due to various causes. For starters, the condition can be difficult to identify, with symptoms ranging from minor to severe, such as fever, headache, muscle pains, and cough. Misdiagnosis or delayed identification can result in consequences such as pneumonia and even death. The growing popularity of exotic pets, such as parrots, has increased human exposure to the virus, especially among bird handlers and pet owners. Lastly, the rise of antibiotic-resistant virus strains poses a substantial public health problem, decreasing the effectiveness of standard treatment methods. Considering the potential for severe effects and limited treatment options, continued research, surveillance, and preventative measures are critical to minimizing the risk of psittacosis and maintaining the health and safety of both humans and animals. We can lower the danger of psittacosis by raising knowledge of the disease's risk factors and implementing appropriate pet-keeping practices (Weston et al. 2022).

2.14. Q FEVER

The disease was originally mentioned as "query fever" because of the unknown nature of its cause, but it was later renamed "Q fever". Humans who have Q fever may develop acute or chronic illnesses which are most commonly contracted by inhaling the bacteria. Q fever is found worldwide and can affect people of all ages (Woldehiwet 2004). The bacterium that causes Q fever, *Coxiella burnetii*, is frequently found in livestock and poultry such as cows, goats, and sheep. The bacteria can be found in their milk, urine, animal waste and other bodily fluids (Tissot-Dupont and Raoult 2008, Hirschmann 2019). The bacteria can be transmitted through exposure to infected animals, ingestion of contaminated milk, or breathing in a contaminated environment. The Q fever infection is mostly spread through inhalation of bacteria-contaminated particles, including dust or soil. Those who interact with livestock, such as vets, farmers, and abattoir workers, are more likely to get the illness (Gwida et al. 2012, Hirschmann 2019). Q fever can cause a range of symptoms that vary in severity and duration. Sweating, fever, headaches, and fatigue are the most typical symptoms. Additional symptoms may include cough, chest pain, and shortness of breath. The symptoms can last for several weeks to several months. Q fever can lead to severe impediments, such as pneumonia, hepatitis, and endocarditis, in some cases (Parker et al. 2006, Honarmand 2012).

The first recorded instances of Q fever in humans were identified in Australia during the 1930s. Since then, outbreaks of Q fever have appeared in many countries around the world, including the United States, Europe, and Australia. In the past, Q fever was commonly linked with exposure to infected animals in the workplace and outbreaks were often linked to the processing of animal products. While Q fever is generally considered a mild illness, severe cases can occur, and fatalities have been reported. In recent years, epidemics have been associated with exposure to infected soil and dust, emphasizing the relevance of environmental variables in disease transmission (McDade and Marrie 1990).

2.15. SEVERE ACUTE RESPIRATORY SYNDROME (SARS)

Coronavirus causes respiratory infections, including severe acute respiratory syndrome (SARS). The disease emerged in southern China in November 2002 and spread to other countries, leading to a global outbreak in 2003. SARS can result in severe respiratory distress, leading to conditions such as acute respiratory distress syndrome (ARDS) and pneumonia, and has a high mortality rate (Lam et al. 2003). The virus was transmitted from bats to people via an intermediate host, according to some theories, possibly civet cats or other mammals. The virus is highly infectious and can spread rapidly through close contact with infected individuals (da costa et al. 2020). Respiratory droplets from infected individuals are the primary mode of transmission for SARS. SARS can spread by contaminated droplets in the air from infected individuals as well as through contact with contaminated surfaces or objects. The infection usually takes from two to seven days to incubate, but it can take as long as ten days (Al Huraimel et al. 2020, da costa et al. 2020). The symptoms of SARS are similar to those of the flu and include fever, cough, and shortness of breath. Some patients may also experience body pain, headaches, and diarrhea (Grant et al. 2020).

The outbreak of SARS during the period of 2002-2003 was a major public health emergency, with 8,098 cases and 774 fatalities recorded across 26 nations. SARS is estimated to have a 10% mortality rate. The outbreak was contained through widespread public health measures, including quarantine, travel restrictions, and infection control measures. Since then, there have been no identified cases of SARS reported globally (Anderson et al. 2004). The persisting COVID-19 pandemic produced by the SARS-CoV-2 virus continues to be an ongoing cause of danger. Even though the virus has been circulating for over a year, new varieties are constantly emerging, some of which may be more transmissible or resistant to current vaccinations. These mutations have the potential to cause fresh waves of infections, undermining global efforts to manage the epidemic Furthermore, there is supporting evidence that long-term health issues, known as chronic COVID, may impact a considerable number of COVID-19 survivors. These effects, which can vary from weariness and trouble concentrating to more serious respiratory and cardiovascular disorders, may have far-reaching consequences for world health even after the epidemic has passed (Gilbert 2020).

2.16. SWINE FLU (H1N1 INFLUENZA)

A strain of the *Influenza A* virus causes swine flu, commonly referred to as H1N1 influenza. The disease first emerged in Mexico in 2009 and rapidly spread to become a global pandemic. The genetic makeup of the H1N1 virus includes elements of the swine, avian, and human influenza viruses, making it very contagious and capable of causing severe illness It is called "swine flu" because the virus originated in pigs (Perez-Padilla et al.2009). The virus can mutate and spread from pigs to humans and then spread in the environment affecting human communities. As a result of respiratory droplets inhaled when an infected person sneezes or coughs, the flu can also be spread from person to person. Another way to catch the virus is to come into contact with it before touching your lips, nose, or eyes (Parmar et al. 2011, Kawanpure et al. 2014). Swine flu symptoms include fever, cough, hoarseness, body aches, malaise, chills, headache, diarrhea, and vomiting, which are similar to seasonal influenza symptoms. Acute respiratory distress syndrome (ARDS), pneumonia, and even death can result from swine flu in extreme instances (Brand et al. 2013).

The swine flu pandemic that occurred between 2009 and 2010 was the first worldwide pandemic in more than four decades. An estimated 1.4 billion individuals were affected by the virus globally and in June 2009, it is declared a pandemic by the World Health Organization (WHO). The pandemic concluded in August 2010, with over 18,000 deaths related to swine flu complications reported. The majority of deaths occurred in the Americas and Southeast Asia. After the 2009 pandemic, swine flu became a seasonal flu virus and vaccines were developed to prevent its spread. While the number of fatalities from swine flu is normally low, certain populations, such as youngsters, pregnant women, and individuals with underlying health issues, may be more vulnerable to severe consequences (Wheaton et al. 2012, Beckman et al. 2013).

2.17. PNEUMONIC TULAREMIA

Pneumonic Tularemia is an infrequent infection caused by *Francisella tularensis*, a bacterium also referred to as rabbit fever. Although pneumonic tularemia is rare, it is considered a potential bioterrorism agent due to its high virulence and ability to be aerosolized (Reed et al. 2011). This bacterial pathogen can survive in the soil for a longer period, it can also colonize in water as well as in the corpses of dead animals. There are four subspecies of the bacterium, each with different levels of virulence. Types A and B are the most dangerous and are frequently prevalent in North America, while Type B may be found throughout Asia as well as Europe. The bacteria is resilient to several popular disinfectants and may live in a variety of environmental conditions (Hepburn and Simpson 2008). Pneumonic Tularemia is spread by direct contact with infected animals such as rabbits, rats, and deer, tick bites, or aspiration of contaminated dust or aerosols. It can also be transmitted through the consumption of contaminated water or food. In rare cases, tularemia can also be transmitted from person to person through direct contact with infected body fluids or inhalation of aerosolized bacteria (Matyas et al. 2007). Pneumonic tularemia symptoms often appear 3 to 5 days following bacterial contact. The disease can manifest itself in many ways depending on how it is spread. Symptoms include fever, chills, exhaustion, spastic muscles, headache, and respiratory symptoms such as coughing, chest discomfort, and shortness of breath. If left untreated, tularemia can be lethal, with a death rate of up to 30% for the pulmonary manifestation of the disease (Penn and Edwards 2019).

Being an uncommon condition, pneumonic tularemia has a fluctuating incidence. Since this was first detected in rabbits in Tulare County, California, in 1911. In the United States, the disease is most commonly reported in rural areas of the western and midwestern states. Referring to the Centers for Disease Control and Prevention (CDC), 230 cases of tularemia were reported in the United States in 2019 (Kwit et al. 2019). Historically, the disease has been associated with outbreaks among soldiers and other military personnel and has been used as a biological weapon in the past. The most current outburst of tularemia occurred in Sweden in 2019, where more than 30 cases were reported among hares and humans (Dryselius et al. 2019, Kwit et al. 2019).

3. CONCLUSION

The impact of zoonotic respiratory diseases on global mortality rates cannot be overstated. From the Spanish Flu pandemic in 1918 to the more recent outbreaks of SARS, MERS, and COVID-19, these diseases have caused significant morbidity and mortality, disrupted the economies, and had led to widespread social and political upheaval. The rapid spread of these diseases highlights the importance of global cooperation and investment in research and response efforts to address emerging threats. To prevent future outbreaks, it is crucial to improve surveillance and early detection systems for zoonotic diseases, particularly in areas where high-risk human-animal contact occurs, such as in wet markets and slaughterhouses. We also need to promote responsible practices in animal agriculture and wildlife trade, such as implementing biosecurity measures and regulating the transport and trade of live animals. Additionally, investing in the development of vaccines and antivirals, as well as supporting research into the genetic makeup and transmission patterns of zoonotic diseases, can help us better prepare for and respond to future outbreaks.

Furthermore, we need to prioritize the equitable distribution of healthcare resources and access to vaccines in the face of future outbreaks. The current COVID-19 pandemic has highlighted the unequal distribution of healthcare resources worldwide, as many low-income countries have struggled to obtain vaccines and other critical resources. Ensuring that healthcare resources and vaccines are distributed fairly can help mitigate the impact of future outbreaks and prevent the further spread of disease. In conclusion, zoonotic respiratory diseases had a major impact on global health and mortality rates throughout history. To prevent and control these diseases, we must remain vigilant and invest in research and response efforts, improve surveillance and early detection systems, promote responsible practices in animal agriculture and wildlife trade, and prioritize equitable access to healthcare resources and vaccines. By taking these steps, we can help mitigate the impact of future outbreaks and safeguard public health.

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-Addressing Emerging Zoonotic Diseases through a One Health Approach: Challenges Opportunities

11

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ABSTRACT

One Health is a comprehensive approach that addresses the interconnected well-being of individuals, animals, and ecosystems, recognizing the interdependence of human, animal, and environmental health. Emerging zoonotic diseases, such as Anthrax, Rabies, Brucellosis, Q Fever, West Nile Virus, Lyme Disease, Leishmaniasis, and coronaviruses like MERS-CoV and COVID-19, underscore the critical importance of adopting the One Health paradigm. These diseases pose significant threats to global health, with origins often traced to complex interactions between environmental factors, climate change, and human-animal interfaces. Each disease presents unique challenges, demanding a multidisciplinary One Health approach for effective prevention and control. Collaboration among veterinarians, physicians, researchers, policymakers, and communities is crucial. Notable successes, such as the substantial reduction of human rabies deaths in Iran and the successful One Health strategy implemented in India for controlling leishmaniasis, demonstrate the effectiveness of such holistic approaches. However, challenges persist, including weak laboratory capacity, limited resources, and legislative gaps. Successful prevention entails rapid disease detection, efficient surveillance, and collaboration across various sectors. Multifaceted collaboration is essential for research, vaccine development, and international information exchange to effectively mitigate the spread of infectious diseases.

Keywords: One Health, Zoonotic Diseases, Emerging Infectious Diseases, Multidisciplinary Collaboration, Disease Prevention

CITATION

Esha EJ, Fazilani SA, Ghosh K, Saikat SI, Hasnine I, Sagor SI, Akter S, Jannat F and Memon MA, 2023. Addressing emerging zoonotic diseases through a one health approach: challenges opportunities. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 156-167. https://doi.org/10.47278/book.zoon/2023.011

CHAPTER HISTORY Received: 28-Jan-2023 Revised: 12-Feb-2023 Accepted: 27-July-2023

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1. INTRODUCTION

One Health encompasses a comprehensive and cohesive strategy that seeks to effectively manage and sustainably enhance the well-being of individuals, animals, and ecosystems. There is a recognition of the interconnectedness and interdependence between the health of humans, domestic and wild animals, plants, and the environment as a whole, which encompasses ecosystems (Adisasmito et al. 2022). This initiative aims to respond to the requirement for uncontaminated water, energy, and air, together with secure and healthy food, while alleviating the consequences of climate change and fostering sustainable development (Erkyihun et al. 2022). Many diseases have emerged because of the convergence of human, animal, and environmental factors, leading to a significant loss of life among newborns and adults daily. Specifically, respiratory and diarrheal disorders pose a significant threat in impoverished countries (Mazet et al. 2009). Aggarwal and Ramachandran (2020) claim that the occurrence and resurgence of infectious and non-infectious diseases can be attributed to the swift alterations in climate and environment. In recent decades, the advent of epidemics and outbreaks of novel infectious illnesses in humans originating from animal reservoirs has brought to light the potential public health risks associated with zoonoses (Rabozzi et al. 2012). The rise of diseases in South Asia can be attributed to various factors, including unsanitary circumstances, human-animal contact, porous borders, climatic change, behavioral changes, and improper food preparation and consumption habits (Dahal et al. 2017).

The recurrence of novel infectious diseases emphasizes the need to consider human, animal, and environmental health in disease prevention and control (Kelly et al. 2020). The highly pathogenic avian influenza and severe acute respiratory syndrome viruses have shown that biological agents and animal breeding practices can threaten public health. Leptospirosis, brucellosis, Nipah virus, and rabies are all endemic; these infectious agents can cause epidemics (Rabozzi et al. 2012; Ahmad M et al, 2023). Emerging infectious diseases (EIDs) originate from wild animal reservoirs under considerable anthropogenic stresses. Thus, the One Health technique has gained popularity in managing EIDs (Kelly et al. 2020). Academic institutions, the human and animal health industries, and other stakeholders are working together to promote this strategy to prevent and control emerging issues. The goal is to enhance interdisciplinary collaborations and communication across various healthcare domains, focusing on individuals, animals, and the environment. So, it is imperative to establish a strong and cohesive partnership among veterinarians, occupational health physicians, and public health experts (Rabozzi et al. 2012). Avoiding emerging illnesses is of utmost importance, as is establishing a specialized early warning system to predict the likelihood of an epidemic or detect the signs of its onset.

This chapter will focus on the prominent emerging zoonotic diseases, their impact, and the preventive actions to be taken, particularly emphasizing the One Health approach.

2. ANTHRAX

Anthrax is a significant zoonotic disease caused by *Bacillus anthracis* (Ahmed et al. 2010). This bacterium has the ability to produce durable spores that can persist in the environment for extended durations (Brossier et al. 2002). Anthrax primarily impacts herbivorous animals, including cattle, sheep, and goats

(Ndiva Mongoh et al. 2008; Goel 2015). However, it is essential to note that humans can also contract infections by touching animals or their derivatives that have been contaminated, such as wool, hides, or meat (Doganay and Metan 2009). Anthrax has been historically linked to human civilization.

The 1979 witnessed a significant anthrax outbreak in Sverdlovsk, USSR, presently known as Ekaterinburg, Russia. That outbreak resulted from an inadvertent release of anthrax spores into the atmosphere by a microbiology facility. At least 66 individuals perished, while over 100 individuals were afflicted by inhaling spores. In 2001, the United States observed an incident when anthrax was employed as a bioterrorism instrument. Numerous media organizations and government establishments were targeted, as they received letters via postal services that contained anthrax spores. According to (Jernigan et al. 2002), the attack led to the unfortunate demise of five individuals, while an additional 17 individuals were afflicted with the infection. According to (Ezhova et al. 2021), an anthrax outbreak occurred in 2016 within nomadic populations in northern Siberia, Russia. According to Ezhova et al. (2021), a total of 2,300 reindeer in the Yamalo-Nenets Autonomous Okrug perished due to anthrax infections. Anthrax is classified as an emerging disease due to its capacity to induce epidemics in regions where it is not naturally prevalent, particularly in the setting of bioterrorism or alterations in the environment. Anthrax has been identified on five out of the seven continents.

Anthrax is a public health concern because of its high mortality rate, potential for intentional release as a bioweapon, and impact on animal health and food security. Anthrax outbreaks have occurred in various regions, especially Africa and Asia, where livestock vaccination and surveillance are inadequate. Anthrax threatens human health when people contact infected animals, their products, or where spores are in the environment. A study shows that anthrax was endemic in Odisha, India, for many years. In 2021, a protocol was published describing One Health's approach to the elimination of human anthrax in this district by strengthening the health care and surveillance system for early reporting of suspected cases of human and animal anthrax, vaccinating livestock, improving hygiene practices in livestock production, raising awareness among the local population. In the first year of the study, the number of human anthrax cases decreased by 50%. Therefore, anthrax requires coordinated efforts from multiple sectors and disciplines to prevent, detect, and control the disease using a One Health approach (Bhattacharya et al. 2021).

3. RABIES

Rabies is a disease that can be transmitted from animals to humans by the bite of a dog, and it is still a major public health concern around the world, causing about 590,000 deaths each year (Taylor and Nel 2015). Rabies virus is a negative-stranded RNA virus that belongs to the *Rhabdoviridae* family and genus *Lyssavirus* (Dietzschold et al. 2008). Rabies can infect any warm-blooded species, while young animals and bats are more vulnerable than adults (Brunker et al. 2018). The virus is disseminated through the bite or contact with infected animals' saliva, albeit the virus loses its infectiousness when it dries (Yousaf et al. 2012). Rabies can also be spread through touch with nerve tissue or aerosol inhalation in bat caves (Gibbons et al. 2002). Few animals have been discovered as asymptomatic carriers, and humans can also carry the virus without showing symptoms for a certain period (Wu et al. 2009). Dog bite causes more than 95% of the cases; most animal cases are also observed in dogs (Campo et al. 2022). The prevalence of rabies is highest in Africa and Asia, where 95% of dog-mediated rabies occur. This is due to several factors, including the higher populations of free-roaming dogs in these regions, the lack of access to vaccination programs, the lack of awareness, and the cultural acceptance of dog-human contact (Rupprecht et al. 2022).

Rabies is a fatal viral disease that can be prevented by post-exposure prophylaxis (PEP). PEP is highly effective if it is started before the onset of symptoms in humans (Hampson et al. 2008). However, once symptoms of rabies develop, the disease is always fatal. Only six people in history have survived rabies after symptoms developed and have been injected with antiviral drugs and sedatives for more extended periods. These survivors all suffered significant brain damage (De Souza and Madhusudana 2014; Mani et al. 2019).

Rabies is a major public health problem in Iran, with an estimated 2000 human deaths per year. During 1994-2004, Iran took the initiative to control rabies by launching a national rabies control program. As part of the program, they vaccinated dogs and cats against rabies, reduced the number of stray dogs, and increased education about rabies prevention. The result was dramatic, where deaths decreased to 100 in 2004. This represents a 90% reduction in human rabies death (Abedi et al. 2019). Rabies is a severe disease, but it is preventable. Implementing initiatives like Zero Death by 2030 can help protect ourselves and our families from this deadly disease (WHO 2018).

4. BRUCELLOSIS

Brucellosis, a zoonotic bacterial disease, has been neglected in scientific and public health initiatives. An etiology of this condition can be attributed to a distinct strain of bacteria characterized by gram-negative properties, facultative intracellular behavior, absence of spore formation, lack of motility, and absence of a capsule (Ameen et al. 2023; Deb Nath et al. 2023). Various species of Brucella can cause brucellosis; *Brucella abortus* is the predominant cause of infection in animals; *B. melitensis* is the most frequently observed pathogen in humans; *B. melitensis*, *B. abortus, B. suis, and B. canis* are also known to cause infections in humans (Bardenstein et al. 2023). The Brucella genus presents a notable public health hazard and incurs considerable economic losses within the livestock sector (Ameen et al. 2023). The incidence of brucellosis exhibited variation contingent upon the occupational activities of individuals and the specific species of animals involved. According to Nasinyama et al. (2014), veterinarians, farmers, and laborers risk contracting brucellosis, an occupational hazard.

There is a dearth of comprehensive data regarding the prevalence and impact of brucellosis in South Asian nations. According to a study by Islam et al. (2013), the prevalence of brucellosis in livestock such as cattle, buffalo, goats, and sheep in Bangladesh varied between 3.6% and 7.3%. According to Suresh et al. (2022), the aggregate pooled prevalence of brucellosis throughout Asian and African nations was almost 8%. Additionally, the prevalence rate of brucellosis, specifically within India's cattle population, was 12%. Human brucellosis transmission is influenced by various risk factors, such as consuming unpasteurized dairy products or raw meat, unsafe hunting practices, occupational exposure, inadequate hygiene practices, environmental conditions, and demographic characteristics (Devi et al. 2021). Several factors contribute to the risk of animal brucellosis, including the acquisition of infected animals as replacements, the specific type of animal production, demographic variables such as age, sex, breed, herd size, and herd management practices, as well as regulatory considerations, climate conditions, and contact with wildlife (Khurana et al. 2021). The mortality rate associated with brucellosis is modest. The disease can have substantial economic implications, leading to reduced cattle productivity and trade limitations.

Adopting a One Health approach to effectively tackling the issues presented by brucellosis is essential. This method entails cooperation and coordination among the human, animal, and environmental health sectors to proactively address, identify, and effectively manage zoonotic illnesses like brucellosis. Implementing the One Health strategy represents a noteworthy progression in working brucellosis control in Sierra Leone (Suluku et al. 2019). This highlights the significance of actively participating in problem-solving methodologies. The potential for the One Health approach to facilitate identifying and reducing risk factors linked with the transmission of brucellosis is evident.

5. Q FEVER

Q fever was first discovered in 1935 in Queensland, Australia, during an outbreak of a febrile illness of unknown origin (Query fever) among abattoir workers (Hirschmann 2019). Q fever, a zoonotic disease, has become a significant public health concern in countries associated with the South Asian Association for Regional Cooperation SAARC (Siengsanan-Lamont and Blacksell 2021). One of the concerning aspects of this bacterium is its ability to survive in the environment for extended periods, which makes it highly resistant and a significant public health concern (Hadush et al. 2016). It is vital to address the presence of *Coxiella burnetii* to prevent the spread of Q fever and Coxiellosis. Q fever is primarily transmitted to humans through inhalation of aerosols from contaminated soil or animal waste (Anderson et al. 2013).
In SAARC-associated countries, where agriculture and livestock farming are prevalent, the risk of Q fever transmission from animals to humans is exceptionally high (Porter et al. 2011). The zoonotic impact of Q fever is significant. Infected animals shed *C. burnetii* in their birth products, urine, feces, and milk, and people can get infected by breathing in dust that these materials have contaminated (Berri et al. 2001).
The occurrence of Q fever is comparable among SAARC nations. The frequency of Q fever ranges from 0.1 to 0.5 cases per 100,000 individuals, and the prevalence varies from 0.005 to 0.02%. Living close to livestock can increase the risk of Q fever as it increases the likelihood of contact with the bacteria that causes the disease (Smit et al. 2012). A country's livestock prevalence is also a significant risk factor for Q fever, and a study in northeastern Thailand found that rice farmers with farm animals such as chickens and cattle had a higher prevalence of acute Q fever (Burns et al. 2023). Environmental factors also affect humans' risk of Q fever infection (Dorko et al. 2012). Warm weather with dry soils and a particular wind direction can increase the risk of exposure to the bacteria (Porter et al. 2011). Wind can carry dust particles in the air that bacteria can attach to, which can be inhaled by humans and animals nearby (Van Leuken et al. 2016) Found that soil texture, roughness elements, and vegetation density were essential predictors of Q fever incidence rate. Certain occupations, such as farmers, veterinarians, and abattoir workers, are at an increased risk of Q fever due to their close contact with livestock (Eastwood et al. 2018). People who process milk, such as dairy farmers and cheesemakers, are also at an increased risk of exposure to Q fever (Esmaeili et al. 2016). People who work in construction and disturb soil or rocks could be exposed to Q fever if the soil or rock contains bacteria. Through contact with infected animal feces, milk, urine, and birth products, Q fever-causing bacteria can be transmitted directly from animals to humans (Esmaeili et al. 2016). Older individuals, particularly men, are more frequently reported for Q fever cases (Maurin et al. 1999).
Limited information is available on whether any countries within SAARC tackle Q fever with an integrated movement. Instead, there are examples of countries in the Asia-Pacific region that have implemented community engagement with a multidisciplinary group of people to fight against Q fever. For instance, in Thailand, Malaysia, Singapore, and Japan, vaccine development was stimulated by the extent and impact of seasonal outbreaks of enteroviruses, including Q fever. Government prioritization and support in some countries facilitated vaccine development. Advocates, funders, technical supporters, and trainers work hard in South Asia to promote One Health research, training, and government support (Cleaveland et al. 2017).

6. WEST NILE VIRUS

The West Nile virus is a flavivirus transmitted to humans through mosquito bites, which can cause various illnesses ranging from mild to severe (Sampathkumar 2003). It belongs to the *Flaviviridae* family, including other viruses such as dengue, yellow fever, and Zika (Sips et al. 2012). The West Nile virus was initially identified in 1937 after being isolated by a woman residing in the West Nile district of Uganda. However, it wasn't until 1999 that the virus was first detected in New York City, signifying its appearance in the Western Hemisphere (Islam et al. 2020). Since then, WNV has spread to every state in the United States and numerous other countries worldwide, including Canada, Mexico, and SAARC-associated nations, except for Bhutan (David and Abraham 2016).

These mosquitoes become infected by feeding on the blood of birds carrying the virus and then transferring it to uninfected birds during their feedings (Sbrana et al. 2005). Although dogs, cats, and bats can contract the virus, they are not significant carriers of the disease, and researchers consider them incidental hosts (Reed et al. 2003). A person can acquire the West Nile virus without exhibiting any symptoms. Some individuals may experience mild symptoms such as fever, headache, body aches, nausea, vomiting, and occasionally a skin rash on their torso (Sampathkumar 2003). Unfortunately, in rare instances, West Nile virus can lead to severe neurological diseases like encephalitis or meningitis, which can cause paralysis, a coma, and even death (Sips et al. 2012).

The Centers for Disease Control and Prevention in the United States has implemented integrated mosquito control programs to reduce the risk of West Nile virus. The programs use Integrated Pest Management strategies, including surveillance, source reduction, larval control, and adult mosquito control (Cleaveland et al. 2017). Thailand, Bhutan, India, Pakistan, and Sri Lanka have all implemented several measures to prevent this disease, including raising awareness of the disease through public education campaigns, conducting surveillance for West Nile virus cases, implementing vector control measures, such as mosquito spraying, and vaccinating livestock against this virus (Tshokey et al. 2017; Ullah et al. 2022).

7. LYME DISEASE

Lyme disease is a significant emerging infectious disease most frequently found in North America and Europe (Steere et al. 2016), but is also present in some regions of Asia (Mead 2015). Although the disease has primarily been recorded in temperate areas, the incidence has increased globally due to increased travel and shifting vector habitats (Sharma et al. 2017).

Lyme disease is the most prevalent vector-borne disease in the temperate areas of the northern hemisphere. Europe reports about 85000 instances a year, according to estimates based on national statistics. However, this number needs to be more accurately stated because case reporting is so uneven in Europe, and so many Lyme infections go undetected. Between 15000 and 20,000 cases are reported annually in the United States, and the disease is endemic in 15 states (Lindgren et al. 2006).

The sole pathogen that causes Lyme disease in the United States is the spirochete *Borrelia burgdorferi*. However, besides B *burgdorferi*, other closely related species, such as *Borrelia afzelii* and *Borrelia garinii,* cause Lyme disease in Europe and Asia. These bacteria are spread throughout the United States by hard-bodied ticks, such as *Ixodes pacificus* on the Pacific Coast and *Ixodes scapularis* in the East and Midwest. *Ixodes ricinus* and *Ixodes persulcatus* are vectors in Europe and Asia (Shapiro 2009).

Ticks have become more common and expanded to higher latitudes and elevations over the past few decades. It has been demonstrated that changes in tick density and dispersion are related to climatic changes. Lyme disease cases and other tick-borne illnesses have also grown during the same period. This might result from improved reporting over time in some regions (Lindgren et al. 2006).

To control the disease, The World Health Organization (WHO), the Food and Agriculture Organization of the United Nations (FAO), and the World Organization for Animal Health have joined forces to assist surveillance for tick-borne diseases by adopting the "One Health" concept (Johnson et al. 2022). In the

UK, the Human-Animal-Infections and Risk-Surveillance (HAIRS) group and the Veterinary Risk Group play a role in determining research ideas, suggesting interventions, and determining disease risk to control the disease (Yamada et al. 2014). According to a One Health approach, national coordination and reporting of tick-borne diseases produces national-level indicators to support an evidence base for policy and influencing international organizations. This data should be included in federal and local multisectoral coordination of tick-borne disease control since it is pertinent to community needs, priorities, and capabilities.

8. LEISHMANIASIS

An intercellular parasite, *Leishmania,* causes leishmaniasis. The *Leishmania* parasite is primarily transmitted by sandflies and is considered a tropical and subtropical disease (Torres-Guerrero and Arenas, 2018). Leishmaniasis is one of the seven most significant tropical diseases, according to the WHO, and it poses a severe threat to global health due to its wide range of potential clinical symptoms (Torres-Guerrero et al. 2017).

Leishmaniasis affects 89 countries worldwide, and Asia, Africa, the Americas, and the Mediterranean are endemic regions (Crecelius et al. 2021). Almost 350 million people globally are susceptible to getting the disease. An estimated 1.5 to 2 million new cases are reported yearly, resulting in 70,000 mortalities (Kashif et al. 2017).

Two types of Leishmaniasis are observed: cutaneous leishmaniasis and visceral leishmaniasis. The estimated annual incidence of cutaneous leishmaniasis ranged from 700,000 to 1.2 million or more, and visceral leishmaniasis has dropped to 100,000 from earlier estimates of 400,000 or more cases (CDC 2020). Leishmania transmission occurs at the point where the parasite, vector, and host intersect, and it depends on a dynamic multifactorial process that is influenced by each of these three (Dostálová and Volf 2012). Leishmania parasites, from amastigotes to infectious metacyclic promastigotes, grow inside the digestive tract of the sandfly. The sandfly is contagious and can spread parasites as it tries to consume more blood (Abdeladhim et al. 2014). These parasites are laid in groups as well. Several groups have shown vector-derived components with sandfly and Leishmania origins throughout the past few decades (Rohoušová and Volf 2006).

Geographically, leishmaniasis affects 88 nations, with 60% of illness foci in specific regions of Bangladesh, India, and Nepal. In 2001 and 2002, respectively, it was anticipated that there would be 15,000 and 11,000 new leishmaniasis cases in India annually. There are 30,000 cases annually in Bangladesh and 1850 in Nepal (Mannan et al. 2021). An initiative aimed at eliminating leishmaniasis was started by the governments of India, Bangladesh, and Nepal to bring the annual incidence down to less than 1/10,000 of the population. In India, to prevent leishmaniasis, they followed a strategy: Development of sensitive tools for early diagnosis and monitoring infections, improving treatment strategy to prevent drug resistance, Strengthening the VL surveillance program, development of transmission dynamic modeling and spatial risk map, improvement of integrated vector management, Community engagement, and participation (Sundar et al. 2018). The proactive case detection, efficient management, and vector control strategies used in controlling and eliminating leishmaniasis aim to reduce morbidity, mortality, and disease transmission (Palatnik-De-Sousa and Day 2011).

Interdisciplinary teams comprising microbiologists, parasitologists, entomologists, ecologists, epidemiologists, immunologists, veterinarians, public health officials, and human physicians will primarily be required to control leishmaniasis effectively. More importantly, the One Health strategy satisfies infection control and surveillance needs.

9. MERS-COV AND COVID-19

Middle East Respiratory Syndrome Coronavirus (MERS-CoV) and Coronavirus Disease 2019 (COVID-19)) are two significant zoonotic diseases caused by coronaviruses (Haider et al. 2020; WHO 2022). Both diseases have gained global attention due to their potential to cause severe respiratory illnesses in humans.

The MERS-CoV was identified for the first time in Saudi Arabia in June of 2012 and is classified as a beta coronavirus (Killerby et al. 2020). Several SAARC countries have reported cases of MERS-CoV, with Saudi Arabia being the most affected. Other countries reporting cases include the United Arab Emirates, Qatar, Oman, Jordan, and Yemen (WHO 2022).

The COVID-19 pandemic emerged in Wuhan, China, in late 2019. It rapidly became a global pandemic, causing millions of infections worldwide. On January 30, 2020, WHO designated it a Public Health Emergency of International Concern, and on March 11, 2020, it was classified as a pandemic.

COVID-19 has had a significant impact worldwide, including in SAARC countries. As of May 10, 2021, the SAARC region was responsible for 25.26 million (15.83%) COVID-19 cases and 0.29 million (8.69%) COVID-19 deaths globally (Salman et al. 2022). Until October 24, 2020, Nepal had the highest prevalence of COVID-19 among SAARC member states, followed by the Maldives, Sri Lanka, India, Bangladesh, Pakistan, and Afghanistan (Saha et al. 2021). India, Pakistan, and Bangladesh have had the highest burden of reported COVID-19 infections in South Asia (Khan et al. 2021). Bangladesh had the highest daily case fatality rate among SAARC member states until October 24, 2020, followed by Afghanistan, India, Sri Lanka, Pakistan, Nepal, and the Maldives, where India has the highest mortality rate per million people (Saha et al. 2021).

The emergence of the COVID-19 pandemic has prompted the establishment of novel One Health coordination initiatives within the United States government. Notably, the One Health Federal Interagency Coordination Committee has been formed to facilitate the convergence of public health, animal health, and environmental authorities from over 20 federal agencies (CDC 2023).

Prevalence, risk factors, and epidemiological data are essential for developing successful preventative and control strategies. It is crucial to embrace the "One World, One Health" ideology at both global and local scales to mitigate the potential occurrence of pandemics like MERS-CoV and COVID-19, given the exponential growth of the worldwide population and urbanization trends (Jorwal et al. 2020).

10. Challenges and Collaboration areas Of Multidisciplinary Sectors In The Prevention And Control Of Eids

The significant challenges of the One Health approach include weak laboratory capacity, human resources limitations, weak surveillance mechanisms, legislation deficiencies, and conflict in prioritizing emerging zoonotic diseases due to lack of data hindering One Health's sustainability. Therefore, the lack of a single entity, budget authorization, and reliable data on disease burden and risk factors hinder collaboration between animal and human health (WHO 2020). Thus, South Asian countries must demonstrate leadership, network, political backing, and need-based funding to institutionalize One Health. Taking a multidisciplinary approach, including various sectors and organizations, is essential to handle the complexity of preventing and managing emerging infectious diseases. The first and most key step in controlling outbreaks is quickly discovering and identifying novel conditions. The development of efficient surveillance systems and diagnostic tools necessitates collaboration among medical specialists, epidemiologists, and data scientists.

Furthermore, the successful implementation of efficient preventative measures and public health initiatives requires collaboration among healthcare professionals, policymakers, and communication specialists to distribute precise information and encourage general compliance effectively. Furthermore, research institutions, pharmaceutical companies, and regulatory agencies must collaborate to enhance the efficiency of vaccination and treatment development processes. Moreover, the interdependence of worldwide travel and trade necessitates international collaboration and the exchange of information across many nations and organizations to effectively mitigate the transmission of contagious illnesses across national boundaries.

Lastly, NGOs, governments, and humanitarian organizations must collaborate to develop a vital healthcare infrastructure in low-resource areas. Engaging in multidisciplinary collaboration can enhance our collective ability to address the problems, strengthening our capability to combat emerging infectious diseases and protect world health.

11. CONCLUSION

In the fight against emerging infectious diseases, the 'One Health' strategy emphasizes the interconnection of human, animal, and environmental health. The highlighted diseases illustrate the significance of interdisciplinary collaboration among specialists, including medical professionals, researchers, veterinarians, policymakers, and others. The benefits of collective action are enormous despite obstacles like a lack of resources and data. Collaborative efforts can make early identification, significant research, public awareness campaigns, worldwide coordination, and improved healthcare infrastructure possible. In a world continuously transforming, the One Health concept has become more crucial in mitigating the risks associated with emerging infectious diseases and safeguarding the well-being and security of communities.

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Chances of Cancer in Veterinarians Due to Zoonotic Cases

12

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ABSTRACT

Zoonosis, an infectious disease transmitted from animals to humans, are inherent occupational hazard in veterinary practice. The potential correlation between the incidence of cancer and the occupational exposure of veterinarians to zoonosis has been discussed. While the risks associated with zoonotic infections have been extensively studied, there is a limited understanding of the potential long-term health consequences for veterinarians, particularly concerning cancer development. The research employs a retrospective cohort design, utilizing health records and occupational histories of veterinarians over an extended period. By analyzing data from diverse veterinary settings, including small and large animal practices, research laboratories, and wildlife rehabilitation centers, this study aims to identify patterns and trends in cancer occurrence among this unique occupational group.

Furthermore, the investigation delves into specific zoonotic agents veterinarians may encounter during their professional activities, such as bacteria, viruses, and parasites, and assesses their potential carcinogenic effects. Factors such as duration of exposure, protective measures, and individual susceptibility will be considered in the analysis to provide a comprehensive evaluation of the relationship between occupational exposure to zoonotic agents and the likelihood of developing cancer.

The findings of this study could have significant implications for veterinary occupational health and safety practices. Understanding the potential risks veterinarians face in their daily interactions with animals and zoonotic agents may lead to the development of targeted preventive measures, improved safety protocols, and enhanced awareness within the veterinary community. Ultimately, this research contributes to the broader conversation surrounding occupational health in veterinary medicine and highlights the importance of proactive measures to safeguard the well-being of veterinary professionals.

Keywords: Cancer, tumors, Zoonosis, public health, veterinarians

CITATION

Asrar R, Yousaf S, Ali A, Bari T, Aslam A, Naqvi SZ-E-h and Rafay A, 2023. Chances of cancer in veterinarians due to zoonotic cases. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 168-181. https://doi.org/10.47278/book.zoon/2023.012

CHAPTER HISTORY Received: 12-May-2023 Revised: 21-July-2023 Accepted: 09-Aug-2023

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1. INTRODUCTION

The study of tumor illnesses in populations is central to the field of cancer epidemiology. A valuable source found in pets for epidemiological research on spontaneously developing neoplasms are cancers (Fiumana et al. 2023). Due to the potential for etiological agents to be transferred to humans through animal food items and the closeness of pets to individuals residing in the same residency, attention has been given specifically to cancer in livestock and companion animals. Furthermore, Epidemiology may offer insight into preventing or understanding neoplasms and cancer (Fiumana et al. 2023).
Radiations, herbicides, anesthetics, and zoonotic infections are among the potential carcinogens to which veterinarians may be exposed (Fritschi 2000; Kinnunen et al. 2022). Only a few studies have looked into the cancer risks associated with this career. Our knowledge includes six pertinent cohort studies. Five of them were done in the United States; one of them, which comprised 5016 white male veterinarians, overlapped the four other studies while the sixth involved a total of 3440 veterinary surgeons who lived in Britain (Tomasi et al. 2022).For a number of reasons, including companionship, entertainment, security, pets have grown to be an integral part of homes (Kinnunen et al. 2022). The greatest rate of pet ownership in the world is thought to be in the US, where an estimated 79.7 million houses (65% of households) keep pets. Other nations have reported data along the same lines. As, 63% of families in Australia, or almost 5 million houses, have a pet (Voice 2019). These numbers probably understate the situation. Fig. 1 highlights the route of transmission of cancer to veterinarians.

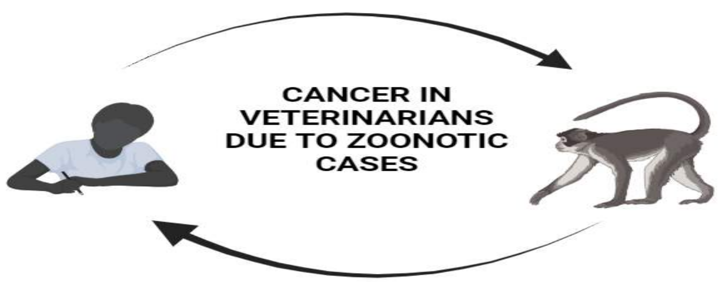

Fig. 1: Cancer transmission to a veterinarian

The benefits to human mental and physical health from interaction with pets and the enhancement of quality of life have been recognized in numerous researches. Because of these factors, using pets as therapy for mental health issues and chronic illnesses is becoming more common (Friedmann and Son 2009). Animal-assisted therapy has been found to have a positive impact on human physiology. Patients with chronic conditions experience a reduction in blood pressure and heart rate. Anxiety levels decrease and social skills improve in mental health inpatients (Moreira et al. 2016). When dealing with the difficulties of a protracted therapy process, which significantly impacts their way of life from a physical and psychological standpoint, oncology patients experience a similar route. Cancer patients receiving aggressive cancer therapy have found AAT (Animal-assisted therapy) to be helpful (Orlandi et al. 2007). AAT mostly employs professionally trained canines (Orlandi et al. 2007). Radiation, anesthetic gases, pesticides (especially insecticides), and zoonotic organisms are just a few of the possibly cancer-causing exposures that veterinarians come into contact while performing their professional duties. The carcinogenic dangers associated with this profession are, however, little understood (Fritschi 2000). Although, there is less data available on the carcinogenicity of exposures in veterinary professionals. In this chapter, the degree of exposure to suspected carcinogens in the veterinary profession will be discussed. This chapter will also analyze the carcinogenicity of these substances in light of the available information.

Cancer is a serious hazard to the health of people worldwide. It is predicted that there will be 19.3 million new cases and nearly 10 million deaths in 2020 (Sung et al. 2021). Pathogens and poor lifestyle choices are just two of the many environmental factors that might contribute to carcinogenesis. 15.4% of cancer cases globally are caused by infectious diseases (Plummer et al. 2016) in developing nations, this percentage rises to 20% (De Martel et al. 2012). By 2050, it has been anticipated that infections will cause a number of cases of human cancer (Zur Hausen 2006). IARC has identified group 1 carcinogens include 11 species of pathogenic microorganisms that are “carcinogenic to humans”. *Helicobacter pylori*, human papillomavirus (HPV), hepatitis B virus (HBV), hepatitis C virus (HCV), and Epstein-Barr virus (EBV) are all known biological carcinogens (Sung et al. 2021). *Opisthorchis viverrini, Clonorchis sinensis*, and *Schistosoma heamatobium* are examples of helminth species that are a part of group 1 (De Martel et al. 2012). Aside from that, *Schistosoma japonicum* and *Opisthorchis felineus* have been categorized as, Group 3 (not classifiable carcinogens) and Group 2B (potential carcinogens), respectively (Bülow et al. 2021; Pakharukova and Mordvinov 2022). In addition, researchers are now evaluating the long-ignored hypothesis that additional metazoan and protozoan parasites may influence the emergence and progression of cancer (Cheeseman et al. 2016; Sawant et al. 2020).

There are different viral (Truyen and Lochelt 2006), putative bacterial species (Swennes et al. 2016), and transmissible tumor cells (Murchison et al. 2014; Ganguly et al. 2016; Stammnitz et al. 2023) that cause cancer. Over the years, certain parasites have been identified as impacting animal health, though their significance was overlooked (Ewald 2018; Porras-Silesky et al. 2021). While advancements in the feline field have led to a reduction in the burden of cancer in the veterinary field (Sarver et al. 2022), the list of pathogens capable of causing animal cancer continues to grow (Rolph and Cavanaugh 2022; Aluai-Cunha et al. 2023).

2. RISK FACTORS FOR DEVELOPING CANCER DUE TO ZOONOTIC DISEASES

In a progressively interconnected world, where the boundaries between humans and animals blur, the threat of zoonotic diseases has gained unprecedented prominence. Beyond the immediate health concerns, a growing body of research has shed light on a concerning link between zoonotic diseases and cancer development. While the origins of cancer are multifaceted, the emergence of zoonotic pathogens as potential risk factors has sparked considerable interest in understanding the complex interplay between human health and the animal kingdom. This exploration delves into the intricate web of risk factors that connect zoonotic diseases to cancer, unraveling the mechanisms and implications that underscore this evolving field of study.

2.1. THE RELATIONSHIP BETWEEN HAVING PETS AND THE RISK OF CANCER

Examples of known human carcinogens include asbestos, silica dust, diesel engine exhaust, and wood dust. Other environmental influences include UV radiation, radon gas, infectious diseases, and others. Pet exposure may also be harmful, according to some studies. The relationship between birds and lung cancer, dogs and breast cancer, and cats and brain tumors or hematological malignancies are all connected to a higher chance of developing cancer.

Concerns arose about the likelihood of a link between cat ownership and a higher risk of malignancies in their owners in a number of researches conducted in the 1970s with relations to cats. In this research, it was proposed that cats might serve as hosts for *Toxoplasma gondi*, FeLV, or FIV, which could result in brain tumors and hematological malignancies. In individuals who own cats and have various hematological neoplasms, however, more recent research has established that there are no evident titers of feline viruses. *T. gondi* commonly spread through cat contact, eating contaminated undercooked or cured meats, and vertical transmission. Adult brain cancer incidence was observed to be greater in nations with higher *T. gondi* antibody prevalence (Thomas et al. 2012). The nations included in this study had *T. gondi* seroprevalence ranging from 4% to 67% and the risk of brain tumors was positively associated with *T. gondi* prevalence in the countries with the highest incidence. Garcia et al. (2016) undertook a sizeable epidemiological investigation so far to investigate links between pet ownership and oncological risk. (Garcia et al. 2016) looked at whether owning pets (particularly canines, felines, or birds) was linked to a minor risk of all cancers. A total of 123,560 participants out of which 20,981 canine owners, 19,288 feline owners, 1338 bird owners, and 81,953 non-pet owners participated in the Women's Health Initiative (WHI) observational study and clinical trials. The findings indicated that there was no correlation between owning a pet and the overall incidence of cancerous tumors. It is also important to bring up the research conducted by (Tranah et al. 2008), whose researchers not only failed to show a connection between pet ownership and human oncologies but also argued for the reverse, saying that having pet animals and being around farm animals may actually be protective against the growth of non-Hodgkin's lymphoma (NHL).

2.2. PET EXPOSURE RISK IN IMMUNE-COMPROMISED INDIVIDUALS

According to Voice (2019), 13 % of Australian residents are of view point that they plan to get a pet animal in the coming year, and surveys show that 77% of households got a pet after receiving a cancer diagnosis. Pet ownership is widespread; as indicated in the introduction, roughly 62% of Australian homes keep pets. Dogs are the most popular pet (approximately 40%), followed by cats (30%).

The possibility of zoonotic diseases is the main issue regarding having a pet in relation to cancer patients, and this might be particularly correct for immune-compromised patients or those getting immunosuppressive treatment (immune-suppressants/chemotherapeutic medicines). Animal bites, scratches, direct skin or mucous membrane contact, contact with bodily fluids, direct contact with urine or feces, and inhaling infected droplets are ways that humans might contract zoonotic diseases. For bacterial, fungal, parasitic, and viral pathogens, there is compelling evidence to substantiate pet origins. *Bartonella* species, *Campylobacter*, *Salmonella*, *Giardia duodenalis*, Cryptosporidium species, Pasturella, Dermatophytes, *T. gondi*, and Lymphocytic Choriomeningitis Virus are some of the common pathogens to be concerned about (Elad 2013).

Instead of this, patient surveys, case reports, and epidemiological research suggest that there are generally few human diseases that may be linked to dogs. However, it is unknown how many immune-compromised patients actually contract zoonotic infections. Due to the rare nature of these instances and the fact that they are typically not reportable infections, there is not a lot of data available. Immune-compromised individuals are not in any greater risk from pet interaction than the general public (Hemsworth and Pizer 2006). This is in line with the results of a few studies on hospital patients who were exposed to rehabilitation dogs (Snipelisky and Burton 2014).

The danger of an illness varies widely, it is acknowledged. The type of cancer patient, the species of animal, its time of life, and characteristics of pet-animal contact relating to animal management and hygiene are some other factors that affect risk. We have a variety of animals available that are the pet species that pose the highest zoonotic risk because they are known Salmonella carriers and can cause severe bacteremia in high-risk individuals, such as those with hematological malignancies (Gradel et al. 2009). Even if having pets is not controversial for the high-risk public, extra safety measures should be taken to prevent the spread of pathogens. Recommendations are typically broken down into pet selection, contact with animals, husbandry practice, and cleanliness habits. In 2017, a survey was conducted to examine the rates of participation in potentially infectious activities among pet owners with compromised immune systems (Gurry et al. 2017). There were three separate patient populations in total, with hematological malignancies being one of them. Only 17% of diseased individuals with pets recalled receipt of instructions about proper pet handling from their physicians, even though 80% of patients engaged in no less than one potentially transmissible activity with their pets, like touching animal feces or sharing a bed. This shows that doctors should counsel people more frequently about responsible pet ownership and interaction. Veterinarians should recommend de-sexing (spaying or neutering) for pets at a young age to reduce roaming and contact with wild animals (Elad 2013; Stull et al. 2015). Fig. 2 shows the occurrence of zoonotic diseases in some closely related species.

Experts and practitioners have a crucial part in educating oncology patients who own dogs about preventative health practices. During a consultation, doctors should actively seek out information about previous interactions with pets and offer pertinent guidance on lowering the risk of zoonotic diseases. Additionally, reportable zoonotic cases should be informed to public health authorities so that particular exposures and behaviors that raise the risk of pet-linked zoonotic disease can be appropriately recognized (Stull et al. 2015).

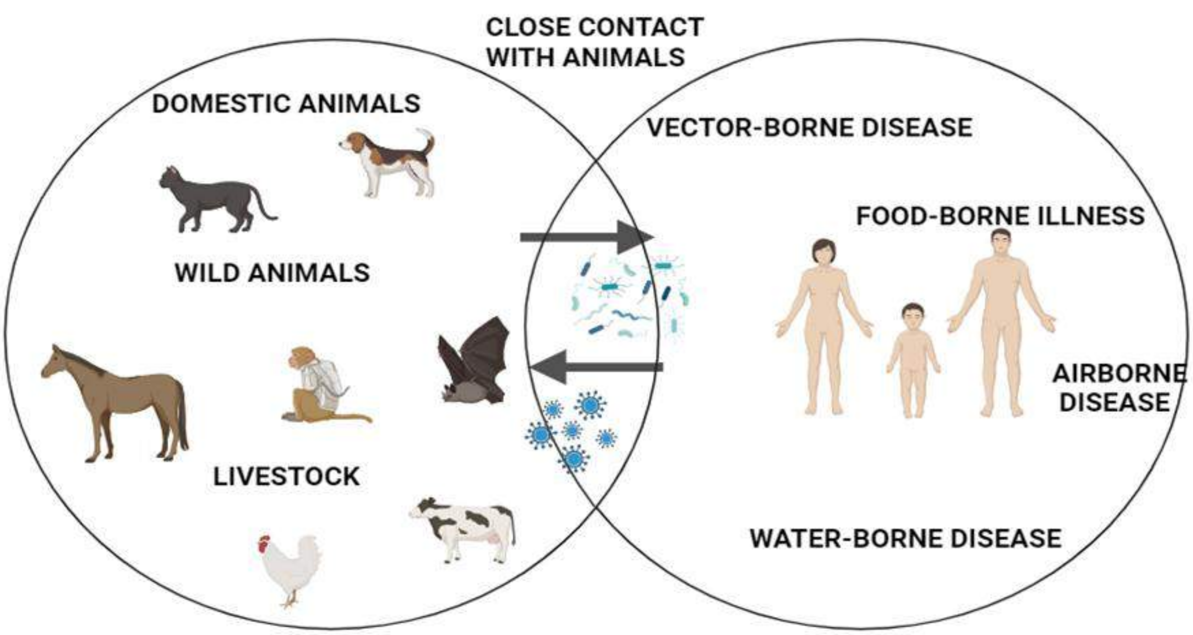

Fig. 2: Zoonotic disease occurs among the closely interacting species

2.3. AREAS FOR INVESTIGATION

There is a positive link between particular viral or bacterial zoonotic infections as a probable cause of malignancy. The methodology was said to have caused some bias in the findings. By using improved procedures, later studies have questioned these conclusions. The majority of the discrepancies could be attributed to undiscovered residual confounding risk factors. Questionnaires were frequently used in the studies to obtain data, which will exacerbate recall bias. Therefore, to remove confounding factors, more rigorous study designs are needed. Uncertainty exists over the precise pathophysiology of the environmental risk factor for cancer. To support or refute the hypothesis, additional research should be done on cancers with potential zoonotic risk links. The pathophysiology of the causal agent's pathogenesis would be useful in better understanding the risk of cancer associated with specific environmental exposures, particularly animal exposure (Elad 2013).

More research is needed to determine the risk factors and advantages of allowing pets in healthcare facilities, even though the majority of studies have found that immune-compromised patients are not more at risk from pet encounters than the general population. This is because zoonotic infections are a persistent concern in this population (Kamioka et al. 2014). A comprehensive investigation is needed to accurately measure the proportion of infectious diseases in humans stemming from interactions with animals, pinpoint particular pathogens, risk factors, and modes of disease transmission, and assess the effectiveness of diverse preventive measures. This thorough data can empower individuals to evaluate the pros and cons of engaging with pets.

3. RISK FACTORS FOR DEVELOPING CANCER IN VETERINARIANS OTHER THAN ZOONOTIC FACTORS

According to reports, the majority of veterinarians in practice use radiographic technology. 64% of respondents in a postal poll of all women receiving veterinary medicine degrees from American institutions in the 1970s admitted to having been exposed to radiation while pregnant with a sample size of total 2427 individuals, this survey had an amazing response rate of 90%.

In another postal survey conducted by Wiggins et al. (1989), it was discovered that approximately 82% of female graduates with veterinary medical degrees from the University of California had potentially encountered ionizing radiation. Once again, the survey boasted a commendable response rate of 86%, and the study encompassed a substantial sample size of 457 individuals. Unlike previous surveys, this one encompassed exposure beyond those related to pregnancy, making it a more representative reflection of typical exposure scenarios.

4. EVIDENCE INDICATES EXPOSURE LEVELS COMPARABLE TO THOSE EXPERIENCED BY VETERINARIANS ARE CARCINOGENIC

It has been known that ionizing radiations are carcinogenic, especially in relation to leukemia, thyroid cancer, and skin cancer (Benson et al. 2012). A case-control study found female dentists and dental hygienists 13 times more likely to develop thyroid cancer than non-dental workers (Bordicchia et al. 2014). These malignancies are associated with higher socioeconomic status and not necessarily with X-rays eviction or work-related chemicals. Record linkage studies showed that people working in medicine had an increased risk of melanoma and an increased risk of colorectal cancer (Bordicchia et al. 2014).

The bovine papillomavirus and the feline leukemia virus are two examples of well-known viruses that cause cancer in a variety of animals and may pose a danger to humans (Bordicchia et al. 2014). Other viruses can also cause cancer in humans, such as Epstein-Barr virus, which causes Burkitt's lymphoma and nasopharyngeal cancer, and herpes papillomavirus, which causes cervical cancer (Benson et al. 2012). In addition, it is said that some viruses, such as cowpox, foot-and-mouth virus, and many arboreal viruses, can be transmitted from animals to humans. These findings led to speculation about the possibility that carcinogenesis in animals could transfer to humans and cause cancer. There is evidence that some of tumors may be caused by a virus; speculation has focused on lymph hematopoietic malignancies. Inadequate exposure assessment limited this investigation of the hazards of zoonotic disease exposure. The absence of animals in the home does not guarantee non-exposure. In addition, it is likely to affect how people respond to questionnaires about exposure to sick animals (Bordicchia et al. 2014).

5. UNVEILING THE CONNECTION: PARASITES AND NEOPLASIA IN DOMESTIC AND WILD ANIMALS, IMPLICATIONS FOR HUMAN ONCOLOGY

The Table 1 provided below enumerates the original research studies discovered during the literature search, concentrating on the correlation between parasites and spontaneous neoplasia within the field of veterinary medicine (Shahvazi et al. 2021). Evidence of a presumed and substantiated association between parasites and carcinogenesis has been established across diverse animal species, encompassing both domestic animals (such as dogs, cats, ruminants, rats, mice, and chickens) and wildlife or exotic species (including prosimians, New and Old-World monkeys, snakes, and muskrats). A total of 15 distinct parasite genera have been identified, with the majority (14) belonging to metazoans, particularly (though not exclusively) helminths. Among the cataloged parasite species are trematodes (*C.sinensis, Fasciola* spp*., O.viverrini*, *Platynosomum illiciens, S.mansoni*), cestodes (*T.taeniformis*), nematodes (*G.pulchrum, S.lupi, Heterakis* spp., *Nochtia nochti, Ollulanus trichuspis, Ophidascaris* spp., *Trichinella* spp.), and arthropods such as pentastomids (*Linguatula serrate*). Furthermore, a protozoan parasite, *T. annulata*, was also identified (Sawant et al. 2020), but recent advancements in diagnostic technologies have shifted attention to other potential parasites, including protozoa (Sawant et al. 2020; Mahdavi et al. 2022; Salim et al. 2022).

There was just one hematological lesion (lymphoma), and there were reports of both mesenchymal and epithelial neoplasms.

6. SOME PRELIMINARY REFLECTIONS OF DIFFERENT DISEASES

6.1. *GONGYLONEMA NEOPLASTICUM*

For millennia, it has been hypothesized (Bignold et al. 2007) that there is a relationship between parasite-related diseases and tumor incidence. However, scientific evidence no longer supports some of these hypotheses, such as the theory of Justammond (1737-1786) that cancer was majorly caused by insects

Table 1: Parasite related neoplasia cases in wild and domestic animals

Phylum	Parasite species	Neoplasms	Cases on record
Nematoda	*Ganglyonema pulchrum*	Esophageal SCC	1
	Heterakis gallinarum	Leiomyoma	8
	Heterakis isolonche	Leiomyoma	2
	Ollulanus trichuspis	Gastric adenocarcinoma	2
	Nochtia nochti	Invasive gastric papilloma	6
	Clonorchis sinensus	Cholangiocarcinoma	2
Platyhelminthes	*Fasciola gigantica*	Leiomyoma	44
	Fasciola hepatica	HCC	11
	Platynosomum illiciens	Cholangiocarcinoma	4
	Taenia taeniformis	Hepatic sarcoma	11
	Taenia taeniformis	Hepatic Fibrosarcoma	55
Arthropoda	*Linguatuala serrate*	Nasal basosquamous carcinoma	1
Apicomplexa	*Theileria annuluta*	Lymphoma	1

consumed through the lymphatic vessels, and the research of Sennert (1572-1637) on the causes of leprosy and carcinoma (Bignold et al. 2007). The scientific basis for the relationship between cancer and infectious agents was established in the early 20th century (Hajdu and Darvishian 2013). The new data showed that the genus *Gongylonem* appeared to be in decline. Zhou et al. (2021) just published the first human case of esophageal squamous cell carcinoma growth associated with esophageal *G. pulchrum* infection. Interestingly, a teenager female lemur (*Lemur macaca variegate*) in a German zoo also showed an association between *G. pulchrum* infection and the same neoplasia (Bleier et al. 2005). The fact that *G. pulchrum* is phylogenetically connected to another spirurid worm, *S. lupi*, whose carcinogenic potential is recognized, calls Fibiger's research into question. Despite the few cases, *G. pulchrum* cancer-causing potential remains unknown. These insights highlight the complexities of this issue while also rekindling interest in Fibiger's work (he himself underlined the importance of multiple components in the genesis of cancer) (Fibiger 1919).

6.2. *SPIROCERCA LUPI*

Dogs who contract spirocercosis are affected by the worm *Spirocerca lupi*, a member of the Spirocercidae family (van der Merwe et al. 2008) *S. lupi* is the only nematode worm known to cause cancer in dogs (Porras-Silesky et al. 2021). This particular parasite has been suggested as an ideal model for investigating the mechanisms through which nematodes function as cancer-causing agents. However, due to its limited zoonotic potential, this parasite is often neglected in the literature. In addition, there are problems with experimental in vivo cancer production of *S. lupi* in laboratory animals (because they act as paratenic hosts) and dogs (for ethical reasons) (Stettner et al. 2005). In recent research, there have been efforts to maintain the vitality of adult *S. lupi* worms within mouse fibroblast cells in an ex vivo environment, although this was achieved only for a limited duration (Sako et al. 2017). Nonetheless, given the rising prevalence of this parasite and its potential implications for combating cancer in the field of human medicine, it is evident that additional research is imperative.

6.3. *CLONORCHIS SINENSIS*

A common zoonotic flatworm called hepatic fluke can damage the liver and bile duct. *C. sinensis* was classified as possibly carcinogenic to human being in 1994. However, more recent and convincing evidence (Choi et al. 2006; Sripa et al. 2012) led to the classification of this substance as highly carcinogenic to humans. Adenocarcinomas account for approximately 70% of cancers caused by *C. sinensis*, while biliary anaplastic and squamous tumors account for the remaining 30% (Choi et al. 2006; Qian et al. 2016). Among these complications, cholangiocarcinoma stands out as the most significant. Surprisingly, recent research indicates that individuals who have both hepatocellular carcinoma and a *C. sinensis* infection experience a poorer prognosis, even in the presence of HBV co-infection (Li et al. 2023). Although there is little information in the domestic literature, experimental animal models have been useful for understanding carcinogenic pathways (Wang et al. 2017).

7. INCREASED SENSITIVITY OF PARASITES TO ENVIRONMENTAL CARCINOGENS

By inducing controlled trematode infections in animal models, researchers recently investigated a process that may indirectly cause cancer. This process can result in a diminished clearance of food or environmental carcinogens (such as nitrosamines, aromatic amines, and aflatoxins) due to mechanical damage, a chronic inflammatory milieu, and the release of parasite ESP, which can impair critical metabolic liver enzymes.

Experimental infections with blood (Schistosoma spp.), liver (Opisthorchis spp.) and/or *C. sinensis* fungi have been found to induce inflammatory changes in the absence of carcinogens. However, the appearance of neoplasia required low doses of nitrosamines, which are not per se carcinogenic (Sripa et al. 2012). Sub carcinogenic oral doses of nitrosamines have been shown to induce biliary tumors in hamsters whose bile ducts were surgically ligated to induce mite infection. It is important to note that an older hypothesis suggested that nitrosamines were the cause of cancer development, with parasite infection acting as a proliferative stimulus to initiate cell proliferation. However, mycological infection of the liver can also promote nitrosation of amine precursors. Aflatoxin B1 (AFB1) and N-dimethylnitrosamine (NDMA) are two carcinogens metabolically activated by the CYP2A5 enzyme that have been implicated in the induction of Opisthorchis and Fasciola infection (Yongvanit et al. 2012). Human and hamster bile ducts have been discovered to contain high quantities of NDMA. *Schistosoma mansoni* has also been experimentally linked to pro-carcinogen metabolic activation via a 300% rise in aflatoxin metabolites (Habib et al. 2006). Undoubtedly, these findings suggest that parasites increase exposure to environmental carcinogens and indirectly increase cancer risk.

8. UNUSUAL ONCOLOGICAL PHENOMENA: EXPLORING HOST-PARASITE INTERACTIONS IN HUMAN AND VETERINARY MEDICINE

An unusual relationship between the host and the parasite is described during carcinogenesis in a 2015 study by Muehlenbachs and colleagues (Muehlenbachs et al. 2015). A dwarf tapeworm (*Hymenolepsis nana*)-infected HIV-positive patient presented with a metastatic tumor of unclear origin. Neoplastic cell morphology suggested a non-human origin. Additional immunohistochemical and genetic testing proved that malignant cells originated from the worm *H.nana* and infiltrated the host's organs (Muehlenbachs et al. 2015), suggesting that the parasite may also possess a carcinogenic mechanism. In this regard, it has been suggested that the absence of conventional host-defense signals (caused by immunodeficiency) can also cause neoplasia in the parasite and abnormal tapeworm growth, tissue dissemination, and neoplasia in the host (Ito 2015). Fig.3 highlights the route of parasites transmission to human through their primary hosts.

This occurrence is prevalent in both the realms of human medicine and veterinary medicine (Conn 2016), *Versteria spp.* (Goldberg et al. 2014; Niedringhaus et al. 2022), Spirometra spp. (Woldemeskel 2014; Arrabal et al. 2020), Mesocestodes (Conn et al. 2010), and other cestodes that infect people and other animals have all been the subject of numerous accounts of abnormal transformation. *Sparganum proliferum*, a lethal zoonotic tapeworm, is a perplexing illustration of how a real neoplastic phenomenon can be separated from parasite life cycle stages based on larval growth (Conn 2016; Kikuchi et al. 2021). More broadly, this hypothetical situation has given rise to the theory of new and unusual host-parasite interactions (de Souza et al. 2016).

Non-human ductal carcinoma has a broad molecular profile, and Veterinary Oncology identifies atypical routes of tumor transmission, such as contagious infectious malignancies in dogs, Tasmanian devils, golden hamsters, and sea urchins (Kattner et al. 2021). However, by analyzing this phenomenon, research in the field of veterinary medicine can become decisive.

9. CROSSING THE SPECIES BARRIER: ZOONOTIC IMPLICATIONS OF CONCURRENT TUMOR OCCURRENCES IN HUMANS AND HOUSEHOLD PETS

Incidences of tumors vary between species, particularly between dog breeds, according to epidemiological studies (Fiumana et al. 2023). Parodi 1977 claim that the boxer dog has a high chance of developing a number of tumors, including thyroid carcinoma, testicular tumors, malignant lymphoma,

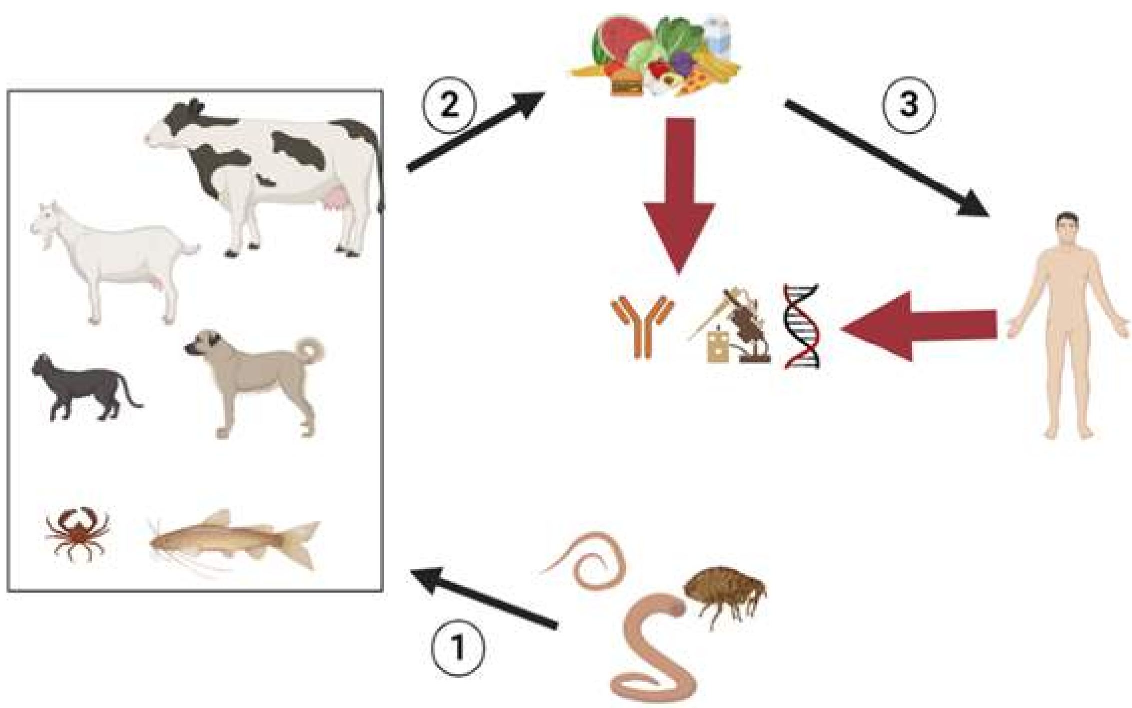

Fig. 3: Parasites through their primary hosts come in the food and thus affect the human causing cancer

and sarcomas of the bone and soft tissues. Large dogs are the primary hosts of skeletal osteosarcomas. Cattle, cats, dogs, and goats with white, non-pigmented skin have an elevated hazard of developing skin squamous cell carcinoma. The absence of melanin's shielding effect against cancer-causing solar radiation has been characterized as a pre-cancerous condition, offering an explanation for this scenario. Depigmentation of hair is linked to equine melatonin illness in grey horses and cutaneous melanomas in miniature swine (Menezes et al. 2003). Ovariectomy in dogs and cats has been shown to be protective against the development of breast cancer, according to case-control studies conducted in the Netherlands. Additionally, it was discovered that the administration of progestogens dramatically raised the risk of the formation of mammary tumors in canine and felines most likely in a dose-related manner (Menezes et al. 2003). These outcomes suggest that early ovariectomy is more effective for preventing oestrus than ongoing progestin therapy. There is a casual link between cat sarcoma tumorigenesis and vaccination against viral illnesses according to recent American studies (Kass et al. 1993).

10. SENTINELS FOR ENVIRONMENTAL HAZARDS

Since pets closely interact with humans in their environment and may act as “sentinel” species for human disease, spontaneous neoplasms in animals may serve as outstanding models for researching the health impacts of environmental risks. Lung cancer in humans is linked to tobacco use. The risk (RR 1.3) of passive smoking in dogs was found to be comparable to that of humans.

11. ZOONOTIC IMPORTANCE

There have been some instances of tumors occurring simultaneously in people and household pets. In one study, cats in leukemia families had greater rates of illness and mortality than cats in families that were chosen at random. The fact that the feline leukemia virus (FeLV) can thrive in human cells in vitro and can theoretically be transmitted to other species made this observation potentially significant (Bordicchia et al. 2014). Nevertheless, epidemiological investigations exploring the potential for cat-to-human transmission have not demonstrated any significant risk associated with FeLV for humans. Despite a comprehensive study that compared cancer incidence between male veterinarians and the broader American population, it was observed that there was an increased occurrence of unexplained cases of leukemia and Hodgkin's disease among veterinarians working in clinical practice.

After adjusting for confounding factors including smoking and occupational exposure, it was discovered that bird keepers in the Netherlands had a 6.7x higher chance of developing lung cancer. For all categories of bird caretakers, there was a similar rise in lung cancer. In addition, exposure to pet birds was linked to an elevated risk of lung cancer in Germany. After he had been exposed for more than ten years, his risk increased. Pigeon raising in Scotland was associated with an increased risk of lung cancer in humans, but not with exposure to domestic ornamental birds. An epidemiological study conducted in the USA on individuals exposed to poultry on the job found no increased incidence of lymphoma, Hodgkin's disease, and leukemia (Beetz et al. 2012).

12. CONCLUSION

In conclusion, the cancer risk relationship between veterinarians and zoonotic cases is a complex and multifaceted topic that deserves continued research and attention. Working tirelessly to care for both animals and people, these dedicated professionals face unique challenges in their work. Despite the fact, that epidemiological studies have offered major information regarding zoonotic concerns. More research is needed to identify the risk factors for cancer in veterinarians. Preventing and mitigating zoonosis, promoting preventive measures in veterinary practice, and monitoring long-term health outcomes in this key workforce are all critical steps to ensure the well-being of these health heroes. Going forward, collaboration between the veterinary and medical communities is key to shedding light on this important issue and developing strategies to protect the health of those who dedicate their lives to caring for animals, and by extension, the health of all of us.

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Zoonosis in Cancer Patients

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ABSTRACT

Zoonoses, which constitute a significant portion of emerging human infections, have been estimated to originate from wildlife in over 70% of cases. The prevalence of zoonotic diseases presents a global public health concern, with impoverished livestock workers in low- and middle-income nations being particularly vulnerable. These zoonoses result in billions of instances of illness and millions of fatalities annually. The chapter delves into the relationship between cancer and the immune system, emphasizing the challenges faced by cancer patients in mounting effective immune responses. Furthermore, it explores the intriguing link between pet ownership and the risk of developing cancer, shedding light on specific associations between certain pets and types of cancer. The transmission routes of zoonotic infections, the diversity of common zoonotic pathogens, and the challenges in diagnosing and managing these infections are thoroughly examined. The impact of cancer treatment on the immune response is explored, emphasizing the importance of understanding immunological dynamics during therapy. In conclusion, this chapter synthesizes information on zoonotic diseases, cancer, and immunology, providing valuable insights into the complex interactions between humans, animals, and the environment. The recommendations and research perspectives presented contribute to a deeper understanding of these interrelated topics, with implications for global health management and the prevention of zoonotic infections.

Keywords: Zoonotic diseases, Cancer, Pet ownership, Transmission routes, Vaccination

CITATION

Khan MA, Bilal H, Abdullah A, Ashraf T, Akram S, Tahir I, Qassim S, Rasheed S, Sarwar S and Nawaz U, 2023. Zoonosis in Cancer Patients. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 182-197. https://doi.org/10.47278/book.zoon/2023.013

CHAPTER HISTORY Received: 23-May-2023 Revised: 12-June-2023 Accepted: 15-Aug-2023

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1. INTRODUCTION

The interactions among humans, animals, and the environment influence the emergence and transmission of various infectious diseases. The majority of infectious diseases that impact the human population originate from animals. According to the report titled "Asia Pacific Strategy for Emerging Diseases: 2010," it was estimated that approximately 60% of emerging human infections are zoonotic (Thompson and Kut 2019). Furthermore, it was found that over 70% of these pathogens originated from wildlife. The emergence of novel diseases in humans during recent decades has been attributed to zoonotic transmission, wherein the diseases originate in animals and are directly linked to the intake of animal-derived food products (WHO 2011).

The term "Zoonosis" originates from the Greek word "Zoo," denoting animal, and "nosis," signifying illness. As per the classification provided by the World Health Organization (WHO), zoonosis refers to any disease or infection that can be transmitted naturally between animals and humans, or vice versa. Approximately, 61% of human pathogens exhibit zoonotic characteristics (Slingenbergh et al. 2013). Fig. 1 shows how zoonotic diseases impact human being.

Zoonosis poses a significant public health concern and represents a direct threat to human health, with potentially fatal outcomes. The impact of the 13 most prevalent zoonoses worldwide has been particularly pronounced among impoverished livestock workers residing in low-and middle-income nations. These zoonoses have resulted in an estimated 2.4 billion instances of illness and 2.7 million fatalities in human annually. Most of these diseases harm animal well-being and result in a decline in livestock productivity (Grace and Ogutu 2012).

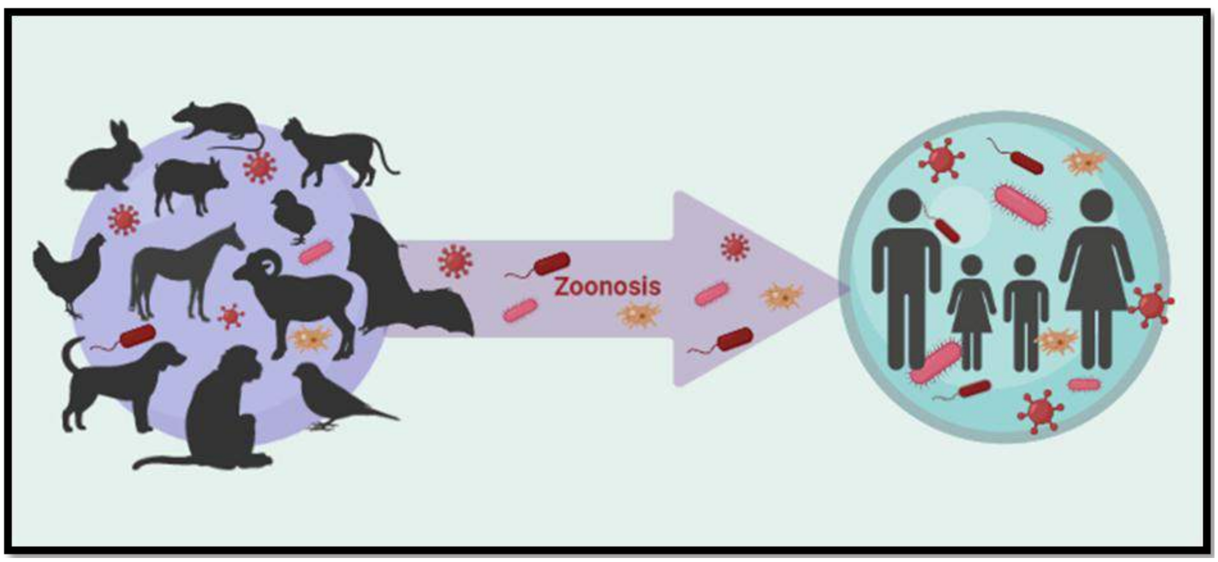

Fig. 1: An infograph on zoonosis. Image retrieved from BioRender.

Zoonosis poses a significant public health concern and represents a direct threat to human health, with potentially fatal outcomes. The impact of the 13 most prevalent zoonoses worldwide has been particularly pronounced among impoverished livestock workers residing in low-and middle-income nations. These zoonoses have resulted in an estimated 2.4 billion instances of illness and 2.7 million fatalities in human annually. Most of these diseases harm animal well-being and result in a decline in livestock productivity (Grace and Ogutu 2012).

2. UNDERSTANDING THE CANCER

Cancer is a pathological state characterized by the aberrant behavior of a cluster of cells that defy the normal regulatory mechanisms regulating cellular proliferation, resulting in unrestrained growth. Cancer cells exhibit a lack of responsiveness to the signals that typically trigger the regular cell cycle. This is due to their inherent self-sufficiency, which ultimately results in the unregulated expansion and multiplication of affected cells. If the uncontrolled growth and division of malignant cells persists, it has the potential to result in a lethal outcome (Waks and Wine 2019). Indeed, it is worth noting that a significant proportion, approximately 90%, of mortalities resulting from malignancies can be attributed to the phenomenon of cancer cell dissemination to distant structural sites, a process commonly referred to as metastasis (Cleator et al. 2007).

During mitosis, the cellular division process, normal cells exhibit interdependence by relying on the presence of external growth factors for their development. If the availability of these growth signals becomes restricted or ceases altogether, cellular replication comes to a halt. In contrast, tumor cells exhibit autonomous growth without any external factors or signaling indicators. Additionally, it is worth noting that normal cells possess a remarkable capacity for contact inhibition. Cell division stops when a sufficient number of neighboring cells are detected, specifically upon reaching a specific threshold (Coffey et al. 2003). In contrast, cancer cells exhibit a deficiency in contact inhibition, resulting in the development of an undesirable aggregation of cellular masses. The existence of a typical cell is intricately regulated; it undergoes approximately 50 rounds of division before undergoing apoptosis, ultimately giving way to cellular renewal through the emergence of another cell. This phenomenon can be attributed to the inherent constraints of DNA replication, which result in a slow degeneration of telomeres due to repeated replication events. In contrast, cancer cells exhibit heightened telomerase enzyme activity, which consistently regenerates the damaged and weakened telomere ends. This relentless renewal process enables unrestricted cellular proliferation (Abbas and Rehman 2018).

3. CANCER AND IMMUNE SYSTEM

Patients with cancer often develop immune responses that specifically target their tumors. While natural killer (NK) cells and tumor-infiltrating lymphocytes work together to attempt to eradicate cancer cells, they are ultimately unsuccessful because cancer cells may avoid efficient immunosurveillance. First, tumor cells generate an interleukin-2 (IL-2) environment that inhibits NK cell division, T-helper cell proliferation, and T-cytotoxic cell proliferation and function by producing immunosuppressive cytokines and prostaglandins. This shifts the immune response toward a Th2 response, in a humoral response with significantly fewer antitumor capacities (Reiche et al. 2004). Second, antigenicity-reducing major histocompatibility complex class I and II and antigen-processing mutations in malignant cells are selected, leading to variations of the cells that are resistant to the immune system. Last but not least, cancer cells may kill T-cells themselves by activation-induced cell death or by launching a counterattack through Fas ligand production (Loose and Van de Wiele 2009).

4. PETS OWNERSHIP AND THE RISK OF DEVELOPING CANCER

There are several known human carcinogens in the environment (ultraviolet light, radon gas, infectious agents, etc.) and in working environments (asbestos, silica dust, diesel engine exhaust, and wood dust). Birds and lung cancer, dogs and breast cancer, and cats and brain tumors or hematological malignancies have all been related to exposure to pets in certain research. Avian exposure was shown to be an independent risk factor for lung cancer in three European studies conducted in the late 20th century (Hemsworth and Pizer 2006). One of the first researchers to look at whether or not keeping birds as pets increased the likelihood of developing lung cancer was Holst et al. (1988). In a case-control study, each of the 49 patients with lung cancer who were 65 years old had their ages and sexes matched with two control participants from the same primary care clinic. Economic status, cigarette smoking, alcohol usage, and vitamin C intake were also measured. Lung cancer risk was shown to be strongly and independently associated with smoking, raising birds, and a deficiency in vitamin C. The chance of acquiring lung cancer was elevated by a factor of 6.8 for those who worked with birds. Almost a decade later, Kohlmeier also reported that having a pet bird was a distinct risk factor for lung cancer based on a German case-control study (Elad, 2013). Between April and October of 1990, researchers in West Berlin interviewed 239 people who had just been diagnosed with cancer of the lungs, trachea, or bronchi. Interview included eight primary topics: healthy living, diet, smoking (both active and passive), pet ownership, workplace exposure to lung carcinogens, current health, and demography. Using the same methods as Holst's study, Kohlmeier discovered a relative risk increase of 2.14 (95% confidence range of 1.35 to 3.40) among those who were in contact with pet birds. While having budgerigars or a canary at home has been linked to an elevated risk of lung cancer diagnosis (odds ratio 3.53, 95% confidence range 1.56 to 7.98). A more recent British research by Gardiner found that keeping pigeons at home was the sole relevant connection (Gardiner et al., 1992). However, it is believed that hypersensitivity pneumonitis brought on by exposure to bird allergens and particulate matter leads to pulmonary interstitial fibrosis and/or dysfunction in the lung macrophages, which may be the exact pathogenesis linking regular avian exposure at home and lung carcinoma (Odendaal, 2000).

5. TRANSMISSION ROUTE OF ZOONOTIC INFECTION

The transmission of pathogens from animals to humans may be either direct or indirect. Direct zoonosis means animal diseases that may spread from animals to humans through the air includes diseases like avian influenza that are transmitted directly from animals to humans through airborne droplets or fomites (Cantlay et al. 2017). Rabies, one of the worst zoonotic illnesses, is spread from infected animals to vulnerable people via bites. The Rhabdoviridae family of viruses is responsible for this disease. The saliva of a rabid dog, bat, monkey, skunk, raccoon, or fox is the vector by which the virus enters a human host. Dengue fever is an example of a disease that may be spread from animal to human through a vector.

Most or all of zoonotic pathogens proliferate in the intestines and are lost in feces many can multiply extensively in tissue, with catastrophic outcomes, and may be transmitted indirectly from animals to humans. Spores released into the environment from bodily waste or decaying animal tissue greatly enhance the prevalence of pathogens that may infect humans. However, infected animals are unlikely to serve as much more than multiplicating hosts, and the organisms do not satisfy the requirements for classification as zoonotic infections (Songer 2010).

6. COMMON ZOONOTIC PATHOGEN

Zoonotic diseases are categorized based on their etiology. Bacterial zoonosis encompasses diseases like anthrax, salmonellosis, tuberculosis, lyme disease, brucellosis, and plague. Viral zoonosis includes rabies, acquired immune deficiency syndrome (AIDS), ebola, and avian influenza (Chomel and Sun 2011). Parasitic zoonoses consist of diseases such as trichinellosis, toxoplasmosis, trematodes, giardiasis, malaria, and echinococcosis. Fungal zoonosis is represented by ringworm. Rickettsial zoonosis includes Q-fever, while chlamydial zoonosis represents psittacosis. Mycoplasma zoonosis refers to *Mycoplasma pneumoniae* infection. Protozoal zoonosis involves diseases caused by protozoa. While diseases caused by acellular non-viral pathogenic agents include transmissible spongiform encephalopathies and mad cow disease (Rahman et al. 2020). Table 1 highlights the major zoonotic diseases, their host, etiology and symptoms.

Table 1: Major Zoonotic Diseases their Host, Etiology, and Symptoms.

Disease	Etiology	Animal Host	Symptoms and Organs involved
		Bacterial Zoonosis	
Tuberculosis	*Mycobacterium bovis, Mycobacterium microti Mycobacterium caprae,*	Cattle, camels, swine, wild boars, and bison	Respiratory organs bone marrow
Campylobacter fetus infection	*Campylobacter fetus , Campylobacter fetus testudinum*	Cattle, goat, and sheep	Enteric disorder
Helicobacter infection	*Helicobacter pullorum, Helicobacter suis*	Poultry and pigs	Peptic ulcer
Salmonellosis	*Salmonella enterica, Salmonella bongor*	Domestic animals, dogs, and birds	Enteritis
Parasitic Zoonosis			
Cryptococcosis	*Cryptococcus neoformans*	Cattle, dog, wild animals, birds, sheep, goat and horse	Respiratory problems, fever, nausea, and vomiting
Cutaneous larval migrans	*Ancylostoma braziliense*	Cats and dogs	Subcutaneous tissue
Hydatidosis	*Echinococcus granulosus*	Buffaloes, sheep, goats, and adult stray or shepherd dogs	Hydatid cysts in the lungs, kidneys, bones, liver, and spleen
Viral Zoonosis			
AIDS	HIV Genus—*Lentivirus* Family—*Retroviridae*	Monkeys and chimpanzees	Immunosuppression, fever, chills, night sweats, rash, swollen lymph nodes and fatigue
SARS	SARS-CoV Genus-*Coronavirus* Family-*Coronaviridae*	Bats, lions, tigers, dogs, minks, and cats	Influenza-like symptoms include muscle pain, fever, pneumonia,
Dengue fever	Dengue virus Genus—*Flavivirus* Family—*Flaviviridae*	Dogs and monkey	High fever, skin hemorrhage, skin rash, and shock
Fungal Zoonosis			
Ringworm infection	*Microsporum spp., Trichophyton spp.*	Cat, sheep, cattle, dog and goat	Skin lesions
Malassezia infection	*Malassezia spp.*	Cat and Dog	Atopic eczema, seborrheic dermatitis, folliculitis, Pityriasis versicolor, and dandruff
Aspergillosis	*Aspergillus spp.*	All domestic birds and animals	Respiratory problems
Histoplasmosis	*Histoplasma capsulatum*	Rat, rabbit, cat and dog	Often asymptomatic, but may exhibit the symptoms like fever, chest pain, hepatosplenomegaly, weight loss, and hematologic disturbances

7. IMPAIRED IMMUNE RESPONSE IN CANCER PATIENT

Individuals exhibiting immunological deficiencies or those whose immune systems are not fully matured, such as children under the age of five, elderly individuals aged 65 years and more, expecting mothers, and cancer patients with medical conditions or undergoing treatments that suppress immune function, are more susceptible to contracting diseases associated with pets (Stull et al. 2013). Nevertheless, the groups of pet ownership practices and the frequency of their interactions with animals are generally comparable to what is observed in the broader population. The ownership of pets, as well as the specific species involved, in households with children who have compromised immune systems and children under the age of 5, are comparable to that of households with children who have fully functional immune systems (Stull et al. 2014).

Recommendations associated with the ownership and interaction with animals have been documented for individuals belonging to high-risk categories, as supported by scientific literature references (Mani and Maguire 2009). Furthermore, supplementary guidelines focusing on animal-assisted interventions within healthcare establishments are also accessible. Considering the advantageous effects of animal companionship on human health and the understandable attachment patients have toward their pets, it is imperative to emphasize the significance of adhering to particular preventive measures. Individuals divided as being at greater risk and their respective domestic units must maintain greater concern regarding the well-being of their companion animals and implement measures to decrease the potential transmission of pathogens. Due to the limited efficacy of animal vaccines in minimizing zoonotic disease transmission, it becomes imperative to explore alternative approaches for minimizing the incidence of pet-related illnesses. The guidelines about pet contact include various aspects such as personal hygiene, the classification and developing stages of organisms, as well as the practices related to the well-being and care of pets (Lefebvre et al.2008).

8. EFFECT OF CANCER TREATMENT ON IMMUNE RESPONSE

Immunotherapy is the most quickly developing field in clinical oncology right now, and it offers the unique possibility of treating and even curing several cancers that were previously incurable. It is becoming clearer that inducing a long-lasting anticancer immune response is essential to the efficacy of chemotherapy and radiation in maintaining disease stabilization (and even cure) long after treatment has been stopped. (Sangro et al. 2021). Indeed, there are dynamic changes in the local immunological infiltration that precede the transition from a preexisting immune response to an immune response generated by treatment. Thus, the immunological contexture, which is established by the tumor's leukocyte infiltrate's density, composition, functional state, and organization, might provide insights into the disease's prognosis, the likelihood of a treatment's success, and other pharmacodynamic factors. Several different tools may be used together to learn more about the immunological context of tumors, identify biomarkers that may help tailor treatments to each particular patient and track their progress while on anticancer drugs (Fridman et al. 2017).

9. INCREASED SUSCEPTIBILITY TO ZOONOTIC INFECTIONS

Zoonotic diseases have exhibited an increasing prevalence owing to a multitude of factors, encompassing urbanization, deforestation, tourism, zoological establishments, climate change, and the poaching of wildlife. These factors have significantly altered the dynamics of daily existence and interactions between animals and humans Led to a surge in the interaction between humans and animals as shown in the Fig. 2 retried from BioRender (White et al. 2020).

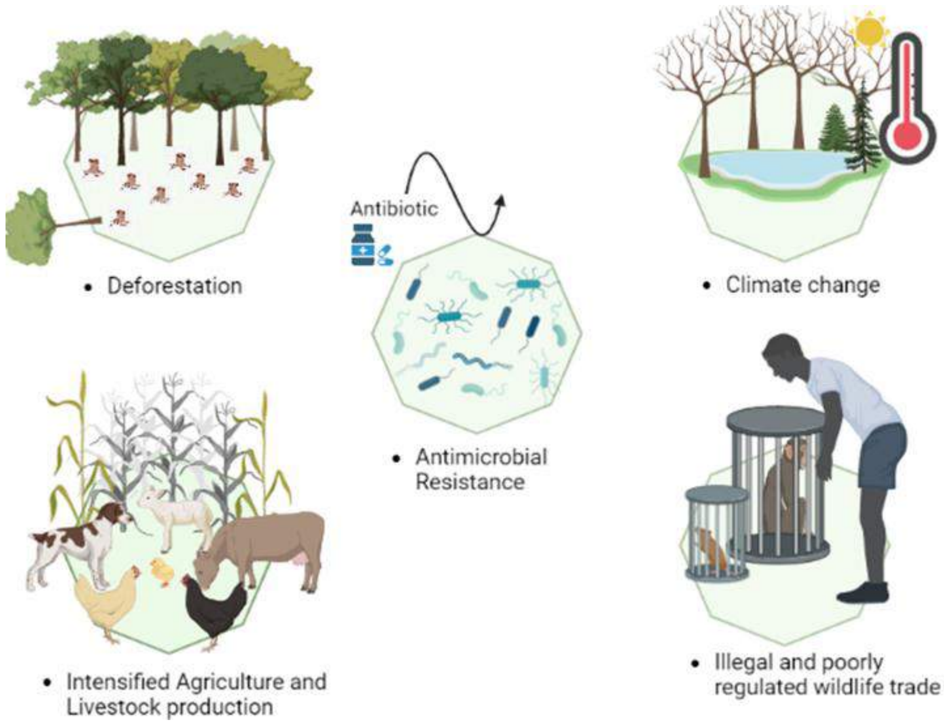

Fig. 2: Factors that cause Zoonotic Emergence.

As natural habitats diminish, animals are compelled to explore human settlements, thereby intensifying the potential for disease transmission. The phenomenon of wildlife trade has also increased contact, which can manifest at various stages of the trade process, ranging from transportation to consumption. All of these factors exhibit similarities in their contribution to the progression of zoonotic disease emergence, while also presenting distinct challenges (Cavallero et al. 2021). One of the recurring themes observed in the context of human-related factors influencing zoonotic diseases is the phenomenon of animals that were previously situated in remote areas, such as the canopy levels of forests, being compelled to engage in interactions with humans at ground level. Moreover, the alterations in the ecological landscape have resulted in the modification of temperature and moisture levels within the surrounding environment (Sabin et al. 2020). These changes can be observed not only due to climate change but also as a consequence of deforestation, which leads to the formation of sunlit pools in areas that have been cleared. Because of these changes, vectors that spread disease proliferate, and animals relocate closer to human populations to take multiple advantage of safety and availability of food given by the shifted environments. Continuing the investigation of these patterns and unraveling the complexities of human-animal interactions and transmissions is of the greatest importance to enhance the formulation of policies, urban risk reduction management strategies, such as pest control, public health education, environmental sanitation initiatives, and preventive measures aimed at mitigating future outbreaks (Ahmed et al. 2019).

10. INFLUENZA

10.1. AVIAN INFLUENZA

Domestic cats are infected with H5N1 flu in Europe (Austria, Germany) and many Asian countries. Captive tigers at a Thai Zoo also fell victim to the disease. Tigers were fed the flesh of avian flu H5N1-infected chickens. There are few reports of H1N1 infection in cats in the United States and Italy (Harder and Vahlenkamp 2010). In South Korean during 2007 pet dogs were reported to have been exposed to an epidemic of avian influenza H3N2. There is no evidence that the H3N2 outbreak afflicting greyhounds in the United States is zoonotic, even though it is linked to an equine influenza virus. It seems that cats and dogs have little role as potential vectors of human illness. Experimental infection was successful in infecting cats, and infected animals were able to spread the disease to uninfected cats. Dogs seem to have an even less role in the transmission of avian flu to people. As was hypothesized for the H1N1 virus, it is more likely that people are the vector of infection for pets (Sponseller et al. 2009).

10.2. SWINE FLU

The H1N1 Swine Flu is a strain of influenza virus, which can spread from person to person and cause a variety of unpleasant symptoms, including a runny nose, a high temperature, a loss of appetite, and possibly pneumonia. Swine flu, or H1N1 swine influenza, is a viral respiratory illness that mostly affects pigs. Swine influenza A (H1N1) causes respiratory illness that may infect pigs' respiratory systems. Swine flu (zoonotic swine flu) has sometimes been transmitted to humans via close interactions with pigs. If the antigenic features of swine flu viruses alter due to reassortment, they might infect humans. When this occurs, is often ineffective in spreading the disease. If influenza spreads from person to person and becomes efficient we might see another pandemic like that in 1918 and 2009 (Farley 2010).
Around 500 million people were infected with the H1N1 influenza virus in 1918, making it one of the deadliest pandemics in human history. Around 50 to 100 million people (3 and 5 percent of the global population) died as a result of the pandemic. The WHO declared a pandemic in 2009 due to the rapid global spread of a novel H1N1 strain of swine flu (Dhamma et al. 2012). Since 2009 H1N1 strain was not transmitted from pigs to people and it cannot be classified as a zoonotic swine flu. Instead, it was conveyed by respiratory droplets from person to person, touching infected surfaces and then touching one's eyes or nose. Reassortment of the viral RNA structure may have facilitated human-to-human transmission of this virus, which induced symptoms identical to those reported in pigs. Although it may seem like consuming pork products (like bacon or ham) will not give you swine flu (Sinha 2009).

11. BACTERIAL INFECTION

11.1. CAMPYLOBACTER JEJUNI

The manifestation of self-limiting gastrointestinal distress, including diarrhea, vomiting, and fever, is frequently observed in cases of *Campylobacter jejuni* infection. Consistent episodes of septicemia and diarrhea are more common in high risk patients (Tenkate and Stafford 2001). Various domesticated species can transmit *C. jejuni* in dogs and cats. These animals can excrete infectious microorganisms through their fecal matter. Young canines and felines exhibit a higher propensity for shedding Campylobacter species compared to their adult counterparts, and the acquisition of a young pup or kitten is linked to the greatest likelihood of transmission (Gras et al. 2013).

11.2. SALMONELLA SPECIES

In individuals with a fully functional immune system, salmonellosis typically manifests as a self-restricting gastrointestinal ailment, although severe manifestations can occur. The disease demonstrates increased severity in individuals with heightened susceptibility, resulting in severe systemic and localized infections, such as neonatal meningitis and osteomyelitis in individuals with sickle cell anemia. Different pet species have been linked to the potential transmission of diseases to humans including amphibians, reptiles, exotic animals, rodents, and young poultry demonstrating the greatest inclination for presenting risks in this context (Mermin et al 2004). Reptiles and amphibians are hypothesized to play a role in approximately 11% of sporadic Salmonella infections observed in individuals below the age of 21. It is worth noting that direct interaction with these animals is not necessary for the transmission of zoonotic diseases. In a particular investigation, it was observed that 31% of cases involving salmonellosis associated with reptiles were found in individuals below the age of 5, with 17% occurring in children who were 1 year old or younger. These results emphasize the increased vulnerability of children to this condition and the possibility of transmission of reptile-associated Salmonella even in the absence of direct interaction with the reptile or its habitat (Whitten et al. 2015). Recent reports have indicated the occurrence of pet-associated salmonellosis outbreaks, involving various species such as hedgehogs, rodents, young poultry, frogs, and turtles. A significant proportion of these cases (35 to 70%) have been observed in children. Furthermore, a multitude of animal-derived sustenance, including uncooked flesh, uncooked ovum, and uncooked delicacies such as swine auricles, are frequently found to be tainted with members of the Salmonella genus. The consumption of these products has been firmly established as a significant risk factor for the development of salmonellosis in domesticated animals, and there have been documented instances of human outbreaks associated with this phenomenon (Leonard et al. 2011).

12. PARASITIC DISEASES

12.1. CRYPTOSPORIDIUM SPECIES AND GIARDIA DUODENALIS

Subclinical or self-limiting diarrheal episodes are commonly observed in cases of cryptosporidiosis and giardiasis, accompanied by weight reduction and the presence of chronic diarrhea in individuals at a higher risk. The manifestation of symptoms in cases of cryptosporidiosis can exhibit variability based on the specific species or genotype of the infecting organism. While it is true that the majority of Giardia assemblages exhibit species-specificity, there exist certain assemblages that have been observed in both animal and human hosts, demonstrating documented instances of zoonotic transmission. Various pet species have been found to potentially host zoonotic Cryptosporidium and Giardia, such as puppies and kittens, which can excrete these organisms in their excretion (Stull et al. 2015).

12.2. TOXOCARA SPECIES

Toxocara, a type of roundworm, generally manifests as either subclinical or self-limited disease in human. However, it is important to note that a small subset of patients may experience the development of ocular or visceral larva migrans. Young children are at the greatest risk due to their heightened susceptibility to a greater amount of infectious material following the consumption of dog or cat feces containing eggs (Lee et al. 2014). Due to the regular deworming practices observed in most domesticated animals, the maturation of larvae into an infective stage typically takes two to three weeks following their excretion in fecal matter. Consequently, the greatest likelihood of exposure arises from interactions with soil that have been contaminated by untreated or feral animals' waste. Such situations commonly occur in areas like sandboxes, gardens, or playing fields (De Boer et al. 2007).

12.3. TOXOPLASMA GONDII

The most frequently observed symptoms following infection with *Toxoplasma gondii* in individuals with a fully functioning immune system are subclinical or self-limited febrile illness and lymphadenopathy.

Toxoplasmosis poses the highest level of concern in pregnant women who have not previously developed immunity, as well as in individuals with compromised immune systems, irrespective of their exposure history (Mani and Maguire 2009). In these individuals, the infection can lead to the occurrence of congenital abnormalities, as well as encephalitis or meningitis. Cats, with their role as the definitive host, play a crucial role in the life cycle of *T. gondii*. On the other hand, humans primarily acquire infections from this parasite through food consumption and environmental exposure (Esch 2013).

13. VIRAL INFECTION

13.1. RABIES

Canis lupus familiaris, commonly known as dogs, serve as the primary reservoir species for the transmission of the viral disease known as rabies. These canines typically transmit the virus through an unprovoked biting behavior. Wild mammals, including foxes, raccoons, skunks, and wolves, serve as reservoirs in specific regions, while bats are infected with lyssa virus in all areas where they have been studied. The etiological agent responsible for the vast majority, approximately 99%, of human fatalities is the canine rabies virus. Rabies poses a susceptibility to all mammals, rendering them potential vectors for the transmission of the virus. This includes feline species, as well as other domesticated animals. However, it is worth noting that monkeys, while very rarely, can also serve as vectors for rabies transmission. Rodent-induced bites pose a minimal risk (WHO 2013).

The prompt for early identification relies on extracting a chronicle of an encounter with a potentially infected mammal, typically occurring in regions of Asia, Africa, or South America where dog rabies prevails. A diverse array of non-specific prodromal symptoms has been observed in individuals with rabies, leading them to seek medical attention from various specialists including rheumatologists, neurologists, psychiatrists, cardiologists, respiratory and acute medicine physicians, ear, nose, and throat specialists, general and transplant surgeons, as well as general practitioners. In the absence of intensive care, individuals who have not received vaccinations and are afflicted with furious rabies encephalomyelitis collapse within a couple of days. In contrast, patients suffering from paralytic rabies may exhibit survival for several weeks (Gautret et al. 2014).

13.2. MONKEYPOX

During May of 2022, the World Health Organization declared a worldwide pandemic of human monkey pox. As of September 21, 2022, 64,290 incidents of monkey pox were confirmed by laboratories across 106 nations, resulting in 20 deaths. The swift increase of the epidemic has coincided with the emergence of a new viral pandemic and public health concern (Wenham and Eccleston 2022).

More than 60 years ago scientists discovered that the monkeypox virus (MPXV) was the cause of monkeypox sickness. In 1959, a report detailing two outbreaks of pox-like illness in *Macaca fascicularis* monkeys at Statens Serum Institut in Copenhagen, Denmark, was published. This was the first time that monkeypox had been documented (Sklenovská and Van Ranst 2018). A newly identified poxvirus, which came to be known as monkeypox, was blamed for these epidemics. Several further outbreaks of monkeypox in zoos and research facilities involving captive monkeys have been documented. In 1970, a 9-month-old boy in the Democratic Republic of the Congo was the first person to be diagnosed with monkeypox virus (MPXV) infection. Since then, researchers have shown monkeypox to be endemic in parts of Central and Western Africa. Human-to-human transmission of MPXV has previously been described in endemic areas in Central Africa, therefore this epidemic is not unprecedented. The 2003 epidemic in the United States (US) is only one example of a non-endemic country experiencing a monkeypox outbreak that was likely caused by imported animals from an endemic zone. The history of monkeypox epidemics has shown the world how important this new zoonosis (Beer and Rao 2019).

The increasing incidence of monkeypox during the last 40 years has been attributed to several variables. One of these variable is increased vulnerability to monkeypox infection after smallpox immunization was discontinued. The efficacy of smallpox immunization in preventing monkeypox is estimated to be about 85%. Consumption of large quantities of animals—potential MPXV reservoirs—may also have a role, especially in areas hit hard by poverty and societal upheavals like civil wars. The increasing human density, the convenience of travel, and ecological and climatic variables (such as the clearance of tropical rainforests) that enhance the danger of exposure to reservoir animals have all been related to the onset of monkeypox epidemics (Rimoin et al. 2010).

14. REVIEW OF ZOONOTIC INFECTION IN CANCER PATIENT

There is still a lack of understanding about the course and effects of severe H1N1 influenza infection in cancer patients. Hajjar et al. (2012) reported on eight incidences of H1N1 infection among patients at a referral cancer center's critical care unit of Estado de São Paulo hospital associated with Universidad de Sao Paulo Medical School in Brazil.

All hospitalized patients with acute respiratory failure from novel H1N1 infection were analyzed for their clinical data. All those who died had autopsies, and viral and bacterial tests by real-time RT-PCR were performed on lung tissue (Hajjar et al. 2012)

A total of eight patients, aged 55 to 65, were hospitalized. There were a total of five patients, three of whom had hematological malignancies and two of whom had solid organ tumors. All five individuals who needed ventilators ultimately passed away. Bronchopneumonia caused by bacteria affected four people. Multiple organ failure was the cause of death in each case. The three survivors all had a less severe type of lung ailment. All patients had a lung tissue examination, which revealed diffuse alveolar injury in the majority of cases. Necrotizing bronchiolitis and massive bleeding were also seen in the lungs (Hajjar et al. 2012).

In cancer patients, an H1N1 virus infection may quickly progress to a life-threatening disease known as acute respiratory distress syndrome. To further understand what factors can indicate a worse outcome for these individuals, more data are required (Hajjar et al. 2012).

15. TREATMENT OF ZOONOTIC INFECTION

Animals with zoonotic illnesses are treated in the same way as those with non-zoonotic diseases, although therapies that delay the shedding of zoonotic organisms should be avoided unless necessary. In cases of simple Salmonella-associated diarrhea, for instance, antibiotic therapy is often not recommended since it may delay the shedding of the offending bacteria. On the other hand, where the infection is subclinical or predicted to self-limit, such as a mild skin lesion due to dermatophytosis, animals that contain zoonotic infections may occasionally be treated to reduce human exposure (Lafaye and Li 2018).

Human infection should be avoided at all costs for the treatment of zoonotic illnesses. The decision of whether to keep the animal at home or in a hospital, requires professional judgment. Considerations include the possible impact of the illness on people, the vulnerability of household members, and the efficacy of barrier nursing, sanitation, and hygiene measures when carried out by humans. If the pathogen may continue in a latent or chronic, subclinical form after treatment, the owner should be fully aware of this. When the animal's life is in danger due to a zoonotic illness, euthanasia may be the only option (Colella et al. 2018).

People who suspect they have caught a zoonotic illness should see a doctor as soon as possible. If the condition is rare and not often on a doctor's radar, it is very important to provide the doctor with as much information as possible to help with the diagnosis. It is preferable to eliminate the infection from both the animal and human hosts at the same time. Public health officials must be notified of the presence of certain zoonotic illnesses, such as rabies (Edwards et al. 2020).

16. CHALLENGES IN DIAGNOSIS AND MANAGEMENT

If there are no BSL-3 laboratories accessible, you should not use any diagnostic technique that involves BSL-3 category live organisms, including culture growth or enrichment. However, even under BSL-2 conditions, the accidental culture growth of pathogens like *Bacillus anthracis* may occur if there is not enough clinical evidence. Infections in the lab may be avoided by adhering to standard operating protocols, limiting opportunities for direct contact, and using hand hygiene products (Weber et al. 2003).

Serology, conventional microscopy, and molecular techniques might be considered if cultural approaches must be avoided for safety concerns. Testing is best done using inactivated samples if the diagnostic methods have been verified with them.

Wherever feasible, inactivated biological material should be used in diagnostic processes. Inactivation protocols that have been shown effective vary by pathogen type. Mycobacteria, for example, have spores and cell walls that contain mycolic acid, making them very resistant to environmental factors and inactivation processes. Mycobacterium spp. can be killed by exposing them to temperatures above 65°C, ultraviolet (UV) light, ethylene oxide, formaldehyde vapor, chlorine compounds, 70% ethanol (in non-protein-containing materials), 2% alkaline glutaraldehyde, peracetic acid, iodophors (depending on the presence of organic matter), and stabilized hydrogen peroxide (Logan et al. 2011).

To effectively kill anthrax spores, a solution of either 5% formaldehyde or glutaraldehyde, a 1:10 dilution of home bleach adjusted to a pH of 7, or a 500 mg/L chlorine dioxide aqueous solution is used. As was recently established for rickettsiae, testing for dependable inactivation should include titration of the least harsh, yet safely inactivating technique and the assessment of time-inactivation curves (Frickmann and Dobler 2013).

Diagnostic methods that come after inactivation techniques that are too harsh might be compromised. For instance, if a considerable amount of human DNA is released from the sample, or if heme is released from lyzed erythrocytes, the PCR reaction may be inhibited. Therefore, the whole pre-analytic process, including the diagnostic method, must always be reviewed simultaneously to guarantee consistent outcomes. Pre-analytical processes that have been thoroughly tested must be maintained in an operational diagnostic context (Alaeddini 2012).

When a crucial pathogen cannot be isolated and put through a battery of further tests to confirm its identification, non-cultural diagnostic methods are often the only option. All non-cultural methods of direct pathogen identification have limits, as discussed in the chapters devoted to individual pathogens. Information on the diagnostic procedure and its performance (sensitivity, specificity, lower detection limit, positive and negative predictive value), limitations, potential errors, disturbances, interference, and cross-reactions, availability of quality control procedures and known reference values, and sample quality should all be taken into account when interpreting diagnostic test results. When dealing with a rare infectious condition, it might be difficult to get credible information on the subject. The aforementioned rule of thumb certainly also applies to culturally dependent methods (Petti et al. 2006).

Cultural techniques are still desired because of some processes, such as the assessment of antimicrobial resistance patterns and numerous typing methodologies discussed in the pathogen-specific chapters. Therefore, even in low-resource situations, there must be BSL-3 reference labs.

Point-of-care molecular diagnostic technologies are often the technique of choice in resource-limited settings without highly established laboratory infrastructure. Some examples of simple point-of-care solutions include the PCR-based GenXpert system (Cepheid, Sunnyvale, CA, USA), the loop-mediated amplification (LAMP)-based Genie II device (Amplex, Gießen, Germany), and the Cobas Liat System (Roche, Basel, Switzerland). For completely automated molecular diagnostic instruments, the manufacturer often defines the number of quality control methods, which should typically include extraction and inhibitory control reactions for molecular diagnostic procedures. To save time and money, fully-automated, closed systems are debating whether or not they may deviate from the stringent rules for molecular laboratories (Porrás et al. 2015).

17. PREVENTION IN CANCER PATIENT

Immuno-compromised cancer patients are vulnerable to opportunistic and healthcare-associated infections. A solid infection prevention program may drastically reduce the risk of infection.
A scientist for the National Park Service (NPS) contracted pneumonic plague after an unprotected encounter with a mountain lion in 2007 and later died. This event triggered an evaluation of staff who work with animals and raised awareness of the risk of contracting a zoonotic illness during employment (Curtis et al. 2018). They surveyed NPS biologists and other wildlife workers across the country online from April to June of 2009 to determine the following:
1) Exposures to zoonotic diseases that may have occurred at work in the previous 12 months
2) Protective practices including the use of PPE
3) Barriers and facilitators to PPE use
The effectiveness of various preventative measures was evaluated and compared to demographic and occupational variables. A total of 238 NPS staff members from 131 parks around the US participated in the survey. There were 71% biologists and technicians, 16% natural resource experts and managers, and 13% people with other occupations. Most respondents only had casual contact with animals, doing things like handling live animals (39%), sick animals (43%), dead animals (46%), or extracting blood (42%), once or twice a year at most. Gloves and proper hand washing were mentioned most often as preventative measures (Sulaiman et al. 2020). Ninety-two percent of respondents agreed that having PPE stocked and easily accessible would promote PPE usage, and ninety-one percent said that having particular PPE kits for use during necropsies and in distant field locations would simplify PPE use. Responses that included reading or reviewing "NPS safe work practices for employees handling wildlife" with a supervisor, including zoonotic disease safety or PPE use in employee performance appraisal plans, or conducting a job hazard analysis for handling wildlife were significantly more likely to have a high summary protective measure score. Ninety people (38%) said they have been trained on how to identify and prevent zoonotic diseases. Our researcher lends credence to the idea that workplace interventions might raise wildlife professionals' awareness of zoonotic diseases and encourage them to adopt preventative practices (Mathews et al. 2021).

18. VACCINATION

Numerous illnesses with high fatality rates and the potential to produce epidemics and pandemics are thought to have evolved in and transmitted to humans from animals (i.e., zoonosis). In addition to affecting cattle output and food security, zoonotic infections are responsible for an estimated 2.7 million human fatalities and 2.5 billion human illnesses per year. By mid-2021, the zoonotic SARS-CoV-2 pandemic, which began in 2020, has already resulted in approximately 4.4 million human fatalities throughout the world (Ronca et al. 2021).

The development of vaccines is among the 20th century's greatest contributions to public health. Vaccination has a long history of success in preventing, controlling, and even eradicating disease, from Edward Jenner's use of cowpox (Variolae) to protect against smallpox. In the 18th century to Pasteur's discovery of how to inactivate the rabies virus to save human lives through vaccination to the urgent need to rapidly create effective vaccines during the explosive SARS-CoV-2 pandemic. Immunization programs for animals have been used to combat zoonotic illnesses by protecting both domestic animals and people from the spread of disease by immunization of wild animals. There is a significant potential research horizon associated with the development of new and better vaccinations to prevent the spread of difficult or developing zoonotic diseases (Monath 2013).

Animal vaccinations have been used for decades for several zoonotic infections. These vaccinations are very cost-effective when administered as part of comprehensive preventative programs, and they have the potential to save lives, boost animal health, and strengthen food and economic security (Wallace et al. 2017).

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Innovative Strategies for the Control of Zoonotic Diseases by using Nanotechnology

14

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ABSTRACT

This book chapter focuses on novel innovative strategies for the prevention and treatment of various types of zoonotic diseases like viral, bacterial, fungal, parasitic, mycoplasma, protozoal and chlamydial infections. The treatment and diagnosis of zoonotic infections are challenging due to drug resistance, genetic mutations and modification of target sites. Therefore, more effective and low-cost theranostics tools are needed to manage the emerging zoonotic infections. Nano-formulations have many advantages over conventional medicines which are used in the treatment of zoonotic infectious diseases by delivering targeted drug delivery, minimizing drug resistance, and causing less toxic effects. Enormous developments have been prepared in manufacturing innovative nano-formulations to control zoonotic diseases based on the usage of mannose-linked thiolated nanocarriers, arginine-based nanocarriers, mannosylated thiolated chitosan (MTC)-coated PM-loaded PLGA NPs, adjuvant pDNA hydrogel, poly (ethylenimine) conjugated nanomicelles and quantum dots to diagnose and treat a huge range of zoonotic infections for examples rabies, tuberculosis, zoonotic influenza, lyme diseases, salmonellosis, leishmaniasis, brucellosis, other emerging infections caused by coronaviruses (COVID-19, MERS, SARS) and West Nile virus in a specially targeted way. The controlled delivery and targeted antimicrobial drugs for treating and diagnosing zoonotic infections via binding to the overexpressed infectious macrophages are the revolutionized development in medicine by nanotechnology. Nano-vaccines and theranostic solicitations of nano-formulation have significant therapeutic potential to combat diverse microbial pathogens. Nanorobots and biocompatible nanoparticles are the nanoscale materials that are used in nanomedicine for the purposes of sensing, diagnosis and drug delivery in the living organism. This chapter reviewed innovative strategies to control zoonotic diseases and future perspectives by using nanotechnology.

Keywords: zoonotic infections, nano-formulations, resistance, targeted drug delivery

CITATION

Anwar M, Muhammad F, Fatima S, Farooq MA, Shafeeq M, Ahmad HMW, Chughtai SA and Aleem A, 2023. Innovative strategies for the control of zoonotic diseases by using nanotechnology. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 198-210. https://doi.org/10.47278/book.zoon/2023.014

CHAPTER HISTORY Received: 15-April-2023 Revised: 14-June-2023 Accepted: 18-July-2023

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1. INTRODUCTION

Zoonotic diseases are numerous infections that are transferred from animals to humans and diagnosis and treatment of these diseases are confusing due to drug resistance, genetic mutations and modification of target sites. Above 60% of the human pathogens have zoonotic in origin that includes various types of viruses, bacteria, protozoa, parasites or fungi and other pathogens. There are numerous factors that have significantly influenced on the zoonosis patterns, distribution, emergence and re-emergence like urbanization, tourism, travel and trade, climate change, vector biology, natural or anthropogenic factors and animal migration (Minakshi et al. 2022). The occurrence of zoonotic emerging and re-emerging infections are increasing day by day predominantly due to the heterogeneity of zoonotic pathogens among the different family. Regardless of their benefits, mostly molecular diagnostic methods have certain limits in terms of sensitivity and repeatability. To solve these disquiets, there is need to develop cost effective and an efficient diagnostic method. Enormous developments have been prepared in manufacturing innovative nano-formulations to control zoonotic diseases based on the usage of mannose linked thiolated nanocarriers, arginine-based nanocarriers, mannosylated thiolated chitosan (MTC)-coated PM-loaded PLGA NPs, adjuvanted pDNA hydrogel, poly (ethylenimine)-conjugated nanomicelles and quantum dots to diagnose and treat a huge range of zoonotic infections for examples rabies, tuberculosis, zoonotic influenza, lyme diseases, salmonellosis, leishmaniasis, brucellosis, other emerging infections caused by coronaviruses (COVID-19, MERS, SARS) and West Nile virus in a specially targeted way (Prasad et al. 2020). Recently established nanoformulations load anti-pathogens with hemocompatibility, biocompatibility and enhanced cellular uptake have shown their ability after oral administration to cross biological barriers. The controlled delivery and targeted antimicrobial drugs for treating and diagnosing zoonotic infections via binding to the overexpressed infectious macrophages are the revolutionized development in the medicine by nanotechnology. The nanoformulations have many advantages over the conventional medicines which are used in the treatment of zoonotic infectious diseases (Minakshi et al. 2022) as shown in Fig. 1. This chapter reviewed the innovative strategies to control the zoonotic diseases and future perspectives by using nanotechnology.

2. TYPES OF ZOONOTIC INFECTIONS

Zoonotic infections are caused by a wide range of pathogens and classified into various types on the basis of etiology like viral zoonoses (avian influenza, rabies, Ebola and acquired immune deficiency syndrome-AIDS), bacterial zoonoses (plague, anthrax, brucellosis, salmonellosis, Lyme disease and tuberculosis), fungal zoonoses (ring worm), parasitic zoonoses (malaria, trichinosis, echinococcosis, toxoplasmosis, giardiasis and trematodosis), protozoan zoonoses, rickettsial zoonoses (Q-fever), mycoplasma zoonoses (*Mycoplasma pneumoniae* infection), chlamydial zoonoses (psittacosis) and acellular non-viral pathogenic zoonosis (Mad cow disease and transmissible spongiform encephalopathy (Chomel 2009). Fig. 2 illustrates the different types of zoonotic diseases with examples.

3. APPLICATION OF NANOMEDICINE IN ZOONOTIC BACTERIAL INFECTIONS

According to World Health Organization (WHO), mainly seven groups of bacteria caused 85–90% infectious diseases and half of the clinical diseases are due to *Staphylococcus aureus* and *Escherichia coli*. Although, due to improvement in diagnostic, prophylactic and therapeutic strategies the number of death due to infectious diseases is expected to reduced but the global emergence of resistant microbial populations and rapid transmission of both anthropozoonotic (zoonotic) and zooanthroponotic (reverse zoonotic) microorganisms are demanding solution of these question mark over this enthusiastic situation (Minakshi et al. 2022). In this perspective nanomedicine can be an effective alternative for manipulating efficient diagnostic, prophylactic and therapeutic approaches to fight the transmissible diseases in a low-cost effective way during the condition of microbial resistance. The uses of nanoparticles (NPs) have illustrated effective bactericidal properties due to distinctive physicochemical properties of numerous nanoformulations. In addition nano-vaccines and theranostic solicitations of nano-formulation have significant therapeutic potential to combat the diverse microbial pathogens. Nanorobots and biocompatible nanoparticles are the nanoscale materials that are used in the nanomedicine for the purpose of actuation or sensing, diagnosis and drug delivery in the living organism (Pati et al. 2018). The recent nanotechnology solicitations in vaccine development against prominent anthropozoonotic and zooanthroponotic bacterial infections have been depicted in Table 1.

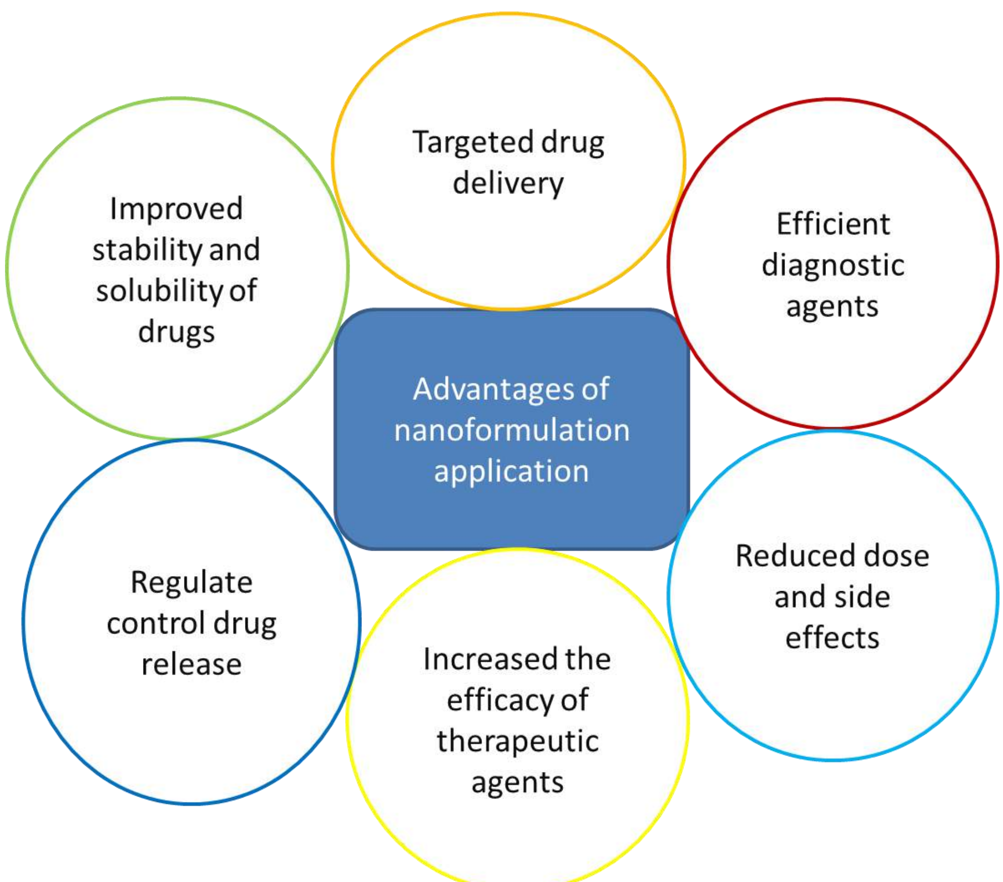

Fig. 1: Advantages of nanomedicines over the conventional medicines for the control of zoonotic diseases

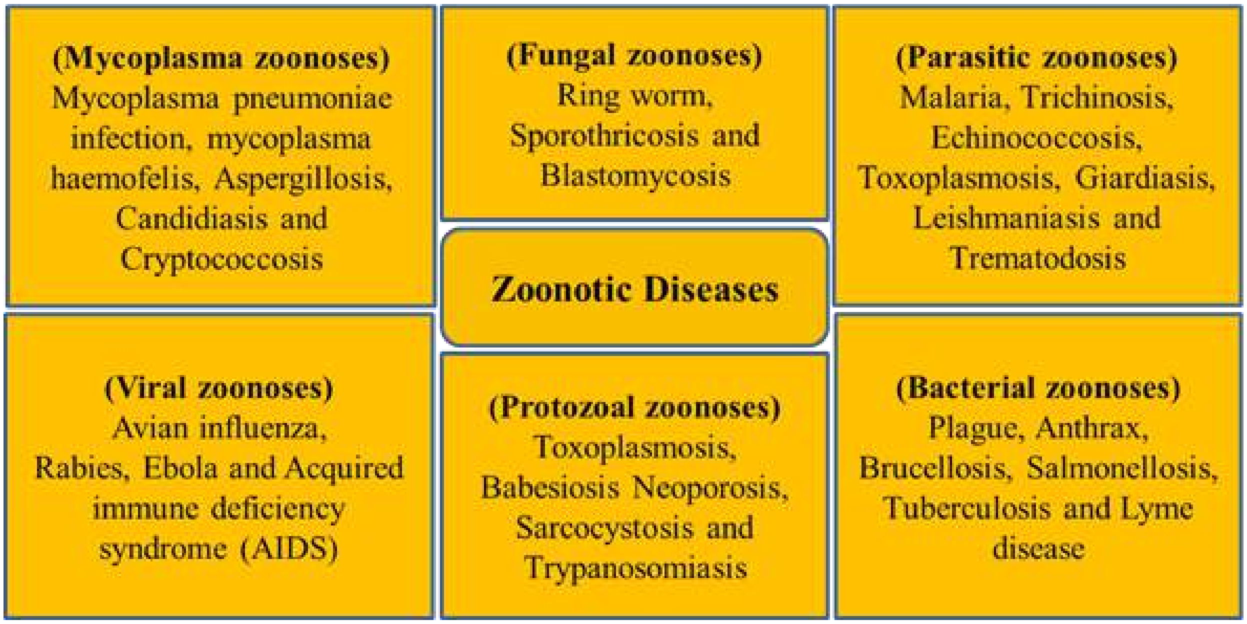

Fig. 2: Classification of different types of zoonotic infections

4. APPLICATION OF NANOMEDICINE IN ZOONOTIC VIRAL INFECTIONS

In the current scenario emerging zoonotic viral infections are major problems with their limitation in prophylactic, diagnostic and therapeutic methods. Mostly viral diseases have wildlife origin and due to deprived knowledge their outbreaks are unpredictable. Therefore, substitute management approaches are needed to improve prophylactic vaccines, rapid diagnostics, efficient drug delivery system and targeted therapeutics. Nanomedicines have been used with promising benefits as adjuvant targeted drug delivery systems, efficient diagnostics, enhancing immunogenicity, specific site therapeutics and reducing the anti-viral drugs side effects (Pelaz et al. 2017). The innovative applications of nanomedicines are enlisted in Table 2 which is used to eradicate the major viral zoonotic diseases to overcome the conventional methodologies limitations.

5. APPLICATION OF NANOMEDICINE IN ZOONOTIC PARASITIC INFECTIONS

There are 3 major groups of parasites including helminths, protozoa and ectoparasites dispersed worldwide. The high prevalence of parasitic infections is due to lack of research in pharmaceutical sciences and appropriate treatment alternatives (Rokkas et al. 2021). Mostly chemotherapeutic anthelmintic, anti-ectoparasitic agents and antiprotozoal drugs are used to treat these parasitic infections but due to overuse of these drugs, resistance has developed with the passage of time. Previously, massive advancement has made in vaccines preparation to regulate these zoonotic diseases. Mostly in vaccine preparation those pathogens are selected which caused the disease outbreaks throughout the world (Pritt 2020). The numerous mechanisms have developed in the parasites that assist them to defend from immune system after exposure of vaccine preparations. Although immune system is involved against parasites but during immunogenic response due to the enormous antigenic variation, the hosts are re-attacks by parasites with antigenic mimicry and antigenic shift that created a big challenge to develop effective vaccine against parasitic infections (Versteeg et al. 2019). In this consequence, nanoparticles are demonstrating a significant and innovative role in the management and

Table 1: Application of nanoformulation against zoonotic bacterial diseases

Sr. No.	Nanoformulation	Bacterial species	Applications	Model	References
1	Gentamycin-AgNPs	*Pasteurella Multocida*	Antimicroibal activity against bacteria resistant to coilstin, gentamicin and amoxicillin	*In-vitro*	(Smekalova et al. 2016)
2	PLGA-gentamycin	*Brucella melitensis*	Activate oxidative burst and significant direction into the mononuclear phagocytic system	Cell culture	(Lecároz et al. 2006)
3	Albumin nanoparticles-gamma interferon	*Brucella abortus*	Enhanced efficacy and bactericidal effect	Mice, *In-vitro*	(Shilpa et al. 2012)
4	Ceftazidine-silver nanoparticles (AgNPs)	*Burkholderia Pseudomallei*	Decrease dose and minimum cytotoxic effect in RBC	*In-vitro*	(Hongsing et al. 2015)
5	ZnONPs-Carvacrol	*Campylobacter jejuni*	100-fold reduction in cell count	*In-vitro*	(Windiasti 2016)
6	Stabilized silver Nanoparticles Glutathione (Ag NPs-GSH)	Multidrug resistant (MDR) *Campylobacter* Strains	Dose dependent cytotoxic effect	*In-vitro*	(Silvan et al. 2018)
7	Silver nanoparticles with nickel or iron	*E. coli*	Bacterial load reduction	Culture	(Abeylatha et al. 2008)
8	Amoxicillin-AgNPs	*E. coli*	Synergistic effects	*In-vitro*	(Li et al. 2005)
9	Ampicillin-AuNPs	*E. coli, Salmonella aureus*	Antibacterial potential against *Micrococcus luteus, Salmonella aureus* and *E. coli,*	*In-vitro*	(Saha et al. 2007)
10	Cinnamon bark Extract-PLGA	*Listeria* (*L.*) *monocytogenes* and *Salmonella typhimurium*	Effective inhibitors, better retention time up to 24 and 72 hours at concentrations ranging from 224.42 to 549.23 (g/mL)	*In-vitro*	(Hill et al. 2013).
11	PLGA-Quercetin	*L. monocytogenes, S. aureus*	Antibacterial activity against Gram +ve bacteria by reducing the bacterial integrity	*In-vitro*	(Arasoglu et al. 2017)
12	Gold nanoparticles-outer membrane proteins	*Salmonella gallinarum*	Synergistic effect to induce immune responses	Chicken	(Anwar et al. 2021)
13	Liposomes-Kanamycin	*Mycobacterium Intracellulare*	Increased antibacterial activity	Mice	(Cosma et al. 2003)
14	Liposome-Rifabutin	Tuberculosis	Improved drug penetration in alveolar epithelium	Wister Rat	(Narayanasamy et al. 2015)
15	Chitosan dexteran sulfate-cefteriaxon or ciprofloxacin	*Salmonella*	Reduces MIC, enhanced retention time and drug delivery, damage the intracellular pathogen	BALB/cmice	(Gnanadhas et al. 2013)
16	Essential oil-silver nanoparticles	*S. epidermidis* and *S. aureus*	Observed additive effects and 62.5 (µg/ml) MIC value was calculated for *S. epidermidis* and *S. aureus*	*In-vitro*	(Ahmadi Ashtiani et al. 2016)
17	Penicillin or oxacillin or amampicillin-Selenium nanoparticles	*S. aureus*	Have synergistic effect	*In-vitro*	(Cihalova et al. 2015)
18	AgNPs-leaf extracts of acalyphaindica	*E. coli , Vibrio cholera*	Reduced MIC value	*In-vitro*	(Krishnaraj et al. 2010)
19	PLGA- Monosialotetra Hexosylganglioside	*Vibrio cholera*	Bind selectively and neutralize the toxin of cholera	Mice and cell culture	(Das et al. 2018)
20	Silica nanoparticles-Chlorhexidine	*Enterococccus faecalis, Streptococcus sobrinus, Streptococcus mutans*	Potent antimicrobial activity, prevent dental caries and decrease biofilm formation	*In-vitro*	(Seneviratne et al. 2014)

Table 2: Application of nanoformulation against zoonotic viral diseases

Sr. No.	Nanoformulation	Viral species	Applications	Model	References
1	Inter-bilayer crosslinked Multilamellar vesicles (ICMVs) with recombinant EBOV antigen (rGP)	Ebola virus	Robust neutralizing antibody response and greater formation of both T cells (poly-functional) and B cells (germinal)	Mice	(Bazzill et al. 2018)
2	Selenium nanoparticles-Ribavirin	Influenza virus	Better antiviral activity and less side effects	Mice, Canine kidney cells	(Lin et al. 2018)
3	Nano beads polystyrene-synthetic peptides	Foot and mouth disease virus (FMDV)	Boosted cell interceded immune response identified by various type of cytokine assays method	Sheep	(Greenwood et al. 2008)
4	Poly-2-hydroxyethyl methacrylate (PHEMA) nanoparticles with whole clone gene in pCAG	Avian Influenza	Immune responses augmented by nanoparticles but frequency of virus shedding from cloaca is significantly not reduced	Hy-line Chicken	(Shan et al. 2010)
5	Chitosan or PLGA with attenuated whole viral antigen (RV-Ag)	Rabies	Minor toxic effect, and enhanced immune responses	*In-viro*	(Nivedh et al. 2016)
6	Silver nanoparticles with inactivated rabies virus	Rabies	Enhanced antibodies that neutralize rabies virus with cell viability adverse effects	Mice	(Asgary et al. 2014)
7	Lipid nanoparticles (LNP)-mRNA vaccine	Rabies/ Influenza virus	Initiation of pro-inflammatory chemokine or cytokines and activation of the immune system (Innate or inherent)	Primates	(Lutz et al. 2017)
8	Polypeptide nanoparticles with B-cell epitope from the virus spike protein	Severe acute respiratory syndrome (SARS) by Corona virus	*In-vitro* infection inhibition assay demonstrated its neutralization activity	Mice or BALB/c	(Pimentel et al. 2009)
9	Protein nanoparticles-Purified coronavirus spike adjuvant	Severe acute respiratory syndrome coronavirus or Middle east respiratory syndrome coronavirus	Improved antibody titer by neutralization	Mice or BALB/c	(Coleman et al. 2014)
10	PLGA nanoparticles-DENV2-E protein	Dengue virus (DENV)	Potent DENV2-specific neutralizing antibody response compared to sRecE protein alone and Nanoparticle induced higher IgG titers without any adjuvant after adsorbed sRecE	Mice or BALB/c	(Metz et al. 2018)
11	VLPs vaccine using prM and E Proteins	Dengue virus	High levels of IL-10 and TNF-α were estimated which stimulated neutralizing antibodies against serotype	Mice	(Liu et al. 2014)
12	Fungal chitosan Nanoparticles with FMDV	Foot and mouth Disease virus (FMD)	CS-FMDv nanoparticles enthused mucosal and humoral immunity and greater serum titers were determined with these nano-formulation as compared to fluid vaccine administered intraperitoneally or with free virus	Guinea pigs	(Tajdini et al. 2014)
13	Gold nanoparticles (GNP) conjugates with pFMDV	Foot and mouth Disease virus (FMD)	8–17 nm size GNPs produced maximal antibody binding that is size-dependent antibody response	Mice and BALB/c	(Chen et al. 2010)
14	DNA vaccines-chitosan nanoparticles	Newcastle disease virus (ND)	Systemic and mucosal immune responses enhanced	Chicken	(Zhao et al. 2018)
15	Virus like particle (VLP) vaccine based on LASV Z, NP proteins and GPC	Lassa virus	Significant production of IgG antibody responses to individual viral proteins after immunization	Mice	(Branco et al. 2010)

control of zoonotic parasitic diseases. During the last decade, in the field of nanomedicine enormous development has made for control of parasitic infections. The nanoparticles of silver and gold have presented encouraging facts in the cures of numerous parasitic diseases. The several molecular and conventional methods are used to synthesize the nanoparticles that have shown great efficacy. There are several mechanisms of action by which these nanoparticles work against parasites like inhibition of protein synthesis, damaging the parasite membrane, disruption of Deoxyribonucleic acid (DNA) and free radical formation (Sousa et al. 2020).
The various other nanoparticles like platinum, nickel and zinc have also presented better outcomes in the control and cure of zoonotic parasitic diseases as enlisted in the Table 3. The intracellular parasites can also be treated effectively by these agents as well. The several research studies have proved the potential of nanoparticles (NPs) used in the cure of many viral, parasitic, bacterial and fungal infections (Aderibigbe 2017; Lin et al. 2018; Chandra et al. 2020; Anwar et al. 2021). It has proved that after reducing to nano-size, various materials undergo wide changes in their properties. These nanoparticles (NPs) have distinct optical, mechanical and chemical properties. The nanoparticles also have cytotoxic effects which vary with form, size, charge, stability and nano-materials purity. The various types of nano-sized particles have been used widely for the effective diagnostic purposes, control and cure of various parasitic infections with outstanding results (Khezerlou et al. 2018; Nafari et al. 2020).

6. APPLICATION OF NANOMEDICINE IN ZOONOTIC FUNGAL INFECTIONS

Fungal infections come in a variety of forms, ranging from superficial infections that affect the skin to systemic infections that invade internal organs (Rai et al. 2017). Every year, millions of individuals around the world are affected by fungus. Of these, over 1.5 million involve offensive fungal zoonotic diseases that necessitate hospitalization and extensive care. Aspergillus, Candida, pneumocystis and Cryptococcus species that are the causative agents of aspergillosis, candidiasis, pneumocystis pneumonia and cryptococcosis

Table 3: Application of nanoformulation against zoonotic parasitic diseases

Sr. No.	Nanoformulation	Parasitic infections	Application	References
1	Iron oxide nanoparticles	Helminth	Induces oxidative stress	(Swargiary et al. 2019)
2	Zinc oxide nanoparticles	Helminth infection	Inhibits the contractile movement of the parasite and adenosine triphosphate (ATP) production	(Chandra et al. 2020)
3	Silver nanoparticles	Leishmaniasis, Helminth infections, Malaria	Improved antihelminthic potential against worms, Better *in-vivo* and *In-vitro* antileishmanial activity, Inhibition of proliferation and metabolic activity of promastigotes. Inhibition of the growth of *Plasmodium* (*P.*) *falciparum*	(Panneerselvam et al. 2015)
4	Gold nanoparticles	Helminth Infections, Malaria	Moderate anti-plasmodial activity against *P. falciparum* which alter physiological functioning of parasite by causing paralysis and leading to death, Moderate to delayed rise in parasitemia	(Pissuwan et al. 2020)
5	Some metal oxides (MO) ($Fe3O4$, MgO, $ZrO2$, $Al2O3$ and $CeO2$)	Leishmaniasis, Malaria	Induction of apoptosis by enhanced cytotoxic effects on promastigotes of Leishmania	(Chikkanna et al. 2019; Tong et al. 2019; Chandra et al. 2020).
6	Albendazole- Solid lipid nanoparticles	*Toxocara canis* infection	Enhanced *In-vitro* activity of albendazole	(Kudtarkar et al. 2017)

respectively, account for the majority of these disseminated infections (Pianalto and Alspaugh 2016). Possibly while they do not usually pose a life-threatening, superficial fungal infections can extent to other parts of the skin and may widespread. They can also spread to other organs and result in secondary bacterial skin infections, which lower a person's quality of life. Dermatophytosis, yeast infections, and mould infections are the three categories into which skin mycoses are usually divided based on the type of fungi that cause these infections (Dantas et al. 2021).

According to their mechanism of action, there are four main types of currently used medicines for treating invasive fungal infections including polyenes, azoles, allylamines, and echinocandins (Nami et al. 2019). They all have disadvantages in terms of drug interactions, pharmacokinetics and pharmacodynamics, resistance mechanisms, and the toxicity of the compounds themselves, in addition to limitations in their range of activity. Additionally, there are some restrictions on clinical efficacy and efficiency, primarily as a result of their physico-chemical characteristics like its low solubility in water due to hydrophobic nature and selectivity issues resulting from the similarity between human cells and fungi (Chang et al. 2017; Souza and Amaral 2017). The nanoparticles have potential to enhance and change the pharmacodynamics and pharmacokinetic features of the medications that make them ideal to use in pharmaceutical formulations. These also have potential to improve the stability and solubility of the drugs, regulate drug control release and show biocompatible with cells and tissues that lead to enhancement in the efficacy of therapeutic agents (Bhatt et al. 2017). Additionally, subcellular size of nanoparticles and high surface area adaptable to modification become the use of nanoparticles in specific target drug release, better therapeutic effects and reducing systemic side effects by lowering the frequency and dose of the administered therapeutic agents (Jinhyun 2015). By conjugating target ligands with peptides on the surface of the transporters and antibodies, it is possible to integrate target ligands at the nanomolecular level, allowing a preferential binding of specific cell types (Rangari 2015; Goyal et al. 2016). In order to increase the therapeutic effectiveness, safety, and compliance of current antifungal medications, it is wise to develop innovative biopharmaceutical systems, particularly nanoparticulate carriers (Sousa et al. 2020).

7. NANOTECHNOLOGY AND MYCOLOGY

The link between mycology and nanotechnology has developed in both directions throughout time. The word "myconanotechnology" was coined as a result of the dynamic interplay between mycology and nanotechnology. With encouraging *in-vitro* and *in-vivo* results, nanotechnology has emerged as an intriguing method to improve the effectiveness and potency of conservative antifungals drugs, to permit a decline in cost and toxicity, to evade an expected degradation and to improve distribution of drug by increasing circulation time and enhancing drug targeting and pharmacokinetics. Furthermore, a variety of synthesized nanoelemental particles and numerous metallic nanoparticles have been utilized against pathogenic plant and human fungi due to their natural antifungal activity (Mashitah et al. 2016).

The metallic nanoparticles have been employed to remove fungi that are pathogenic to plants and humans because nanoparticles have natural antibacterial action and antifungal properties. There are main three pathways including (a) damage of cell wall/cell membrane through accumulation (b) nanoparticles direct uptake (c) reactive oxygen species (ROS) production by indirect activity of nanoparticles. The precise mechanisms through which this activity occurs are only hypothesized. According to Slavin et al. (2017), it is quite likely that the interaction of these multiple mechanisms causes antimicrobial activity. The nanoparticles can dissolve due to their electrochemical potential that causes nanoparticles to discrete into ions in the microbial fluid and culture medium. Additionally, these ions build up in the exterior or interior that inhibits microtubules. Nanoparticle buildup outside of microtubules results in the development of layers that break down the microtubules by blocking the cellular respiratory chain (Qidway et al. 2018).

The interaction that takes place between the medicine and nanoparticle are depends on its electrical charge. The electrostatic mechanism explains why silver nanoparticles were the first to be shown to have antibacterial action. Since the positively charged nanoparticles membranes and negatively charged bacteria cellular membranes are electrostatically attracted to one another, it is commonly acknowledged that for the antimicrobial activity of the nanoparticles there is compulsory need of positive charge silver ion. Adenosine triphosphate (ATP) production is decoupled by Ag^{+} because of its strong affinity for the thiol groups in the cysteine of respiratory chain enzymes. Additionally, Ag^{+} binds to respiratory chain transport proteins, which results the breakdown of the proton motive force and proton leakage. It also prevents phosphate from being absorbed, which encourages the outflow of intracellular phosphate. The concentrations of silver nanoparticles against *Candida albicans* are ranging from 1 to 7 mg/mL and minimum inhibitory concentration (MIC) of 25 mg/ml. The silver nanoparticles show strong antifungal activity against ATCC strains of *Trichophyton mentagrophytes* and clinical isolates (Zhang et al. 2016). Simvastatin increases the antifungal effect in an additive and synergistic manner, possibly because as an inhibitor of ergosterol synthesis it causes disruption of cell membrane of fungi that allow the nanoparticles entry (Bocate et al. 2018). The nanoparticles of silver also show greater antifungal activity against *Aspergillus niger* by preventing biofilm formation and inhibiting spore germination (Bocate et al. 2018).

Chitosan and its derivatives have been used as building blocks in drug delivery system due to their biocompatibility, biodegradability, and mucoadhesive chemical properties. These materials have some advantages due to their potential to prolong the release of low molecular weight compounds to macromolecular drugs and *in-situ* gelling performance. It has been demonstrated that chitosan nanoparticles have excellent antibacterial action against Candida infections. According to published research and literature, the negatively charged lipopolysaccharides on the surface of microbial cells and proteins and positively charge amino groups interrelate with each other that lead to disintegration of cell membrane. The ability of nanoparticles to attach with DNA molecules may inhibit the formation of protein and mRNA (Calvo et al. 2019).

Table 4: Application of nanoformulation against zoonotic fungal/mycotic diseases

Sr. No.	Nanoformulation	Fungal infection	Applications	References
1	Amphotericin B-Zinc oxide nanoparticles	Leishmaniasis and Fungal Infections	Decrease dose, less nephrotoxic effects, potent *In-vitro* antifungal activity	(Adler-Moore et al. 2002; Stone et al. 2016; Lanza et al. 2019)
2	Liposomal Amphotericin B	Severe fungal infections	Less nephrotoxic	(Minodier et al. 2003)
3	Amphotericin B lipid complex	Invasive mycoses	Safer than amphotericin B alone, little nephrotoxicity	(Lister 1996)
4	Nanocrystal based Griseofulvin	Ringworm infection	Enhanced bioavailability	(Aoyagi et al. 1982)
5	Zinc oxide nanoparticles	*Microsporum canis, Candida albicans, Trichophyton mentagrophyte* and *Aspergillus fumigatus*	Antifungal activity	(Eman et al. 2013)

Chitosan specifically inhibits the spore germination and sporulation in case of fungal infection by interfering with the action of the enzymes that promote growth (Kucharska et al. 2020). The antifungal activity of zinc oxide nanoparticles (ZnONPs) has been demonstrated against pathogenic fungi like

Candida and Aspergillus species and other skin infections. In the meantime, it was assessed that ZnONPs have synergistic antifungal activity in conjunction with conventional antifungal drugs. The inhibitory efficacy of the antifungal drugs was not only augmented with ZnONPs combination but also reduced it toxicity (Sun et al. 2018). Additionally, these nanoparticles may offer an intriguing and exciting replacement for current preservatives in cosmetics (Singh and Nanda 2013). Dendrimers exhibit antifungal activity in addition to the aforementioned nanoparticles, opening the door to complex therapies in which dendrimers assist as an adjuvant component of the dose form and drug carrier (Winnicka et al. 2012). Table 4 represents the application of nanoformulation which are used for the control of fungal zoonotic diseases.

8. CONCLUSION

The majority of infectious diseases that affect people are animal-borne. Due to the emergence and re-emergence of numerous zoonotic diseases because of strong interrelatedness among humans and animals, research concentrating on one health approach to manage devastating zoonotic infections. Nanotechnology is the most recent technique in medical and pharmaceutics that has brought vast benefits over conventional medicines for the treatment and control of infectious diseases by delivering targeted drug delivery, minimizing drug resistance, and causing less toxic effects. It is certain that nanotechnology will advance medical science in the future by improving existing therapies and presenting novel treatment with significant clinical advancements.

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Effects of Climate Change on Emerging and Reemerging Zoonotic Diseases

15

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ABSTRACT

The impact of globalization and climate change on newly emerging and reemerging zoonoses and animal illnesses has been unparalleled on a global scale. The climatic variability caused by naturally occurring climate phenomena like El Nio, La Nia, and global monsoons is linked to extreme weather events that alter tropical rainfall patterns. As a result, harmful bacteria, viruses, and fungi are given better habitats to survive in and are encouraged to spread to other places, disrupting natural ecosystems and leading to the emergence of zoonotic diseases. Bird migration patterns, waterfowl species populations, and the cycle of the avian influenza virus can all be affected by climate change. Due to the effects of temperature, humidity, and the demographics of the vectors, vector-borne diseases are highly vulnerable to changing environmental circumstances. Transmission is at its peak in the months with high humidity and rainfall rates for both dengue fever and malaria, which also exhibit notable seasonal variations. Aedes mosquitoes, which carry the Rift Valley fever virus, transmit it to vertebrate hosts. In addition to vector-borne diseases today, climate changes have revealed the severity of waterborne, food-borne, rodent-borne and airborne zoonoses. To better understand how climate and weather affect health outcomes, researchers should continue their research. To better understand why some communities of people and animals are more susceptible to the health effects of climatic variability and change, as well as how people respond to threats from new zoonotic diseases, physical, biological, health, and social scientists must work together. It is important to continue focusing on an integrated strategy for gathering, analyzing, and raising awareness of zoonotic illness using epidemiological, entomological, and environmental data. Therefore, Understanding the connection between zoonoses and climate change is essential to making predictions and controlling the consequences that may be encountered in various epidemic scenarios,

Keywords: Globalization, Climate change, Zoonoses, Influenza virus, Transmission.

CITATION

Yeni DK, Nazir MM, Ijaz MU, Rafique A, Ali T and Ashraf A, 2023. Effects of climate change on emerging and reemerging zoonotic diseases. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 211-225. https://doi.org/10.47278/book.zoon/2023.015

CHAPTER HISTORY	Received:	29-July-2023	Revised:	05-Aug-2023	Accepted:	20-Sep-2023

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1. INTRODUCTION

More and more, it is understood that future epidemics and the emergence of novel illnesses are a result of interactions at the animal-human interface. According to estimates, up to 75% of newly discovered or developing infectious diseases and 60% of recognized infectious diseases have zoonotic origins (CFR workshop 2023). In this study, a zoonotic disease is one that affects both humans and animals and manifests regularly in animals but cannot be transmitted from person to person (Naicker 2011). An emerging zoonosis, according to the World Health Organization, is one that has "newly evolved, or that has already occurred but exhibits an increase in incidence or expansion in geographical, host, or vector range." How climate-sensitive zoonotic diseases are influences both their spread and occurrence. The pathogen, host, vector, or ecological determinants, as well as combinations of the aforementioned elements, are the main contributors to the emergence and spread of zoonotic illnesses (Cediel et al. 2013). The word "zoonoses" comes from the Greek words "zoon" (animal) and "noson" (disease). Additionally, it is believed that this term is the most appropriate in comparison to "anthropozoonosis" (transmission from animals to people) and "zooanthroponosis" (transmission from humans to animals), which focus on the primary method of transmission between humans and other animals (Wilson 2003). A zoonosis is any disease or infection that can transfer spontaneously from vertebrate animals to people or from humans to animals, according to the World Health Organization (WHO). About 61% of human pathogens are zoonotic in origin (Abebe et al. 2020). Zoonoses are a direct risk that poses a major harm to human health and has the potential to be lethal. The poor livestock workers in low- and middle-income countries suffer the burden of the effects of the 13 most widespread zoonoses, which annually result in 2.4 billion cases of illness and 2.7 million fatalities in humans. In addition to having a negative impact on human health, these diseases also have a significant economic impact (Christou 2011).

Zoonoses are ailments and infections that naturally spread from vertebrate animals to people (World Health Organization 1951). The transmission of zoonoses from an infected vertebrate host to humans can occur directly through contact, indirectly through the use of mechanical, biological, or fomite-related vectors, or indirectly. To complete their infectious cycle, several zoonotic illnesses need more than one species of vertebrate or invertebrate (Chomel 2009). The genesis and global spread of zoonoses are essentially being impacted by the rise in animal-human contact. Currently, zoonotic infections account for 60% of emerging infectious diseases (EIDs). These diseases usually originate as a result of dynamic interactions between populations of humans, animals, and cattle as well as rapidly evolving environments. Many EIDs have their origins in wildlife. Emerging zoonoses pose a massive and growing threat to the world's health, economy, and security (Rupasinghe et al. 2022). The current SARS-CoV-2 pandemic is a good example. Recent research indicates that both the prevalence of EIDs and their financial cost are on the rise. At the moment, post-emergence epidemic management, seclusion, vaccine research, and drug development —all of which require significant work, resources, and funding—are the main methods used to lessen the effects of EIDs. In order to effectively avoid future epidemics, respond to them more quickly, and lessen the burden of EIDs globally, it is essential to take a more proactive approach that identifies and reduces the risk elements that have aided in the disease's emergence and the spread of zoonoses (O'Callaghan-Gordo and Antó 2020).

Due to their respective roles in the maintenance and transmission of contagious diseases, wildlife, people, domestic animals, and the environment are intricately linked. For instance, animals has long been "accused" of being the cause of zoonotic diseases that affect humans, very likely unjustly (Thompson and Kutz 2019). In any event, increased viral or bacterial diseases may spread as a result of increased human-animal contact. Zoonotic diseases are defined as "diseases and infections that are naturally transmitted between vertebrate animals and man" by the Expert Committee on Zoonoses in 1951 (Halabi 2019). But at the end of the 19th century, German pathologist and doctor Rudolf Virchow coined the term "zoonoses" to refer to illnesses that affect humans and animals alike (Leal Filho et al. 2022). However, these names have been used interchangeably for any illnesses that affect both people and animals. A third term, "amphixenoses," has also been developed to characterize illnesses that can spread either way and persist in people and lower vertebrate animals. Numerous pathogens have been transferred from animals to people. Prior to posing a threat to a population, a pathogen must first come into touch with an animal (Baker et al. 2022). A pathogen is defined as "an organism that transmits disease to its host; the pathogenicity of the disease symptoms is referred to. Pathogens include bacteria, viruses, unicellular and multicellular eukaryotes, as well as other taxonomically diverse species. (Balloux and van Dorp 2017). The pathogens that cause zoonotic diseases include, but are not limited to, *Salmonella spp*., *Campylobacter spp*., and *E. coli* pathotypes. The two most typical routes of infection are by direct animal contact and the fecal-oral route (including food and drink). Emerging infectious disease (EID) is a phrase used to describe An infectious disease that "has either appeared and first affected a population, or has existed previously but is rapidly spreading, either in terms of the number of people getting infected or to new geographical areas." (Leal Filho et al. 2022).

The rise of zoonoses is influenced by a number of additional factors, including globalization, international trade, changes in land use, and, increasingly, climate change related to vector-borne zoonoses. Through effects on the populations of hosts that serve as hantavirus reservoirs, changing climatic conditions may also be linked to the spread of hantaviruses. Over 200 zoonotic disease types have been identified so far, and they are responsible for a sizable part of newly discovered and ongoing human ailments. Additionally, it is known that around 60% of all human pathogens and 75% of new infectious diseases are animal-borne (Mohammadpour et al. 2020).

1.1. CLASSIFICATION OF ZOONOSES

Numerous microorganisms are responsible for zoonotic illnesses. According to their etiological causes, zoonoses can be divided into bacterial, viral, parasitic, fungal, rickettsial, chlamydial, and microbiological zoonoses as shown in Fig. 1. Bacterial zoonoses include illnesses like plague, anthrax, salmonellosis, tuberculosis, Lyme disease, and brucellosis. Among the viral zoonoses is rabies, AIDS and Ebola (Rahman et al. 2020).

Therefore, zoonotic illnesses are split into four classes based on epidemiological classification that takes into account the zoonosis maintenance cycle: direct zoonoses (orthozoonoses), cyclozoonoses, pherozoonoses (metazoonoses), and saprozoonoses (Rahman et al. 2020).

1.1.1. DIRECT ZOONOSES

(Orthozoonoses) can be transferred mechanically, through direct contact with a fomite, or by contact with an infected vertebrate host. The agent goes through little to no propagative modification and little developmental changes during such a process. Only a few instances are anthrax, brucellosis, trichinosis, and rabies (Grace et al. 2012).

1.1.2. CYCLOZOONOSES

A few kinds of vertebrate hosts, but no invertebrate hosts, to finish the agent's evolutionary cycle. The three most common cyclozoonoses are pentastomid infections, echinococcosis, and human taeniasis.

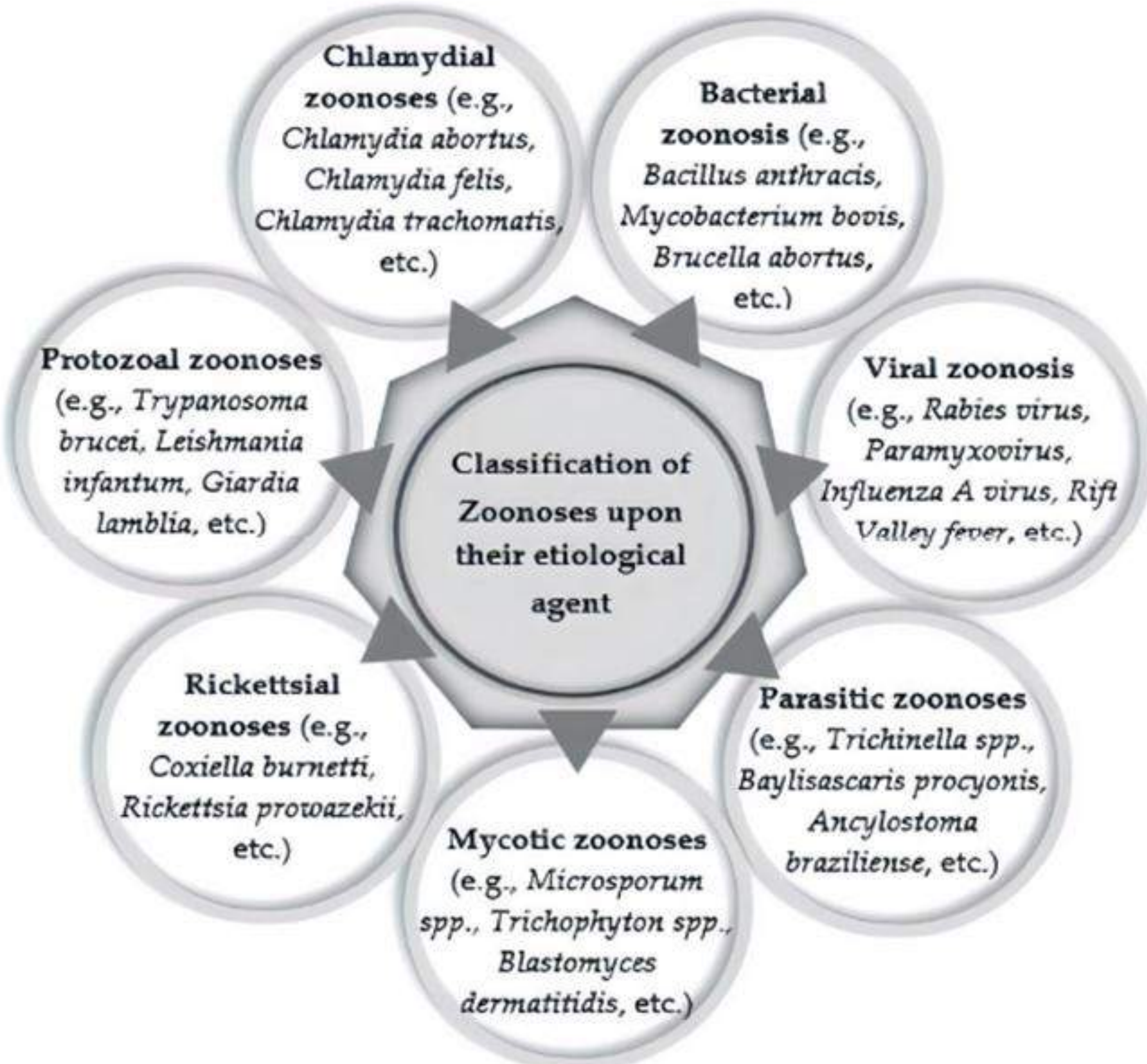

Fig. 1*:* Classification of zoonoses upon their etiological agent (main groups) (Leal Filho et al. 2022)

1.1.3. INVERTEBRATE VECTORS TRANSMIT PHEROZOONOSE (METAZOONOSES)

Wherever conceivable, before transmission to another vertebrate host, there is a prepatent phase of intrinsic incubation. The agent in the invertebrate multiplies, changes, or does both. Schistosomiasis, plague, and arbovirus infection are only a few specimens.

1.1.4. SAPROZOONOSES

They have an animal host that is a vertebrate and a non-animal reservoir for growth, such as food, soil, and plants. Examples include numerous larval migrations and some mycosis types (aspergillosis) as shown in Fig. 2. (Rahman et al. 2020).

1.2 CLIMATE CHANGE AND ZOONOSES

The greatest significant threat to human and animal populations is climate change, which has an impact on some species' population densities, reproductive success, and population dynamics. Furthermore, climate change may extend the current boundaries of agricultural activity, raising the possibility of interactions between species that would not typically occur there. Numerous microorganisms with zoonotic potential are excreted by livestock. These infections can spread through food and water, and the risk of human infection rises if food crops are watered with tainted water (Atwill 2005). Urban areas that are extremely crowded, especially those with poor sanitation, are a major public health problem because they can spread disease outbreaks (Singh et al. 2011).

Disease transmission is substantially impacted by climate change. Variable temperatures are thought to be a contributing factor in the rise in zoonotic disease cases because they prolong periods of vegetation growth and increase habitat availability, which in turn gives zoonotic pathogens and associated vectors better living conditions that support survival and reproduction. In addition, rising temperatures are causing the permafrost in the region to thaw, raising fears that this could uncover ancient human graveyards and lead to the resurgence of vectors that spread deadly illnesses (Singh et al. 2011).

The geographic distribution of diseases that are spread by insects may potentially be impacted by climate change (Singh et al. 2011). Zoonotic viruses that were formerly restricted to hot climes, such as the tropics, have been found to have expanded to subtropical climates and high altitude regions. Various geographical

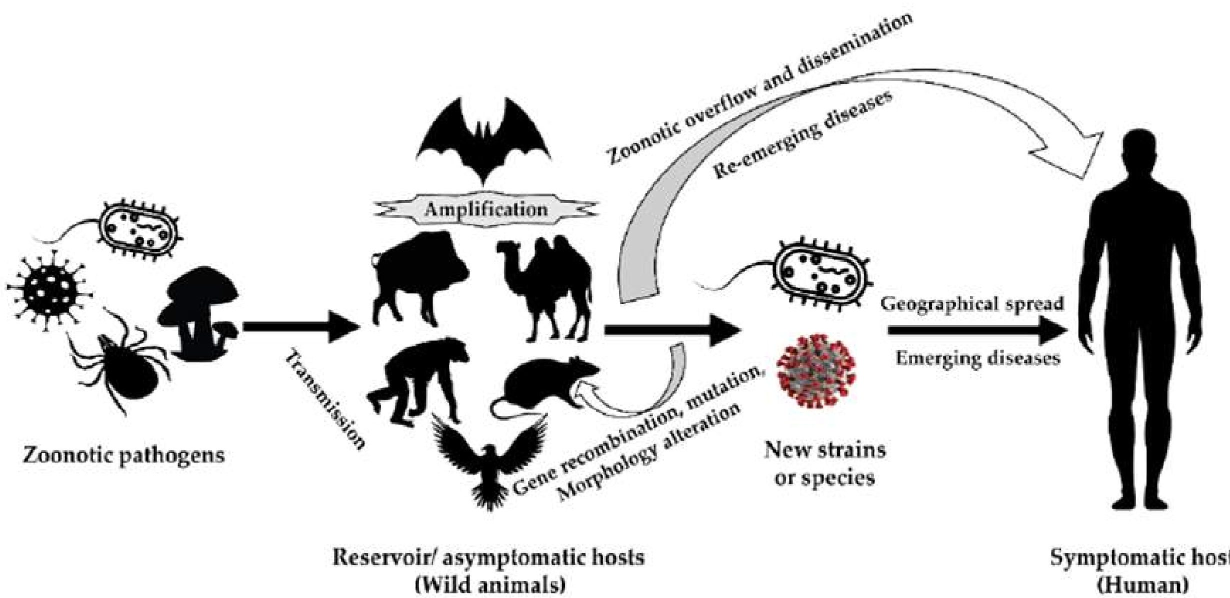

Fig. 2*:* The role of wild animals in zoonoses' emergence and reemergence, as well as in the transmission and amplification of their etiological agents (Rahman et al. 2020)

regions have experienced temperature shifts due to climate change, which has led to an increase in infection prevalence in formerly disease-free areas. Additionally, if people's overall health declines as a result of climate change, zoonotic infections are more likely to spread, as demonstrated by the dengue and Zika viruses, which are currently a worldwide problem (Polley and Thompson 2009). More frequent droughts and flooding have reduced freshwater supply in less developed areas, which has led to human

intake of Zoonotic waterborne infections like schistosomiasis contaminate the water (Patil 2010; Polley and Thompson 2009).
In addition, diseases and vectors have had to create adaption mechanisms as a result of the climate changes. Due to this development, illnesses have become more resilient to conventional therapies as a result of their improved survival strategies, which favors the spread of infection. In some cases, climatic changes may help bacteria and viruses become more resistant, making treatment more difficult and promoting the spread of disease (Pal et al. 2013).

2. CLIMATE CHANGE PRODUCE GLOBAL WARMING

Geoclimatic changes can be explained by variations in land and ocean temperatures, sea level and acidity, precipitation and wind patterns, land characteristics and use, soil conditions, and extreme weather events such heavy rain, floods, extreme wind events, heat waves, and droughts. Global warming is the unusually rapid increase in Earth's average surface temperature over the past century, and it is primarily the result of greenhouse gas (GHG) emissions caused by human activity (Ussiri and Lal 2017). The Intergovernmental Panel on Climate Change (IPCC) projects that, compared to the 1850–1900 (preindustrial) period, the average global surface temperature increased by 1.09˚C (0.95–1.20˚C) between 2011 and 2020. For the same time period, increases over land were higher (1.59 [1.34–1.83] than over water (0.88 [0.68–1.01]˚C). The pace of temperature increase has nearly doubled over the preceding 50 years (NOAA National Centers for Environmental Information, 2018). According to the IPCC, under scenarios with extremely low (SSP1-1.9) to very high (SSP5-8.5) greenhouse gas concentrations, temperatures will rise by 0.2˚C (0.1˚C) every decade and by 1.4˚C to 4.4˚C by the end of the 21st century. CO^2 emissions (Intergovernmental Panel on Climate Change 2021; Allen et al. 2018b). In addition to many other negative effects, rising sea levels brought on by melting glaciers and polar ice caps would result in coastal floods and altered ocean currents. The atmosphere, hydrosphere, cryosphere, lithosphere, and biosphere are among the Earth's systems that interact intricately to control the climate. These interactions between elements of the Earth system will be impacted by global climatic changes, which will change the usual hydrological cycle. A substantial risk to human populations can result from changes in the hydrological cycle, which can alter mean meteorological observations and increase the frequency of extreme occurrences such excessive precipitation, storm surges, floods, and droughts. Water supply, quality, and accessibility may be impacted by a number of circumstances (Ussiri and Lal 2017). Precipitation and the frequency of heavy precipitation events have both increased by 0.5-1% over most of the mid- and high-latitude continents of the northern hemisphere in the 20th century. The average global water vapour concentration, precipitation (especially in the deep tropics and polar latitudes), and year-to-year variability in precipitation are all predicted to rise during the twenty-first century. The RCP8.5 scenario predicts that the average global sea level will rise by 0.52 to 0.98 m at a rate of 8 to 16 mm per year by the year 2100. (Church et al. 2013). The El Nio-Southern Oscillation (ENSO), sometimes known as the ENSO, is a set of irregular, cyclical oscillations that affect the surface temperature and air pressure of the equatorial Pacific Ocean. Extreme weather phenomena including heat waves, torrential rain, droughts, floods, tornadoes, and hurricanes are more likely while it is in its warming (El Nio) or cooling (La Nina) stages. Several oscillations, including the North Atlantic Oscillation (NAO), Pacific Decadal Oscillation (PDO), and Antarctic Oscillation (AAO), have been connected to extreme events (Machado et al. 2021). These extreme weather events will happen more frequently and with increasing severity as a result of climate change. By the 2080s, according to various emission scenarios, an additional 2 to 50 million people worldwide may experience annual coastal flooding (Nicholls, 2004). The ferocity of tropical storms (hurricanes and typhoons) is anticipated to increase due to climate change

(Ussiri and Lal 2012). Global warming and geoclimatic changes alter the dynamics of hosts, vectors, and infections as well as their interactions, which has an effect on the epidemiology of zoonotic diseases. For example, it has been noted that there is a strong link between ENSO/extreme weather events and epidemics of a number of new illnesses, such as the hantavirus, malaria, cholera, plague, and rift valley fever (RVF) (AchutaRao et al. 2006). The zoonoses Lyme borreliosis and tularemia were linked to NAO in earlier studies (AchutaRao et al. 2006). The PDO and above-average temperatures were connected to plague in the Western United States, according to Ari et al. (2008). PDO increases precipitation, which increases flea survival and the availability of food for small animals (Glass et al. 2002).

3. FACTORS INFLUENCING PREVALENCE OF ZOONOSES HUMAN FACTORS

There are numerous anthropogenic reasons causing zoonotic illnesses to emerge, persist, and spread.

3.1 TRAVEL AND TOURISM

Travel across continents makes it easier for new viruses to spread. Disease containment is challenging due to effective air and land transportation links, as the SARS-coronavirus outbreak shows (Poon et al. 2004). Eco-adventure travel is becoming more and more popular, as is travel to increasingly exotic locales. Additionally, widespread across Asia and Africa is volunteerism. Non-immune travelers are thereby exposed to endemic diseases. Athletes participating in adventure sports are exposed to "recreational zoonoses". Leptospirosis epidemics have been linked to water sports such as canoeing, kayaking, and river rafting because animals excrete the bacteria in their urine (Sejvar et al. 2003).

3.2 TRADE

As a result of globalization, items can now be transported by air, rail, sea, and land to almost any location on the earth. For mosquitoes (*Aedes aegypti* and *Aedes albopictus*) adapted to urban environments and small-container reproduction, the trade in used tyres provided as a breeding ground. This made it possible for the Asian tiger mosquito to invade quickly, shifting the previous chikungunya outbreaks from sylvatic to widespread human epidemics (Gould and Higgs 2009). Moreover, during trade, international traffic of products such as wool, bone meal, meat, etc. obtained from a region where some zoonoses are endemic, allows the disease to be transmitted to new regions.
Multiple exotic species are brought together in Asia's live animal marketplaces, producing a breeding ground for the spread of interspecies diseases. The coronaviruses found in civet cats are 99% identical to the strain. In the province of Guangdong, it was the cause of the SARS coronavirus (SARS-CoV) outbreak. Civet cats helped the disease spread to people, which started in these trading markets, despite not being its native reservoirs (Gould and Higgs 2009).

3.3 PETS

Zoonotic disease transmission is linked to close interaction between companion animals and their humans. Humans can become infected with pet-associated zoonotic infections by biting, scratching or direct contact of their skin or mucous membranes, contact with animal saliva, contaminated feathers, feces and bodily secretions, and aerosol (Mani 2009) Salmonellosis in humans is linked to owning exotic reptiles as pets. Urban areas frequently host petting zoos, and animal contact has resulted in Escherichia coli O157:H7 epidemics (Alelis et al. 2009).

The domestic dog serving as the primary reservoir host has contributed to the recent rise of zoonotic leishmaniasis in Europe. In the Mediterranean region, Leishmania infantum causes cutaneous and visceral leishmaniosis, which can spread through travel and the importation of infected dogs (Alelis et al. 2009).
The primary reservoir for Bartonella species is domestic cats. Due to the likelihood that the reservoirs will not be eradicated, diseases such as Cat Graze Disease, Baculiform Angiomatosis, and Peliosis are likely to remain and even worsen (Chomel et al. 2006).

3.4 AGRICULTURAL PRACTICES AND LIVESTOCK FARMING

The rapid growth in human population increases the need for food, increases the amount of land used for farming, and causes ecosystems to be disrupted.
Dams and canals constructed for agricultural purposes could serve as new mosquito vector breeding grounds. The production of large-scale animal husbandry is increasing to meet consumer demand. Because there are many animals or different species being raised together, there is a greater chance of infection between different species (Chomel et al. 2006). Animal farming enables novel viruses to proliferate exponentially. This "high intensity" farming enables diseases, such as E. coli O157:H7 strains, which may only be present in trace amounts, to spread quickly. The zoonotic diseases that affect domestic animals can be found in them. One of the earliest reports of methicillin-resistant *Staphylococcus aureus* (MRSA) associated with pig husbandry was made (Wulf et al. 2008). These ST398 porcine strains, which are circulating throughout Europe, cannot be typed using standard techniques. Livestock-associated MRSA (LaMRSA) is now thought to be at danger due to farming. Antibiotic resistant strains of bacteria have emerged in cattle and poultry as a result of the selection pressure brought on by the use of antibiotics in livestock production to enhance growth and treat infection (Wulf et al. 2008).

3.5 FOOD-BORNE

Food delivery, processing, and manufacture on a large scale are all contributing to an increase in food-borne zoonotic diseases. There are 31 main food-borne pathogens that are responsible for infections; these significant elements, including Salmonella nontyphoidal, Campylobacter, Listeria, and Escherichia coli, are tracked by national agencies and control and eradication studies are carried out to prevent potential outbreaks (Gupta 2016) Undercooked meat is linked to epidemics of hemorrhagic E. coli O157:H7. Antibiotic addition to poultry feed was linked to the growth of Campylobacter species that were resistant to flouroquinolones. *Salmonella* spp. strains *S. Typhimurium* DT104 that are multi-drug resistant are also becoming more prevalent (Velge et al. 2005).

3.6 DEFORESTATION AND URBAN EXPANSION

The "dilution effect" of deforestation's loss of biodiversity has an effect on how zoonotic illnesses spread. According to this logic, the disease is less severe in places with great biodiversity because more animals support disease vectors. The burden of disease is greater when there are fewer species. While selective cutting may increase the risk of zoonoses if the forest's biodiversity is protected, the risk of zoonoses is not increased by clear-cut logging. (Velge et al. 2005).
Deforestation disrupts the natural balance of different species and changes ecosystems. For instance, deforested areas' water puddles are better mosquito breeding grounds because they are less acidic, opening up new biological niches for some vectors. (Velge et al. 2005). The frequency of interactions

between people and Population development and the expansion of human settlements into natural environments result in an increase in wildlife, which facilitates the transmission of zoonotic diseases. This has been demonstrated in Malaysia by the human-to-macaque transmission of *Plasmodium knowlesi* (Velge et al. 2005).

Additionally, urbanization draws immigrant settlers. The danger of bringing in new pathogens or diseases exists with human migration for job or refuge. Additionally, people who go to foreign lands lack immunity to diseases that may exist there. These informal communities, which typically have poor infrastructure and rodent- and tick-borne zoonoses, are common in developing nations. Emerging illnesses spread more readily as a result of the expansion of road and rail networks. New highways expose rural, immune-deficient people to emerging diseases (Velge et al. 2005; Naicker, 2011).

3.7 BUSHMEAT AND HUNTING

Deforestation and logging operations facilitate hunting in emerging nations. In certain nations, like Cameroon, the trade in bushmeat has resulted in an increase in hunting activities. It has long been recognized that hunting non-human primates causes the creation of new illnesses. the threat of zoonoses spreading through contact, droplets, and the air is significant when corpses are butchered in woods. Tularemia is one of the most important diseases transmitted by hunting. Hunters should take precautions especially when handling wild animals such as rabbits, hares and rodents. Game meat should be thoroughly cooked. They should wear gloves during contact. (Karataş yeni, 2021) The risk associated with cooking and eating the meat may be reduced (Naicker 2011).

3.8 HOST SUSCEPTIBILITY

Immunosuppressive drugs, chemotherapy, the development of HIV/AIDS, and organ transplantation. All alter human susceptibility to infections in negative ways. Leishmaniasis co-infections are more common in patients with HIV/AIDS. Additionally more prevalent are bacillary angiomatosis, peliosis, and cryptosporidiosis (Naicker 2011).

3.9 PATHOGEN ADAPTATION

Zoonotic infections may develop new virulence features that provide advantages for survival. The A336V mutation, which is exclusive to strains of *A. albopictus* mosquitoes, has helped the chikungunya pathogen adapt. *Salmonella* spp., which are multidrug resistant, serve as an example of how antibiotic use may exert a selective pressure that leads to the emergence of antibiotic resistance. Madagascar's antibiotic resistance has led to the outbreak of Yersinia pestis there (Naicker 2011).

3.10 ANIMAL MIGRATION

Herd migration contributes to the dissemination of RVF. RVF may spread to new areas as a result of any changes to this brought on by deforestation or altered land use. Wild bird migration has a role in the spread of WNF. Seasonal variations may result in modifications to migration patterns and duration (Naicker 2011). Highly pathogenic avian influenza (HPAI) is a natural reservoir in wild aquatic birds, and it has been demonstrated that these migratory birds excrete and spread HPAI across long distances (Naicker 2011).

3.11 ROLE OF WILDLIFE

The likelihood of zoonotic diseases emerging is influenced by how frequently different wildlife species come into contact with humans. For instance, *P. knowlesi* is known to exist naturally in long-tailed and pig-tailed macaques, and it has now been found that *Anopheles cracens* mosquitoes, which feed on humans, are the vectors of this disease. Unknown diseases have known hosts that may unexpectedly transcend the species barrier include several animals. Other infections may have an animal source that is not yet identified, like in the case of the coronaviruses that resemble SARS that were found in bats as the SARS-CoV's most likely natural reservoir. The significance of this diverse and extensive species for the spread of new zoonotic illnesses including the Nipah virus, Hendra virus, Marburg, Ebola, and mutant rabies is demonstrated by this (Naicker 2011).

4. EMERGING TYPES OF ZOONOSES DUE TO CLIMATE CHANGES

4.1 VECTOR-BORNE ZOONOSES

Many pathogens that affect animal and human health play a role in the formation of vector-borne zoonoses (VBZ). It can transmit bacteria, protozoa, helminths and viruses by transmission of many vectors such as mosquitoes, ticks, fleas, sandflies, lice. In particular, these diseases depend on many factors such as climate changes, geographical location, socioeconomic status. It is quite common in poor rural areas in subtropical regions. It affects the whole world as a major public health problem (Filipe 2014). With the exception of a few isolated regions in north-west India, a rise in average temperature of 2.5°C to 5°Cand an overall increase in rainfall intensity of 1mm to 4mm/day are predicted by climate change predictions. The intensity and timing of the migration of these vectors, their rates of survival and reproduction, and the rates of pathogen development, survival, and reproduction inside their hosts are all assumed to be impacted by these climate variations (Singh et al. 2011). Changes in global climate affect the distribution of vector arthropods and are transmitted to new regions by infecting susceptible animals. In Turkey, 107 zoonotic infections in all have been documented. 19 of them are spread by arthropod vectors. 21 of these zoonotic illnesses are also of high priority in Europe. Likewise, notifications come from different countries (Düzlü 2020) In the South-East Asia region, including India, vector-borne diseases have recently become a severe public health concern. Numerous of these illnesses, in particular dengue fever and Japanese encephalitis, are now epidemic in nature and practically yearly, generating significant morbidity and mortality. The risk factors that are essential to dengue and other vector-borne illness transmission include:

- Globalisation,
- Unplanned
- uncontrolled
- urbanisation,
- development projects
- subpar domestic water storage
- subpar drainage of water
- frequent travel
- human migration are all examples of environmental sanitation issues.

These problems are quite troubling and require thorough attention. Given that these diseases are widespread in the surrounding nations; it is difficult to fight vector-borne diseases because of how easily they can cross international borders. For instance, Pakistan has reported cases of West Nile disease virus-neutralizing antibodies have been found and the Crimean-Congo hemorrhagic fever virus, which is the underlying cause of CCHF (Singh et al. 2011), is widespread in Pakistan. vector prevalence Vector-borne zoonoses inflict significant harm. There have been reports of three genera of soft ticks and seven genera of hard ticks (Singh et al. 2011).

5. CLIMATIC VARIATION ON VIRUS TRANSMISSION

5.1 CHIKUNGUNYA VIRUS

Due to an increase in mosquito population caused by climate change, Chikungunya virus (CHIKV) exposure was favored, which helped the virus emerge in some regions. (Chretien et al. 2007). Asian tiger mosquitoes (Ae. albopictus), which are currently established in Southern Europe, are more adapted to cooler temperatures than Ades aegypti, the primary vector of the Chikungunya and dengue viruses (Woolhouse and Gaunt 2007).

5.2 DENGUE HEMORRHAGIC FEVER VIRUS

Dengue hemorrhagic fever typically affects youngsters and most frequently occurs in Asia. Haemorrhage, shock, and occasionally death make it more difficult. The dengue virus is spread and reproduced by mosquitoes. Ae. aegypti thrives in increased nighttime warming temperatures, although Ae. albopictus has been allowed to endure subfreezing temperatures (Chunsuttiwat 2001).

5.2 WEST NILE VIRUS

Climate variables have a direct impact on the zoonotic pathogen West Nile virus's ability to spread. The virus is stored in birds, and mosquito vectors transmit it from birds to people. According to the four seasons, the virus's strength varies throughout the year, peaking in the summer and troughing in the autumn and winter when the mosquitoes sleep. The number of mosquitoes will increase due to wetter, warmer summers, and the virus will move more readily in milder winters (Barker and Lindsay 2000).

5.3 AVIAN INFLUENZA VIRUS H5N1

Avian influenza is an excellent illustration of a zoonotic disease pandemic that could be affected by climate change. Wild birds' naturally occurring avian influenza viruses don't make them sick, but the H5N1 form of the virus does, which is extremely virulent and can infect humans and have a high case fatality rate, is currently a serious worry. Climate change has the potential to affect bird migration patterns, waterfowl species numbers, and the cycle of avian influenza virus transmission (Slenning 2010).

5.4 RIFT VALLY FEVER (RFV)

The virus that causes Rift Valley fever is predominantly a zoonotic illness that is transmitted between vertebrate hosts via the mosquito Aedes species. Culex mosquitoes may bite infected ungulate hosts, usually during flood circumstances. Culex mosquitoes may bite infected ungulate hosts, usually during flood circumstances. Because it also feeds on humans, this vector is known as a "bridge species," which causes the virus to propagate outside of the typical zoonotic cycle (Wilson 2001).

5.5 LYME DISEASE

Tick dispersal has been discovered to be impacted by climate change. The boundary of tick distribution in the EU is moving northward and up into higher elevations; in addition, the change to milder winters may result in an increase in the tick population and, as a result, a greater risk of Lyme borreliosis and tick-borne encephalitis exposure in humans. Additionally, there have been reports of alterations in the sand fly's geographic range, which is a vector for Leishmania species (Myaing 2011).

5.6 HANTA VIRUS

Numerous zoonoses, such as the Hantavirus, plague, and leptospirosis, are transmitted by rodents. Hantavirus is a zoonosis that can be spread to people directly and is kept in rodent reservoirs by nature. It is more contagious when the reservoir is more prevalent locally (Parmenter et al. 1999). Impacts of climatic variations on zoonoses has been shown in Fig. 3.

6. RE-EMERGENCE OF ZOONOSES

Globally applicable preventative approaches and efficient therapies are required in response to the (re)emergence of zoonoses and the rising threat of antibiotic resistance. Customized strategies are now possible thanks to research in several fields, including enhanced hygiene practises, cutting-edge vaccinations and antibiotics, the use of bacteriophages, and extremely targeted immunomodulatory therapies. However, due to microorganisms' flexibility, (co-) evolution, and gene exchange between different species, science is a never-ending endeavor (Huber et al. 2020).

A widely acknowledged idea for examining zoonoses and combating infectious diseases is the One Health approach (Bidaisee and Macpherson 2014), as a number of elements affect the dynamics of their occurrence and propagation. Climate, ecosystems, food safety, animal and human health, public health, environmental safety, and a full bio-medical analysis of the infections, their vectors, and hosts must all be taken into account. Ecosystems, soil dynamics, land use, and climate change. Ecosystems in permafrost adapt to climate change rather quickly. As a result of warming in subarctic areas, which is reportedly ten times quicker than the average pace for the entire world, permafrost thawing, wildfire frequency, and lake size all are increasing (Bidaisee and Macpherson 2014). The status of the frozen ecosystems and landscapes in Eastern Siberia has already been significantly impacted by the 2-3°Cincrease in mean annual air temperature over the past three decades. Higher ground temperatures between 0.4°Cand 1.3°Ccause the seasonal melt to intensify and cryogenic processes to accelerate. The emergence of thermokarst affects the ecology and land usage in places devoid of forests. The northward expansion of many animals' and plants' habitats has also signaled a substantial change in the geographic and natural zones. Because of this change, new plant and animal species, including diseases and crop pests, are being introduced into the northern regions. The University of Hohenheim's Sergey Blagodatskiy and Holger Pagel expanded on this scenario by mentioning additional elements including animal and human movement, the soil's suitability for farming and animal husbandry as well as its capacity to release greenhouse gases. The greenhouse effect will be amplified and the rise in land surface temperature will be hastened if CO_2 and CH_4 emissions are increased in response to global warming. This could make greenhouse gas emissions particularly important. The mineralization of organic soil matter, which is primarily controlled by temperature and moisture, is the main source of greenhouse gas emissions from soil. Resilient ecosystems and "soil health," or the ability of soil to function in accordance with its potential and management techniques, are ensured by maintaining the proper balance between natural processes and anthropogenic activities (Doran 2002). Both are seen to be crucial for preserving biodiversity and advancing human welfare. A poster presentation on the latter

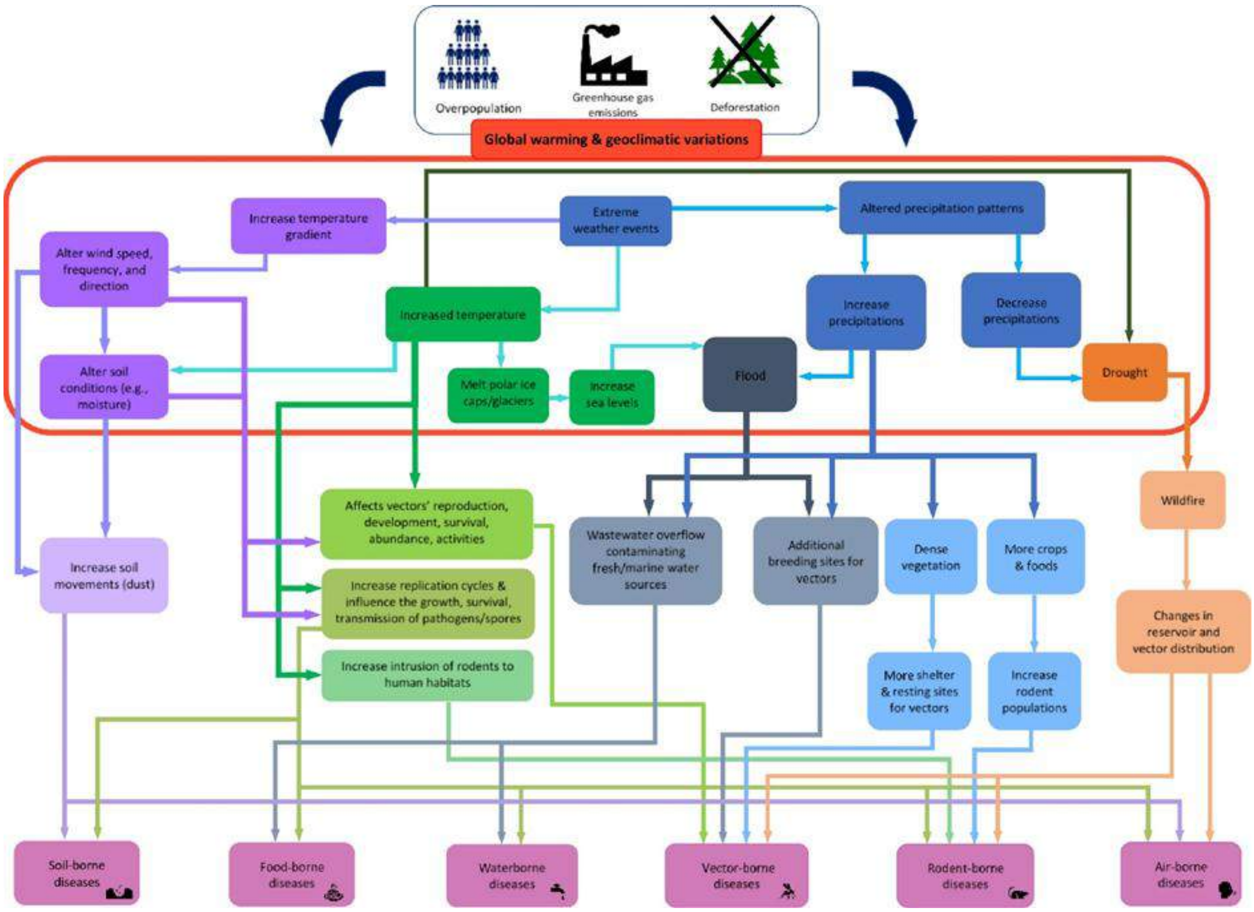

Fig. 3*:* Impacts of climatic variations on zoonoses. (Rupasinghe et al. 2022)

covered the experience and potential for preserving agro-biodiversity in the face of shifting permafrost conditions. Yakutia's predicted warming may cause the permafrost to thaw quickly, which might affect a variety of "soil health" factors, including a greater danger of losing arable land owing due to the opening of burial places, there is a higher risk of disease and exposure to thermokarst processes (Doran 2002). In the next five years, there is a 48% possibility that temperatures would climb above the 15˚Ccap set by the Paris Agreement, according to the proclamation on human health and climate change that was issued on October 25, 2022. This situation will especially affect any zoonosis type that is transmitted through water, food, a vector, rodents, or the air, and it will increase the number of novel diseases that have the potential to spread throughout the world (Diseases TLI 2023).

7. CONCLUSION

Zoonotic diseases are becoming a more serious global environmental issue. The proclamation on human health and climate change, which was released on October 25, 2022, estimates that there is a 48% chance that temperatures would rise above the 15˚Climit set by the Paris Agreement during the next five years. This circumstance will particularly impact all zoonosis kinds coming from water, food, vector, rodents, or air and will increase the number of new illnesses with the potential to spread globally. In order to conduct testing for yet exotic or rare diseases, disease monitoring must be linked with a network of professional institutes with the proper diagnostic capabilities. For the benefit of worldwide experts' knowledge sharing and enhancement, an integrated strategy to epidemiological, entomological, and environmental data collecting and analysis is crucial. A thorough investigation of zoonoses diseases that calls for the collaboration of entomologists, epidemiologists, and climatologists to look into the relationships between shifting vector habitats, disease patterns, and climatic conditions. One of the first measures to be taken should be to seek remedies to stop climate change. We must take major measures to reduce the risk of zoonotic disease. In order to predict possible hazards, it is important to create various models and plan precautionary strategies. Identifying disease surveillance in areas experiencing climate change, especially geographically, provides the basis for an effective fight against new and emerging zoonoses. International organizations such as WHO, the Food and Agriculture Organization of the United Nations (FAO) and the World Organization for Animal Health (OIE) should continue to work with cross-country policies, collaboratively and comprehensively, to prevent and manage the threats of such pandemics across countries. Aware of and ready for animal diseases. The impact of climate change on the future epidemiology of zoonotic and other illnesses has to be studied further.

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One Health Approach to Zoonosis: Integrating Medicine, Veterinary Science and Environmental Science

16

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ABSTRACT

Zoonotic diseases that transmit from animals to humans pose a major global health threat, accounting for over 60% of infectious diseases. Tackling these complex "one health" challenges requires integrating human medicine, veterinary science, and environmental monitoring into a unified framework. This chapter of the book provides a comprehensive overview of the One Health approach for addressing zoonosis. Tracing foundational concepts from Hippocrates through seminal thinkers like Virchow and James Steele, it chronicles paradigm shifts recognizing interdependencies between human, animal, and environmental health. Detailed case examples illustrate effective applications of One Health principles, from curbing sleeping sickness in Uganda by linking human outbreaks with animal reservoirs and vector control, to mitigating Rift Valley Fever in Kenya through joint animal-human health response systems. Core One Health focus areas for zoonosis include strengthened surveillance coordinating human and animal data streams to detect outbreaks early, comparative research on disease transmission pathways across species, and collaborative policies supporting prevention and control programs. The chapter emphasizes that overcoming systemic barriers limiting cross-sectoral coordination is essential to managing these complex risks, requiring medical experts, veterinary professionals, and environmental scientists to align efforts within an interconnected framework. Key recommendations include fostering interdisciplinary cooperation, establishing regular communication platforms, addressing resource constraints limiting One Health infrastructure, and actively engaging local communities. Ultimately, this holistic approach creates a shared defence against endemic and emergent zoonosis by enhancing preparedness, resilience, and risk reduction at the human-animal-environment interface.

Keywords: Zoonosis, One Health, Public health, Veterinary Public Health, Interdisciplinary collaboration.

CITATION

Mukhtar MU, Fayyaz Z, Aftab MM, Nawaz MH, Javed MA, Hussain B, Shahid R and Ullah F, 2023. One health approach to zoonosis: integrating medicine, veterinary science, and environmental science. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 226-236. https://doi.org/10.47278/book.zoon/2023.016

CHAPTER HISTORY Received: 12-Feb-2023 Revised: 23-May-2023 Accepted: 15-June-2023

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1. INTRODUCTION

1.1. EXPLANATION OF ONE HEALTH AND ITS RELEVANCE TO ZOONOSIS

As we enter the twenty-first century, the global community is dealing with a shift in the landscape of infectious diseases that impact humans and animals. Some of these diseases significantly risk our overall health and welfare. The One Health (OH) concept has emerged as a solution to this issue, emphasizing the importance of integrating human, animal and environmental health. The approach of One Health recognizes that the health of humans, animals, and the environment is interconnected (Zumla et al. 2016). The idea of One Health isn't novel, but it has gained renewed attention in recent years, primarily due to the increase in zoonotic infectious diseases. A zoonotic disease is a disease that can be very commonly transmitted between animals and humans. These diseases can be transmitted from animals to humans, either through direct contact or indirectly via vectors. There are around 1,500 pathogens and 75% of the newly emerging infectious diseases are known to be zoonotic in nature (Sabour et al. 2022). . The "One Health" approach refers to the special and complex relationship between humans, animals, and pathogens that coexist in the same environment. The effects of these diseases on the well-being of humans, livestock, and wildlife, and their economic implications, have prompted global health organizations and governments to recognize the need to collaborate in tackling these health issues (Gibbs and Gibbs 2013).

1.2. OVERVIEW OF ZOONOSIS AND ITS IMPACT ON HUMAN AND ANIMAL HEALTH

Recently, zoonotic diseases have become increasingly important in both public and animal health. Over the past few years, there have been numerous new diseases emerging unexpectedly, causing serious issues for both animals and humans (Brown 2004). Zoonotic pathogens are spreading more rapidly due to various factors. These include increased animal movement, expanding global trade, urbanization, environmental changes, and a rise in the number of immune-compromised patients. (Bender and Tsukayama 2004). There are various zoonotic viral diseases, such as Ebola, Middle East Respiratory Syndrome, West Nile, SARS-Corona, Nipah, Hendra, Avian influenza, and Swine influenza. These illnesses have been a major danger to both the wellbeing of the general public and the economies of the world. The *Japanese encephalitis virus* (JEV) is currently spreading throughout Asia and Australia, with reported cases even in non-endemic countries such as the United States due to travel (Weaver and Reisen 2010). The increased use of horses for various purposes such as trade, sports, and breeding has heightened the risk of equine diseases spreading to new areas. There are various viral diseases that can impact horses, including Eastern equine encephalitis (EEE), Western equine encephalitis (WEE), and Venezuelan-equine encephalitis (VEE). These diseases can be highly contagious and can spread through aerosol transmission (Roy et al. 2009), West Nile fever has recently spread to many new areas (Chancey et al. 2015). Other than viruses and bacteria there are several parasites infections that are of both veterinary and medical importance. Particularly, zoonotic cestods are reported from different areas of Pakistan in rat, goat and cattle (Alvi et al. 2021; Alvi et al. 2020).

2. UNDERSTANDING THE ONE HEALTH APPROACH

2.1. HISTORICAL DEVELOPMENT AND EVOLUTION OF ONE HEALTH

The notion of One Health cannot be traced back to a single origin in human thought. Instead, it is a foundational aspect of life on our planet that has been rediscovered and studied throughout history. Historically, the health and well-being of humans have been closely connected to animals and the planet they inhabit. The idea of One Health has its roots in the cultural and spiritual beliefs of many ancient civilizations and modern indigenous communities. This concept highlights the connection between humans, animals, and the environment. It can be seen in various forms throughout Western thought, as it pertains to social, medical and ecological aspects. The concept of One Health can be traced back to the works of the physician Hippocrates (460 BCE-367 BCE). He highlighted the connection between a healthy environment and public health in his work titled 'On Airs, Waters and Places'. The edict of "Primum Non Nocere," which means "above all, do no harm," is attributed to him. This principle is agreed upon by all health practitioners, who strive to follow it (Wear 2008).

Giovanni Maria Lancisi, an Italian physician, veterinarian, and pioneering epidemiologist, recognized the crucial role that the environment plays in the transmission of diseases to both humans and animals almost 2,000 years after they were first discovered. Many consider him to be a trailblazer in dealing with rinderpest in cattle by promoting animal depopulation and quarantine methods. There are those who propose that he may have been the first to suggest draining swamps and using protection against biting flies as a means of preventing and managing human malaria (Evans and Leighton 2014).

Rudolf Virchow, a renowned German physician and pathologist (1821 to 1902), is widely recognized for introducing the term "zoonosis." Moreover, he is well-known for advocating that there should be no distinction between animal and human medicines (Natterson-Horowitz and Bowers 2013). He understood that environmental factors played a crucial role in determining health outcomes. For instance, he suggested that the best way to stop a long-lasting typhus epidemic, was to offer the affected area with greater independence, better transportation, and quality educational institutions.(Ackerknecht and Schwalbe 1953; Virchow and Rather 1985).

James Steele (1913-2013) and Calvin Schwabe (1927-2006), both hailing from the United States, are now recognized for their innovative leadership in promoting the link between animal and human health as well as the environment. Steele established the veterinary public health unit in 1947, which eventually evolved into the Centers for Disease Control and Prevention in the USA. He also played a crucial role in establishing graduate education in public health as a new veterinary specialty. The WHO established a veterinary public health unit based on the warnings regarding the socio-economic consequences of zoonotic diseases (Dunlop and Williams 1996).

Today's One Health concepts are a new way of thinking about managing health that takes into account the rapid changes in the environment over the last century, which have coincided with the explosive growth of the world's population. Today, the Earth is home to a larger population than ever before, and our actions and impact on the environment are more significant and faster-paced than ever before (Cohen 1995; McNeill 2001). The global population of domestic animals has surged alongside the growth of the human population, leading to increased usage of natural resources. Unfortunately, this has also resulted in a rise in environmental changes that pose risks to the health of both people and animals. The pace of change has exceeded the natural rate of adaptation for both humans and animals. However, the One Health approach offers a glimmer of hope and flexibility in achieving optimal health in a disrupted environment. The objective is to promote mutualism and integration to attain optimal health for humans, animals, and the environment. This approach acknowledges that all three domains must work together to achieve health simultaneously, or not at all (Evans and Leighton 2014).

2.2. KEY STAKEHOLDERS AND THEIR ROLES IN IMPLEMENTING ONE HEALTH

The One Health concept recognizes that human, animal, and environmental health are interconnected and should be approached holistically. To successfully implement the One Health approach, it is essential for multiple stakeholders to work together in a collaborative and coordinated manner. (Hailat et al. 2023). The One Health framework involves several key stakeholders such as government agencies, public health authorities, veterinarians, environmental scientists, and community representatives (Johnson et al. 2018). The development of policies and regulations to promote interdisciplinary cooperation and allocate resources for One Health initiatives is a crucial task carried out by government agencies. Public health authorities play a crucial role in monitoring and responding to disease outbreaks in humans and animals. They also facilitate the exchange of information between different sectors. Veterinarians play a crucial role in providing medical care to animals, identifying zoonotic diseases, and evaluating the overall health of wildlife populations. They are essential stakeholders in these areas. Environmental scientists examine how environmental factors affect human health and develop plans to reduce potential risks. (Zinsstag et al. 2012). It is crucial to involve community representatives as they possess valuable local knowledge, encourage community engagement, and facilitate behavior changes that promote sustainable practices and improved health outcomes for everyone. The stakeholders involved in One Health work together to advance research projects, exchange information and monitor the emergence of diseases. They collaborate to enhance communication and knowledge sharing among different sectors, thereby improving early detection and response to potential health hazards (Sinclair 2019). Furthermore, these people or organizations support programs that aim to improve the abilities of those involved and encourage educational efforts that highlight the interdependence of human, animal, and environmental well-being (Allen-Scott et al. 2015). By working together, the important players in the One Health strategy can enhance the healthcare system's resilience and integration. As a result, we can expect better prevention, control, and management of infectious diseases, reduced antimicrobial resistance, and improved health outcomes for both people and ecosystems.

3. UNDERSTANDING ZOONOSIS

3.1. ZOONOSIS AND ITS VARIOUS TYPES

Zoonosis (plural: zoonoses) is a term created by Rudolph Virchow in the late 19th century. It comes from two Greek words - 'zoon' meaning animals, and 'noson' meaning disease. This term is used to refer to illnesses that humans can catch from animals. There are various categories of zoonotic illnesses, depending on the type of pathogens implicated. These may include viral, bacterial, parasitic, mycotic, or unconventional (prions) (Chomel 2009).

3.2. CAUSES AND TRANSMISSION PATHWAYS OF ZOONOTIC DISEASES

There are various causes and transmission pathways for zoonotic diseases (Loh et al. 2015), which include:

3.2.1. DIRECT CONTACT

Contact with the body fluids, tissues, or feces of infected animals can lead to transmission. Examples include handling livestock, pets, or wildlife. Zoonotic diseases can be transmitted through bites or scratches from infected animals. Rabies is a well-known zoonotic disease transmitted through animal bites.

3.2.2. INDIRECT CONTACT

Pathogens shed by infected animals can contaminate the environment, leading to human exposure. For example, zoonotic infections like histoplasmosis can be contracted by inhaling spores from bird or bat droppings. Another way of indirect contact is consuming undercooked or contaminated meat, unpasteurized milk, or contaminated water can lead to zoonotic infections such as salmonellosis and brucellosis.

3.2.3. VECTOR-BORNE TRANSMISSION

Ticks, mosquitoes, fleas, and lice are types of vectors that can transmit zoonotic pathogens from animals to humans. For example, ticks can transmit Lyme disease and mosquitoes can spread diseases like *West Nile virus*.

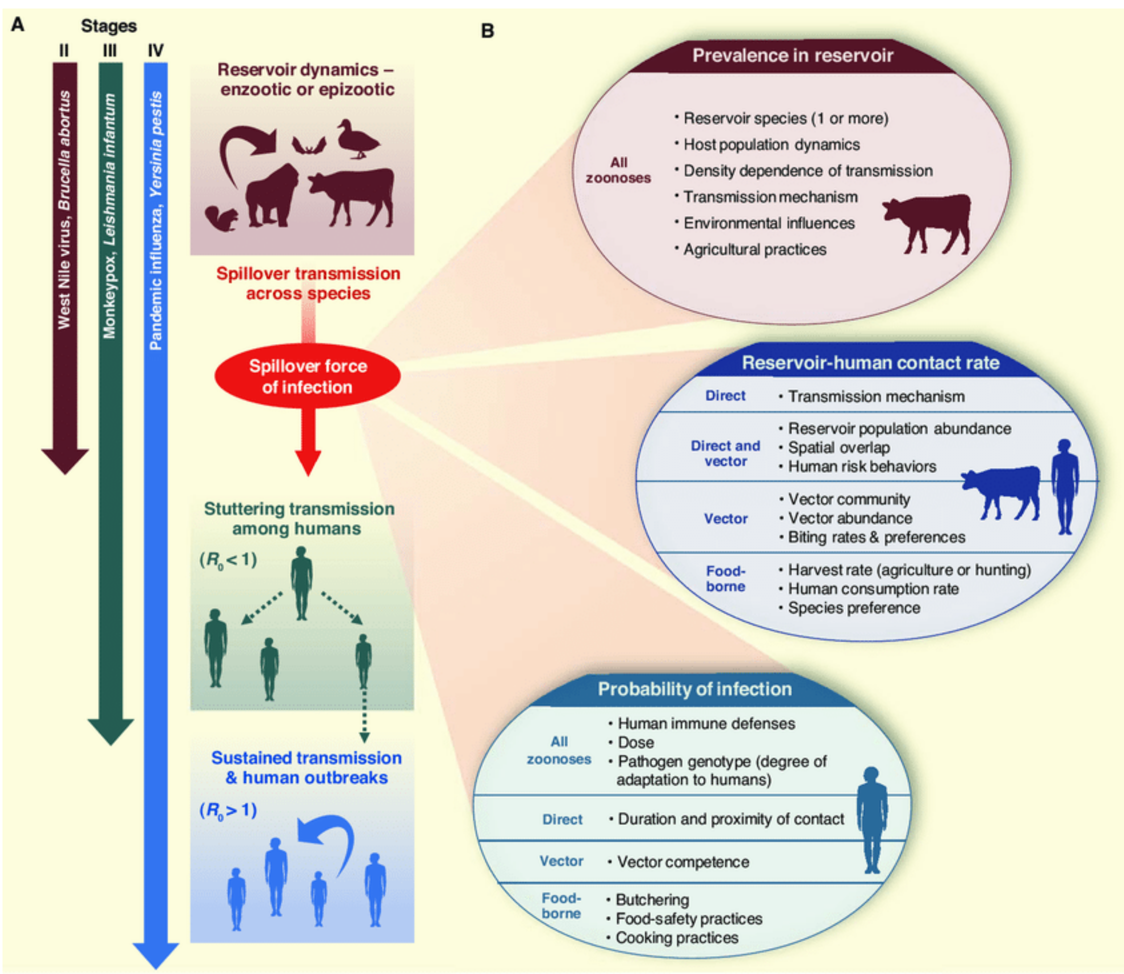

Fig. 1: Schematic diagram of zoonotic transmission pathways and dynamics. Modified from (Lloyd-Smith et al. 2009)

3.2.4. Airborne Transmission

Some zoonotic diseases can spread through the air, where respiratory droplets containing pathogens are released by infected animals. Inhaling these droplets can lead to infections. An example is avian influenza (bird flu).

3.2.5. Nosocomial Transmission

In healthcare settings, zoonotic diseases can be transmitted from infected patients or animals to healthcare workers, visitors, or other patients if proper infection control measures are not followed.

3.2.6. Anthropozoonosis

It is possible for zoonotic diseases to spread from humans to animals, which is referred to as reverse zoonoses or anthropozoonoses. This can lead to a continuous cycle of transmission between humans and animals. For example, tuberculosis can be transmitted from humans to animals and vice versa.
It's crucial to understand that zoonotic diseases vary in their transmissibility and severity when transmitted to humans. Many zoonoses can be prevented or controlled through various measures, including proper hygiene practices, vaccination of animals, surveillance and monitoring of disease in animals, and public health awareness programs. Understanding the causes and transmission pathways of zoonotic diseases is crucial for preventing and managing outbreaks that could have significant impacts on both animal and human health.

3.3. EXAMPLES OF ZOONOTIC DISEASES OF MEDICAL AND VETERINARY IMPORTANCE

Zoonotic diseases can affect the health of both humans and animals, including domestic animals, pets, and companion animals. The impacts of these diseases can be far-reaching. An example of a significant concern in both public health and veterinary medicine is bovine zoonoses. Out of all the zoonotic diseases, tuberculosis is considered the most crucial one. *Mycobacterium bovis* and *M. tuberculosis* cause this disease, which has caused significant economic loss in animal production (Torgerson and Torgerson 2010). Although developed countries have managed to largely eradicate bovine tuberculosis, other parts of the world are still grappling with significant zoonotic effects. Human tuberculosis is the second most prominent cause of death after AIDS, and *M. bovis* is responsible for 5-10% of all tuberculosis cases in humans, with children accounting for about 25% of those cases (Samad 2011). Anthrax is a serious illness caused by the *Bacillus anthracis* bacteria that poses a significant public health concern. The disease can spread to humans through close exposure to infected animals like cattle and goats, as well as their byproducts such as meat, skin, hides, and bones. Data shows that between 2,000 to 20,000 individuals worldwide are impacted by anthrax cases annually (Goel 2015). Countries that rely on agriculture for their economy, particularly developing nations, continue to face dangerous consequences caused by anthrax.
Brucellosis is a bacterial disease that is widespread among animals and can be transmitted to humans. It leads to more than 500,000 cases annually worldwide (Hull and Schumaker, 2018). Humans typically contract brucellosis by consuming unpasteurized milk or milk products. It is rare for the disease to spread from one human to another. It has also been reported that transmission can occur through inhaling aerosols and coming into contact with secretions (Corbel 2006). Brucellosis in animals can lead to abortion, lameness, abscess, a decrease in milk production, and a reduced chance of survival

for newborns (Rahman et al. 2006). Individuals who work in dairy farms, care for animals, work in abattoirs, provide veterinary care, and reside in rural areas face a greater risk of contracting brucellosis infection.

In recent decades, there has been a rise in the number of pets and companion animals. However, these animals can also carry disease-producing agents, making them a potential source of illness. Surprisingly, a significant portion of pet owners, ranging from 14% to 62%, permit their beloved pets to enter their bedrooms. Unfortunately, this practice may potentially increase the risk of zoonotic diseases spreading (Chomel and Sun 2011). Pets and companion animals can carry various infectious diseases that can come from viruses, bacteria, parasites, and fungi (Halsby et al. 2014). Many people may be at risk of catching new zoonotic illnesses from their pets, companion animals, and exotic birds and animals.

Zoonoses can have various effects on the health of humans and animals. While it is difficult to measure the impact of zoonoses, we can evaluate it based on factors such as disease occurrence, frequency, sickness, death, and financial loss. Zoonoses can significantly impact human lives and wellness, which highlights the need for a joint approach from healthcare professionals, veterinary specialists, and environmental experts to control their effects and prevent future outbreaks.

4. ONE HEALTH APPROACH TO ZOONOSIS

Collaborating across various fields using the One Health method can result in better monitoring, prevention, and management of zoonotic disease outbreaks. Moreover, it can improve the safety and security of food products while decreasing the proliferation of antibiotic-resistant infections for the benefit of both humans and animals. This approach highlights the significance of enhancing surveillance systems, exchanging data, boosting laboratory diagnostic systems, and creating an early response network for zoonoses, which fosters efficient collaboration among concerned sections. This method enhances prevention and control of diseases that can be transmitted between animals and humans, and trains emergency response teams to work together efficiently. All of the tactics employed work towards reducing the spread of these types of diseases.

The One Health approach prioritizes international health security by promoting effective collaboration, coordination, and communication among relevant industries. It specifically addresses the health risks that arise at the intersection of these sectors (Sinclair 2019). It provides a comprehensive and proactive strategy to tackle zoonotic diseases, mitigating risks, and promoting the well-being of both animals and humans while preserving the health of the environment.

Although there is significant interest in One Health, its implementation at the country, local, and project levels is limited. This is most likely because there aren't enough practical and proven methods for implementation and metrics for evaluation (Baum et al. 2017). Zoonoses present a unique challenge as they involve multiple sectors, including pharmaceuticals, crop and animal agriculture, food processing, water resources, and public health. The issue arises from and impacts all of these areas (Abbas et al. 2022). Each sector has its own incentive structures and is influenced by different disciplinary perspectives. Therefore, One Health collaborations and partnerships are essential for efficient surveillance and response to zoonotic diseases.

Numerous One Health initiatives have proven effective in managing zoonotic diseases and containing their transmission. The continent of Africa is a pertinent location for studying One Health policies, especially in the context of controlling endemic and "neglected" zoonotic diseases. In Uganda, there has been notable advancement in the management of Human African Trypanosomiasis (HAT), commonly referred to as sleeping sickness, and the corresponding disease in livestock known as Nagana, transmitted through the bite of infected tsetse flies. To achieve this, the country has employed a One Health approach, involving cooperation among health officials, veterinary services, and entomologists. They have carried out active monitoring of both human and animal cases, enforced measures to control tsetse flies, and encouraged community involvement in disease control efforts. Consequently, the number of reported HAT cases has considerably decreased in recent times (Welburn et al. 2006).

Kenya has had multiple outbreaks of Rift Valley Fever (RVF), which have caused significant economic losses in livestock and posed a public health threat to humans. RVF is a viral zoonotic disease that affects both animals and humans. To tackle this problem, the Kenyan government collaborated with international partners and researchers to adopt a One Health approach. This involved enhancing surveillance and monitoring of both animal and human cases, promoting safe livestock handling practices, and raising awareness among communities. In the 2006/07 outbreak of RVF, which had a wider geographic spread, prompt diagnosis and coordinated response led to improved disease control. This resulted in a decrease in human and animal morbidity and mortality, despite 700 suspected human cases and 90 deaths. These collaborative efforts successfully curbed the spread of RVF and lessened its effects on animals and humans (Munyua et al. 2010).

5. ONE HEALTH STRATEGIES TO ADDRESS ANTIMICROBIAL RESISTANCE IN ZOONOTIC DISEASES

Antimicrobial resistance (AMR) poses a significant health risk to humans and animals on a global scale. To effectively tackle this complex problem in zoonotic diseases, the implementation of One Health strategies is essential. With One Health, we can establish strong surveillance systems for both human and animal health, allowing for the monitoring of the spread of zoonotic diseases and the development of AMR. Collecting data on this topic can help detect and track resistant pathogens early, which in turn can aid in implementing timely interventions. One Health can also assist in developing and deploying quick and precise diagnostic tools to identify zoonotic infections and determine antimicrobial susceptibility patterns. This will lead to a more targeted and suitable use of antibiotics, ultimately reducing the risk of resistance development (Velazquez-Meza et al. 2022).

The One Health approach promotes judicious and careful usage of antimicrobials in human and veterinary medicine. This can be achieved through educating healthcare professionals, veterinarians, farmers, and the public about the significance of using antibiotics appropriately and the negative outcomes of misusing or overusing them. One Health strategies have the potential to create and enforce regulations on the production, sale, and application of antimicrobials in both human and animal healthcare sectors, which can help prevent misuse and overuse of these medications. This, in turn, can decrease the selection pressure for resistant pathogens (Aslam et al. 2021). Mitigating the risk of AMR in zoonotic diseases requires collaboration between the human health, animal health, and environmental sectors. This can be best be achieved by adopting One Health strategies.

6. ENVIRONMENTAL FACTORS, ONE HEALTH AND ZOONOTIC DISEASES

Infectious zoonotic diseases are a significant concern in One Health. This is because the environment where humans come into contact with farm animals, pets, or wild animals plays a critical role in disease transmission. The ecosystem and how it is influenced by human activities such as agriculture are important factors in assessing the risk of zoonotic diseases spread (Landford and Nunn 2012). Climate change is a significant environmental factor that has a severe impact on both wild and domestic animal populations, food chains, and human health (Europea 2006). The climate's changes, such as fluctuations in temperature, can have a significant impact on the spread of diseases. They can affect how infectious pathogens, such as bacteria, viruses, parasites, and fungi, migrate and adapt. Climate change can create new environments where these pathogens can thrive, leading to the emergence of diseases in previously unaffected regions (Wu et al. 2016).

When assessing One Health initiatives, there is often a focus on veterinary and medical themes, while the environment is frequently overlooked (Humboldt-Dachroeden et al. 2020). The environment is present all around us and has a significant impact on human and animal health. Healthy soils and clean water play a crucial role in preventing the spread of diseases. Maintaining clean environments in slaughterhouses, preserving natural habitats of animals and biodiversity can also aid in reducing disease infections in both animals and humans. The environment and our health are closely interlinked (Keith et al. 2016). It is crucial to prioritize conservation and sustainable practices as part of the One Health approach. This approach aims to protect the health of both humans and animals, while also preserving the environment. By preserving natural habitats and safeguarding wildlife biodiversity, we can maintain a delicate balance in ecosystems, which reduces the risks of zoonotic diseases emerging and spreading. By using responsible land use and sustainable agricultural practices, we can reduce contact between humans and wildlife, which decreases the risk of diseases being transmitted. It's also crucial to mitigate climate change to protect habitats and biodiversity, ensuring ecosystems remain resilient and preventing diseases from emerging. When we prioritize conservation and sustainability within the One Health framework, we create a harmonious coexistence between humans, animals, and the environment, which promotes the well-being and health of all interconnected species.

7. CHALLENGES AND FUTURE DIRECTIONS

To effectively combat zoonotic diseases and their associated risks, it is crucial to address the barriers hindering the implementation of the One Health approach. One of the most significant challenges is the fragmentation of efforts among various sectors and disciplines, which hinders seamless collaboration and information sharing. Overcoming this obstacle requires fostering a culture of interdisciplinary cooperation and establishing platforms for regular communication between public health, veterinary, and environmental professionals. The implementation of comprehensive One Health programs and surveillance systems is hindered by inadequate funding and resource limitations. To overcome this, it is important for governments and international organizations to prioritize investing in One Health initiatives and infrastructure. Raising public awareness about the interconnectedness of human, animal, and environmental health is also crucial in garnering support and promoting behavior changes that can reduce zoonotic disease transmission. By actively engaging communities, healthcare providers, and policymakers in the One Health approach, we can break down barriers, strengthen global cooperation, and ultimately create a stronger defense against zoonotic diseases.

Efforts in research should prioritize advancing our understanding of how zoonotic diseases are transmitted, including examining the factors that contribute to spillover events and host-pathogen interactions. It is essential to integrate One Health principles into national and international frameworks as a policy priority. Governments must prioritize investing in zoonotic disease prevention and preparedness, with a focus on environmental conservation and sustainable practices. To prevent and control zoonotic outbreaks worldwide, it is crucial to strengthen cross-border cooperation and information exchange. Encouraging private sectors and industries to adopt One Health approaches can also support disease prevention efforts. Healthcare professionals, veterinarians, and other stakeholders should undergo capacity building and training programs to gain the necessary skills to respond effectively to zoonotic diseases. Embracing these future directions for research, policy, and practice can establish a comprehensive and proactive approach to disease prevention and control, safeguarding the health of individuals, communities, and the planet as a whole.

8. CONCLUSION

The One Health approach is a thorough framework that tackles the intricate challenges that arise from zoonoses and the interrelatedness of human, animal, and environmental health. The One Health approach emphasizes the importance of recognizing the interdependencies between human, animal, and environmental health. It encourages collaboration among professionals from different disciplines, breaking down traditional silos. This collaborative effort enables a deeper understanding of the complex dynamics of zoonotic diseases, leading to more effective prevention, early detection, and control strategies.
Integrating medicine, veterinary science, and environmental science in the One Health approach is crucial for preventing and mitigating zoonotic disease outbreaks. It facilitates the implementation of comprehensive surveillance systems that monitor disease trends in both human and animal populations. Detecting zoonoses early and responding quickly is crucial to reduce the impact on both public health and animal welfare. In addition, the One Health strategy acknowledges the significant influence of environmental factors in the development and spreading of zoonotic diseases. Considering the ecological context, this approach promotes conservation practices and sustainable strategies that protect ecosystems and mitigate the risk of disease spillover. Looking to the future, it is essential to emphasize the continued adoption and promotion of the One Health approach. Integrated approaches are crucial in addressing the persistent threat of zoonotic diseases and emerging infectious diseases that pose significant risks to global health.

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An Overview of the Selected Zoonotic Diseases in Pakistan

17

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ABSTRACT

Zoonosis is a class of diseases that specifically originates in the animals. Pakistan is particularly susceptible to zoonotic illnesses because of its varied environment, large-scale cattle husbandry, and intimate relationships between humans and animals. This chapter looks at the epidemiology, clinical presentation, and public health consequences of various zoonotic diseases that are of high priority in Pakistan: anthrax, Avian Influenza, brucellosis, rabies, Salmonella infections, tuberculosis, Crimean-Congo hemorrhagic fever (CCHF) and Leishmaniasis. The complex interactions between humans, animals, and the environment that contribute to the appearance, spread, and transmission of various illnesses sign and symptoms, economic importance and possible remedies of the aforesaid diseases and infections. The text draws attention to the difficulties Pakistan has in managing zoonotic illnesses, which include inadequate resources, insufficient knowledge, and subpar surveillance systems. Additionally, the chapter offers a number of intervention techniques, highlighting the necessity of multi-sectoral cooperation and the advancement of One Health programs. Improved public awareness campaigns, immunization campaigns, better animal husbandry techniques, better veterinarian services, and better disease tracking and reporting are some of these tactics. In Pakistan a significant number of human and animal population are susceptible to these diseases. As these diseases have the competency to spread from the infected animals through skin contact and body fluids which is most of the time lethal, Pakistan may guarantee the health and safety of its populace while considerably lowering the burden of zoonotic illnesses by tackling these issues and putting into practice efficient treatments. However, some common traits include the capacity to spread by contact with sick animals or their products, the capacity to produce a range of symptoms in both humans and animals, and the capacity to be lethal. It's crucial to be informed about the zoonotic diseases that are common in Pakistan and to take precautions against them.

Key words: Anthrax, brucellosis, CCHF, influenza, rabies, Salmonella

CITATION

Ullah S, Ullah A, Khan T, Gul S, Taj R and khan I, 2023. An Overview of the Selected Zoonotic Diseases in Pakistan. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 237-254. https://doi.org/10.47278/book.zoon/2023.017

CHAPTER HISTORY Received: 28-Jan-2023 Revised: 23-Feb-2023 Accepted: 10-March-2023

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1. INTRODUCTION

Zoonotic diseases are the class of diseases that are either wildly or domestically originated in animals. As it has two points of origin however policymakers and researchers pay much attention to the wild origin of zoonotic diseases as the wild source of origin has a great impact on global health and biodiversity conservation. The invasion of SARS-CoV-2 from an unidentified origin led to the COVID-19 pandemic situation globally. The wild and unidentified origin requires much attention due to (A) the incorrect use and broad use of terms such as the field researcher coined a term with any evidence or proof that “bat is the reservoir of MERS-COV and/or SARS-COV-2 (Balkrishna et al 2021). Unstable usage (B) unstable usage of terms such as Bats were both called endemic and vector leading to public confusion. (C) Incorrect explanation of biological mechanisms or their products publicly such as “spillover /Novel” and (D) incorrect decoding of the proof or evidence of a biological process (serological evidence, Phylogenetic evidence) due to the lack of knowledge among the audience. An overview of various zoonotic diseases has been enlisted in Fig. 1. Hence at the start of the chapter, we are going to define some of the terminologies related to zoonotic diseases as follows.

1.1. PATHOGEN

A Pathogen is a microbe that causes or has the capability to induce a disease in a susceptible host. Such as a virus, bacteria fungus, or a eukaryotic entity all this class of microbes have the potential to induce a specific disease in a host body.

1.2. PATHOGENICITY

A microbe's capacity to transmit disease or harm to the host Definition of zoonotic diseases. The Greek term that gave rise to the phrase zoonoisis is nosos, which denotes sickness and zoon, which refers to animals (Balkrishna et al. 2021). If we look at the broader definition of the term zoonosis we priorly said an infection that originates from animals According to the WHO 1951, any disease transmitted between vertebrate animals and humans through any possible way is referred to as zoonosis However, a definition is required since it will enable accurate categorization of pertinent infections, direct comprehension of their connections and larger, non-medical characteristics Through public health Initiatives and modifications to social, medical, and veterinary policies that influence the effect of zoonoses a correct definition would also enable the functional targeting of the elements that support the persistence of zoonotic illness. The word sapronoses describes illnesses with an abiotic substrate as their source, whereas the term "anthroponoses” describes illnesses that have an infectious human source Anthropozoonoses and zooanthroponoses are additional terms used to describe zoonoses when they are made from people to animals, respectively. In rare instances, zoonotic illnesses that are spread in either direction have been referred to as amphixenoses following that WHO expert committees dropped all of the subterms. The word zoonoses often refers to diseases that can be transmitted from animals to people because of our art anthropocentric perspective on nature, whilst the opposite remains a topic that is only of interest to environmental specialists (Abdullah et al. 2019).

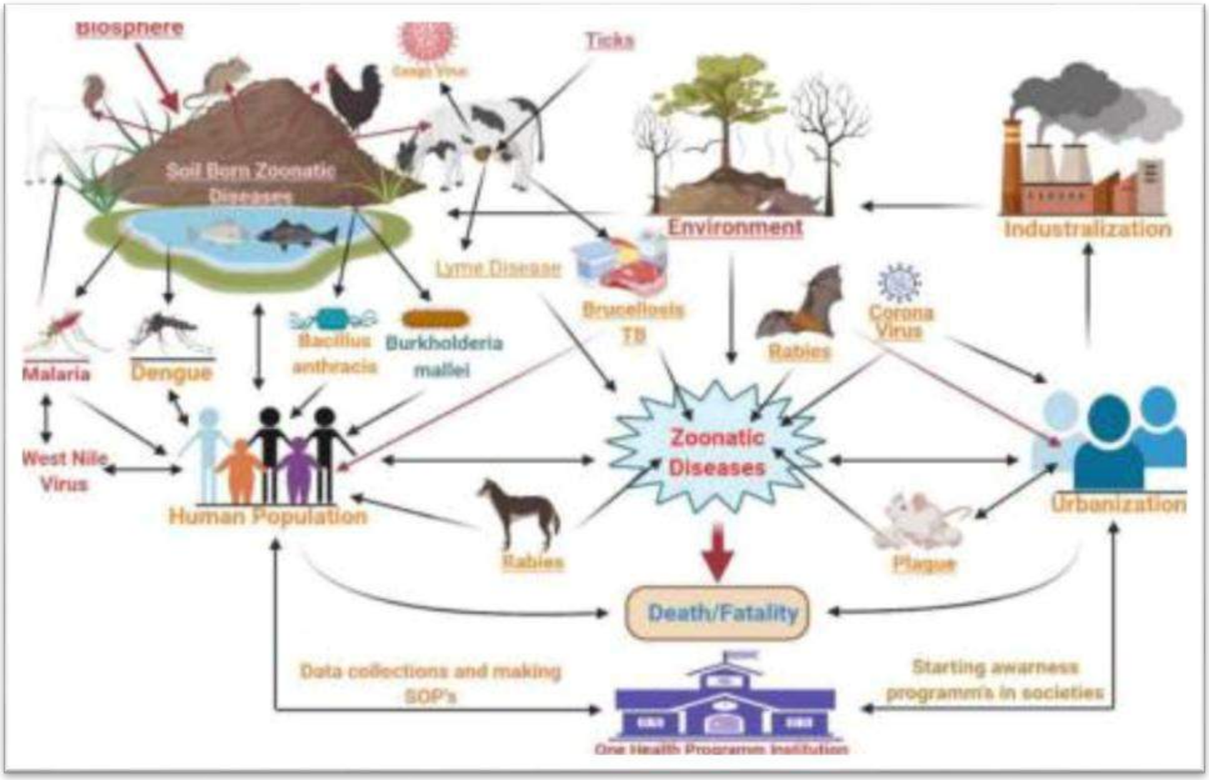

Fig. 1: Overview of different zoonotic diseases (Yasmeen et al. 2021).

2. ZOONOTIC DISEASES IN PAKISTAN

Since zoonoses make up about 60% of all infectious illnesses and are the source of 75% of newly developing transmissible pathogens, they represent serious risks to public health. The most prevalent zoonotic illnesses in Pakistan include tuberculosis, Q fever, Lyme disease, Crimean-Congo hemorrhagic fever (CCHF), brucellosis, leishmania, Chagas diseases/trypanosomiasis, balantadiasis, avian influenza, Giardia, foot and mouth disease, and anthrax. Infections caused by soil-borne zoonotic pathogens including *Burkholderia mallei* and *Bacillus anthracis* have been reported in the Punjab province in both humans and animals. Furthermore, DNA-based research has shown that Pakistan has a significant incidence of B. anthracis (Yasmeen et al. 2022). Mycobacterium bovis and drinking raw cow milk were major contributors to human tuberculosis infections during the 19th and 20th centuries. The enormous population of cattle in Pakistan is well suited to the regional environmental conditions and provides 1.63 million tons of meat yearly. Bovine tuberculosis infections are lethal to calves and can be passed to humans by aerosols (through cough, and sneezes) or consuming unpasteurized cow's milk. When it comes to countries where the seroprevalence of TB is comparatively Elevated, Pakistan comes in fifth. Out of which 510000 new TB cases are reported per year. For instance, M. bovis was discovered with an overall prevalence of 10.18 and 11.53%, in 4 cattle and 17 buffaloes respectively. A study was conducted in three major slaughterhouses of Peshawar, that included lung and liver tissue samples from 124 buffaloes and 28 cattle (Muqaddas et al. 2023). The high prevalence of bovine tuberculosis has been associated with not doing proper medication and unhygienic conditions at slaughterhouses indicating a lack of veterinary inspection and monitoring for the prevention and management of animal TB. Inspection and monitoring procedures should be followed to improve the quality of animal meat and prevent the spread of TB from infected animals to humans. A single-stranded RNA virus that not only infects humans but also warm-blooded animals is among the worst. The rabies virus is a member of the *Rhabdoviridae* family and is one of the deadliest viruses. The three species that transmit the virus to people are dogs, bats, and raccoons, which are the most affected. Dog bites are responsible for 50,000 fatalities per year and 5 million documented cases (Jafar et al. 2014). In many rural areas of Pakistan, rabies remains a severe hazard, according to the National Rabies Control Programme of Pakistan (NRCP), and 54.7% of dogs that have bitten people have not received rabies vaccines. Additionally, according to another estimate, around 70 dog bite victims receive daily medical care in both public and private facilities. So, it is more possible that there are up to 9 million cases of rabies worldwide. Several dengue outbreaks have recently been reported in different parts of Pakistan since the first outbreak was reported in 1994. Most specifically the Lahore outbreak (in 2011) resulted in cases exceeding 21000 out of which 350 died, in 2019 44,415 cases were reported 66 died and the Karachi outbreak resulted in more than 6000 incidences and up to 55 deaths. Although the number of cases is elevated annually however the death ratio has shown to decline (Abdullah et al. 2019).

3. MORPHOLOGICAL CHARACTERISTICS OF ZOONOTIC DISEASES

3.1. BRUCELLOSIS

Brucellosis is one of the Zoonotic contagious infections that is generally present in both wild and domesticated animals. Sir David Bruce, Hughes, and Zammit helped to completely understand the disease while they were conducting their study in Malta. Bang recognized brucellosis (brucellosis, also known as undulant fever)-causing bacteria B. abortus, which causes abortion in cattle and brucellosis in humans. With more than 500,000 new cases each year and a prevalence rate that surpasses ten cases per 100,000 individuals in some countries, the illness continues to be the most widespread bacterial zoonosis in the globe, with organized agricultural workers having a higher incidence rate Christopher (2010).

Brucellosis is not well diagnosed and documented, even though it is widespread in many underdeveloped nations. In humans, it greatly affects public health and causes substantial economic losses, and in livestock, it has causes caused about a 20-25% reduction in productivity, less milk production, miscarriages, and weak offspring. Moreover, it greatly affects general livestock trading. It also causes temporary or permanent infertility in the livestock. Despite being widespread, this disease has a significant impact on the general populace and livestock in underdeveloped nations where it is prevalent due to inadequate monitoring of public health, domestic animal health programs, and diagnostic facilities. Brucella is a gram-negative, species-specific, non-motile, anaerobic bacterium. Different Brucella strains, including two marine and six terrestrial species, are the primary cause of brucellosis. Fetal fluid, uterine exudates, semen, and aborted fetuses are the major sources of Brucella transmission. It causes epididymitis, seminal vesiculitis, orchitis, and lifelong infertility in men, whereas fetal membrane damage, retained placental contents, and severe metritis that can lead to death occur in women (Jamil et al. 2021). The physiology of the disease is still controversial. To date, numerous research studies have described that the Brucella arrives inside the body through GIT, mucosal layers, and respiratory tract, and spreads throughout the body. Similar to other intracellular infections, Brucella spp. are facultative intracellular bacteria with the capacity to escape the killing mechanism and grow inside macrophages. Brucella must successfully undergo four processes in order to be an effective infectious agent: linkage, incursion, establishment, and dissemination within the host. Following ingestion, Brucella moves within the cell while being swallowed by a phagosome. In order to prevent the Brucella-containing vacuole (BCV) from fusing with a lysosome, a number of virulence factors help

Brucella evade the phagocytic pathway (Ouahrani-Bettache et al. 2019). These elements consist of the type-4 secretion system, launched by the *vir*B operon, the two-constituents system BvrR/BvrS, the cyclic beta-1,2-glucan, which most likely functions via cholesterol release, SepA, which prevents the development of active lysosome by excluding the LAMP1 lysosomal protein, RicA, which controls vesicle transportation and other potential proteins. According to in vitro experiments, the utilization of macrophage cell lines, the T4 Secretion System is mandatory for the BCV to develop into an ER-like compartment (Guo et al. 2023).

There are three stages of brucellosis in animals: the development or incubation phase, when the bacteria proliferate vigorously and the infection is often undetected or the first pathological indications emerge; the incubation period, during which *Brucella* enters the host without generating any clinical symptoms; In the chronic stage, upon bacterial loads peak before dropping and occasional clinical signs emerge. Animals that are sexually mature are generally affected by the virus. The third trimester of pregnancy, when women are more susceptible to infection, enhances this vulnerability. Except for *Brucella suis* infection in pigs, Mortality is quite rare, and there is no pyrexia like in people. Instead, as long as there are no other systemic abnormalities, infection is frequently self-limiting. Lameness, tissue abscesses, arthritis, lumbar and sacral spondylitis, and limb paralysis are some of the clinical symptoms of the latter illness. The continual discharge of *Brucella* from reproductive organs or mammary glands secretion over a prolonged period is what determines chronicity, in any case. Therefore, *Brucella's* persistence in the environment and ability for propagation are ensured by infertility, numerous abortions, and early stillbirth (Rivas et al. 2022).

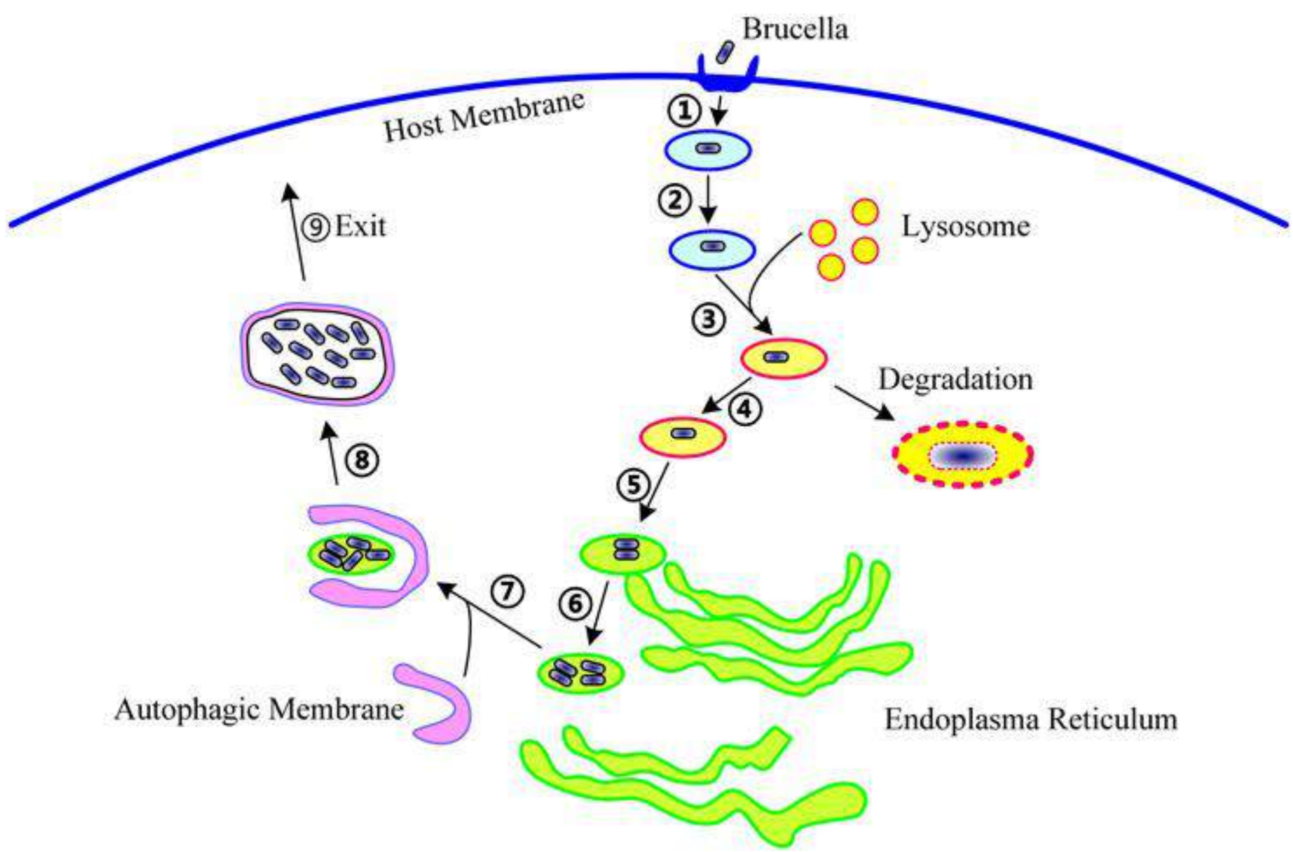

Fig. 2*:* Life cycle of Brucella; Source: (Ke et al. 2015).

3.2. TUBERCULOSIS

Food-borne zoonotic pathogens can infect both humans and animals, causing a variety of potentially lethal diseases (Alvi et al. 2021). Pakistan has the fifth-highest ratio of tuberculosis. Regular annual increase in the prevalence of is observed among which 20% of cases belong to extrapulmonary tuberculosis (EPTB). In underdeveloped nations all across the world, TB has been a major source of sickness and mortality (Tehseen et al. 2020). According to a survey conducted in 2019, there are around 10 million TB cases worldwide. Access to healthcare facilities, lack of diagnostic tools, and under-reporting of diagnosed people are the reasons blame to main reasons for the high prevalence. TB is still being spread by undiagnosed patients. Those who live in households with patients who have undiagnosed pulmonary TB are at an especially high risk of transmission. According to studies, household contacts of contagious people experience an infection rate of 25%–45%, with the incidence in children under 5 reaching 70%. 12% to 23% of persons with TB infection go on to acquire the illness throughout the course of their lifetimes, and this percentage rises even more for those with immunocompromised, such as those who also have HIV infection (Hussain et al. 2021).

3.2.1. MORPHOLOGY OF MYCOBACTERIUM TUBERCULOSIS AND M. BOVIS

The virus *Mycobacterium tuberculosis (Mtb*), which mostly infects the lungs, causes the infectious illness known as tuberculosis (TB), which is communicable and results in characteristic pulmonary TB symptoms. The extra pulmonary form of tuberculosis (TB) can also affect all other organs and tissues that includes lymph nodes, brain, kidneys, and spine. Mycobacterium tuberculosis (Mtb) is the globally prominent infectious killer, taking about 1.4 million lives annually is the causing agent of tuberculosis (TB). Since the MTB only resides with in the living organisms not having any ecological role (Ghodousi et al. 2019). The life cycle events of *M. tuberculosis* as shown in Fig. 3.

The life span starts by reaching the alveolar spaces of the lungs (distal part). It is embedded in the mucosal or epithelial layer. As a result of their constant exposure to airborne infections and particles, alveoli have alveolar macrophages, specialized innate immune cells that gather and interact with air-borne antigens. Beside alveolar macrophages, dendritic cells in the interstitial space counter the airborne particles. As a result, the first infection, MTB that penetrates the alveolus infects both alveolar macrophages and interstitial dendritic cells, which are present in the alveolar area. It can also enter the body through an alternate way which is infecting of type II alveolar epithelial cell by the Mtb. Both alveolar macrophages and dendritic cells fails to control the infection with high ratio of cell death. The enormous cell death of alveolar macrophages is the important mechanism through Mtb enters the mucosa. Alveolar macrophages infected with Mtb and dendritic cells both function to initiate an adaptive immune response and act as early repositories of infection. Alveolar macrophages that are infected move into the interstitial space from the alveolar sac (Jee 2020). These diseased cells act as infection reservoirs and initiate the immune response. The cells travel from the alveolar sac towards the interstitial spaces. Sometimes the infected cell permanently resides in the interstitium while sometimes the infected cells migrate into the draining lymph nodes in order to launch the B and T cell to limit the progress of infection. Here the cells engulf the bacteria and the infected cells are released. When extracellular bacteria escape phagocytosis or flee from dying cells, resident interstitial macrophages in the interstitium devour them. Alveolar and interstitial macrophages that have been infected as well as non-infected macrophages, inflammatory monocytes, neutrophils, and T cells that have been drawn in by the inflammation and tissue damage go on to create the distinctive TB granuloma. It is yet unknown whether the presence of this multicellular structure inhibits or promotes Mtb infection. But for many primary infections, the illness is managed either

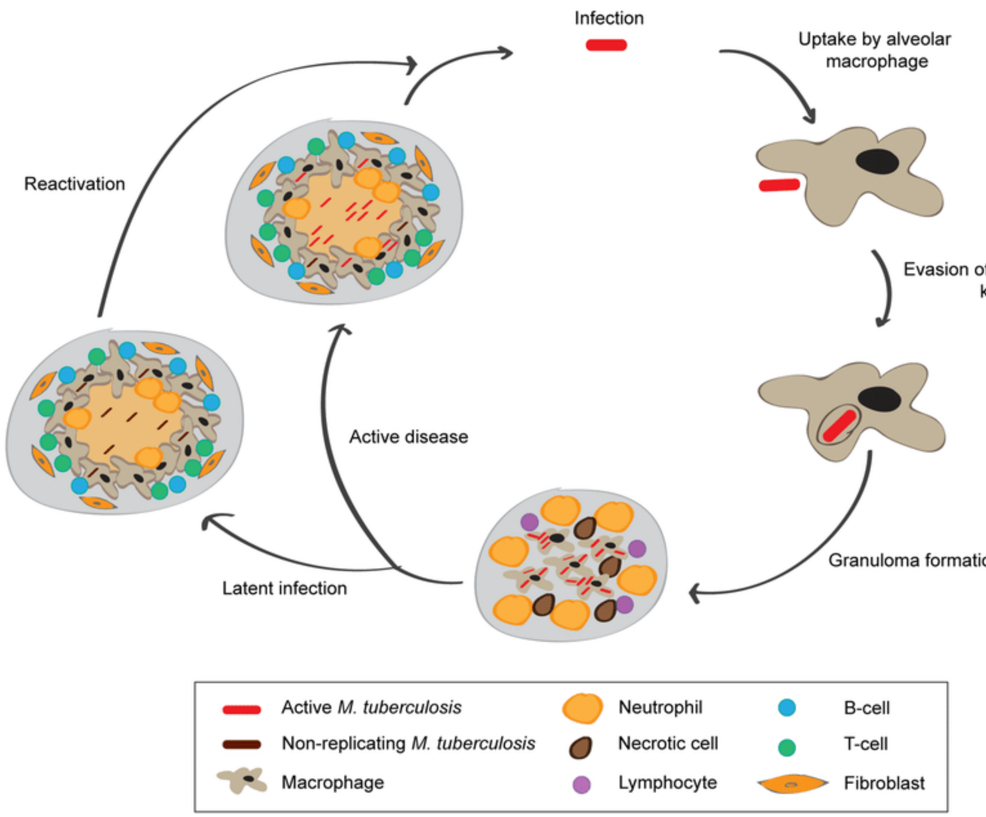

Fig. 2*:* Life cycle of M. tuberculosis shown schematically. By inhaling aerosolized droplets produced by a person with active illness, person-to-person transmission takes place. Alveolar macrophages in the lungs absorb bacteria that have traveled there. The reactive oxygen (ROS) and nitrogen (NOS) species that macrophages produce inside the alveolar macrophages expose bacteria to these substances.

by total eradication of the bacteria, leaving just an immunologic memory of the contact, or by the development of a permanent granuloma (Ernst 2012).

3.3. AVIAN INFLUENZA

3.3.1. MORPHOLOGY OF INFLUENZA A VIRUSES

AIVs are negative sense, single-stranded RNA viruses that typically infect wild ducks and other water-dwelling birds from the order *Anseriformes* and *Charadriiformes*. The genomes of AIVs consist of eight genomic RNA sections that encode twelve viral proteins minimum. The two surface glycoproteins hemagglutinin (HA) and neuraminidase (NA) are joined to form the nomenclature for viruses. Wild aquatic birds have sixteen HA (H1-H16) and nine NA (N1-N9) subtypes known to date, whereas bats have two novel HA (H17 and H18) and two new NA (N10 and N11) subtypes. Due to sporadic AIV transfer from waterfowl to domestic bird species, there are multiple stable AIV lineages in domestic poultry. However, some subtypes (namely A/H5 and A/H7) are able to mutate into highly infectious (HPAIV) variants that are able to cause elevated death ratio in domestic avian species. These domestic lineages generally circulate in poultry flocks that carry low pathogenic (LPAIV) variants, triggering negligible illness. The subsequent dissemination of these HPAIV lineages to wild bird species accelerated the disease's international expansion (Annika Suttie et al. 2019).

Several labs have investigated the mouse model to study the pathogenicity of the avian H5N1 virus in mammals. The H5N1 viruses powerfully multiplied in the respiratory tracts of BALB/c mice without the prior adaptation, frequently required for human influenza A virus to proliferate in this host. The human H5N1 viruses were responsible for the two distinct H5N1 phenotypes that were found in inbred mice. Animals were only able to reproduce low pathogenicity viruses in the respiratory system and often without dying after cleaning the virus up to 9 days post-infection (p.i). On the other hand, high pathogenicity viruses proliferated not just in the respiratory tract but additionally in other systemic organs, depleted the animals' lymphocytes, and ultimately caused their death 6 to 9 days after infection. The congenital mouse model led to several clinical features of human disease, and pathogenicity in mice is frequently associated with the severity of the disease in humans, so it was crucial to conclude whether the pathogenicity of the H5N1 viruses look like those in other, outbred mammalian hosts. The life cycle events of H5N1 virus has been enlisted in Fig. 4.

The deterioration of the alveoli is frequently extensive in the lungs. The most frequent symptoms in cases with a short illness duration (10 to 12 days) include edema, fibrous exudates, and hyaline membranes. Interstitial fibrosis and changes related to the fibrous proliferative phase (organizing diffuse alveolar damage) have been observed when the sickness has been present for a prolonged period of time (Korteweg et al. 2008). In most cases involving autopsies, type II pneumocyte hyperplasia has been shown. Pneumocytes have not been shown to exhibit viral inclusions or other cytopathic alterations. Within the alveoli, macrophages seemed to predominate, whereas T lymphocytes, whether they include neutrophils or not, can be seen in the interstitium. In some instances' lungs were found to have sporadic histiocytes that were hemophagocytic in activity. Other histological abnormalities that have been reported include bronchiolitis, cystically dilated air spaces, haemorrhage, symptoms of interstitial pneumonitis that resemble pleuritis, and apoptosis in alveolar epithelial cells and leukocytes Imai et al (2012). There have been two reports of fungi-related potential superinfections. Hence above-mentioned histopathological traits are not unique to H5N1 influenza, it may be tough to differentiate between diffuse alveolar

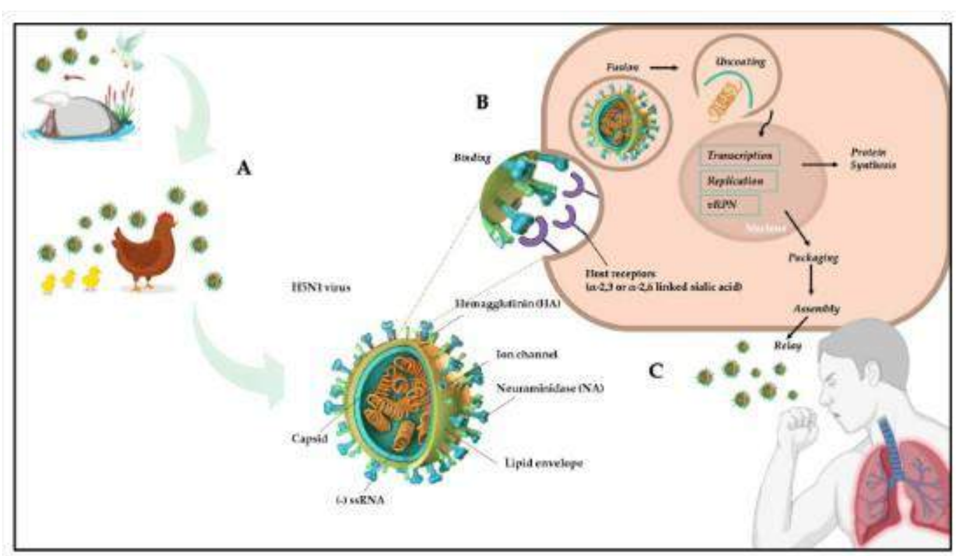

Fig. 3: Lifecycle of the H5N1 virus. (A) The spread of AVI among aquatic birds and domestic fowl. (B) Local replication of the virus' pathogenic mechanism. (C) Clinical symptoms and environmental spread.

impairment initiated by H5N1 virus infections and diffuse alveolar damage caused by other microorganisms like the SARS coronavirus (SARS CoV) or by other factors like aspiration or oxygen toxicity.

More specialist tests, such in situ hybridization, reverse transcription-polymerase chain reaction (RT-PCR), and virus separation, must be used to approve H5N1 infection (Takadate et al. 2023).

The level of tissue damage and the length of the illness are likely determined by a combination of the several components that determine the pathogenesis of H5N1 influenza. A noteworthy amount of research has been done on the role of dysregulation of cytokines and chemokines in the pathogenesis of H5N1 influenza, which may be one of the key processes. Viral replication also causes damage, but this damage is not the only factor. Other factors, such as elevated levels of TRAIL (tumor necrosis factor-related apoptosis-inducing ligand) and reduced cytotoxicity of CD8 cells, are also thought to be linked, though the specific nature of their role in the pathophysiology is now less clear. Below, we go over these elements and associated processes. The H5N1 virus is believed to reproduce similarly to human influenza infections, triggering cytolytic or apoptotic reactions that kill cells and organs. In the respiratory system, there are unmistakable signs of viral replication in progress. The virus has been identified in postmortem lung tissues, aspirates of the throat, and trachea (Offeddu et al. 2016).

Birds to humans transmission is the major way that the H5N1 virus infects people. Infected patients revealed a past history of contact with sick or dead chickens. The incubation phase can last up to 7 days, although it usually lasts between 2 and 5 days. According to recent statistics, human infections mostly affect the respiratory system but can also affect the digestive or central neurological systems. Rarely, respiratory symptoms may also go along with a headache, myalgia, sore throat, rhinorrhea, conjunctivitis, and/or bleeding gums. In extreme cases, multi-organ failure may also include renal dysfunction, lung hemorrhage, pneumothorax, and pancytopenia. Death due to respiratory failure may be accelerated by reactive fibroblasts, hyaline membrane development, lymphocyte infiltration into the interstitial area, and widespread alveolar destruction. The most frequent laboratory abnormalities are transaminitis (AST > ALT), increased lactate dehydrogenase, creatine kinase, and hypoalbuminemia (Jimenez et al. 2023). In order to decrease virulence and the likelihood of mutation accumulation, vaccines and medications are crucial. The key targets for medicines fighting the influenza virus are HA and NA since they are necessary for viral replication. The two most popular antiviral medications on the market now are amantadine and rimantadine. They interact with each other through the viral M2 protein's transmembrane area, which stops the disease causing viral nucleic acid from entering the host cell. They occasionally appear to prevent the replication of viruses from starting. With a particular focus on NA inhibition, researchers worldwide are looking for drugs that may be capable of targeting the NA and the M2 viral proteins. This is due to newly disclosed instances demonstrating an increased prevalence of resistance to this medication (Offeddu et al. 2016).

3.4. RABIES

Canine rabies is a deadly zoonotic illness that has been around for a very long time and affects both humans and animals fatally. The Sanskrit word "rabhas," which means "to do violence," is where the word "rabies" originates. Aristotle first articulated the importance of rabid dog bites in the spread of infection in the fourth century BC, over four thousand years after the Babylonian Code of Eshnunna (2300 BC), which mentions the disease's transmission by dogs. It is mentioned in the ancient Indian holy text Atharvaveda and has been recognized in India since the Vedic era (1500–500 BC) (Chaudhary et al. 2020). The first known fatal zoonotic viral disease, rabies, only affects warm-blooded species. Direct contact with saliva or brain/nervous system tissue from the animal that has the rabies virus (RABV), such as through injured skin or mucous membranes in the eyes, nose, or mouth (Fig. 5). In the end, RABV causes mortality and brain disease by primarily affecting neurons. The virus particle enters the cell by endosomal receptors and moves through the cell. After a few days or months, the virus's life cycle resumes, and it eventually infects the peripheral nerves. As seen in the illustration, retrograde flow in the axons then transports it to the brain. (Khalafalla AI and Ali YH 2021).

In 1804, Zinke proved that saliva could spread the rabies virus. In the first century AD, Celsus blamed wild animals for the transmission of rabies. Pasteur established neurotropism of viruses in 1881. After Joseph Meister was attacked by a rabies-infected animal in 1885, Pasteur developed the rabies vaccine and gave it to him. The rabies virus was discovered by Remlinger and Riffat-Bay in 1903 (Kumar et al. 2023). Kissling was the first to successfully cultivate the rabies virus in tissue culture in 1958. During the 1940s, the Kaliningrad region saw the first red foxes (Vulpes vulpes) contract the rabies virus. Within a few decades, Central and Western Europe had also been infected. In 1978, Switzerland conducted the first round of oral rabies vaccinations for animals. Fox field testing began in Switzerland in 1978, and the oral rabies vaccine was developed for field use in the USA in 1971 Dietzschold (2005).

4. ECONOMIC IMPACT OF RABIES IN LIVESTOCK

The 8.6 billion USD estimated cost of canine rabies is mostly attributable to lost productivity as a result of early mortality, post-exposure prophylaxis (PEP) costs as well as revenue losses caused by PEP-related costs. The cost of livestock mortality was USD 512 million per year, mostly in Asia (China, India, Bangladesh, and Pakistan) and in parts of Africa that depended economically on cattle (such as Sudan, Ethiopia, and Tanzania). In Bhutan, the spread of rabies causes in the death of cattle and a reduction in their output, which directly harms farmers' livelihoods and costs the government money to contain outbreaks and provide widespread rabies PEP. In Asia and Africa, rabies claimed the lives of the most people. 55,000 estimated rabies-related human fatalities occur each year, with roughly 31,000 of those deaths occurring in Asia and 24,000 in Africa (John et al. 2021).

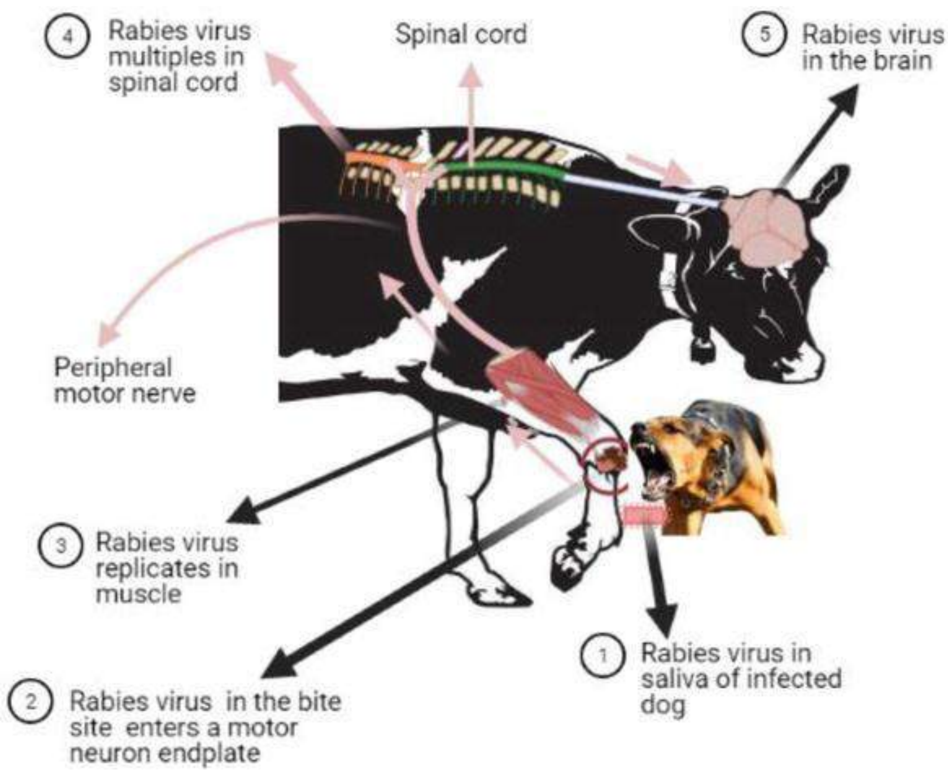

Fig. 4: Demonstration of how the rabies virus spreads in animals from the site of the bite to the central nervous system. (Khalafalla et al. 2021).

The primary methods for preventing rabies are immunizing sensitive animals, mostly dogs and cats, eradicating or controlling stray dogs, and immunizing susceptible people before and after exposure. Recombinant vaccines are used for wildlife, cats, and dogs, whereas live attenuated virus is used for wildlife and wild dogs. Inactivated viruses are used for companion animals and cattle. Cattle in affected areas began receiving vaccinations in 2012 in the USA, when a rabies epidemic was identified. To protect them against the disease that affects cattle, horses, goats, and sheep, more than 200 animals received two doses of the vaccination (Kumar et al. 2023).

5. SALMONELLOSIS

Young children, expectant mothers, immune-compromised people, and the elderly are the main populations that are affected by the gram-negative intracellular pathogenic bacteria known as salmonella (Villegas et al. 2021). Each year, the virus kills millions of people worldwide, and a sizable number of new infections are also reported each year. Approximately 97.9 million people have gastroenteritis each year throughout the globe, which results in roughly 155,000 fatalities, as opposed to the 21 million documented the occurrence of typhoid fever, which cause an estimated 200,000 deaths annually (Lublin A and Farnoushi Y 2023). Salmonella species can either exclusively infect a certain kind of host or infect a range of host types, resulting in a variety of disease pathologies. *Salmonella enterica*, and *Salmonella bongori*, have seven subspecies (I, II, IIIa, IIIb, IV, VI and VII) and one subspecies (V) respectively, are the two species of Salmonella, according to taxonomy (Pearce et al. 2021). Fig. 6 shows the virulence factors responsible for the spread of pathogen.

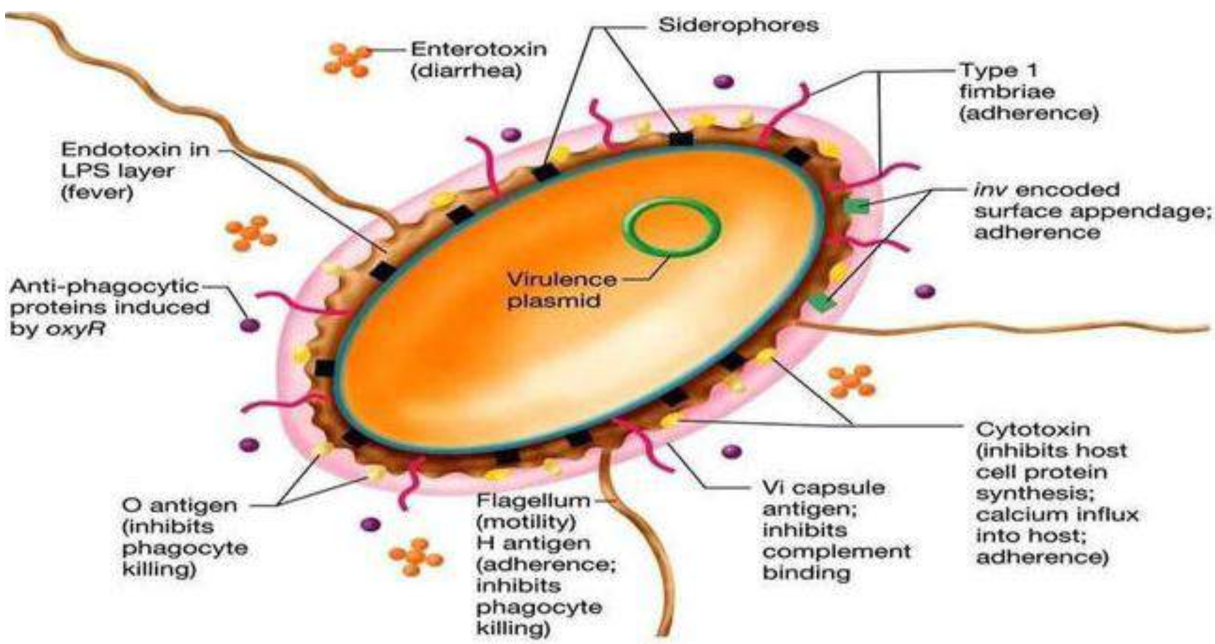

Fig. 5: The virulence factors of Salmonella typhi (Al-Khafaji et al. 2020).

The primary pathogenicity genes of the bacteria that have been produced by horizontally acquired pathogenicity islands (PAIs) include those that code for virulence genes including adhesion molecules, toxic substances, invasins, secretion of proteins systems, absorption of iron systems, etc. *Enterobacteriaceae* family member *Escherichia coli* (*E. coli*) is where PAI was initially identified. The genomes of pathogenic organisms include PAIs, but those of nonpathogenic organisms or closely related species do not. The bulk of the virulent genes in Salmonella are found in islands of pathogenicity that have been acquired horizontally and are known as Salmonella pathogenicity islands (SPIs) (Saini et al. 2023). These islands are crucial for infection and intracellular survival, and Salmonella also has several regulatory mechanisms. Salmonella is one of the most effective infections due primarily to TTSS, its effector proteins, and horizontally inherited islands of pathogenicity (Kalafatis and Slauch 2021). The importance of HGT events as well as evolution in disease is demonstrated by the fact that Salmonella split from E. coli by acquiring many virulent genes through HGT during evolution. Approximately one-fourth of the Salmonella genome is obtained because of this process. Salmonella or any other organism that enters the human body runs across obstacles such intestinal mucosa, low stomach pH, and intestinal epithelial cell barriers (Kushwaha et al. 2020). It is widely recognised that Salmonella has the potential to overcome these barriers and successfully transmit infection. Salmonella's complex membrane structure enables it to survive until it reaches the lower intestine of the host and binds to the epithelial cell wall. Salmonella enters host cells via the Microfold (M) cells in the Peyer's patch, a collection of lymphoid tissue that is dispersed throughout the small intestine and which assesses and responds to the harmful bacteria in the gut (Richards AF 2021). About 10% of the cells in the patches of Peyer are M cells, which have an outer surface covered in numerous lymphoid cells including lymphocytes and phagocytes and an inner surface that faces the intestinal lumen. Salmonella may enter the host cell in two main methods. One method involves transcytosis, a passive process whereby M cells passively take in bacteria starting at the lumen till basolateral side. The second approach involves absorption brought on by bacteria secreting SPI-I TTSS effector proteins, which promote membrane disruption by rearranging the cytoskeletal structure of the epithelial cells. At the site of entry, immune cells such as neutrophils, T cells, B cells, dendritic cells, and macrophages among others infiltrate after the entry-related inflammation. Invading the nearby enterocytes from the M cells, these bacteria breach the intestinal epithelial barrier. Bacteria arrives at MLN via blood and lymphatic system, where they are further eaten by immune cells inside the lamina propria before going on to deeper organs like the spleen, liver, and even the bone marrow. As seen in the picture below, bacteria are located in the macrophages of all of these organs in Salmonella-containing vacuoles (SCV), which are specialist modified endosomal compartments (Al-Khafaji et al. 2021). Fig. 7 shows the basic steps in Salmonella pathogenesis.

6. ANTHRAX

Anthrax has been mentioned in conventional literature going back to Virgil's writings. It was the first sickness that could be definitively accredited to a microbe (Bacillus anthracis), discovered by Robert Kochin in 1877 Savransky (2020). Even though it is mostly a zoonotic disease spread by animals and contaminated soil, the Centres for Disease Control and Prevention (CDC) have designated it as a Class A potential agent for bioterrorism. In Soviet Union in 1979, Japan 1995, and the United States in 2001, B. anthracis has been considered responsible for mortality. In both the World Wars I and II, it most certainly served as a weapon. Anthrax disease is brought on by the rod-shaped, gram-positive, endospore-forming, facultatively aerobic bacterium B. anthracis. Large (1.0-1.5 mby3-8 m) and non-motile, the bacilli can be found alone or in short chains. The main factor in Bacillus anthracis' pathogenicity is the interaction between two plasmids, pXO1 and pXO2. They are in charge of generating anthrax toxins and creating poly-d-glutamic acid (PGA) capsules. The operon for the production of capsules is found on pXO2, whereas the genes for the anthrax toxin are found on pXO1 (Swick et al. 2016). Similar to how the PGA capsule safeguards the bacilli, the polysaccharide capsules of other harmful bacteria, like meningococci and pneumococci, also shelter bacilli from phagocytosis and immune response. Thus, the capsule

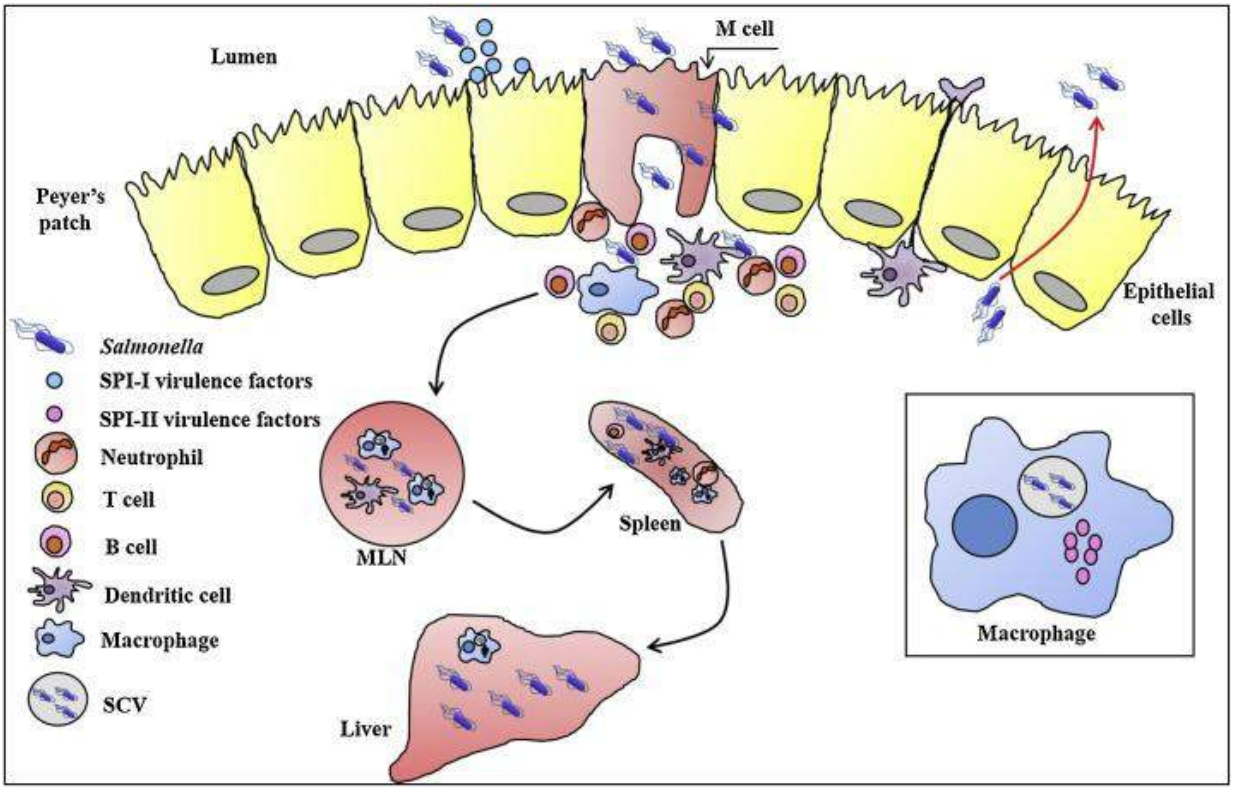

Fig. 6*:* Basic steps in Salmonella pathogenesis (Pradhan et al. 2019).

mediates the invasive phase of the infection. Protective antigen (PA), edoema factor (EF), and lethal factor (LF) are the three distinct polypeptide chains that make up the anthrax toxin. The pXO1 plasmid-encoded LF, EF, and PA combines to generate the lethal toxin (LT) and edoema toxin (ET). LF is a zinc-dependent metalloprotease that targets mitogen-activated kinase kinases (MAPKKs or MEKs) (Cote et al. 2015). LT also disrupts the signaling networks that regulate cell cycle, proliferation, and stress defense by severing the N-termini of these enzymes. The severe edoema linked to anthrax illness is brought on by a calmodulin-dependent adenylate cyclase EF. EF alters the host cell's signaling pathways by elevating cyclic adenosine monophosphate (cAMP) levels. By attaching to receptors (TEM8 and CMG2), PA causes a hole to develop in the membrane, allowing the toxin to pass through and enter the cytoplasm of the host cell. Anthrax toxin's method of action has been well investigated over the past few decades, and it is now understood.

7. CRIMEAN-CONGO HEMORRHAGIC FEVER (CCHF)

The most well-known illness spread by ticks is Crimean-Congo hemorrhagic fever (CCHF), which is brought on by the CCHFV virus. The Crimean-Congo hemorrhagic fever virus (CCHFV) is thought to be the most common tick-borne illness, producing CCHF. This zoonotic virus is widespread in around 50 countries across Africa, Asia, and Europe. As a result, there is a risk to human health due to acute and possibly deadly severe hemorrhagic syndrome as well as subclinical human infections. Additionally, both domestic and wild animals frequently get CCHFV through subclinical infections (Fanelli and Buonavoglia 2021). This zoonotic virus is widespread in around 50 countries across Africa, Asia, and Europe. As a result, there is a risk to human health due to acute and possibly deadly severe hemorrhagic syndrome as well as subclinical human infections. Additionally, both domestic and wild animals frequently get CCHFV through subclinical infections. The length of the development period is influenced by the source of the contaminated blood or tissue, the disease's mode of transmission, and the viral load. Following a tick bite, the incubation period lasts 1 to 5 days, and it lasts 5-7 days after coming into touch with contaminated blood or tissues. When distributed by tick bite, it can last 3-6 days, with a extreme of 9 days, however when disseminated by contaminated blood or other infectious material, it can last 5-6 days, with a maximum of 13 days (Shahhosseini et al. 2021). The prehemorrhagic phase is distinguished by the abrupt development of a broad range of non-specific prodromal symptoms that remain for 4-5 days and are similar to those of other viral illnesses. The hemorrhagic phase typically lasts two weeks and has haemorrhage that progresses quickly. During this stage, symptoms might range from petechial to widespread ecchymosis (McEntire et al. 2021). Additionally, it can reveal bleeding from the gums, nose, internal organs, or digestive tract. Hepato-splenomegaly may also be seen in certain cases. In patients who make it through the first phases of the disease, the convalescent period often starts 10–20 days after the sickness first manifests. There has not been enough research done on the long-term impact of CCHFV infection in survivors to identify any specific issues. For patients to get treatment early and for the fast use of suitable precautions and infection control measures to stop the spread of CCHF, a quick and accurate diagnosis is crucial (Aftab et al. 2019). Laboratory testing, epidemiological considerations, and clinical signs are used to make the diagnosis. Due to the disease's random onset and vague first symptoms, clinical diagnosis is challenging to make until the hemorrhagic stage sets in. Therefore, a laboratory diagnosis is thought to be more certain and trustworthy. Its diagnosis is mostly accomplished using molecular, serological, and isolation approaches. Serum or plasma are the biomaterials that are sampled most frequently for their detection. Highest polymerase chain reaction (PCR) efficiency is ensured by blood taken in EDTA tubes (González et al. 2022).

8. LEISHMANIASIS

Infectious diseases, especially parasitic infestations, are major public health concerns in both animals and humans (Alvi et al. 2022; Alvi et al. 2023). Leishmania is a protozoan parasite of the Trypanosomatidae family that infects humans and other animals, triggering cutaneous, mucocutaneous, and visceral disease in both the Old and New Worlds. Around 91 nations in Asia, Africa, the Arab world, Central America, and South America are affected by leishmaniasis, a neglected tropical disease that mostly affects the world's poorest population. Current estimates of the prevalence of cutaneous leishmaniasis (CL), which are probably under-reported, vary from 700,000 to 1.2 million cases annually, with more than 95% of cases occurring in the Americas, the Mediterranean basin, the Middle East, and Central Asia. With more than 95% of cases reported to the World Health Organization (WHO) from Brazil, China, Ethiopia, India, Kenya, Nepal, Somalia, and Sudan, estimates of annual visceral leishmaniasis (VL) are presently fewer than 100,000, a considerable decline from earlier estimates of 400,000. Leishmaniasis risk factors include impoverishment, population movement, hunger, poor hygiene, and immunocompromised conditions. Among neglected tropical illnesses, leishmaniasis has the third-highest fatality rate, after only Chagas disease and sleeping sickness. However, the related morbidity of the condition is commonly misunderstood and overestimated by medical professionals and researchers. The real health cost of leishmaniasis is underestimated for a variety of reasons. First, only 32 of the 88 nations that are plagued by leishmaniasis are covered by the reporting requirements. Second, due to the disease's low mortality rates, it is well recognized that poverty is a major factor in its spread, and those who are afflicted, and their families often conceal it. When infected sand flies

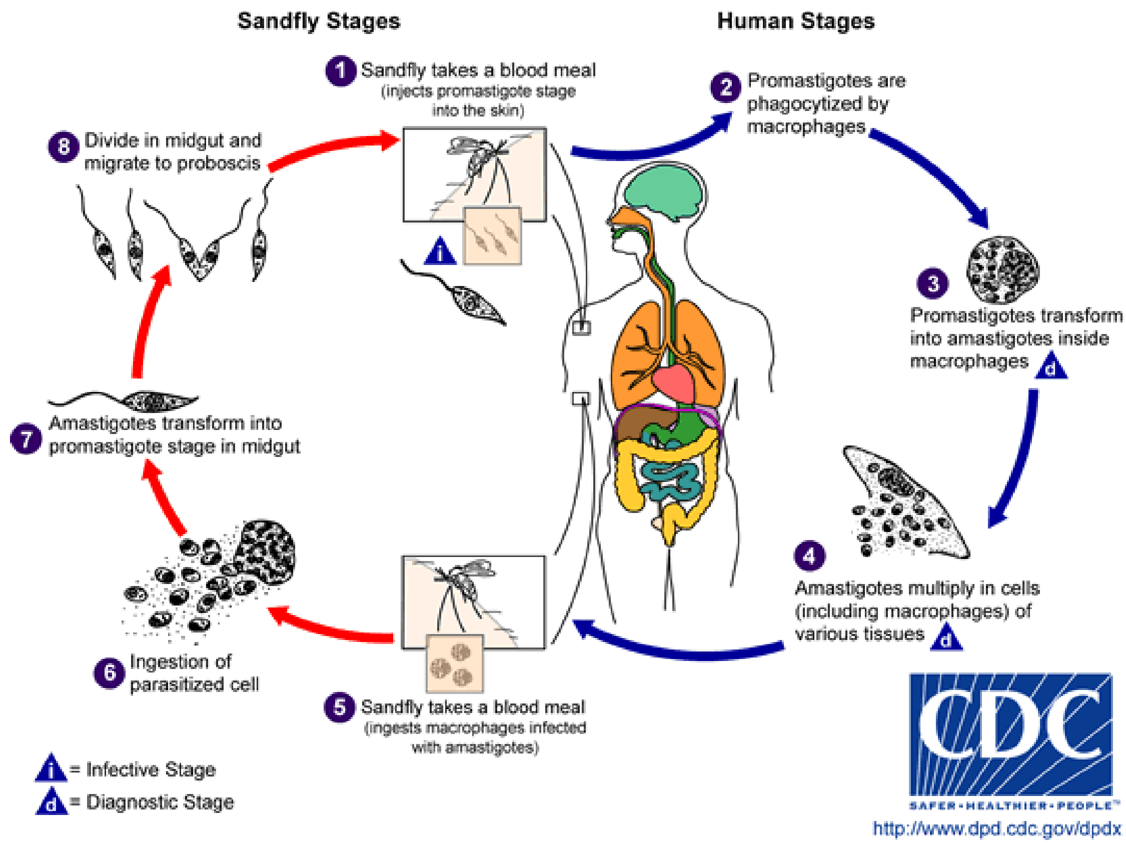

Fig. 7: The life cycle of leishmania (different phases of leishmaniasis) (DPDx 2020).

bite humans, they are exposed to Leishmania species (Roatt et al.2020). Metacyclic promastigotes in the sandfly's anterior midgut or foregut were regurgitated into the invertebrate's skin during the blood meal. As soon as possible, phagocytic cells like neutrophils and macrophages engulf the promastigotes. In the phagolysosome, the pro mastigotes form separate into dividing, aflagellated amastigotes. It's crucial to remember that the parasite that lives in sandflies originated in an infected host. Following the lysis of the host cells, the amastigotes transform into procyclic promastigotes. They utilise their flagella to link to the fly midgut via surface glyconconjugates in order to start the infection. Leishmaniasis therapy options are limited, and the drugs that are available have significant toxicity and unfavorable side effects. In addition, the emergence of drug-resistant strains, co-infections such as HIV/Leishmania spp., the constrained therapeutic toolbox, and the low investment needed for the discovery/development of new drugs force researchers and global health organizations to search for novel approaches to combat and control this serious neglected disease (Mann et al. 2021). In this situation, novel approaches with significant advancements in physical and local therapies, such as the use of CO2 lasers and thermotherapy, as well as topical pharmacological therapies using NO compounds and intralesional drug injection, have improved the outlook for patients with CL (Roatt et al. 2020).

9. CONCLUSION

In Pakistan, zoonotic diseases constitute a significant public health risk. Both humans and animals are susceptible to these diseases, which can result in significant illness and even death. Depending on the particular disease, zoonotic diseases might have different physical and physiological properties. However, some common traits include the capacity to spread by contact with sick animals or their products, the capacity to produce a range of symptoms in both humans and animals, and the capacity to be lethal. It's crucial to be informed about the zoonotic diseases that are common in Pakistan and to take precautions against them.

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Control and Preventive Measures to Tackle Zoonotic Diseases from the Fish

18

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ABSTRACT

Zoonotic diseases (ZD) exert a profound global impact on public health, presenting a formidable threat to human populations worldwide. Although mammals and birds are widely acknowledged as primary sources of zoonotic pathogens, the role of fish as potential carriers and transmitters of these diseases should not be underestimated. Both wild-caught and farmed fish can harbor and transmit diverse zoonotic pathogens to humans through consumption, handling, or exposure to contaminated water. Fish act as hosts for a wide spectrum of ZD i.e., by salmonellosis, a disease caused by Salmonella bacteria, frequently linked to the consumption of inadequately cooked or raw fish products. Another notable concern associated with fish consumption is Vibrio infections, prominently caused by Vibrio vulnificus and Vibrio parahaemolyticus. Moreover, parasitic infections such as anisakiasis, attributed to nematode worms, can be transmitted to humans through ingestion of raw or undercooked fish. These diseases manifest a spectrum of symptoms ranging from gastrointestinal distress to severe infections, provoking potentially dire repercussions for human health. Fish-associated ZD results from diverse risk factors: inadequate handling, consumption of raw fish-derived food, exposure to contaminated environments, and interactions with infected fish. A comprehensive approach is indispensable including proper techniques, food safety regulations, surveillance, and public education. Collaboration among fisheries, health authorities, and the public is also crucial. Therefore, the current chapter will primarily emphasize the strategies essential for the control and prevention of zoonotic disease from fish.

Keywords: Zoonotic disease, Prevention, Control, Techniques, Organization

CITATION

Akbar A, Ijaz MU, Ehsan N and Kiran S, 2023. Control and preventive measures to tackle zoonotic diseases from the fish. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 255-268. https://doi.org/10.47278/book.zoon/2023.018

CHAPTER HISTORY Received: 23-Feb-2023 Revised: 29-May-2023 Accepted: 29-July-2023

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1. INTRODUCTION

Zoonoses, refer to diseases transmitted from animals to humans, pose a significant threat to human health and their direct impact could potentially be fatal (Bonilla-Aldana and Rodriguez-Morales 2022). The thirteen most prevalent ZD have had a detrimental effect on human health worldwide, resulting in 2.4 billion cases of illness and 2.7 million human fatalities each year. This risk is particularly predominant among low and middle-income nations, where the disease burden is borne heavily by impoverished livestock workers. Addressing the issue of ZD holds immense importance as it exerts a potential role in protecting the overall well-being of the global population and minimizing the devastating impact these diseases impose on human lives. By prioritizing efforts to tackle ZD, we can effectively safeguard global public health and significantly reduce the burden they impact on individuals and communities worldwide (Grace et al. 2012). The genesis and transmission of different infectious diseases are greatly affected by human beings, animals as well as the environment (Thompson and Kutz 2019). The majority of contagious diseases that seriously threaten human health are spread by animals. According to the "Asia Pacific Strategy for Emerging Infectious Diseases," more than 70% of these pathogens originated from animal species, and they are responsible for causing over 60% of novel infections in humans (WHO 2014).

According to Tumbarski et al. 2020), fish-borne trematodes have been identified as a significant cause of infection among approximately half of the world's population. Moreover, Slingenbergh 2013) asserted that the majority of newly discovered human diseases were associated with animals and, in particular, with the consumption of animal-derived food products. The Food and Agriculture Organization's (FAO) 2019 report identifies aquaculture as the fastest-growing sector in food production, highlighting the significance of fish in the global economy as a source of food. Historically, the risk of fish-borne ZD was thought to be limited to anglers and fish keepers (processing plants). However, with the widespread expansion of fish farming and aquarium hobbies, there has been a marked increase in the documented incidence of fish-borne zoonoses since the late 1950s. The 1980s in particular saw a high number of such incidents (Lehane and Rawlin 2000).

Food-borne zoonotic pathogens can infect both humans and animals, causing a range of potentially fatal diseases (Alvi et al. 2021). The growth of globalization and mechanization has led to changes in domestic and international markets. In the past, food-borne zoonoses were typically found in underdeveloped nations due to poor hygiene and handling practices. However, the aquaculture industry has emerged as the fastest-growing sector in food production, and it is important to ensure high standards of hygiene and food safety to prevent the spread of these diseases.

Fish have been identified as carriers of various zoonotic microorganisms (Boylan 2011), with bacterial infections being the most common. Although fish that are immune to certain diseases can make people quite sick, such opportunistic infections are rare. These pathogens can be acquired by fish from their natural aquatic environment, which can be contaminated by agricultural practices, animal and human waste, domestic garbage, and wild animals (Antuofermo et al. 2023). Poor hygiene during the exploitation of aquatic species or their products may lead to the transmission of zoonotic infections to humans. Additionally, the consumption of raw or undercooked aquatic foods can result in the spread of food-borne illnesses (Fig. 1) (Boylan 2011).

Helminth parasites transmitted by fish & shellfish products are responsible for prominent health issues caused by food-borne diseases, affecting over half a billion people globally, including those in developed countries (WHO 1995). Certain types of parasites, which can be very dangerous, are transmitted to humans through the consumption of uncooked fish. In recent years, the prevalence of these ichthyozoonoses has significantly escalated due to various factors, including the expansion of the global market for fish & fish products, the rise in consumption of sectoral fish dishes, and the development of advanced diagnostic methods (Robinson and Dalton 2009; McCarthy and Moore 2000; Nawa et al. 2005; Keiser and Utzinger 2005;). To better understand the relationship between parasite zoonoses &

circumstances such as poverty, aquaculture intensification, and waste disposal, the healthcare significance of these zoonoses must be defined (Pal and Ayele 2020).

2. MAJOR ZOONOTIC AGENTS FROM FISH ENGAGED IN INFECTING HUMANS

Infectious diseases including parasitic infestations are important health problems in both animals and humans (Alvi et al. 2022; Alvi and Alsayeqh 2022). Infectious diseases with zoonotic potential may be transmitted to humans through various pathways, involving ingestion, animal bites, vector-borne transmission & contact with animals or their excretions (Gauthier 2015; Rahman et al. 2020). These diseases are caused by a broad range of pathogens, including bacteria, viruses, parasites & fungi, which are typically harbored by animals and may be transmitted directly or indirectly to humans (Fig. 2) (Wolfe et al. 2007).

1.1. PARASITES

The presence and transmission of tapeworms, roundworms, and flukes derived from fish species, such as *Dibothriocephalus latum*, *Anisakis spp*., and *Metagonimus yokogawaii*, to human beings predominantly occur through the ingestion of undercooked fish-based items (Antuofermo et al. 2023). These parasitic organisms pose a significant health risk, leading to various illnesses but generally not resulting in fatality (Cong and Elsheikha 2021). Sufficient knowledge exists regarding the importance of seafood in the worldwide human diet, alongside the escalating problem pertaining to seafood-borne disease and related parasitic infections. Certain fish species, which form a significant part of the human diet, are recognized as hosts for parasitic organisms (Shamsi 2019).

A multitude of these parasitic organisms have the potential to be transmitted to humans, and certain species, such as gnathostomiasis and anisakiasis, can impose significant risks to the health of humans (Herman and Chiodini 2009; Audicana et al. 2002; Daengsvang 1981). Among various disease-causing factors, fish products hold a prominent position (Huss et al., 2000). In addition to their widespread occurrence, parasites are often neglected in discussions concerning the safety of seafood (Shamsi 2020). Consequently, parasites originating from fish frequently evade diagnosis and remain responsible for the emergence of numerous ZD (Dorny et al. 2009; Shamsi 2019).

The methodologies employed for the detection of pathogenic organisms and the standards for food inspection exhibit significant variations across nations, often lacking adequacy and consistency (Williams et al. 2020). Despite this, in industrialized areas of the world, regulations pertaining to food handling & restrictions of import for zoonotic parasites (ZP) infections are occasionally overlooked (Shamsi 2016).

The escalation in the incidence, geographic frequency & distribution of ZD associated with fish consumption can be attributed primarily to global warming and the increasing demand for exotic, undercooked, and raw food (Shamsi and Sheorey 2018). This rise in health issues has been supported by studies conducted by Chai et al. (2005) and Lõhmus and Björklund (2015). Notably, an estimated 680 million individuals are considered to be at risk of being affected by freshwater fish liver flukes, with approximately 45 million people currently affected by these parasites (Saijuntha et al. 2021). Helminthic pathogens, in particular, pose a significant concern among seafood parasites owing to their diverse nature & abundance in tropical aquatic environments, leading to their frequent transmission to fish (Chai et al. 2009; Ogbeibu et al. 2014). For instance, in Vietnam alone, 268 species of helminth have been identified in 213 species of fish (Nguyen et al. 2021).

One of the major contributing factors to the persistence and transmission of parasites is the trophic-oriented life cycle, wherein the parasites rely on the food web to be transmitted to their host (Polley and Thompson 2009). Furthermore, numerous edible fish species particularly teleost are believed to act as intermediate hosts for parasitic infections, thereby increasing the risk of infection in relation to the host's

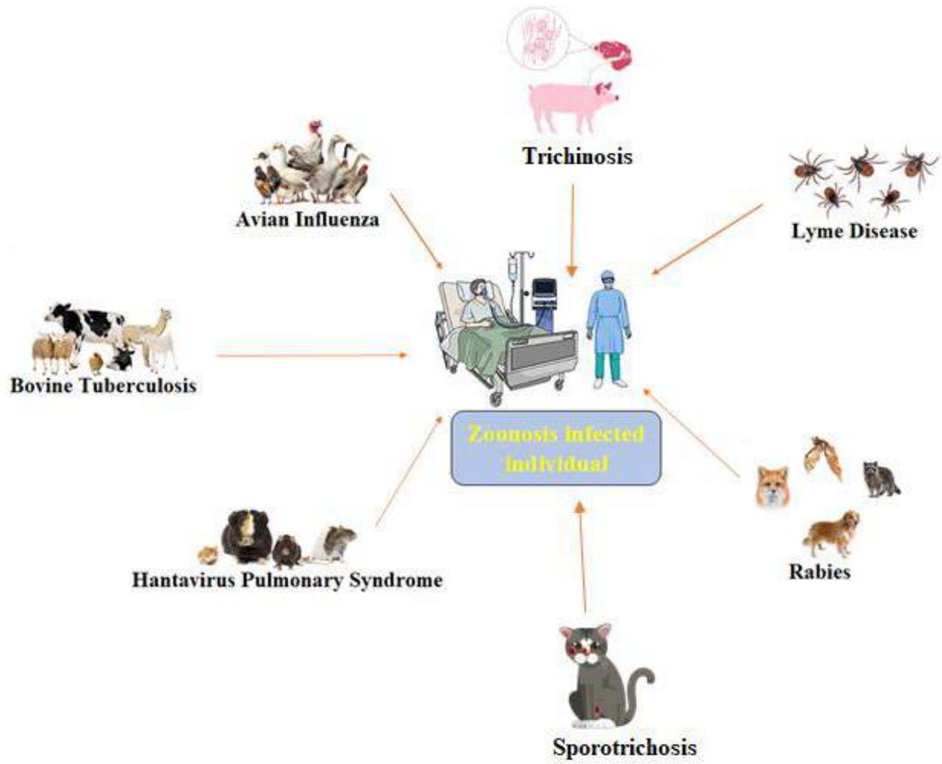

Fig. 1: A global nexus of zoonotic disease, interaction between animals and humans

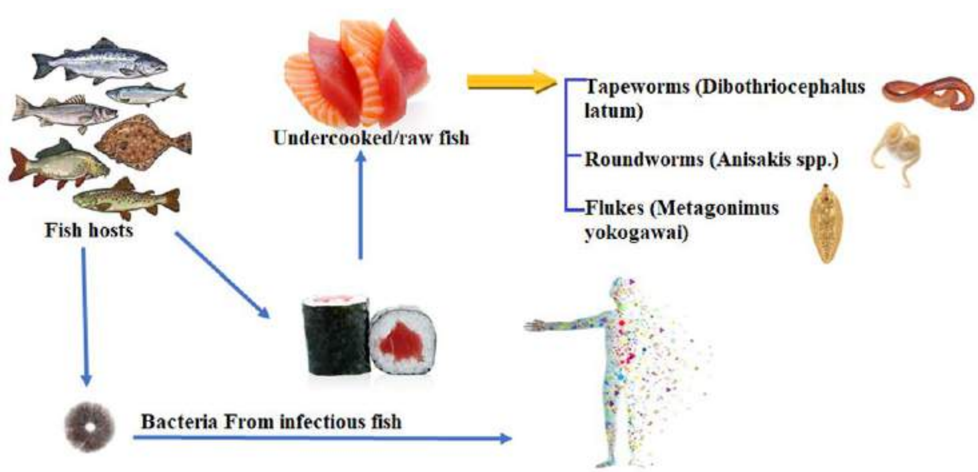

Fig. 2: Bacterial zoonotic pathogen transmission from fish to humans.

size (Marcogliese 2003). In general, the parasite load tends to increase in proportion to the trophic level of the host, with larger fish species harboring a considerable number of parasites. Unfortunately, many ZP may not exhibit visible signs of infection in the infected fish, posing challenges in diagnosis, particularly when the larvae are small and present at low levels (Lowry and Smith 2007; Shamsi and Suthar 2016).

In accordance with Shamsi (2019), there are approximately forty species of fish parasites capable of infecting humans. Whereas some of these parasites may be rarely encountered, others may be extremely pathogenic & induce significant public health risks (Deardorff 1991). Estimates suggest that helminthic parasites alone may threaten the well-being of more than 500 million individuals (dos Santos & Howgate 2011). Furthermore, this figure is expected to increase due to the effects of global warming (Fiorenza et al. 2020).

Fish-borne helminthic diseases can give rise to severe clinical manifestations, including brain hemorrhage, hemiparesis & even malignancies, in addition to mild to severe allergic reactions and gastrointestinal disorders i.e., stomach pain & diarrhea (Sripa et al. 2011; Germann et al. 2003; Cong and Elsheikha 2021). A study aimed at assessing the prevalence of ZP i.e., *Isoparorchis sp.* in *Bagridae* fish imported into Australia, *Euclinostomum sp.* in *Channidae fish,* and *Eustrongylides sp.* in *Channidae fish* (Williams et al. 2022). Regular investigation is crucial to prevent the introduction of ZP, even if freezing imported edible fish can render the parasites inactive (Williams et al. 2022).

1.2. FUNGAL ZOONOTIC AGENTS

Fungi, a taxonomically diverse assemblage of non-photosynthetic microorganisms, exhibit a broad spectrum of ecological roles, including parasitism of humans, plants, and animals, as well as saprophytic lifestyles in soil as well as decaying organic substrates (Cullings et al. 2023). Among the vast array of fungal pathogens that have been identified, a mere 300 have been certainly demonstrated to exert a threat to the health of humans, as attested by the authoritative Center for Disease Control and Prevention (CDC) in 2017. However, fungal infections caused by ubiquitous environmental fungi remain a persistent public health challenge. Moreover, the zoonotic potential of fungi, which can be transmitted among humans and animals, is a source of growing concern for global health authorities, given the potential for serious negative impacts on public health. Regrettably, despite the pressing need for targeted prevention and control strategies to address zoonotic fungi, inadequate attention has been established to this issue in the context of global public health initiatives (CDC 2017).

1.3. BACTERIA

Bacteria, being the most prevalent fish-born zoonotic pathogens, pose a significant concern for humans (Fig. 2). The transmission of these pathogens commonly occurs through the introduction of infectious fish or contaminated treatment fomites to the skin, particularly through cuts, penetrating wounds, or abrasions (Souza 2011). The proliferation of bacteria is facilitated by the amplified organic load observed in recirculating systems, as it provides an excellent substrate for bacterial growth. In order to minimize the risk of infection, it is imperative for veterinary clinicians to consistently wear personal protective equipment (PPE), such as gloves, since the majority of the microorganisms discussed herein are frequently present even in fish that do not exhibit clinical symptoms. Although certain gram-positive microorganisms hold significance in the field of medicine, the pathogenic microorganisms primarily belong to the gram-negative category (Boylan 2011). The incidence of bacterial zoonotic pathogens in fish exhibits periodic variation, necessitating regular assessment of the occurrence of pathogens in both wild & cultivated fish stocks (Meron et al. 2020; Regev et al. 2020). Furthermore, ornamental fishes can serve as a significant reservoir of bacterial zoonotic pathogens, often exhibiting high levels of antibiotic resistance (Weir et al. 2012).

1.4. VIRUSES

Noroviruses represent a distinct group of viruses responsible for inducing acute gastroenteritis when individuals consume contaminated fish & shellfish products. This illness has become a major concern of global public health, causing not only human suffering but also economic losses (Pavoni et al. 2013; Marsh et al. 2018; Kittigul et al. 2016). These viruses, characterized by their nonenveloped nature and possession of a single-stranded RNA genome, pertaining to the *Caliciviridae* family and are categorized into 7 genogroups, with GI and GII being the most frequently encountered in human infections (Vinje et al. 2000). The symptoms of Norovirus-induced gastroenteritis encompass symptoms such as vomiting, diarrhea, abdominal pain as well and flu-like symptoms, which generally manifest within 12 to 48-hour after consuming contaminated food. While the disease is typically self-limiting, individuals with compromised immune systems may experience prolonged infections (Reeck 2010).

Additionally, hepatitis A virus can cause hepatitis, characterized by liver inflammation, upon consumption of frozen & fresh food products, i.e., bivalves, fish, & water, that are polluted with the virus. Symptoms of hepatitis A encompass nausea, fatigue, diarrhea, vomiting, dark urine, jaundice, abdominal pain, fever, muscle pain & joint pain which can persist for several weeks or even months. However, severe cases can lead to liver failure or prove fatal, particularly among elderly individuals and those with pre-existing chronic liver disease (Roldán et al. 2013).

2. ROUTES OF TRANSMISSION TO HUMANS

Zoonotic bacteria possess the capability to be transmitted to humans through various routes. Among these routes, 64% of transmissions occur via the oral route, primarily through the consumption of untreated food derived from fish species. Additionally, 23% of transmissions occur through skin contact as well as cutaneous ulcers, while 19% are attributed to water contaminated with these bacteria (Raissy 2017). The escalating production and consumption of aquatic animals by humans have contributed to the increase in the risk of developing ZD (Haenen et al. 2013). Consequently, the need for rapid, accurate, and specific methods for the identification of pathogenic bacteria in the aquatic environment has been intensified in recent years, parallel to the increased nutritional reliance on fish. Numerous studies have successfully employed quantitative, rapid as well as accurate techniques to identify these pathogenic bacteria (Novotny et al. 2004) Table 1.

Table 1: Routes of transmission for zoonotic pathogen into the human body

Routes	Percentage	Reference
Oral	64%	
Skin contact	23%	(Raissy 2017).
Water contamination	19%	

3. TECHNIQUES FOR DETECTION OF ZOONOTIC AGENTS

With the growing need for more rapid and accurate detection of zoonotic bacteria, various molecular techniques have been developed (Koo et al. 2023). Among these, the polymerase chain reaction (PCR) has become a widely used method for detecting many types of pathogens due to its sensitivity and specificity (Law et al. 2015). In addition to conventional PCR, other PCR-based techniques have been developed to further improve detection capabilities. Multiplex-PCR allows for the detection of multiple pathogens in a single reaction, while real-time (qRT)-PCR enables the quantitative detection of bacterial DNA in real-time (Park et al. 2014). Droplet digital PCR (ddPCR) is another PCR-based technique that enables precise as well as absolute quantification of DNA molecules, allowing f the detection of levels of zoonotic bacteria (Fykse et al. 2007).

Random amplification of polymorphic DNA (RAPD) and restriction fragment length polymorphism (RFLP) are employed for bacterial differentiation. Isothermal techniques, including recombinase polymerase amplification (RPA), nucleic acid sequence-based amplification (NASBA), Small Molecule Accurate Recognition Technology (SMART), and rolling circle replication (RCA), offer the advantages of identifying bacteria in resource-limited settings without the need for specialized equipment (Farzadnia and Naeemipour 2020).

Advanced techniques in bacterial detection include RT-NASBA and LAMP-on-a-chip, which offer rapid, efficient, as well as cost effective solution. Biosensors, such as electrochemical immunosensors, fiber optic microchannel biosensors, and quartz crystal microbalance (QCM)-based biosensors, provide effective means of identifying zoonotic bacteria. These techniques demonstrate exceptional efficiency, enabling the simultaneous monitoring of multiple pathogens in aquatic environments. Moreover, the microarray technique facilitates the assessment of gene expression under diverse cell growth condition and allows for the simultaneous detection of several bacterial genera, presenting a comprehensive approach to bacterial analysis (Farzadnia and Naeemipour 2020).

Recent developments in biosensors have significantly improved the identification of bacterial species, making them a preferred detection method over molecular techniques. Among these sensors, electrochemical immunosensors, fiber optic microchannel biosensors, and quartz crystal microbalance (QCM)-based biosensors are highly efficient, cost-effective, and can detect zoonotic bacteria in multiple steps. These biosensors have the advantage of being sensitive, specific, and have the potential to be used for real-time monitoring in the aquatic environment (Ulrich 2004).

4. PREVENTION AND CONTROL

Microorganisms present in fish can significantly contribute to public health complications, making it crucial to raise awareness among the people about these microbial agents and the risks associated with consuming raw or undercooked fish (Kobuszewska and Wysok 2023). As a result, regular monitoring and implementation of quality control measures for consumed fish become imperative. Such measures not only facilitate the effectiveness as well as prompt control of diseases but also provide essential information for the treatment and prevention of aquatic zoonotic microorganism, ensuring the safety of individuals and overall public health (Bibi et al. 2015).

The control of zoonotic agents in fish poses a significant challenge as fish farming is predominantly reliant on natural environmental conditions. The degradation of the aquatic environment significantly impacts fish health and is the primary cause of most fish diseases. Thus, a multidisciplinary approach that encompasses knowledge of potential fish pathogens, an understanding of fish biology and comprehensive awareness of environmental factors is necessary to implement suitable measures for the prevention and management of various diseases (Toranzo et al. 2005).

Efficient cleaning sterilization of ponds are essential to disrupt the lifecycle of certain nematode species and reduce the population of intermediate hosts. Failure to clean and sterilize ponds properly can lead to the persistence of a significant number of intermediate hosts even after refilling (Clausen et al. 2012; Hedegaard et al. 2012; Tran et al. 2019). The prevalence of fish derived ZD in populations is influenced by various factors such as geographic location, accessibility to fresh seafood, sanitation practices, fish farming procedures and diets. Additionally, individual and social behaviors also play a crucial role (Deardorff 1991). Unlike many other lethal diseases, fish-derived ZD are not confined to specific regions and can occur globally regardless of income levels (Chai et al. 2005).

The significance of fish-derived diseases has increased remarkably in developed nations worldwide due to factors such as consumer demand, a growing international market, demographic changes and improved transportation systems (Shamsi 2016). To mitigate the risks associated with zoonotic infections throughout the stages of harvesting, processing, storage and post-processing, several measures can be implemented. Government agencies and the seafood sector can effectively address the challenges posed by zoonotic fish-derived Helminthes through the implementation of initiatives such as good manufacturing practices (GMPs) and Hazard Analysis and Critical Control Points (HACCP) systems (Adams et al. 1997).

Antibiotics are often considered a key component in controlling various zoonotic factors, making antibiotic treatment a prominent strategy for managing bacterial zoonotic pathogens (Durborow 1999; Shin and Park 2018). Individuals involved in fish and fish derived food productions must be well-informed about zoonotic pathogens and preventive measures to reduce the risk of these diseases. Given the unavoidable interaction with water and fish in aquaculture systems, prevention remains the most effective strategy to mitigate the risks associated with zoonotic illnesses (Smith 2011). In the cases of food-borne zoonoses, the transmission of multidrug-resistant animal pathogens to humans through contaminated food is a significant concern. Addressing this critical issue necessitates the monitoring of multidrug-resistant microorganisms in both animals and humans, emphasizing the importance of collaborative efforts between veterinarians, physicians and environmental experts (Chowdhury et al. 2021).

It is important to take precautions such as avoiding direct contact with fish mucus and wearing disposable gloves. Consulting a physician is necessary, even if experiencing nonspecific symptoms. Regular handwashing, especially after direct contact with water and fish is the most effective measure. It is also important to refrain from eating or drinking without handwashing. Transmission of ZD-causing agents can occur through indirect or direct contact with insects, vectors, contaminated objects, inhalation and ingestion (Boylan 2011).

Adequate technological facilities and proper methodologies for handling fishing vessels are necessary to prevent fish contamination with various microorganisms, including parasites. Cooking fish at 62^{o}C for approximately 15 seconds is sufficient to kill parasites, but it may not be enough to detoxify certain bacterial toxins present in fish. To eliminate parasites from fish and test for their presence, informing fish sellers to inspect remaining fish and ensuring complete cooking of fish and fish-derived products are viable options (Seafood Health Facts 2020).

Research has shown that heat inactivation or freezing is the most effective method for reducing the risk of ZD (Ahuir-Baraja et al. 2021). Aquaculture systems, ranging from personal aquariums to large ponds, contain nutrient-rich water that promotes bacterial growth. Therefore, various studies have explored the use of chemicals for efficient disinfection of contaminated environments. To effectively prevent fish related zoonoses, it is important to handle chemicals safely, consider contact time, and ensure accurate dosage. Interestingly, drying or desiccation has also been identified as a reliable method for disinfecting zoonotic bacterial diseases (Chen 1995; Murrell 2002). While freezing can deactivate parasites in imported edible fish, not all captured fish undergo freezing conditions (Williams et al. 2022). The preference of consumers for cooked seafood products, including raw fish slices, can contribute to the transmission of zoonotic pathogens (You et al. 2021).

The effectiveness of preventive and control strategies in preventing outbreaks of ZD can be influenced by cultural practices. Consuming ready-to-eat raw fish products such as sushi and sashimi poses a biological hazard, highlighting the importance of strict governmental regulations to ensure the safety and quality of fish used for these purposes (Lehel et al. 2021). Additionally, the significant expansion of the freshwater ornamental fish sector has led to increased human-fish contact, which can contribute to the transmission of zoonotic infections. The presence of Mycobacterium species in freshwater ornamental fish has been observed, underscoring the magnitude of this challenge (Phillips Savage et al. 2022).

Fish handlers and veterinarians should take precautions to protect themselves from potential exposure to waterborne pathogens, particularly if they have abrasions or open wounds. Wearing disposable gloves is highly recommended during various activities involving fish such as handling fish tissues, mucus or waste products. In case where water contact is unavoidable, the use of gels, tissue glue and topical ointment such as triple antibiotic and silver sulfadiazine can provide additional surface wound protection, although gloves remain the preferred option (Grant and Olsen 1999; Boylan 2011).

Deep wounds should be promptly washed with regular or saline water and then disinfected using appropriate substances such as alcohol, hydrogen peroxide, betadine, or chlorhexidine. Serious injuries require immediate medical attention and pose a higher risk. Veterinarians play a crucial role in educating stake holders about ZD, demonstrating proper use of personal protective equipment, and informing patients to provide a comprehensive history if a suspected fish-derived zoonosis is identified. Effective communication between veterinarians, staff, patients, and hospitals is essential for education and management of fish-derived zoonoses (Grant and Olsen 1999; Boylan 2011).

To effectively address the complex issues of One Health related to seafood safety, it is imperative to foster active stakeholder engagement and establish strong interrelationships among them (Shamsi 2019). The World Health Organization (WHO) has documented that globalization and the widespread movement of people and animals have facilitated the worldwide dissemination of ZD. Furthermore, the absence of adequate public health facilities in rural areas, substandard transport systems for specimens and a dearth of proper laboratory facilities for early disease diagnosis have contributed to pathogen transmission. WHO reports have emphasized that the main barriers to controlling zoonotic infections and implementing a One Health System are diagnosis and detection, disease management, organizational challenges as well as halting pathogen transmission. Accordingly, the recommended measures include enhancing early disease and pathogen identification, managing infections, controlling vectors and rodents as well as promoting effective collaboration between animal & human health officials (World Health Organization 2021).

In order to effectively address zoonoses and prevent disease outbreaks, it is crucial to incorporate the "One Health" approach into the training of university students, research institutions, research teams as well as international organizations. The One Health (OH) framework is a comprehensive and interdisciplinary strategy that operates at various levels, aiming to achieve optimal health outcomes by recognizing the interconnectedness between animals, humans, plants as well as their shared environment. Successful implementation of the One Health system requires international collaboration and coordination between healthcare staff and veterinarians. To control fish-derived ZD and potential epidemics, it is imperative to combine regulated fish farming practices with measures such as minimizing water pollution and enhancing disease surveillance systems (Fig. 3) (Marbán-Castro et al. 2019; Aggarwal and Ramachandran 2020).

5. ORGANIZATIONS OVERLOOKING THE SPREAD OF FISH ZOONOSES AND SUCCESS STORIES

Numerous organizations have been established globally to prevent and control fish zoonoses. Although fish zoonoses pose minimal threats to humans, WHO recognizes the importance of addressing the issues (WHO, 2014). The Kenyan ZD Unit (ZDU), is an example of secretariate under the Zoonoses Technical Working Group (ZTWG), established in 2001 through the WHO One Health program. The ZDU is responsible for providing technical advices on fish zoonoses prevention and control in Kenya and is chaired on a rotational basis by the Director of Veterinary Service and the Director of Medical Service of the Government of Kenya. Control programs have been successful in Thailand for fish-borne trematodiases and in Peru for *Taenia solium* cysticercosis using available tools. Scaling up control strategies in endemic areas is essential to control the transmission of fish zoonoses. For instance, the “Lawa project” is working with a transdisciplinary team to control fish-borne trematodiasis in the north-eastern Lawa Lake region of Thailand, which had a high community prevalence of 67% before control activities began. The transmission of fish zoonotic trematodes (FZT) in fish nurseries was found to be high in northern Vietnam which can potentially seed a large number of grow-out farms with ZFTs. The prevalence of FZTs in fish decreases from 70% to 1% over ten years after a successful campaign. Despite the existence of One Health programs and ministries in every country, progress on fish zoonoses remain limited and the focus is primarily on other issues such as antibiotic resistance and parasitic infestations. The low prevalence and threat posed by fish-borne zoonoses contribute to the lack of successful studies in this area (Bardhan 2022) Table 2.

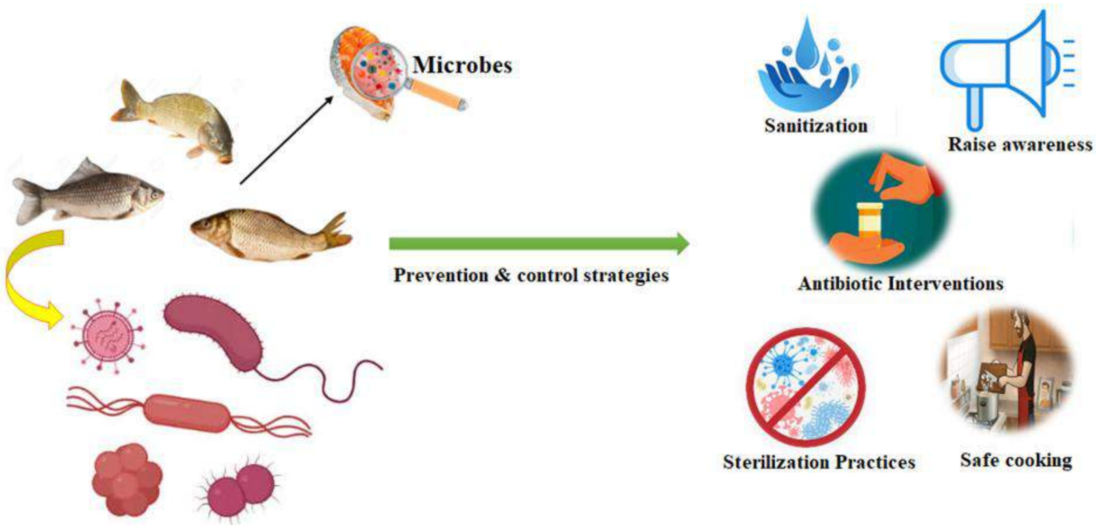

Fig. 3: Overview of prevention and control strategies of zoonotic diseases from fish.

Table 2: International initiatives addressing zoonotic risks associated with fishes

Project/organization	Country	Contribution	Reference
ZDU	Kenya	Prevention of fish-borne trematodiasis	
ZDU	Thailand		
ZDU	Peru	Controlling *Taenia solium cysticercosis*	(Bardhan 2022)
Lawa project	Thailand	Fish-born trematodiasis prevention	

CONCLUSION

In conclusion, the comprehensive strategies elucidated in this chapter underscore the imperative of proactive measures for preventing and controlling zoonotic diseases originating from fishes. By integrating rigorous surveillance, biosecurity protocols and collaborative research efforts, we can effectively mitigate the risks posed by these diseases at a global scale. Furthermore, the diverse range of international organizations dedicated to this cause exemplifies the concerted endeavor towards safeguarding human health.

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Assessment of Emergence, Economic Losses and Prevention of Zoonotic Infections

19

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ABSTRACT

Zoonotic diseases are emerging infections which can transmitted from animals to human and vice versa. Since decades, zoonotic infections such as monkeypox, buffalopox, camelpox, Covid-19, avian influenza virus, West Nile virus and Swine Influenza pose significant health concern which leading to substantial economic losses. This chapter will discuss all the aspects of zoonotic diseases regarding the emergence, economic losses, and preventive measures. The emergence of zoonotic diseases is a complicated process which is influenced by various sorts of factors such as climate, urbanization, deforestation, wildlife trafficking and human-animal interactions. The outbreak of zoonotic infections results in economic losses such as treatment, medical expenses, containment efforts, low productivity, trade restrictions and limited tourism. The pandemic Covid-19 serves as glaring example which adversely effect the world economies. Therefore, the prevention of these infections is indispensable to maintain the livelihood of human and animals. Various strategical measures such as surveillance, early detection systems, social distancing, isolation from infected person or animal, and vaccination can mitigate the risk of getting zoonotic diseases. Furthermore, strong collaboration between animal and human health sectors can facilitate the timely sharing of resources and information. Moreover, enhancing biosecurity measures such as trade of livestock and wildlife, animal trafficking, research and development of vaccines, modern diagnostic techniques and various sorts of therapeutic agents can limit the development of zoonotic diseases. In conclusion, zoonotic outbreaks have emerged, challenging, and inflicting substantial economic losses as well as affecting human health. However, by following aforementioned strategical measures, we can strive toward minimizing the occurrence of zoonotic diseases.

Key words: Zoonotic infections, Covid-19, Economic losses, preventive measures, Pandemic

CITATION

Hayat MF, Javed M, Ijaz MU, Khan HA, Ashraf A and Imran M, 2023. Assessment of emergence, economic losses and prevention of zoonotic infections. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 269-278. https://doi.org/10.47278/book.zoon/2023.019

CHAPTER HISTORY Received: 09-Jan-2023 Revised: 20-March-2023 Accepted: 21-June-2023

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1. INTRODUCTION

The word zoonosis is derived from two Greek words “Zoon” and “nosos”, which means animal illness. Any infection that is naturally transmissible from humans to vertebrate animals and from animals to humans is referred to as a zoonotic disease (Morand et al. 2014). The zoonotic diseases are further classified into anthropozoonosis, zooanthroponosis, amphixenosis, and euzoonosis (Messenger et al. 2014). Anthropozoonosis are those infections that can be transmitted to humans, such as rabies while zooanthroponosis refers to those diseases that are transmitted from human to animals such as tuberculosis can be transmitted to cats and monkeys. Whereas Amphizoonosis infections have the potential to spread bidirectionally such as infections spreading due to staphylococcus bacteria (Rahman et al. 2020) (Fig. 1).

It is documented that there are numerous pathogens underlying the development as well as progression of zoonotic diseases (Wang and Crameri 2014). On the basis of diseases etiology, zoonotic infections are apportioned into various categories such as viral zoonosis (AIDs, rabies), fungal zoonosis (Malaria, trichinosis), bacterial zoonosis (Plague, lyme disease) mycoplasma zoonosis, rickettsial zoonosis, protozoal zoonosis as well as non-viral pathogenic species such mad cow infection (Rahman et al. 2020). Asokan et al. (2011) summarized the data of infectious species which are referred to as pathogenic to humans. They recognized 1,415 species which include 217 viruses and prions, 307 fungi, 538 bacteria and rickettsia, 66 protozoa while 287 helminths. Zoonotic infections take place via three primary routes such as fecal, oral (by food and water) and via direct physical contact with infected animal or human (Balloux et al. 2017) (Fig. 2).

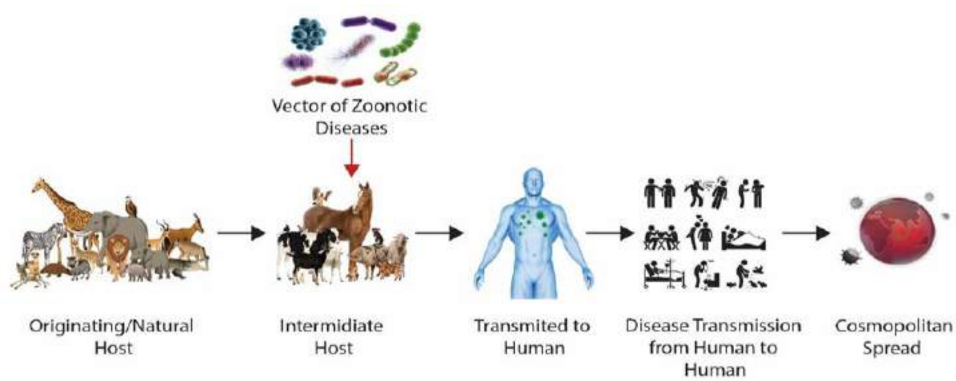

Fig. 1: General layout of various zoonotic infections transmission among various hosts

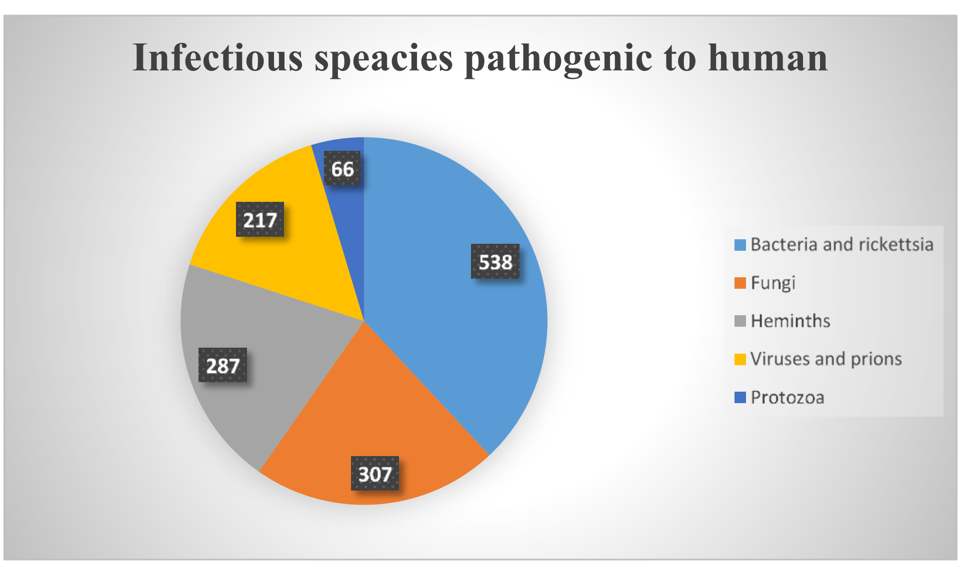

Fig. 2: Prevalence of various pathogenic species and their potential to infect humans

Zoonotic diseases are one of the most emerging infections around the world. Infectious diseases not only affect the health of the animals but also lead to severe economic losses (Alvi et al. 2023). An emerging zoonotic disease is referred to as newly identified, recently evolved, or previously observed infection that exhibits an increase in incidence or an extension in geographical, host, or vector range (WHO 2020). It is estimated that about two-thirds of newly and emerging infections are zoonotic diseases (Rahman et al. 2020). Over the past 70 years, approximately 250 zoonotic diseases have been reported as emerging infections. Owing to high incidence ratio and geographical distribution, many diseases have spread quickly over the globe (Woolhouse and Eleanor 2005). According to statistical data, almost 335 emerging infectious diseases (EID) are reported between 1940-2004. Moreover, COVID-19 and SARS-CoV-2 are also enlisted as EID of recent times (Yoo and Yoo 2020).

Various factors are responsible for the transmission of zoonotic infections such as adaptability of pathogenic species, habitat, behavior of animals and humans, vector biology, hygienic practices in animal yards, production systems of livestock, climate alterations, deforestation, urbanization, and food safety (Lindahl and Delia 2015). Wildlife is considered as the key reservoir for zoonotic infections which leads to the emergence and progression of zoonotic diseases (Kruse et al. 2004; Alvi et al. 2021). It is evidenced that up to 60,000 annual deaths are reported due to rabies and other diseases such as, the Elbola virus, Rift valley fever and Avian Influenza which exert a negative impact on the health of humans and animals (Grace et al. 2012). Most prominent emerging zoonotic diseases include Covid-19, thrombocytopenia syndrome, Ebola virus, encephalopathy, Nile fever, rabies, norovirus, leptospirosis, monkeypox, camelpox, hantavirus, MRSA infections and rotavirus diseases (Chomel et al. 2009; Kruse et al. 2004; Wang et al. 2020). While, rabies, brucellosis and tuberculosis (*M. bovis*), are considered as re-emerging zoonotic diseases (Table 1).

Table 1: Major outbreaks of zoonotic diseases and their way of transmission

Zoonotic diseases	Pathogen	Host	Mode of transmission	References
Monkeypox	Orthopox virus	Human, Dogs, Chimpanzee	By direct contact and sexual transmission	(Nuzzo et al. 2022)
cowpox	Orthopox virus	Human, Cat, Rat, Cattle	By direct contact with infected cow and other animals	(William et al. 2020)
camelpox	Orthopox viral disease	Human, camel	Direct contact with skin lesion, Air bone saliva droplets	(Khalafalla et al. 2017).
Avian Influenza	Type A viruses	Poultry	Exposure to infectious animals or environment	(Hill et al. 2022)
Swine Influenza	Type A influenza virus	Pig	Spread through air in droplets, contact with pig	(Meng et al. 2022)
Chikungunya virus	Viral disease	Small animals (like bats) along with non-human primates	By the bite of infected *Aedes mosquitoes*	(Burt et al. 2012)
West Nile virus	Single stranded RNA virus	Bats, birds, hors	Mosquitoes between birds and mammals.	(Suthar et al. 2013)
MERS-CoV	Infectious diseases	Bat	Unknown	(Reusken et al. 2013)
Filoviruses (Ebola and Marburg diseases)	Ebola and Marburg viruses	African fruit bats	Activities related to bushmeat, such as capturing and killing wild animals	(Amman et al. 2013)
Hendra virus	Bat born virus	Australian flying foxes, horse	Humans who had close contact with infected horse	(Clayton et al. 2013)
Nipah virus	Bat borne virus	Bat	Transmission from a bat directly to a human and vice versa.	(Homaira et al. 2010)
Crimean-Congo haemorrhagic fever virus	CCHF virus	Ticks	By tick bites that are infected or direct contact with tissues and blood	(Bente et al. 2013)

2. VARIOUS VIRAL ZOONOTIC DISEASES

2.1. MONKEYPOX

Monkeypox is termed as the most recent emerging disease which occurs owing to a DNA virus called "Monkeypox". The transmission of monkeypox is attributed to different factors such as physical contact with infected animals, people, or contaminated objects such as direct contact with monkeypox rash, scabs, large respiratory droplets, contaminated bedsheets, skin lesions or body fluids from an infected person with (Nuzzo et al. 2022). Monkeypox develops various sorts of complications such as pneumonitis, encephalitis, keratitis, and secondary bacterial infections. (WHO 2022).
The infection rate of monkeypox is observed to be high in individuals age less than 50 years while 69% of infected individuals were male. Monkeypox is considered a cosmopolitan disease owing to its prevalence in various regions of the world such as Europe, the Eastern Mediterranean, the Americas, and the Western Pacific (Simpson et al. 2020). More than 1,500 cases have been documented in 43 countries including Europe and North America by June 2022. Although the monkeypox virus is common in central and western Africa, its occurrence in the industrialized world has raised alarming indicators for its potential global emergence (Kumar et al. 2022). Studies show that the risk of serious consequences is higher in infants as well as in those individuals who have very low immunity such as people with HIV (Kozlov 2022).

2.2. BUFFALOPOX

Buffalopox is a common zoonotic disease found in buffaloes such as *Bubalus babalis* and rarely in cows due to viral infection. The primary causative agent of buffalopox is buffalopox virus which is the core member of Orthopoxvirus and closely resembles to Vaccinia virus. In the last 40 years, the prevalence of buffalopox has become high with a morbidity rate of 80% among domestic buffalo herds and cows (Singh et al. 2007; Yadav et al. 2010). Venkatesan et al. (2010) elaborated that it has been found in both young and old buffaloes. India is considered the origin of buffalopox but later it was spread to various other countries including Eastern and Western Europe. Milkers become highly susceptible to buffalopox owing to their physical connection with animals (Eltom et al. 2020). Clinical signs of buffalopox include wartline lesions on the udder, teats, inguinal region, and base of the ears (Borisevich et al. 2016). After infection, the infected person developed pyrexia, axillary lymphadenopathy, and general malaise along with pox-like local lesions on their hands, forearms, and forehead (Essbauer et al. 2010).

2.3. COWPOX

Cowpox (CPXY) is a rare zoonotic infection that is spread through physical contact with infected cows and other animals such as rats as well as cats in the workplace (William et al. 2020). It can infect milkers, resulting in a pustular eruption on the face, hands, or forearms, as well as a mild fever and lymphadenitis. Due to the wide range of hosts, this zoonotic disease can spread to unintended hosts such as rats, cats, cattle, horses, llamas, zoo animals, and humans, and frequently recorded a high ratio of incidence in Europe. Direct exposure to an affected cat, zoo animals, or pet rats has been the predominant method of CPXV zoonotic transmission (Switaj et al. 2015). There have been multiple cases of CPXV which transmit from cows, cats, and rats to people (Switaj et al. 2015; Lapa et al. 2019). Humans infected with CPXV frequently experience a restricted external lesion along with fatigue fever, lymphadenopathy as well as sores on the hands, fingers, and rarely on other parts of the body (Grönemeyer et al. 2017).

2.4. CAMELPOX

Since 2014, a plethora of evidence has demonstrated the transmission of camelpox virus (CMLV) from camels to humans in Eastern Sudan (Bera et al. 2019). Humans develop various symptoms of infections including fever, malaise, itching, and erythema, which ultimately lead to the development of nodules after 7–10 days. In 2012, Saudi Arabia recognized the first case of CMLV and in a few days' infection, approximately 1500 people were infected while 580 fatalities were reported (Al-Ahmadi et al. 2019). The number of cases was higher in those countries that are involved in rearing domestic camels such as Iran. It is reported that the milk as well as the meat of infected camels are contagious to humans and have potential to develop roots of CMLV. Furthermore, improper importation or smuggling of camels from nearby nations such as Afghanistan, Pakistan, and the United Arab Emirates (UAE) are major factors underlying the progression of CMLV. It is documented that camels having an age under 2 years are highly susceptible to CMLV with a fatality rate of 12-25% (Joseph et al. 2021). The camelpox virus (CMLV) in dromedary camels (*Camelus dromedarius*) and Bactrian camels (*C. bactrianus*) can cause respiratory distress, gastrointestinal distress, fever, nasal discharge, as well as the appearance of lesions on the head, neck, mouth, lips, limbs, inguinal and perianal areas, as well as in scrotum (Bera et al. 2011; Joseph et al. 2021).

2.5. CORONA VIRUS

Three catastrophic Coronavirus outbreaks have occurred in the previous 20 years, including the most recent pandemic of Coronavirus Disease 2019 (COVID-19) in China. Coronaviruses are diverse group positive sense, single stranded RNA as well as enveloped viruses (Zumla et al. 2016). Various evidence from infected individuals determined the mode of transmission. It is reported that COVID-19 transmits from human to human primarily through physical contact or respiratory droplets (Li et al. 2020; Chan et al. 2020). Severe respiratory problems are largely caused by this virally induced inflammatory illness of the lungs and airways. More than 200 nations and regions have recorded millions of incidences of COVID-19, which have caused health problems, fatalities, and financial losses (Ahmad et al. 2022). As discussed earlier, zoonotic infections have the potential to spread from animals to *Homo sapiens* such as infection of severe acute respiratory syndrome coronavirus 2. There is a substantial difference between the transmission of viral infection, potential to spread, death rates in various species as well and potential to adapt to a new habitat and ensure their persistence in population. The potential of corona virus to adapt and survive in a population as well as the pace at which they disseminate, escalates the rate of sickness and death in human (Kelvin and Salvatore 2020) (Table 2).

3. ASSESSMENT OF ECONOMIC LOSSES DUE TO ZOONOTIC DISEASES

A strong relationship exists between poverty and zoonotic diseases everywhere particularly where livestock is the main source of income (Cleaveland et al. 2017). Over the past 10 years, it is estimated that zoonotic infections account for more than 220$ billion in losses to growing economies (Narrod et al. 2012). Recent widespread pandemics such as COVID-19, H1N1, Swine flu, Ebola, and Nipah virus have had an impact on both animals and human health as well as their livelihoods. Buffalopox virus BPXV infection is currently becoming more prevalent and disseminated throughout Punjab, Pakistan. It is declared that annually approximately 6455$ USD in financial losses are owed to BPXV (Usmani et al. 2022). More than 1350 cases of monkeypox have been documented from 31 nonendemic states globally till June 09, 2022 (Guarner et al. 2022). Similarly, highly pathogenic avian influenza viruses (AIVs) are able to significantly increase bird fatality rates. About 1533 new cases out of which 607 human demises had been formally

Table 2: Various zoonotic diseases, their vector, host, and early symptoms of infection

Diseases	Caused by	Symptoms	Reference
Monkeypox	Monkey	Begins with fever and leads to pneumonitis, encephalitis, keratitis, and secondary bacterial infections	(World Health Organization 2022)
Buffalopox	Milch buffaloes (Bubalus Bubalis) and, rarely, cows.	The following symptoms include lymphadenopathy, fever, and malaise, severe blisters on the extremities of the body, face, and mouth.	(Borisevich et al. 2016)
Cowpox	Cattle, cats, dogs, horses, gerbils, voles, rats, mice	Lethargy, anorexia, dyspnea, eye discharge, and sneezing. Additionally, Observed abdominal distention and pneumonia.	(William et al. 2020)
Camelpox	Bactrian camels (*C. bactrianus*) and Dromedary camels (Camelus dromedarius).	Fever, nasal discharge, shingles on the limbs, inguinal and perianal regions, and scrotum; respiratory distress; and digestive discomfort.	(Bera et al. 2019)
Coronavirus	Wild cats, pigs, dogs, and chickens, bat species (Rousettus aegyptiacus).	2–5 days of malaise, headache, and fever. Lesion on the scrotum, vulva, or mouth.	(Ahmad et al. 2020)

documented till September 27, 2017 (Virlogeux et al. 2018). According to the European Commission, the EU economy would decline by more than 10% in 2020 due to the Covid-19 pandemic. The statistical data of 2020 revealed that the pandemic substantially decreased approximately 147 million full-time jobs which resulted in an economic loss of 3.8 billion dollars globally (Agovino and Gaetano 2022). Since 2020, COVID-19 collapsed the livestock as well as crop industries of China by about 2.3% and 1.1% respectively (Gong et al. 2021). Similarly, in 2014, the Ebola virus adversely affected the production of coffee (50%) and rice production (20%) in Ghana, thus ultimately reducing the agricultural economic growth (Zhang et al. 2020). In terms of socioeconomic impact, camelpox is noteworthy due to the immense losses attributed to sickness, death, abortion, weight loss, and decreased milk production. Rabies claims 60,000 lives each year, resulting in an 8.6-billion-dollar economic loss each year when direct and indirect costs are taken into consideration (Hampson et al. 2015).

4. PREVENTIVE MEASURES

The management of newly emerging and re-emerging zoonotic diseases requires ongoing, focused, and multidisciplinary approaches. Surveillance, laboratory testing, preparedness planning, and outbreak response are suitable approaches to mitigate the influence of zoonotic diseases (Van der Giessen et al. 2010; Kheirallah et al. 2021). Fig. 3 shows general layout to trace and control zoonotic infections.

According to WHO guidelines, a patient with moderate to severe infection of monkeypox should be isolated from other household members and appropriate infection prevention should be followed. Antipyretics and painkillers should be given to patients as symptomatic therapies, while malnourished individuals require sufficient diet and water (Ahmed et al. 2023). The United Nations System Coordinator for Combating Avian and Human Influenza (UNSIC) and the World Health Organization (WHO) collaborated to establish an international strategy for minimizing the risk of emerging zoonotic diseases with a greater emphasis on animal and human health issues. (Feng et al. 2014). It is reported that poultry incubation and vaccinations may prevent the progression of various zoonotic infections (Gao et al. 2014). It is documented that personal safety precautions are performed to mitigate the prevalence of respiratory viruses such as COVID-19, particularly prior to the availability of vaccines (Qualls et al. 2017). The five basic personal precautions recommended by the WHO against COVID-19 are "self-isolation," "frequent handwashing," "maintaining social distance," "avoid touching the eyes, nose, or mouth," and "respiratory etiquette". Similarly, the cost-efficient and most practical way to control and eradicate camelpox is on-time immunization as well as maintaining distance from infected animals (Narnaware et al. 2021). Targeting stray dogs as well as immunization of dogs significantly (70%) reduced rabies-based mortalities around the world (Fitzpatrick et al. 2016). Canine rabies vaccination is advised by the World Health Organization (WHO) to eradicate the illness in canine populations and subsequently in human populations (Schneider et al. 2007).

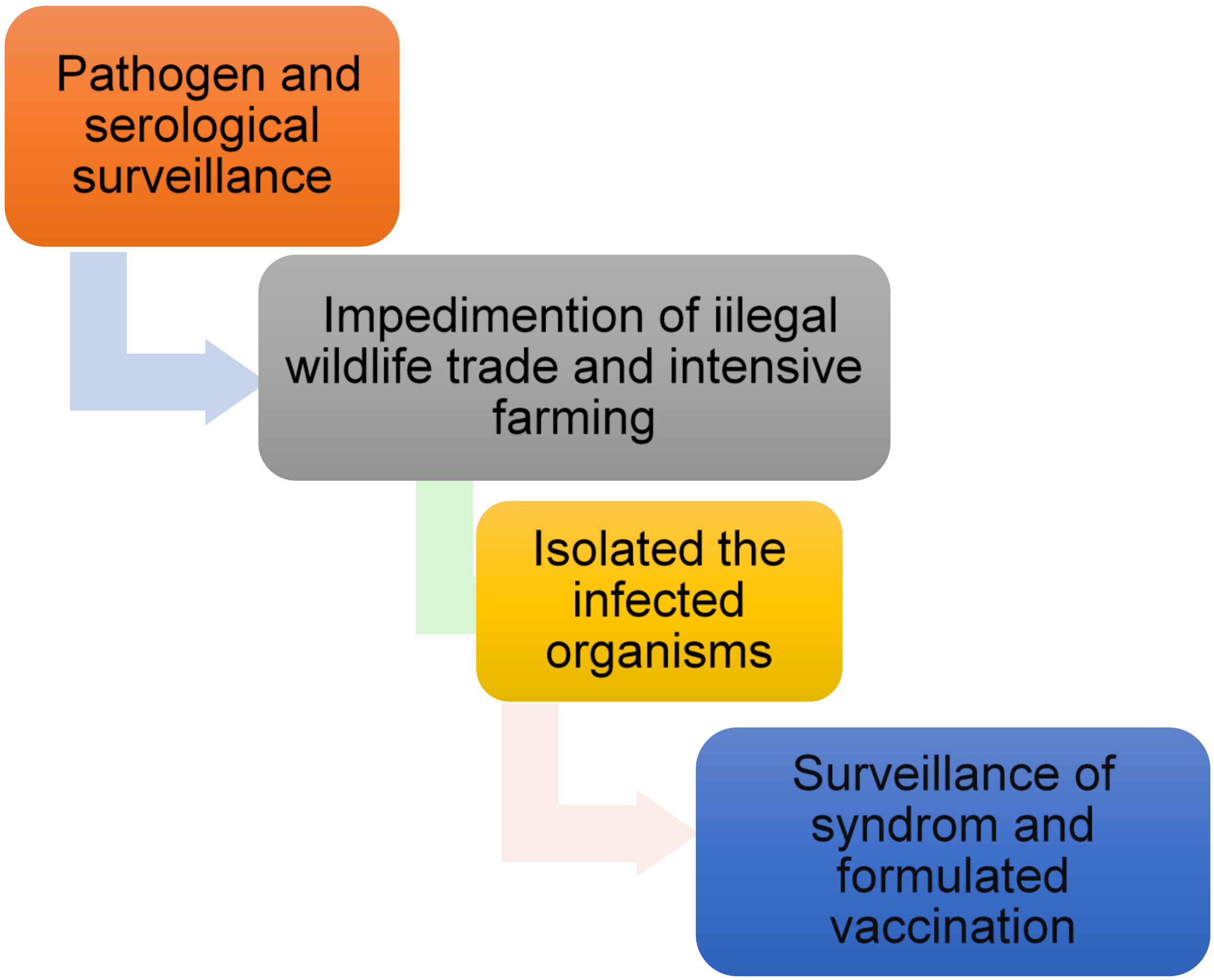

Fig. 3: A general layout to trace and control Zoonotic infections

5. CONCLUSION

In conclusion, the intricate relationship between humans and animals in our ecosystems has underscored the prevalence of various zoonotic diseases. The occurrence of various zoonotic diseases such as monkeypox, cowpox, buffalopox, camelpox, and COVID-19 established a vulnerable co-existence between animals and humans in the same place. These zoonotic diseases exert profound impacts on our economy and remarkably disrupt the balance of financial assets. To overcome the risks of these infections, multifaceted preventive measures are the dire need of the current era. These strategies involved monitoring and surveillance, wildlife management, rigorous hygiene practices, and the development of robust vaccines. Furthermore, a strong collaboration among environmental scientists, policymakers, health professionals, and communities is a pivotal part of preventive measures and control.

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Companion Animal Zoonosis: One Health Approach to Prevention and Control

20

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ABSTRACT

Zoonoses, infectious diseases transmissible between humans and animals, pose significant threats to global health. Despite the joy and companionship offered by pets, they can also harbor zoonotic pathogens, making it crucial to comprehend and manage this dynamic. The One Health philosophy, integrating veterinary expertise, medical knowledge, and collaboration among diverse professionals, emerges as a comprehensive strategy. The chapter explores the transmission patterns of zoonotic diseases in companion animals, highlighting their role as potential reservoirs. It examines the One Health Concept, emphasizing preventive actions such as vaccinations, regular screenings, and responsible pet ownership. The interconnectedness of human, animal, and environmental health necessitates a unified effort for effective prevention and control. The importance of research, surveillance, and global collaboration in understanding and combating zoonotic diseases is underscored. Adopting a One Health approach is pivotal to ensuring the well-being of both humans and their cherished animal companions. The chapter advocates for multidisciplinary cooperation, responsible pet care, preventive measures, and thorough research as essential components of a holistic strategy. By embracing this approach, the global community can create a safer and more interconnected system for managing zoonotic illnesses, fostering a healthier coexistence between people and their beloved pets.

Keywords: Zoonotic diseases, One Health approach, Companion animals, Disease transmission, Preventive measures

CITATION

Batool A and Dur-e-Najaf H, 2023. Companion animal zoonosis: one health approach to prevention and control. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 279-292. https://doi.org/10.47278/book.zoon/2023.020

CHAPTER HISTORY Received: 25-Feb-2023 Revised: 23-June-2023 Accepted: 20-Aug-2023

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1. INTRODUCTION

The concept of zoonosis looms large as a constant reminder of our susceptibility to infectious diseases in a connected world where people and animals live. The sneaky infections known as zoonoses, which exist between different species, have the power to cause havoc in people's lives, put a strain on the medical system, and even start worldwide pandemics. Companion animals play a special part in the complex dance of disease transmission, despite. Companion animals have a special place in our hearts and are steadfast in their love and loyalty. We have a variety of furry friends who provide us happiness, comfort, and unwavering love, including dogs who welcome us with wagging tails, cats who cuddle up on our laps, and other animals. Behind this appearance of camaraderie, however, there is a hidden threat since these beloved pets may also be home to zoonotic diseases that could spread disease to humans. The importance of comprehending and managing the complex interaction between companion animals and zoonosis necessitates the use of a One Health approach, a comprehensive and cooperative strategy that cuts across conventional lines because it enables us to combine the knowledge of veterinary specialists, medical professionals, epidemiologists, researchers, and pet owners. Together, we can traverse the complex world of zoonotic diseases, putting prevention, control, and the improvement of human and animal health as our main priorities. The interesting world of companion animal zoonosis will be examined in this chapter through the prism of the One Health philosophy. We shall understand the intricacy of disease transmission patterns within our closest animal companions by examining the dangers companion animals provide as potential reservoirs or carriers of zoonotic infections. We will also look at creative therapies, collaborative projects, and inventive tactics that make use of One Health's guiding principles to prevent and manage zoonosis in companion animals.

In the end, we may pave a route toward a future where the joys of friendship with our furry friends need not be overshadowed by the specter of zoonotic diseases by leveraging the power of information, collaboration, and shared responsibility. We can secure the health and well-being of both people and their beloved animal friends by adopting a unified One Health approach. This will promote peaceful interspecies cooperation and protect the relationship that has enriched our lives for millennia. This chapter reviews some important zoonotic diseases of companion animals and their prevention by achieving optimal health outcomes by understanding the interconnectedness of humans, animals and their common environment.

2. VIRAL DISEASES

2.1. RABIES

Rabies is caused by a single-stranded RNA virus belonging to family Rhabdoviridae. It is a deadly disease in humans as well as animals that have been around for a long time. According to World Health Organization data, rabies infection causes between 30000 and 70000 deaths worldwide each year (Krebs et al. 2004). Rabies is typically spread by dogs. Most people in underdeveloped nations contract rabies from canine bites, while in opulent countries the disease is more commonly spread by contact with wild animals such as bats and foxes (Tang et al. 2005). Extensive vaccination of domesticated dogs was used as part of a rabies control program in the United States, leading to a decrease in the prevalence of the disease (Krebs et al. 2004). Based on size and area of the inoculating lesion, the incubation period for rabies can be anywhere from a few days to several years. Hydrophobia, agitation, anxiety, bewilderment, hallucinations, and other symptoms may be displayed by patients. Post-exposure prophylaxis with multiple doses of human rabies immunoglobulin (HRIG) can prevent rabies in time duration of 14 days after a suspected canine bite. Using water and liquid soap to clean the wound can drastically cut down on the virus's head start, and infection with rabies is likely (Lucas et al. 2008). Fig. 1 shows the pathogenesis of rabies.

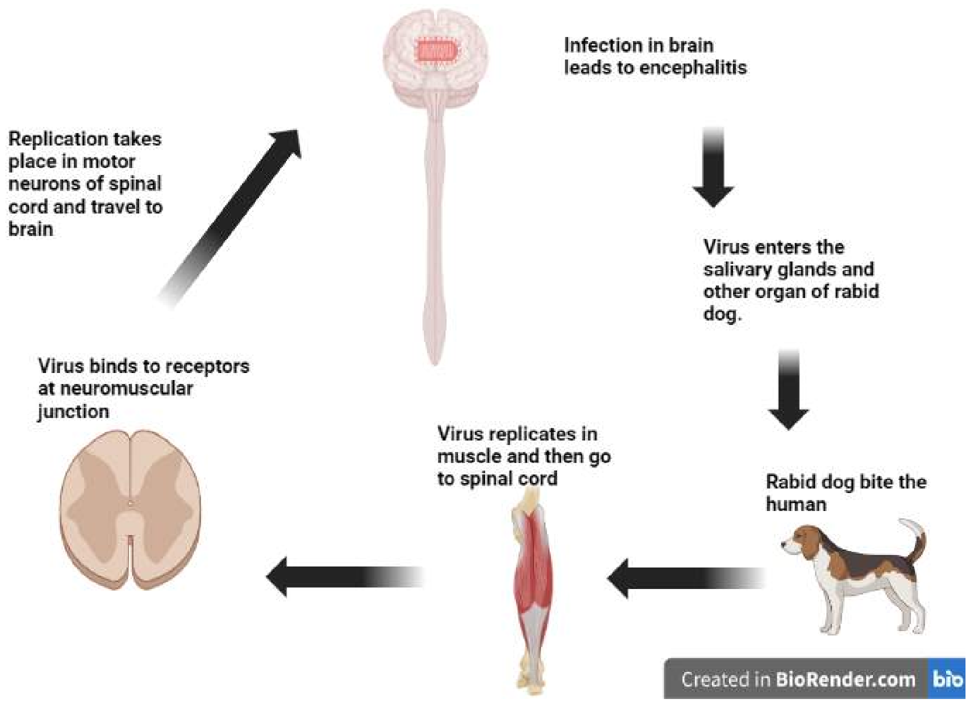

Fig. 1: shows the pathogenesis of rabies virus.

2.2. NOROVIRUSES

Noroviruses are a diverse group of single-stranded RNA viruses that are classified within the *Caliciviridae* family. The majority of cases of sporadic and epidemic gastroenteritis in humans are caused by *noroviruses* (Summa et al. 2012). All age groups are susceptible to this virus. Infected canine faeces and diarrhea contain the virus since it is produced in the dog's digestive system. Infected persons can spread the disease to others through contact with contaminated food or water, and the fecal oral rate can cause the infection to spread rapidly through a population. In cases of acute gastroenteritis, serum treatment may be beneficial for the patient.

3. BACTERIAL DISEASES

3.1. PASTEURELLA

Pasteurella belongs to Gram-negative coccobacilli that are predominantly present in animals. Pasteurella species are commonly found as part of the normal microbial community inhabiting the canine and feline URT (upper respiratory tract). A human can contract *Pasteurella* by direct contact with an infected animal, such as a dog or cat, or through indirect contact, such as through a dog or cat's bite, lick, or scratch. *Pasteurella* infection has the potential to be transferred to humans through both direct and indirect means, including contact with dog or cat bites, licks, and even scratches inflicted by cats (Oehler et al. 2009) . *Pasteurella* spp. is responsible for causing numerous infectious diseases in the human population. The transmission of *Pasteurella* spp. is primarily associated with the soft tissue infection, which holds significant importance in the realm of infections. Nevertheless, conditions such as meningitis, as well as bone and joint infections, *Pasteurella* spp. have the potential to serve as a vector for the transmission of respiratory infections. In a future research project of the United States, it has been presented that this organism exhibits the highest frequency. Dog and cat bites served as the source for the organism (Talan et al. 1999). *Pasteurella* Infections can be effectively treated through the utilization of second and third generation therapeutic interventions. Cephalosporin, macrolides, and fluoroquinolones are classes of antibiotics commonly used in clinical practice. The medications cotrimoxazole and penicillin have been mentioned. Fig. 2 shows mechanism of pathogenicity of *Pasteurella multocida.*

3.2. SALMONELLA

Salmonella species are anaerobic, motile gram-negative bacilli that can colonize the large intestine of many mammals, including dogs. They have a strong preference for the colon's distal portion and the mesenteric lymph nodes. Infections can also be transmitted to humans via feces. This mode of transmission can lead to the development of various infectious diseases, including gastroenteritis, enteric fever, bacteremia, and osteomyelitis. GIT infections represent the most commonly observed symptom of salmonella infection affecting both humans and canines. It is worth noting that a significant proportion of infected individuals, whether they are animals or humans, do not exhibit any symptoms and can continue to excrete the pathogen through their faeces for up to six weeks. Despite not showing any symptoms themselves, these carriers could potentially spread the disease to others. In developing countries, the prevalence of *Salmonella* spp. is higher compared to developed countries (Leonard 2014). It is advisable to conduct an antibiogram for patients who have contracted this organism. Effective treatment can be done using different classes of antibiotics such as fluoroquinolones, beta-lactams, and macrolides (Leonard et al. 2011).

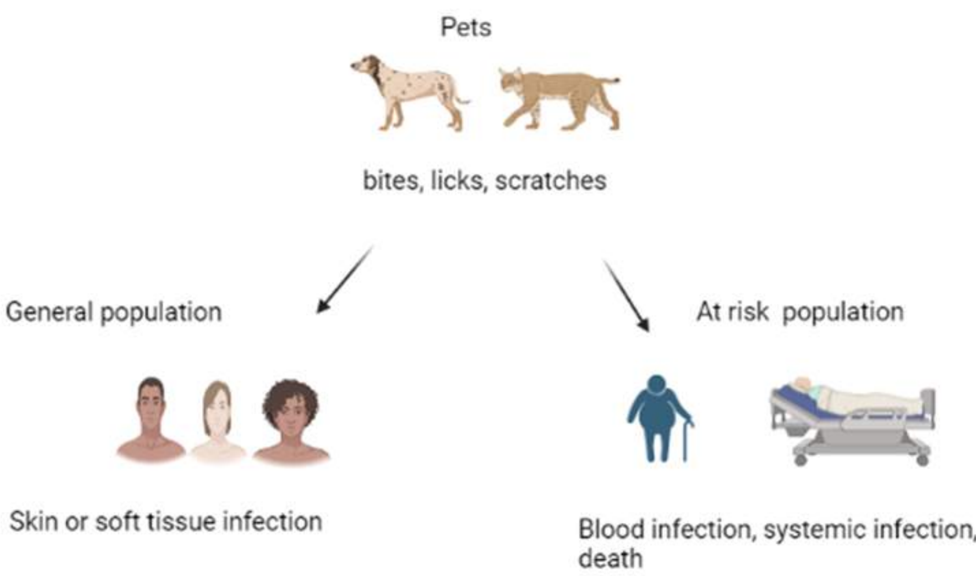

Fig. 2: Mechanism of pathogenicity of *Pasteurella*

3.3. BRUCELLA

Brucellosis is a highly prevalent zoonotic disease that places a significant burden on national healthcare systems. The transmission of the disease to humans often occurs through the consumption of dairy products that have not undergone the process of pasteurization. Multiple strains of brucella spp. have been identified, leading to the occurrence of human brucellosis, *Brucella(B.) canis*'s role as a frequent human brucellosis pathogen has remained underrecognized. However, *B. canis* has been relatively less recognized as a common pathogen in human brucellosis infections (Seleem et al. 2010). While *B. canis* does not typically cause brucellosis infection in humans, there have been reported instances of this infection primarily among farmers who have had previous contact with bodily fluids from dogs that were infected with *B. canis*. The incubation phase typically lasts for one to four weeks, but it can go on for months in extreme situations. Symptoms include pyrexia, night sweats, and low back pain, may be experienced by patients, especially in endemic areas, or asymptomatic individuals. It is important to distinguish these symptoms from those of tuberculosis and other types of malignancies (Roushan et al. 2004). Treatment of brucellosis is imperative to mitigate the potential complications and sequelae associated with the disease. Combination therapies, commonly utilized in the management of brucellosis, involved the administration of doxycycline in conjunction with either streptomycin or rifampin for duration of 6 weeks (Pappas et al. 2005).

3.4. YERSINIA ENTEROCOLITICA

Yersinia (Y.) enterocolitica is a zoonotic pathogen, coccobacillus and gram-negative in nature responsible for causing yersiniosis in both humans and animals. Various animals serve as primary reservoirs for *Y. enterocolitica*, encompassing avian species, swine, cervids, and bovines. In certain studies, the pathogen has been identified and separated from a wound caused by a dog bite (Fredriksson-Ahomaa et al. 2009). In the early stages, patients may exhibit no symptoms, but upon invasion of the mucosal surface of the intestine by the pathogen, they may experience the presence of watery or bloody diarrhea. The pathogen has the potential to affect the payer’s patches and manifest symptoms similar to appendicitis. *Yersinia enterocolitica* is primarily a self-limiting illness that typically does not necessitate the use of antibiotics. Nonetheless, individuals with severe infections and compromised immune systems should receive treatment involving a combination of an aminoglycoside and doxycycline.

3.5. CAMPYLOBACTER

Campylobacter species, such as *Campylobacter jejuni* and *Campylobacter coli*, are classified as gram-negative bacteria and are commonly associated with the development of enteritis. It typically inhabits the GIT of various animal species. The primary mode of campylobacter transmission is through close proximity to infected animals or their byproducts. Canines, including both adult dogs and young puppies, serve as the primary hosts for the bacterium known as *campylobacter*. In a conducted study, it was observed that approximately 47% of the fecal specimens obtained from dogs were found to contain isolated campylobacter (Janda et al. 2006). The duration of the incubation period in *campylobacter enteritis* exhibits variability, ranging from one to seven days. Most patients exhibit symptoms such as fever, vomiting, diarrhea, and abdominal pain. Moreover, it is noteworthy that bloody diarrhea has been observed in over 50% of the afflicted individuals. In certain patients, convulsion and seizure may be observed. This infection typically exhibits a self-limiting course and does not necessitate the administration of antimicrobial therapy. Hydration and balance of electrolytes should be given due consideration. Patients with severe disease are recommended to undergo antibiotic therapy using fluoroquinolones, macrolides, or aminoglycosides (Ternhag et al. 2007).

3.6. CAPNOCYTOPHAGA CANIMORSUS

The gram-negative bacterium *Capnocytophaga canimorsus* is a member of the typical microbial population of the canine and feline oropharyngeal tract. The spread of microbe to humans primarily occurs through dog bites, resulting in a severe sepsis that is particularly prevalent among elderly individuals, those with compromised immune systems, or patients who have undergone splenectom (Janda et al. 2006) . Additionally, the pathogen has the potential to cause various life-threatening infections such as meningitis, osteomyelitis, arthritis, lung abscess or emphysema, and endocarditis. Furthermore, it is worth noting that *Capnocytophaga septicemia*, particularly in individuals with compromised immune systems, has been found to be potentially linked to thrombotic thrombocytopenic purpura and hemolytic uremic syndrome (Biedermann and Deligne 2004). Evidence from the literature suggests that around thirty-three percent of people infected with *Capnocytophaga* will die from their infection within a year. As a result, people who have received a canine bite should seriously consider starting early empirical treatment with third-generation cephalosporins.

3.7. BORDETELLA BRONCHISEPTICA

The bacterium *Bordetella bronchiseptica* belongs to the genus Bordetella and is a gram-negative rod. Canine and feline upper respiratory tracts are common reservoirs for the infection that can be spread to humans via airborne droplets. *Bordetella (B.) bronchiseptica* has the potential to cause acute tracheobronchitis in canines, characterized by a harsh and persistent cough commonly referred to as kennel cough (Woolfrey and Moody 1991). The incidence of human infection with *B. bronchiseptica* is infrequent; nevertheless, this pathogen has the potential to induce pneumonia and upper respiratory tract infection in individuals who own dogs (Hemsworth and Pizer 2006). Multiple studies have provided evidence indicating that this particular organism exhibits resistance to macrolides and cephalosporins. However, it has been observed in various studies that the organism displays sensitivity to fluoroquinolones and Trimethoprim/sulfamethoxazole.

3.8. COXIELLA BURNETII

Coxiella(C.) burnetii is a gram-negative bacterium that is classified as an obligate intracellular pathogen. It is responsible for causing Q fever, a zoonotic disease in humans. Infection normally occurs when a person breathes in aerosolized pathogen or comes into touch with the fluids of an animal that is already affected. A study indicated that about 10% of farm dogs carried C. burnetii, despite the fact that dogs are not thought to be the principal reservoirs for this bacteria (Cosman et al. 2013). Furthermore, a separate study conducted by Buhariwalla and colleagues revealed that transmission of *C. burnetii* from an infected parturient dog to humans was observed. Furthermore, the patients exhibited symptoms consistent with Q fever, such as fever, chills, nausea, vomiting, and a productive cough. Opacity is a frequently observed characteristic in chest radiography, while crackles may be detected through auscultation during physical examination. The study estimated that the incubation period following exposure to the infected animal ranged from 8 to 12 days. Successful treatment of patients infected with *C. burnetii* can be achieved through the administration of fluoroquinolones or doxycycline (Patel et al. 2011).

3.9. LEPTOSPIRA

Leptospira (L.), specifically *L. interrogans*, is a type of aerobic spirochete that serves as the primary etiological agent responsible for the occurrence of Leptospirosis in humans. Leptospirosis is a globally prevalent zoonotic disease that is primarily transmitted to humans through various environmental sources, such as soil, water, urine, or infected animal tissues as shown in Fig. 3. Rodents serve as the primary reservoirs for the transmission of Leptospirosis. Nevertheless, it is worth noting that domestic animals, such as dogs, can also contribute significantly to the transmission of Leptospirosis in regions where the disease is prevalent (Moore et al. 2006). Direct contact of infected urine with mucosal surfaces of the human body, such as the eye, vagina, nose, mouth, or erosive lesions, is the primary mode of transmission of Leptospirosis (Fig. 3). This infection has an incubation period of 2–26 days, with a median of 10 days. Leptospirosis can cause a wide variety of symptoms, from no symptoms at all to high fever, a persistent but non-productive cough, a sore neck and back, a loss of appetite, stomach cramps, bloody diarrhea, vomiting, and even a bleed in the lungs or brain (meningitis). A variety of antibiotics, including doxycycline, ceftriaxone, cefotaxime, penicillin, amoxicillin, and ampicillin, have demonstrated efficacy in the treatment of Leptospirosis (Kobayashi 2001).

3.10. STAPHYLOCOCCUS

Staphylococcus(S.) intermedius is a species of bacteria that belongs to the Staphylococcus genus. *S.s intermedius* is a coagulase-positive, gram-positive bacterium that lives in the anterior nasal cavity of many animals, including dogs, pigeons, and horses. Multiple lines of evidence show that the gingival region of healthy canines is also a viable source for isolating this particular virus (Hoekstra and Paulton 2002). *S. intermedius* is not frequently observed as a zoonotic pathogen in the human population. Nevertheless, multiple studies have provided evidence suggesting that this bacterium has the capability to cause infection in humans who have suffered dog bite wounds, leading to the development of cellulitis (Barr et al. 1953). It is imperative to differentiate this pathogen from *S. aureus*. Penicillin and amoxicillin-clavulanate have been found to be efficacious in the therapeutic management of this particular infection.

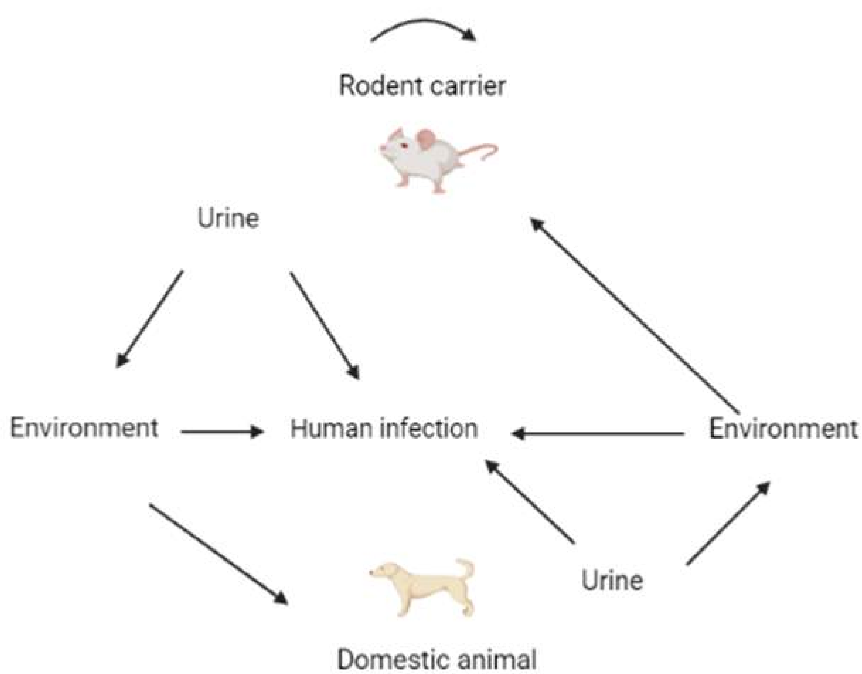

Fig. 3: Transmission cycle of Leptospirosis

3.11. METHICILLIN-RESISTANT *STAPHYLOCOCCUS AUREUS* (MRSA)

Methicillin-resistant *Staphylococcus aureus* (MRSA) is a significant contributor to lethal infections in the human population. Multiple studies have documented the isolation of this pathogen from various animal species, including pigs, horses, cattle, cats, and dogs. Among the individuals surveyed, a subset held the belief that companion animals served as the primary reservoirs for the transmission of MRSA, as they were capable of transmitting the bacterium through direct contact with their human owners. However, it appears that the transmission of MRSA from animals to humans is predominantly observed in individuals with compromised immune systems. However, there is evidence indicating that this bacterium has the potential to be transmitted to humans who are in possession of an infected animal (Välimäki et al. 2005). The efficacy of conventional antibiotics against MRSA infections is not superior. Therefore, recent pharmaceuticals such as vancomycin, linezolid, and daptomycin have gained significant usage in the management of MRSA infections (Morgan 2008).

4. ENDOPARASITES

Toxoplasma gondii and *Toxocara(T.) cati* are two examples of protozoan and ascarid zoonotic parasites, respectively, that mostly infect felids (both domestic and wild). *B. procyonis*, like raccoons, serves as a host for these parasites, and excretes the highly resistant eggs (*Toxocara*) or oocysts (*Toxoplasma*) (Hernandez et al. 2013). Infected humans may not show symptoms until months or longer period after the cat has successfully removed the parasite egg. Because of this factor, outdoor recreational areas such as playgrounds, garden soil, sandboxes, and similar locations that are contaminated with cat faeces have the potential to act as a reservoir for human infection (Holland and Smith 2006). The occurrence of *T. cati* was found to be more prominent in urban regions compared to rural regions. *T. cati*, unlike its canine counterpart *T. canis*, was more commonly found in soil samples from metropolitan parks. The study indicates a positive correlation between elevated levels of T. cati and the presence of free-roaming cats in urban environments. Infections caused by *T. cati* have been linked to larval migrans affecting the viscera and eyes, which can lead to irreversible ocular impairment in affected individuals (Lee et al. 2010).Toxoplasmosis is primarily contracted by humans through the ingestion of sporulated oocysts found in soil or water contaminated with cat faeces, or through the consumption of undercooked or raw meat containing tissue cysts (Elmore et al. 2010). According to researchers, it was shown that the frequency of T. gondii was lowest in indoor-only cats and highest in free-roaming cats (Kulasena et al. 2011). The primary risk factor for human toxoplasmosis has been demonstrated to be contact with infective *T. gondii* oocysts in cat feces. For a significant period of time, the likelihood of contracting an infection from oocysts has been regarded as significantly less prevalent compared to the risk of infection resulting from the consumption of undercooked or raw meat. In a recent study conducted by (Hill et al. 2011), a specific antibody called TgERP, which is associated with embryogenesis in *T. gondii*, has been developed. This antibody is unique to sporozoites, enabling the differentiation between oocyst and tissue cyst infections. This distinction is possible because sporozoites are exclusively found in oocysts. Approximately 6-8 months after infection, the TgERP can be detected, allowing for early identification of oocyst infection. Researchers found that 103 (or 63%) of 163 patients in the acute infection stage tested positive for TgERP. This finding suggests that a significant proportion of human infections can be attributed to oocyst infection. Toxoplasma infections have the potential to present themselves as ocular diseases, neurological impairments, and can result in blindness, abortions, and birth defects, specifically hydrocephalus, in human beings (Dubey and Odening 2001). Toxoplasmosis poses a substantial risk to individuals undergoing immunosuppressive therapy, as well as transplant recipients, and is a prominent contributor to systemic infection and mortality among immunosuppressed patients, such as those with HIV/AIDS. There have been suggestions of a heightened susceptibility to schizophrenia, autism, Alzheimer's, and other neuro-inflammatory diseases in relation to T. gondii infection (Fekadu et al. 2010). However, additional investigation is necessary to gain a comprehensive understanding of the neurological impacts of T. gondii. Toxoplasmosis poses a significant disease concern for wildlife, affecting various species of wild birds and mammals, particularly marine mammals and Australian marsupials. This has been well-documented in scientific literature by researchers such as (Dubey and Odening 2001) .Furthermore, toxoplasmosis plays a significant role in inducing abortion in domestic animals such as sheep and goats. Furthermore, there have been documented cases of human infections with domestic cat hookworms, specifically *Uncinaria stenocephala*, *Ancyclostoma tubaeforme, A. brazilense*, and *A. ceylanicum* (Bowman et al. 2010). Hookworms are parasites that infect both animals and humans through their filariform larvae, which emerge from hookworm eggs after defecation. Skin lesions caused by infective larvae are called cutaneous larva migrans (CLM), and they can also cause pneumonitis, muscular infection, and ocular symptoms, albeit these are much less common. In some instances, A. ceylanicum has the potential to mature into a fully developed hookworm within the human body, resulting in abdominal discomfort(Prociv 1998) . There have been multiple documented cases of human infections caused by feline hookworms, which have been reported in soil found beneath residential structures or on beaches where cats have defecated. According to (Anderson et al. 2003), approximately 75% of the free-roaming cats in Florida tested positive for *A. tubaeforme*, while 33% were found to be positive for *A. braziliense*. In the year 2006, a total of 22 individuals received a diagnosis of Cutaneous Larva Migrans (CLM) while attending a children's camp located in Miami-Dade County. The Centers for Disease Control and Prevention (CDC) reported in 2007 that while free-roaming cats were observed near the camp, the exact origin of the infection could not be ascertained. According to a personal communication from the Miami-Dade Health Department, in 2010, at least seven confirmed and eight probable cases of human hookworm infections trace their origins to beaches in Miami-Dade County that were contaminated by cat feces. To reduce the likelihood of further human illnesses, the County public health agency paid for and took responsibility for trapping the stray cats as well as disposing of the feces left behind. A tapeworm of the genus Echinococcus infection is referred to as echinococcosis. Despite spending a portion of its life cycle inside rodents (who are its intermediate hosts), E. multilocularis is principally a parasite of coyotes and foxes. Echinococcosis can be transmitted to dogs by the consumption of diseased rodents (such as mice and squirrels) or other small mammals, such as rabbits(Mani and Maguire 2009). Alveolar echinococcosis and cystic echinococcosis are the two most significant types in humans. Humans can become infected by eating or drinking contaminated food, water, or soil, or by coming into close contact with animal hosts. Treatment for echinococcosis is frequently expensive and difficult, and it may call for significant surgery or protracted pharmacological therapy. Dog deworming is the main component of prevention programs because dogs are the only hosts. In the case of cystic echinococcosis, additional preventive measures include dog deworming, slaughterhouse cleanliness, and community awareness campaigns. Echinococcosis affects more than 1 million individuals at once. Cystecercosis is caused by *Taenia solium.* Humans are the definitive hosts, followed by domestic and wild pigs, and sporadically other mammals like humans, as intermediate hosts. Where pigs are raised and have access to human waste, the cycle can continue. Most occurrences occur in rural regions with poor sanitation in Africa, Asia, Central America, and the US. Sporadic cases can occur in affluent nations like the US, particularly in foci where human carriers transmit eggs to other humans. Eggs may be found in water, vegetables (or other food infected by human carriers), dirt, or even in water. Ingestion of eggs (including autoinfection from eggs shed by adult parasite in human intestine) is a likely method of transmission to humans. Clinical instances are most frequently documented in subcutaneous tissues, the central nervous system, and the eye in humans. Numerous cysts in the muscles can also be symptomatic.

5. ECTOPARASITES

Ectoparasites that infest domestic cats, particularly the cat flea (*Ctenocephalides felis*), play a significant role in the transmission of zoonotic diseases. There are three significant diseases that are associated with fleas in cats in the United States. These diseases include cat-scratch disease (CSD), flea-borne typhus, and plague (McElroy et al. 2010). Cat-scratch disease, also known as bartonellosis, is attributed to the pathogenic gram-negative bacterium. Cats are the most important reservoir of Bartonella henselae, despite the fact that they show no outward signs of sickness. There are a number of ways in which animals can transmit disease to humans, including by entering an open wound, scratching a human, or biting a human. Additionally, transmission can also happen through the contamination of flea faeces with B. henselae. Fleas obtain B. henselae bacteria through a prior blood meal from a cat that is infected. Symptoms observed in individuals affected by cat scratch disease (CSD) encompass fever, headaches, and localised lymph node enlargement. This particular ailment represents a commonly encountered diagnosis of benign lymphadenopathy among paediatric populations. According to(McElroy et al. 2010), this study focuses on the population of young adults. Atypical complications, such as encephalitis, retinitis, and endocarditis, have been observed in 5-15% of humans infected with CSD (Chomel et al. 2004). Additionally, recent studies have found an association between Bartonella spp. infection and chronic rheumatic symptoms that resemble those of chronic Lyme disease in humans (Maggi et al. 2012). Studies show that the seroprevalence of B. henselae in cat's ranges from 14% to 93% (Case et al. 2006). In addition, it was observed by (Nutter et al. 2004) that the seroprevalence was substantially greater in free-roaming cats compared to pet cats. Besides the ability to spread CSD, cat fleas can also spread rickettsial diseases including murine typhus (Rickettsia typhi) and the closely related zoonotic disease agent Rickettsia felis. In places with high densities of cats, rodents, or fleas, these diseases could spread and endanger human health (Case et al. 2006). In a manner analogous to that of CSD, R. typhi can be carried by cats without causing any outward signs of illness (Case et al. 2006). In addition, it was observed by (Nutter et al. 2004) that the seroprevalence was substantially greater in free-roaming cats compared to pet cats. Besides the ability to spread CSD, cat fleas can also spread rickettsial diseases including murine typhus (Rickettsia typhi) and the closely related zoonotic disease agent Rickettsia felis. In places with high densities of cats, rodents, or fleas, these diseases could spread and endanger human health (Case et al. 2006). Just like CSD, felines carry R. typhi without showing any visible symptoms, and instances of outbreaks have been linked to the presence of free-roaming cat colonies in Hawaii (Jessup et al. 1993). Additional documented instances of murine typhus in the United States have been primarily observed in central and south-central Texas, as well as the Los Angeles area (Adams et al. 1970). In the study conducted by (Sorvillo et al. 1993), it was observed that 90% (n=9) of the cats collected in the Los Angeles R. typhi focus were found to be seropositive for R. typhi antibodies. Conversely, no seropositive cats (n=21) were identified in the control areas where no human infections had been reported. The initial course of action in public health often involves the suppression of fleas. Nevertheless, if the population of free-roaming cats is not effectively managed, it can result in subsequent outbreaks of disease. Moreover, there have been documented cases of human bacterial diseases such as tularemia, which is caused by Francisella tularensis, and plague, caused by Yersinia pestis, being linked to direct contact with cats or cat fleas (McElroy et al. 2010). Around 8% of plague cases in the USA are linked to transmission from cats. Reports of cat exposure associated with plague occur throughout the year, while cases related to flea transmission are typically limited to warmer months. Cats commonly exhibit a higher susceptibility to the pneumonic variant of the plague, a highly contagious form that poses a greater risk to humans in close proximity. This particular strain of the plague leads to a rapidly advancing and often fatal illness. Both tularemia and plague have the potential to induce a range of symptoms and can potentially result in fatal respiratory disease or multiorgan failure in both humans and other animals (Spagnoli et al. 2011). It has been suggested that cats, in addition to hosting infected fleas, may carry the bacterial agents of tularemia and plague in their oral cavities when preying on infected rodents. Consequently, there is a potential for cats to transmit these bacteria to humans through bites or scratches.

6. PREVENTION AND CONTROL OF ZOONOTIC DISEASES WITH ONE HEALTH PERSPECTIVE:

Human, animal, and environmental health are all intertwined, so it is important to use a One Health approach to preventing and controlling zoonotic infections in household pets. Pets play a major part in the transmission of zoonotic illnesses, which are infections that can be passed between animals and humans. Many people consider their dogs to be members of their family, making it all the more important to take measures to ensure their safety and well-being. In order to effectively implement a One Health strategy, it is necessary for human health experts, veterinarians, environmentalists, and other interested parties to work together. Regular contact and information exchange between these groups can aid in the detection and investigation of possible disease outbreaks. The ability to detect and respond quickly to new risks is enhanced by a systematized approach to monitoring zoonotic infections in household pets. The One Health Concept, Depicted in a Fig. 4.

The One Health philosophy relies on taking preventative action. Vaccinations are an important part of keeping pets healthy because they protect them from infectious diseases and lessen the likelihood of zoonotic transmission. In addition, getting checked and screened regularly can aid in early diagnosis, which is crucial for prompt treatment and halting the spread of diseases. The One Health movement also emphasizes the importance of responsible pet ownership. Proper cleanliness and responsible pet care can be emphasized in educational and awareness programmes aimed at pet owners. Hand washing following contact with pets, especially before eating, is an easy way to prevent the spread of zoonotic diseases. The environment also plays a significant influence in the spread of zoonotic illnesses from pets to humans.

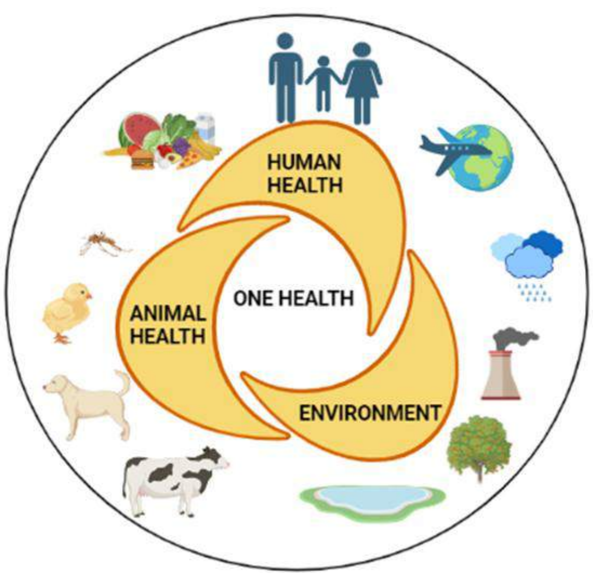

Fig. 4: Shows the one health perspective.

Proper waste disposal and sanitation procedures are fundamental in protecting people from infectious diseases. The dangers of zoonotic illnesses can be lessened by keeping pet enclosures clean and disposing of pet waste in the right places. In addition, it is crucial to do research that draws from other fields of study in order to completely grasp the complexities of zoonotic illnesses in domesticated animals. Disease prevention and control efforts can benefit greatly from research understanding the frequency, transmission, and behavior of diseases in animal populations. More effective measures against zoonotic illnesses can be developed with a deeper knowledge of the interplay between animals, humans, and their environments. Because zoonotic illnesses can appear anywhere, worldwide collaboration and information exchange are essential parts of the One Health concept. Disease surveillance information, research results, and effective control measures must be shared across governments and organizations. The genesis and spread of zoonotic illnesses in pets and their potential transfer to people can be thwarted with the help of coordinated efforts from around the world.

18. CONCLUSION

Zoonoses refer to diseases that affect both humans and animals, and can be transmitted through contact with domestic pets or wildlife animals. Numerous animal species and their associated products have the potential to serve as reservoirs for zoonotic pathogens. Among these, canines are accountable for the dissemination of various zoonotic ailments to their human carriers. Therefore, it is imperative to educate dog owners about zoonotic diseases and their modes of transmission in order to mitigate the prevalence of these infections among the human population. Numerous preventive and treatment approaches have been implemented with the aim of reducing the incidence of zoonotic diseases. It is advisable to engage in hand hygiene practices subsequent to any form of direct physical contact. In the presence of their canine companions, individuals may encounter various substances such as their belongings, bodily waste in the form of urine or faeces. In order to reduce the number of people who become ill from zoonotic diseases, proper food hygiene practices, including thoroughly washing vegetables and properly preparing meats, should be strictly adhered to at all times. In addition to that, dogs need to be treated for any diseases that cause diarrhea. Additionally, in order to prevent infections caused by campylobacter and salmonella, owners of dogs should only feed their pets meat that has been prepared. Dogs should never be given raw meat or eggs due to their increased risk of contracting an infection from the foods. The rabies vaccination is something that should be considered for domestic dogs, and dog owners should be aware of the benefits of getting vaccinated against rabies both before and after being bitten by their dogs. Numerous writers have found that raising the knowledge of dog owners regarding dog-associated zoonotic illnesses and prevention techniques can drastically lower the number of zoonotic infections that occur in dog owners and their families. In conclusion, maintaining the health and well-being of both animals and humans requires using a One Health approach to the prevention and control of zoonotic illnesses in pets. We can make the world a better place for pets and the communities they call home by encouraging multidisciplinary cooperation, emphasizing the need of responsible pet ownership, taking preventative steps, and undertaking thorough research. In addition to reducing the threat of zoonotic infections, adopting this holistic strategy will pave the way for a more robust and interconnected global health management system.

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General Principles for Treatment, Prevention and Control of Zoonotic Diseases

21

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ABSTACT

Zoonotic diseases are animal-borne and capable of transmission to human, present substantial risks to human health worldwide. In order to identify potential epidemics, effective strategies commence with surveillance and early detection through the utilization of robust monitoring systems. For containment, rapid response mechanisms, such as coordinated efforts between the human and animal health sectors, are indispensable. Interdisciplinary collaboration is critical for prevention, with an emphasis on the one health approach, which unifies the health of humans, animals, and the environment. Vaccination initiatives that target both humans and animals are crucial in disrupting the cycle of transmission. Public awareness campaigns facilitate comprehension of zoonotic hazards by endorsing measures that reduce exposure. Furthermore, disease reduction is aided by stringent regulations governing the trade of high-risk animals. Treatment protocols place emphasis on the importance of timely diagnosis and targeted therapeutics, acknowledge the wide range of zoonotic pathogens. Antimicrobial stewardship is crucial in the fight against the emergence of antibiotic resistance. Strong international cooperation strengthens global defenses against zoonotic threats by facilitating the exchange of information, allocation of resources, and development of capabilities. In essence, the management of zoonotic diseases necessitates a holistic and cooperative approach that incorporates strategies for monitoring, averting, and treating such conditions. By applying these overarching principles, readiness can be improved, hazards can be reduced, and ultimately, global public health can be protected.

Keywords: Treatment, Prevention, Cross-species transmission, Disease management, Epidemiology.

CITATION

Humayun A, Tahir AH, Humayun T, Khan A, Sindhu ZUD, Naeem RF, Somal S and Zafar MA, 2023. General principles for treatment, prevention and control of zoonotic diseases. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 293-303. https://doi.org/10.47278/book.zoon/2023.021

CHAPTER HISTORY Received: 01-May-2023 Revised: 20-July-2023 Accepted: 10-Aug-2023

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1. INTRODUCTION

A zoonotic disease is an infectious condition that is transmitted from living animals to humans. Around 1,400 pathogens (viruses, bacteria, fungi, protozoa, and helminths) that may infect people exist, and 60% of them are zoonotic (Microbiology 2011). These figures might alter given that 75% of newly discovered human illnesses are thought to have animal origins. There are several factors that make emerging and reemerging illnesses a growing public health problem. Increased globalization, habitat degradation, climate change, increased tourism and other factors can all make it easier for diseases to spread over species boundaries and into new ecological habitats (Cutler et al. 2010).

Infections that may spread from human to animals are referred to as anthroponosis (sometimes known as reverse zoonosis); Examples include streptococcus and methicillin-resistant Staphylococcus aureus (MRSA) (Kasela et al. 2023). Generally speaking, anthroponotic diseases are less of a concern in shelters, disease prevention methods and associated issues with animal management have a similar impact on shelter operations to zoonotic diseases. Workers in shelters should be aware of the spread of zoonotic (and anthroponotic) diseases can happen in a number of other ways beyond from coming into touch with an affected animal. The ability of diseased animals to spread an illness to a vulnerable host may exist even when they appear to be healthy (Steneroden et al. 2011). The following are the most typical means of pathogen transmission;

i. Direct contact with saliva, blood, urine, mucus, faeces, skin (hair), or other body fluids of an infected animal through bites, scratches, petting, contaminated wounds, or other ways (Rahman et al. 2020).
ii. Indirect contact with pathogen-contaminated soil or other objects, such clothing, equipment, or animal bedding (Rahman et al. 2020).
iii. Inhaling or ingesting infected bodily tissues, aerosols, secretions and excretions (Rahman et al. 2020).
iv. Vector borne zoonosis that spread through ticks, fleas, or mosquitoes, which are arthropods that are infected (Rahman et al. 2020).

The consequences of a zoonotic illness on shelter populations (both human and animal) can be lessened by keeping up with the pathogen transmission pathways and altering shelter operations to decrease the likelihood of infection. A safe working environment that is better suited to fulfil the needs of the animals and locals in the shelter's community may be supported by careful consideration of the environmental features of the shelter, animal handling protocols, human safety measures, and adherence to basic sanitary practices (Fowler et al. 2016).

2. CHALLENGES IN ZOONOTIC DISEASE TREATMENT

There are certain posed challenges in treatments of zoonotic diseases, i.e.

2.1. LIMITED KNOWLEDGE

As zoonotic illnesses frequently arise from new pathogens, thus medical professionals have little understanding of the biology, transmission and behaviour of these infections in human hosts. The creation of efficient therapies is made more challenging by this knowledge gap (Carpenter et al. 2022).

2.2. DIAGNOSTIC DIFFICULTY

Due to the overlapping symptoms of zoonotic diseases with those of other prevalent diseases, diagnosing zoonotic diseases can be difficult. Additionally, it may be difficult to get diagnostic instruments in environments with a lack of resources, which might delay early diagnosis (Carpenter et al. 2022).

2.3. ANTIMICROBIAL RESISTANCE

The overuse and improper use of antibiotics in both human and veterinary medicine has led to an increase in zoonotic diseases that are resistant to antibiotics, which makes treatment more challenging (Murphy et al. 2019).

2.4. ZOONOTIC SPILLOVER AND EPIDEMICS

Zoonotic illnesses have a random tendency to spread from animal reservoirs to human populations, resulting in epidemics that need quick and effective responses from healthcare systems (Rahman et al. 2020).

2.5. CROSS-SPECIES TRANSMISSION

Some zoonotic illnesses have the capacity to experience genetic alterations that increase their capacity to infect and transfer between various animal and human hosts, complicating treatment efforts (Rahman et al. 2020).

3. STRATEGIES FOR ZOONOTIC DISEASE TREATMENT

Following are the strategies that can be used for treatment of zoonotic diseases;

3.1. EARLY IDENTIFICATION AND MONITORING

Establishing reliable surveillance systems to keep tabs on zoonotic diseases in animal populations can help with early recognition and action. This necessitates close coordination between the human and animal health sectors in order to monitor and report any zoonotic events (Murphy et al. 2019).

3.2. RAPID DIAGNOSTIC TECHNOLOGIES

Zoonotic infections may be identified more quickly and precisely because of improvements in molecular diagnostic methods including PCR-based testing, next-generation sequencing, and point-of-care diagnostics (Carpenter et al. 2022).

3.3. ONE-HEALTH STRATEGY

The complete treatment of zoonotic illnesses can be aided by the adoption of a One Health strategy that combines human, animal, and environmental health. Officials in charge of public health, veterinary professionals, ecologists, and other pertinent parties must work closely together to achieve this (Murphy et al. 2019).

3.4. SPECIFIC THERAPIES

Specific antiviral, antibacterial, or antiparasitic therapies may be offered for some zoonotic infections. These medications aim to stop the causal agent's development or replication. The particular course of action depends on the pathogen that has been identified and how responsive it is to available treatments. To stop the emergence of resistance, it is essential to employ the right dosages and durations (Meng et al. 2023).

3.5. VACCINATION AND PREVENTION

For many zoonotic diseases, vaccination is a very efficient prophylactic approach. In high-risk locations, it is feasible to lessen the spread of the illness between species and stop outbreaks by immunizing both people and animals. Individuals exposed to specific zoonotic infections may occasionally benefit from post-exposure prophylaxis using vaccinations (Meng et al. 2023).

3.6. ANTIMICROBIAL STEWARDSHIP

Implementation of programs will encourage ethical antibiotic use and stop the rise of drug-resistant zoonotic diseases (Murphy et al. 2019).

3.7. EXPERIMENTAL THERAPIES

When there are no effective treatments available then experimental therapies such as monoclonal antibodies, antiviral medications, and immunomodulatory therapy may be tried (Murphy et al. 2019).

3.8. COMMUNITY INVOLVEMENT AND EDUCATION

Increased public awareness of zoonotic diseases and community participation in disease prevention and control programmes can both stop transmission cycles (Carpenter et al. 2022).

3.9. DIAGNOSIS

For effective therapy, a correct diagnosis is essential. Since zoonotic diseases frequently exhibit symptoms that resemble those of other conditions, a comprehensive medical history, clinical examination, and the right diagnostic tests are crucial (Rahman et al. 2020).

3.10. ISOLATION AND PREVENTION

When zoonotic illnesses are extremely infectious, isolation of sick people is crucial to stop the spread of the disease. To avoid infecting healthcare personnel, the proper personal protective equipment (PPE) should be used (Meng et al. 2023).

4. ANTIBIOTICS AND ANTIVIRAL DRUGS

These drugs may be provided, depending on the type of disease and the bacterium that is causing it. Antibiotics are used to eradicate or stop the development of germs in bacterial illnesses (Dafale et al. 2020). Antiviral drugs may be used to lessen symptoms and limit viral reproduction in viral infections. Some zoonotic infections, however, are not specifically treated with antiviral medications (Dafale et al. 2020).

Mass therapy for animal reservoirs include the antibiotic treatment of imported parakeets to prevent human psittacosis and the treatment of all dogs in a certain region to avoid echinococcosis and break the cycle between dogs and sheep (Acha and Szyfres 2003). Mass treatment is reducing a lot of the issues related to human intestinal parasites. Fascioliasis is treated with diethylcarbarnazine, while onchocerciasis is treated with ivermectin (Martinma 2007). Schistosomiasis and African trypanosomiasis incidence have decreased thanks to mass treatment combined with vector control (McQuiston and Childs 2002; Rahman et al. 2020). China has declared that venereal disease (pre-AIDS) has been eradicated by mass therapy using syndrome monitoring as a measure of effectiveness (Beers et al. 2006).

5. CONTROL OF ZOONOSES

Zoonoses represent a significant hazard to human health around the globe. According to a study, between 58 and 61 percent of human illnesses are contagious, and up to 75% of diseases that are spread between humans and animals are zoonotic (Al-Tayib 2019). Thus, interactions between people, animals, and the environment must be considered when developing effective zoonosis management strategies (Aenishaenslin et al. 2013). Surveillance is crucial for the prevention and management of zoonotic diseases. It may be used to locate "hotspots" and early infection stages, infected humans and animals, reservoirs, vectors, and endemic locations (Meng et al. 2023).

It helps to reduce human and animal morbidity and mortality, adjust control methods against emerging and reemerging illnesses, and properly manage sickness. The coordinated monitoring measures at the local, regional, national and international levels are essential for the successful management of zoonoses (Meng et al. 2023). Zoonoses (like SARS and HPAI) may spread swiftly throughout the globe and pose a hazard to international communities. It is important to keep an eye on all the potential zoonotic sources, including wild animals, rodents, aquatic life, avians and exotic species. It is necessary to employ a variety of surveillance techniques (Van der Giessen et al. 2010). A well-equipped lab, enough diagnostic tools, experienced employees, and sufficient funding are required for effective and efficient monitoring.

There are four methods of the surveillance used to combat zoonoses;

1. Pathogen detection and identification.
2. Serological surveillance, which involves monitoring immune responses to detect the presence of infections in the blood of humans or animals.
3. Symptom surveillance to detect illness propensity by data analysis. It is impossible to detect the presence of infections with this analysis-based surveillance.
4. Risk surveillance to identify risk variables that contribute to disease transmission. The prevalence of various illnesses and their clinical characteristics cannot be determined using this control technique (Pieracci et al. 2016).

The management of zoonoses can be carried out using the broad concepts of disease control, such as treating sick people, immunizing healthy people and animals, restricting animal migration, regulating animal populations, and test and cull (for anthrax, glanders, and Rift Valley fever). To lower the risk of contracting new diseases, infected items must be decontaminated. For instance, proper abortion disposal can lower the incidence of brucellosis. It is necessary to practice personal hygiene management and the use of personal protective equipment, such as gloves, masks, lab coats, helmets and goggles. To help stop the spread of brucellosis, salmonellosis and tuberculosis, it is necessary, where applicable, to thoroughly disinfect infected items and surroundings (Murphy et al. 2019).

The management of emerging and re-emerging zoonoses necessitates concerted and interdisciplinary efforts. Arboviral infections spread by vectors are the cause of many newly and re-emerging illnesses, including dengue fever, Zika, and chikungunya (Hassell et al. 2017).

Risk variables that contribute to the emergence or reemergence of an organism include vector biology, host dynamics, pathogen niche and virulence, animal distribution, land use, and socioeconomic situation. Controlling pests and vectors is also necessary to fight many bacterial and parasitic zoonoses spread by ticks, lice, and insects that resemble mosquitoes and function as their carriers. Integrated pest management and integrated vector management systems are examples of physical, biological, and/or mechanical methods that should be used in vector control strategies (Rahman 2017).

Despite posing a very serious threat to the public health, particularly in poor nations, many zoonoses are avoidable yet nonetheless go unchecked. Factors pertaining to both people and animals must be taken into consideration while developing zoonoses management programmes. Coordinated strategies must be used for zoonoses management in areas where many neighboring nations are afflicted. Veterinarians,

physicians, occupational health specialists, public health administrators, conservation officers, and environmental officers must all be involved in the development of zoonoses control strategies in order for them to be effective (Hassell et al. 2017). A research project named Integrated Control of Neglected Zoonoses for the control of neglected zoonotic diseases in Africa increased the awareness of academics and professionals from 21 European and African countries of one health-based concept (Pal et al. 2014).
Every disease control method requires a substantial investment, which is frequently unattainable for developing countries. The industrialized nations, international donors and international organizations such as World Health Organization (WHO), must help the impoverished nations for effective zoonoses management. Intergovernmental Research collaboration is one option for obtaining funding (Gibbs 2014).
In order to control food-borne zoonoses, it is essential to offer consumers a large supply of secure food. This might be accomplished by putting into practice the two main methodologies of risk assessment and risk management of food items. Legislation should be passed and objectives should be set in order to exercise risk management. Gathering and interpreting data, as well as making recommendations based on importance, are all methods of risk assessment. Meat, milk, and eggs must be derived from healthy animals that are free of zoonotic infections. An accurate ante- and post-mortem examination of the animals is necessary to ensure the safety of food obtained from them. Every step of the food processing process, including the worker's personal hygiene, must be carried out in a hygienic way (Murphy et al. 2019).

6. PREVENTION OF ZOONOSES:

There is a crucial contrast between the term’s preventive and control. Preventing the spread of a disease agent to a region, a particular population, or a person is the definition of prevention. Control measures are actions made to bring a disease condition under control and keep it there. When a certain infectious disease agent is already existing, the word "control" is more applicable. The terms "primary prevention" and "secondary prevention" are occasionally used to describe preventive and control (Sohn et al. 2003).
Primary prevention aims to keep the population healthy by halting the spread of illness. After a disease has been diagnosed, secondary prevention works to reduce harm. When rehabilitation is used as a last resort after primary and secondary prevention have failed, the term "tertiary prevention" is used (Martinma 2007).
There are three most fundamental tenets of zoonoses prevention and control programmes center on severing the epidemiological transmission chain (Meng et al. 2023).

a) Reservoir
b) Transmission
c) The predisposed/ susceptible hosts

The principle of control and prevention are described in the following section;

7. RESERVOIR NEUTRALIZATION

The infected reservoir host is the main point of zoonotic infection. Other sources of infection gradually diminish in importance or vanish whenever infection in the reservoir can be lowered or eliminated. The primary site of zoonotic infection is the infected reservoir host. When infection in the reservoir can be reduced or removed, other sources of infection progressively lose their significance or disappear altogether. There are three methods used to neutralize the reservoir (Pieracci et al. 2016);

- Infected individual removal
- Rendering of infection
- Environmental manipulation

Mass treatment or test-and-slaughter are the two methods available to eradicate an infected animal (Martinma 2007). A herd of animals might be cleared of infection by testing them and slaughtering those that test positive for the illness. This method has proven successful in treating cattle brucellosis, horse glanders, and horse dourine. A test must be sensitive and specific enough to identify all infected animals if all infection is to be eradicated without eradicating a sizable percentage of false-positive animals (Schellenberg et al. 2003).

Another method for removing infected persons from the general population is mass treatment. The mass treatment is typically limited to a small area where all possibly infected persons/animals must be going through screening first for the identification of disease (Acha and Szyfres 2003; Martinma 2007; Fowler et al. 2016). It is feasible to avoid the transmission of *Taenia saginata* from feedlot staff to cattle by providing enough toilets and the necessary monitoring and training to assure their usage. Workers may utilize haystacks, feed bunks, or other locations if facilities are inaccessible, which might lead to the contamination of cattle feed (Ibrahim 2010). It has been quite successful to use fermentation lagoons to eliminate infections spread orally by faeces. The survivability of pathogenic organisms found in organic wastes has recently been decreased due to the use of aerobic, thermophilic bacteria in composition. Before applying effluent to pastures, proper sewage treatment is required to stop the spread of viable parasite eggs (Jones et al. 2006). The effectiveness of introducing sterile males to eradicate screwworms depends on how the arthropod reproduces and moves through its life cycle. The use of biological control strategies such as natural predators or vector-borne diseases has reduced the population of mosquitos with moderate success. Examples include the fish gambusia introduction into water to consume the larvae. Removal of the Australorbis spp. snails, which act as an intermediate host for Schistosomes, by Marisa cornuarietis, a rival snail. This approach is dependent on the vector's population density and has ecological drawbacks (Jones et al. 2006; Rahman et al. 2020).

8. ENVIRONMENTAL MANIPULATION

Management of the environment to manage rodents, inhibit the migration of wild animals, and control vectors. Environmental manipulation refers to changing the environment in a way that affects how zoonotic illnesses spread from animals to people. This can include habitat changes as a result of causes like deforestation and urbanization, the influence of climate change on disease vectors and host behaviors, agricultural practices that encourage the spread of illness, and water management practices that provide breeding grounds for disease vectors. The danger of zoonotic disease spread can rise as a result of these changes. Conservation initiatives, sustainable land-use methods, ethical farming, and public health measures are crucial for lowering the likelihood that zoonotic diseases may be spread due to environmental changes (Walter et al. 2022).

8.1. CONSUMER PROTECTION

This stage, which is more crucial in the case of food-borne zoonotic illnesses, is accomplished by stringent pre- and post-harvest inspections, such as meat inspection, adoption of contemporary food preservation techniques, and pasteurization of milk. Controlling foodborne zoonotic illnesses can be accomplished through the use of ISO 9000 and Hazard Analysis and Critical Control Point (HACCP) methods (Pieracci et al. 2016).

8.2. DETECTION OF ZOONOTIC DISEASE

Detection of zoonotic diseases by keeping an eye on human and animal populations, their carriers, the severity of illness, and environmental variables that may be impacting the disease. This will make it possible to identify the foci of the endemic disease and organize the necessary control measures (Meng et al. 2023).

8.3. REDUCING CONTACT POTENTIAL

A key criterion for minimizing the infection is to restrict the transmission of infectious agent to the healthy individuals, reducing the possibility of interaction by isolating sick animals, protecting against vectors, and taking biosecurity precautions. The known affected and possibly exposed susceptible groups are taken into consideration for controlling illness (Meng et al. 2023).
There are three approaches for controlling illness (Pieracci et al. 2016):

- Case isolation and treatment
- Placing potential infectious people in quarantine
- Population management

A strategy for lowering contact potential is herd immunity, which will be discussed in the section on disease prevention via boosting host resistance. Herd immunity, which will be covered in the section on disease prevention via enhancing host resistance, is a method for reducing contact potential. When there are enough immune animals in a group, less vulnerable animals are likely to come into touch with ill (shedder) animals, reducing the entry and spread of a disease agent spread by direct contact (Acha and Szyfres 2003; Jones et al. 2006; Meng et al. 2023).

8.4. VECTOR CONTROL

Vectors including fleas, ticks, and mosquitoes spread many zoonotic illnesses. Disease transmission can be reduced by limiting these vectors by the use of pesticides, planned insecticide spray campaigns, environmental changes, and public awareness campaigns (Meng et al. 2023).

8.5. HYGIENE AND SANITATION

Encouraging hygienic habits, such as washing hands after coming into touch with animals and their surroundings, might lessen the risk of zoonotic transmission. In cattle and animal production facilities, proper waste disposal and sanitation practices are crucial for preventing the spread of illness (Matilla et al. 2018).

8.6. INCREASING HOST RESISTANCE

Increasing host resistance to infection is another method for controlling zoonoses. The aim is to prevent infection, but in many cases, boosting host resistance may only result in a reduction in the severity of disease without a corresponding boost in infection resistance (Martinma 2007; Dafale et al. 2020). In veterinary medicine, genetic selection for resistance and stress reduction through better nutrition or housing are prevalent practices. Animals that are kept at the right nutritional level have improved resistance to illness as well as improved capacity to react to vaccination. Genetic selection for resistance can happen spontaneously in human medicine, as in sickle cell anemia and malaria resistance, but it is not accepted as a method for applying disease management. By improving nutrition and shelter, we may lessen stress, which serves as a method of lessening the effects of epidemics by improving the population's capacity for survival. This is widely known given the higher case fatality rates during epidemics among malnourished populations (Dafale et al. 2020).

However, there are two methods i.e. chemoprophylaxis and immunization, for boosting host resistance that are suitable for presentation (Beers et al. 2006; Walter et al. 2022).

8.6.1. CHEMOPROPHYLAXIS

When workers are unintentionally exposed to a drug-susceptible agent (including certain zoonotic pathogens), chemoprophylaxis is used in laboratories. In contrast to mass treatment, which is intended to eradicate infection, this is done to avoid infection. However, people who have already been exposed to the disease may retain some immunity after receiving mass treatment. Chemoprophylaxis may entail a negative medication response. The agent may occasionally be resistant (Taylor et al. 2007; Murphy et al. 2019). Chemoprophylaxis is typically used when there are no better methods to safeguard the host. Chemoprophylaxis is a choice for any high-risk populations when an efficient medication is available but a sufficient vaccination or appropriate protective equipment is not available. (Bereket 2008). Some of the most often used chemoprophylactic items for domestic animals are insect repellents to ward off arthropod vectors and anti-heart worm medications for dogs. Both approaches come with risks, therefore they are two-edged swords. Exposure to some chemical repellents can quickly make cats unwell. An anti-heartworm medicine given as a preventative dosage to a dog that has previously been parasitic infected can be lethal as worms (adults) are killed and then displaced towards heart which results in emboli (Jones et al. 2006; Murphy et al. 2019).

8.6.2. IMMUNIZATION

Vaccines are used to both limit the transmission of infectious agents by strengthening the immune system and to safeguard those who are vulnerable to illness or disease. The immunization stimulus must be adequate to prevent both infection and illness in order to be most successful in managing disease. If just sickness is stopped, there is no decrease in the reservoir of infection in maintenance hosts. If carriers continue to exist, the danger of infection still exists from any vulnerable individuals who are brought into the community. Immunity levels required for disease prevention and infection prevention are not always the same. The percentage of the population that attains the required degree of immunity is used to determine how effective vaccination is as a disease prevention measure (Martinma 2007). The first step in the design of any immunization programme is to identify the population at risk (those who are vulnerable and likely to be exposed). The next phase is to choose the specific disease control target, such as decreasing the incidence of the illness to only a few rare instances or eliminating the agent. Relative risk is used to determine whether or not to vaccinate (Beers et al. 2006; Carpenter et al. 2022). The various factors involved with the processes are far too frequently overlooked because immunization is typically so successful and widespread as a disease management strategy (Taylor et al. 2007). Failures in the immune response or the delivery method for the immunization might also result in failures (Carpenter et al. 2022).

9. HEALTH EDUCATION AND PUBLIC KNOWLEDGE

To enable people and communities to take care of themselves, it is essential to raise knowledge of zoonotic illnesses, their modes of transmission, and the precautions that may be taken. Urban and rural populations can benefit from education initiatives that aim to reduce risk factors and encourage behavior modification. Health education of general public by public health workers, private practitioners, doctors and veterinarians and non-governmental organizations would also help in controlling zoonotic diseases particularly in rural areas (Pieracci et al. 2016).

10. INTERNATIONAL COLLABORATION AND SURVEILLANCE

Zoonotic diseases do not respect national boundaries. Countries can respond collectively to new zoonotic risks by exchanging knowledge and skills (Pieracci et al. 2016).

10.1. RESEARCH AND INNOVATION

To remain ahead of new hazards, ongoing research into zoonotic illnesses, their transmission, and potential cures is essential. Investing in cutting-edge research and development can enhance disease prevention plans (Pieracci et al. 2016).

11. CONCLUSION

Zoonoses are diseases that naturally transfer from vertebrate animals to humans. Bacteria, viruses, parasites, or other uncommon agents may be the cause of zoonoses. Zoonotic illnesses are brought on by three factors: the type of the etiologic agent, the life cycle of the reservoir host, and the life cycle of the infecting organism. Disease, monetary loss, a detrimental impact on staff morale, unwelcome publicity, and medico-legal repercussions are only a few of the major outcomes of zoonoses. Reservoir neutralization, contact potential reduction, and host resistance are the three main tenets of zoonoses prevention, control, and eradication.

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From Awareness to Action Promoting Behavior Change for Zoonotic Disease Prevention Through Public Health Education

22

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ABSTRACT

An infection that can naturally spread from animals to humans is known as a zoonotic disease and the majority of people interact with animals in some capacity, as a result, over 60% of diseases that affect humans have zoonotic origins. The emergence, re-emergence, distribution, and patterns of zoonoses have been significantly impacted by several factors, including anthropogenic influences, urbanization, animal migration and commerce, travel and tourism, vector biology, and climate change. The causes of the main zoonotic illnesses, their effects on human health, and management-improving control techniques were all covered in this chapter with a piece of strong advice that One Health procedures be put into place to effectively prevent and control any zoonosis-type infection. By integrating animal, human, and environmental health through cooperation and communication among osteopaths, wildlife, doctors, veterinarians, public health and environmental experts, nurses, dentists, physicists, biomedical engineers, plant pathologists, biochemists, and others, the one health concept plays a significant role in the control and prevention of zoonoses. Issues about the animal-human-ecosystem interface cannot be resolved by one industry, group, or individual working alone.

Keywords: Zoonosis, Pathogens, Illness, Virus, Bacteria, Health

CITATION

Nasir MF, Naz G, Rasheed M, Rafiq H, Rafique A, Javed U, Hassan Z and Khalid N, 2023. From awareness to action promoting behavior change for zoonotic disease prevention through public health education. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 304-315. https://doi.org/10.47278/book.zoon/2023.022

CHAPTER HISTORY Received: 20-March-2023 Revised: 19-May-2023 Accepted: 21-July-2023

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1. INTRODUCTION

Zoonoses or zoonotic diseases are induced via microorganisms that are commonly spread to humans from animals. Zoonoses term comes from two Greek words "zoon" which means animal and "nosos" which means disease. WHO (the World Health Organization) classifies any infection or condition that can be transmitted naturally by vertebrates (animals) to human beings or from people to vertebrates (animals) as zoonotic disease. Different contagious diseases originate and spread because of interactions among people, animals, and the environment. The continued prevalence of zoonotic diseases poses serious concerns to human health. Subsequently, more than sixty percent of total contagious illnesses are zoonotic diseases and animal origins are the source of 75% of newly appearing infectious pathogens (Mangili et al. 2016; Supramaniam et al. 2018; Espinosa et al. 2020). Zoonoses are more frequently spread primarily to human via animals and secondary through the interaction with a vector or an agent (McArthur 2019). The emergence of zoonotic illnesses is influenced by a number of factors, including population growth, urbanization, global environmental changes, animal movement, and tourism (Rahman et al. 2020). The majority of industrialized nations have adopted the "One Health" approach, which allows various sections to cooperate in an attempt to enhance health consequences. The objective is to support and promote the worldwide health system through enhancing efficient teamwork, contribution and cooperation at a connection of humans, animals and the environment (McEwen and Collignon 2018; Behravesh 2019).
In South Asia, Pakistan is a nation that borders the Arabian Sea and at the 6th position among the most populated countries in the world (208 million people). According to CIA (Central Intelligence Agency) 2016, the livestock population in Pakistan is more than 300 million (animals), including 147 million poultry and 83 million large and 103 million small ruminants. A great variety of wild and domestic animal species, as well as a diversified natural topography and climate found in Pakistan (Turnbull 2008). Likewise, ecosystem diversity, social inequality, lack of politics, climate change, poverty, and regional conflicts may all affect public health and disease surveillance systems (Ashraf et al. 2014).
In underdeveloped nations like Pakistan, where the widespread distribution of infectious diseases and dangerous biological elements has greatly harmed the environment and human and animal welfare, the "One Health" idea has not yet been extensively adopted. For instance, in 2017 a report noted more than 800 people were infected by the Chikungunya virus across Pakistan. In Pakistan, 63 persons were infected with Crimean-Congo Hemorrhagic Fever (CCHF), which led to 11 deaths (Altmann et al. 2019). Pathogenic microorganisms have several possibilities to disperse due to relations among people, animals, and an ecosystem. To avoid or control zoonoses in Pakistan, a variety of non-governmental organizations (NGO) and government organizations, like Ministries of Climate Crisis, trade, Food Safety, and Education are responsible for developing and putting useful and modern strategies into action (Bartges et al. 2017).

2. ZOONOTIC DISEASES PREVALENCE (MOST COMMON) IN PAKISTAN

TB (tuberculosis), Lyme disease, Brucellosis, Rabies, Q fever, Encephalitis, Leishmaniosis, Foot and Mouth disease, Giardia, CCHF, Avian Influenza, Anthrax, Chagas disease/Trypanosomiasis, and Balantidiasis are the most Common Zoonotic Illness in Pakistan (Table 1, 2; Feng and Xiao 2011; Shabbir et al. 2015; Yousaf et al. 2018; Ahmed et al. 2020; Iqbal et al. 2020). In Punjab, Pakistan zoonotic microbes carried by soil like *Burkholderia mallei* and *Bacillus anthracis* have been reported in animals and humans (Shabbir et al. 2015).

2.1. BOVINE TUBERCULOSIS

During the 19th and 20th centuries, a large number of human TB cases spread due to a bacterium (*Mycobacterium bovis*) and the intake of raw cattle milk (Khan et al. 2014). Pakistan is ranked 5th among nations where tuberculosis is a serious problem (Shah et al. 2017). Almost 510,000 cases of tuberculosis are reported each year. The high frequency of tuberculosis is attributed to a lack of antiseptic medicines and control measures (Leghari et al. 2020). To enhance the meat quality and avoid tuberculosis emission to humans by sick animals, proper examination and observation should be put into place (Leghari et al. 2020).

2.2. RABIES

Rabies virus is a member of the Rhabdoviridae family. It is the deadliest and single-stranded RNA virus affecting people and animals. This infection mostly occurs in raccoons, bats, and dogs, and these animals transmit the disease to people. 5 million cases are notified every year and fifty thousand deaths occur because of dog bites (WHO 2018). In accordance with NRCP, in Pakistan, rabies is a threat to several village areas, and about 54.7 percent of unvaccinated dogs are against disease, and attack humans (Noureen 2018). Furthermore, according to another research, public and private hospitals treat 70 dog bite cases per day. Therefore, it is estimated that there are around 9 million cases of rabies (World Health Organization 2018).

Table 1: Direct contact or contamination

Diseases	Symptoms	Source of Transmission	Risk factor	References
Anthrax	Vomiting, fever, abdominal pain, nausea, diarrhea	Contact with diseased animals, polluted food, livestock products	Lack of cleanliness	Ali and Ejaz 2023; Rashid et al. 2020
Brucellosis	Body pain, abdominal pain, fever, poor appetite, weight loss	Contact with fecal wastes, vaginal fluids, urine, placenta, aborted fetus, semen	Intake of raw milk products, work exposure	Jamil et al. 2021; Ali et al. 2018
Bovine TB	Irregular coughing, large prominent lymph nodes, weakness and weight loss, fever diarrhea, loss of appetite	Raw milk product, contaminated food and water, direct contact with diseased animals, livestock products	wildlife reservoirs, poor living condition, livestock farming, occupational exposure	Leghari et al. 2020
Escherichia coli Food-borne disease	Vomiting, respiratory disorders, diarrhea, and fever	Direct contact with diseased animals, contaminated food and water, livestock products	lack of cleanliness, poor living condition	Ismail et al. 2021
Hepatitis E	Fatigue, vomiting, fever, abdominal pain, liver failure, yellow skin, nausea, loss of appetite	Eating uncooked meat, contaminated food and water with sewage	Poor living condition, lack of cleanliness	Farooqi et al. 2022
Leptospirosis	Jaundice, chest pain, coughing with blood, fever, shortness of breath, nausea, swollen limbs, headache, loss of appetite	Polluted Soil and water by animal urine	Occupational exposure, skin injury	Sohail et al. 2020; Ijaz et al. 2018
Rabies	Hydrophobia, encephalitis, weakness of motor neuron, hyper-excitability, paralysis	Bites via animals, such as dogs	Hardly pets, stray and owned dogs	Ahmad et al. 2021; Kumar and Bakhru 2022
Salmonellosis	Vomiting, fever, diarrhea, nausea, abdominal pain	Direct contact with diseased animals, contaminated food and water, livestock products	Lack of cleanliness, living condition	Saeed et al. 2019; Hussain et al. 2020

2.3. DENGUE FEVER

Since an initial epidemic of dengue was recorded in 1994, several disease outbreaks have been documented in various parts of Pakistan during the last thirty years (Khan and Khan 2015; Ali et al. 2019; Junaidi 2019; Fatima et al. 2021). Particularly in 2005, an outbreak with more than 6 thousand cases and 52 deaths was reported in Karachi. In 2011, more than 21000 cases and 350 deaths were documented in Lahore; and in 2019 outbreaks, 44415 cases and 66 deaths were reported (Junaidi 2019). Though the incidence of dengue virus increases every year the total death rate is reduced. Regional government and nongovernment organizations worked together to encourage testing, house-to-house monitoring, and training and developed workshops for the acknowledgment of the public, which helped to achieve this landmark (Fatima et al. 2021).

2.4. TYPHOID FEVER

Typhoid fever is caused by *Salmonella typhi* which is frequently transmitted by polluted water, food, and by the interaction of humans and animals. According to estimates, the disease affects 11–20 million people worldwide, killing 120–220,000 people each year (Mogasale et al. 2014). Consequently, in order to control this condition, appropriate surveillance and monitoring measures are required (Fatima et al. 2021).

Table 2: Vector-borne diseases

Diseases	Symptoms	Source of Transmission	Risk factor	References
Chikungunya	Joint paint or swelling, muscle ache, fever, skin lesions, headache	Virus is remained in an ecosystem among mosquitoes, vertebrates, and humans	Virus transmitted via Aedes mosquitoes from diseased to healthy person	Badar et al. 2020
Crimean-Congo hemorrhagic fever	Liver failure, fever, vomiting, sore throat, back pain, liver enlargement, dizziness, headache, neck pain, sleepiness, petechial rash, confusion, myalgia	Contact with diseased animal, tick bites	Human movement, occupational exposure	Zohaib et al. 2020; Butt et al. 2021
Foot and mouth illness	Loss of appetite, lesions on the palms, fever, irritation in newborns, irritability in youngster, wounds on the sole,sore throat, pain, wounds on the gums, and tongue, buttocks	Pet and wild swine, cows, sheep, and people	Goat and sheep can transmit the virus	Ali et al. 2022; Nawaz et al. 2019
Leishmaniasis	Skin lesion, liver enlargement, fever, weight loss, spleen enlargement	Female phlebotomine sandfly can transmit leishmania parasite, almost 70 species of animal are common sources, people also includes	Malnutrition, lack of hygiene, environmental changes, poor living condition, growth in cities, poverty, people movement	Khan and Awan 2021; Khan et al. 2021
Rift valley fever	Symptoms that from a slightly flu-like to acute hemorrhagic sickness	Bites via mosquito raw milk, get in touch with diseased animal's blood and other body parts	Work orientation	Waqar et al. 2023; Wright et al. 2019

2.5. ANTHRAX

Anthrax is caused by *Bacillus anthracis*, which also has a significant negative influence on animal health, particularly in sheep, goats, and cows. *Bacillus anthracis* is also easily transmitted to people. In places where humans and animals frequently interact, such as slaughterhouses, the risk of *B. anthracis* infections is higher. Vaccination is an important segment of an efficient disease examination strategy and is required to avoid further outbreaks (Rashid et al. 2020).

2.6. CRIMEAN-CONGO HEMORRHAGIC FEVER

Crimean–Congo is a deadly viral illness transmitted by ticks, identified by hemorrhage and fever. Due to quick climatic alteration, rising industrialization, population density, and agricultural and occupational activity, CCHF is more prevalent in Pakistan. Poor hygiene conditions in farms, rural areas, and towns, unhygienic animal movement and slaughter in the urban areas, inefficient control of ticks initiatives, migrant way of life, and medical professionals shortage are all factors that contribute to the spread of CCHF. Every major city has CCHF, including Peshawar, Karachi, Multan, and Quetta. The absence of an efficient disease surveillance system in Pakistan is considered a contributing factor to the infection outbreak (Yousaf et al. 2018). Local and provincial governments should educate citizens, farmers, and healthcare professionals about CCHF transmission and its effects. To control and remove this deadly disease from the nation, it is urgently necessary to implement the disease examination strategy as well as protective measures, identification, and medication (Butt et al. 2021).

3. A LIST OF MOST COMMON PREVALENT DISEASES CAUSED BY ZOONOSES IN PAKISTAN

3.1. IMPACT OF ZOONOTIC DISEASES

There is raising evidence that animal diseases have a significant influence on worldwide productivity (Rushton et al. 2018; Pinior et al. 2019). Animal diseases not only result in production loss but also high implementation costs for mitigation measures and pose dangers to human health connected with Zoonoses (for example any infectious disease that is naturally transmitted from ruminants to people) (Brunauer et al. 2021; Conrady et al. 2021). Salmonellosis is one of the zoonoses that is most commonly reported in the European Union. Salmonellosis from contaminated food can make people ill with fever and bloody diarrhea. Salmonellosis can spread through a variety of channels, including contaminated eggs, domestic animal's milk and meat, uneven cooking techniques (Vajda et al. 2021). Australia's livestock sector has lost 16% of its value due to epidemics that affected sheep and beef (Rahman et al. 2020). Another economically significant disease is brucellosis. Brucellosis is a bacterial zoonotic illness that usually affects horses, sheep, buffaloes, cattle, camels, and dogs, it can also inadvertently spread to people. It ranks among neglected zoonotic illnesses, which mostly affects the underprivileged and diminished populations. The monkey pox virus can be found in semen, according to reports on a few other viral zoonotic diseases. This could be brought on by a blood-testes barrier breakdown, local or systemic inflammation, and viral replication in accessory glands (Salam et al. 2017).

Zoonotic diseases like avian influenza, bovine spongiform encephalopathy, and anthrax can obstruct global traffic in animals, livestock products such as eggs, milk and meat, and animal by products. Necessary steps for disease control and elimination include zoonosis examination, diagnosis, isolation or quarantine, limitation on movement of animals, cure and vaccine programs, analysis of milk and beef, and biosafety, have a significant negative impact on the economy. Zoonotic outbreaks had a greater than 120 billion USD economic impact on the world between 1995 and 2008 (Cascio et al. 2011; Sajjad et al. 2021; Rasheed 2013).

4. SOURCES OF ZOONOTIC DISEASE

Some ecological obstacles need to be overcome in order to stop the early transmission of illnesses from animals to humans. The transmission pathway, which serves as an initial barrier, limits the infections that humans can contract from particular vertebrate animals. Zoonotic diseases can be transmitted to humans by vertebrate animal hosts through a variety of routes, including direct contact with infected animal tissues or bodily fluids through wounds or abraded skin, animal bites and scratches (for example, rabies virus and *Brucella abortus*), indirect contact with a contaminated environment or source (for example, *Burkholderia pseudomallei* and *Leptospira interrogans*), and airborne transmission via aerosol (Fig. 1) (Dharmarajan et al. 2022). Any of the aforementioned entry points can be used by diseases of animal origin that are capable of spreading effectively from person to person. However, zoonotic events that spread illnesses to people can occur through atypical transmission pathways that are different from both the typical human and animal reservoir transmission pathways. Despite the fact that simian immunodeficiency virus was first exposed to humans through repeated contact with infected wild primates' blood or cuts received while butchering meat, HIV is effectively transmitted between humans only through sexual contact. Similarly, flea bites or occasionally eating infected meat can spread plague among rodents and from rats to humans; however, pneumonic transmission or lice can spread plague between people (Dharmarajan et al. 2022).
Insect vectors play a major role in the spread of many zoonotic diseases with a wildlife origin. For instance, mosquitoes are well-known carriers of a number of zoonoses that affect wildlife, including Japanese encephalitis, horse encephalitis, and Rift Valley Fever. Fleas can disseminate *Y.pestis*, flies can spread *Bacillus anthracis* spores, and sand flies can spread *Leishmania*, but ticks are crucial in the spread of

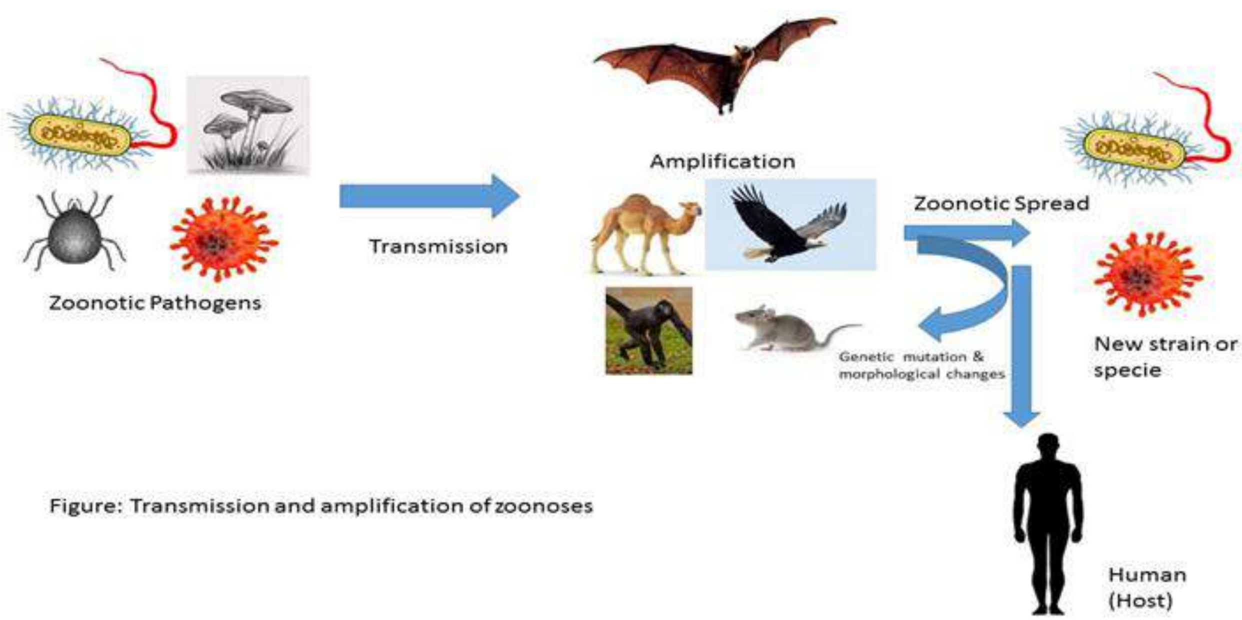

Fig. 1: Transmission and amplification of zoonoses

Ehrlichia/Anaplasma and *Borreliaburgdorferi*. *F.tularensis* is an excellent example of a zoonotic agent with a variety of transmission methods. The primary carriers of the disease are rodents and hares, and hunters are particularly vulnerable to contracting it (Kruse et al. 2004). The clinical presentation in humans is likewise impacted by the transmission mode. The pathogen can spread through tick or mosquito bites, which initially result in skin signs like ulcers, as well as direct contact while handling an infected cadaver. Infection can also spread through inhaling contaminated dust, which can result in a pneumonia-like sickness, or eating improperly cooked meat from an infected animal or drinking contaminated water (Kruse et al. 2004). Hantaviruses are also found in wild rodents as a reservoir. Humans are typically infected aerogenically by breathing contaminated aerosols, and the viruses are shed in urine, feces, and saliva. Important environmental elements like as precipitation, habitat design, and food availability have an impact on rodent population dynamics, animal-to-animal virus transmission, and ultimately the likelihood of human infection (Kruse et al. 2004).

Animals can transmit a wide range of infectious disease-causing organisms to humans via a number of different routes, including ingestion, animal bites, vectors (such as insects), and animal-to-human contact (such as skin/mucous membrane contact or inhalation of respiratory particles) (Gauthier 2015; Rahman et al.2020).

Sapronoses are conditions caused by zoonotic diseases that may live and multiply inside dead organic matter, such as saprophytes. Through direct or indirect contact, diseases from these animals can spread. The transfer could take place inside, outside, in pet stores, hospitals, or other places. Transmission frequently happens when these animals and birds are taken to exhibitions and competitions. Animal bites and scratches are the most common ways for humans to become infected with diseases like Pasteurellosis and cat scratch fever (Rahman et al. 2020).

5. SOLUTION TO OVERCOME ZOONOTIC DISEASE

Animals spread zoonotic diseases, and keeping track of them helps pinpoint their origin, route of transmission, and pathogenesis as well as focus preventive measures. (Supramaniam et al. 2018).

5.1. EPIDEMIOLOGICAL INSPECTION

For community health management to identify related risk variables accountable for disease persistence and dissemination, epidemiological surveillance is essential. However, in Pakistan, it is uncommon to get population-based information on the widespread presence of zoonosis (Brown and Nading, 2019).

5.2. HOSPITAL BASED OBSERVATION

Typically, hospital-based monitoring data have been utilized to show that many zoonotic illnesses are highly prevalent. To create policies that address illness persistence, clinicians, epidemiologists, expert in veterinary medicine and environmental health may be combined (Breslin et al. 2017).

5.3. INTERPRETATION OF ZOONOTIC DISEASE

Strong support has been given to the idea of one health, a worldwide integrative concept. The prevention and control of disease effectively depend on surveillance and monitoring activities. Considering the close relationship between human and animal health, it is presumable that a cross-sectoral data interpretation of zoonotic disease information will enhance zoonotic disease prevention, prediction, and control. A literature analysis was done to give an overview of the systems that are now in place around the globe that combine data on zoonotic illnesses from both people and animals (Wendt et al. 2015).

5.4. VETERINARY POLICIES AND AWARENESS CAMPAIGN

In order to minimize the spread of zoonoses to people and other issues related to uncontrolled animal populations, veterinary public policy players should base their judgments on scientific data. This will help regulate dog and cat numbers in metropolitan areas. Since there is no public sterilization service for dogs and cats in the city, sporadic local sterilization campaigns are carried out with advance notice to the owners to bring their animals to a particular veterinary clinic for sterilization (Zahid 2018).

5.5. STERILIZATION PROGRAM

Since there are no shelters for giving up unwanted pets, abandonment is the main issue brought on by irresponsible pet ownership. There is no public sterilization service for dogs and cats in the city, sporadic local sterilization campaigns are carried out with advance notice to the owners to bring their animals to a particular veterinary clinic for sterilization (Dias et al. 2015).

5.6. VACCINATION PROGRAM

Public education campaigns about vaccination should be started as well. Tools for such projects are available in the "One Health" network, reporting, and analytical measures toolkit. (Iqbal et al., 2020) There are swine influenza vaccinations available for both humans and animals globally. H1N1 (swine flu) and H3N2. are the components of the influenza vaccine in Pakistan (Parums 2021).

6. BIOSAFETY TOOLS FOR PREVENTING ZOONOSIS

The prevention of zoonotic agents is based on a set of policies and practices aimed at lowering the danger of disease introduction and dissemination (Saegerman et al. 2012). Several methodologies for biosafety measurements could be used depending on the disease.

6.1. HAND WASHING AND HYGIENE

- Wash your hands for at least 20 seconds with warm water and soap.
- Wash your hands frequently, supervise youngsters to ensure thorough hand washing, avoid direct contact with animal excrement, and use antimicrobial hand gels even if your hands are not obviously dirty.
- Sanitize any spaces that pets can reach. In the event of bites or scratches, the wounds need to be carefully cleaned under running water, and treated with chlorhexidine and the reference on the hematology center should be notified in case antibiotic prophylaxis is necessary. Animals should have short nails and shouldn't engage in rough play to reduce this risk (Hemsworth and Pizer 2006).

6.2. PERSONAL SAFETY WHILE OUTSIDE

- Refrain from approaching any animals or waterfowl.
- Keep ticks and mosquitoes (among other insect vectors) at bay; and Apply vector control methods to the area around your house (Saegerman et al. 2012).

6.3. FOOD SAFETY

- Safe food handling and preparation.

- Immediately clean any cooking utensils or surfaces that come into contact with raw meat or eggs.
- In addition to providing animals with high-quality food and water, home-prepared food should be cooked and/or pasteurised.
- To prevent hunting, interaction with uneaten food, and exposure to other animals' excrement, animals should be kept indoors (Pal et al. 2023).

6.4. CHILDREN AND ANIMALS

- When working with animals, adults should always keep an eye on kids, especially those under the age of five (Saegerman et al. 2012).

6.5. PET HEALTH

- Keeping pets healthy can reduce the spread of zoonotic infections.
- Avoid letting pets interact with wildlife.
- Don't let your pet eat other animals' feces.
- Don't feed your pet raw or undercooked meat. Instead, feed them high-quality commercial pet food (Saegerman et al. 2012).
- It's essential to practice good everyday hygiene. Individuals with immune-competent bodies must clean kennels, garbage boxes, cages, and toys carefully, and feces must be bagged. Coat cleaning is also important for maintaining healthy skin and hair. Pet food dishes and litter boxes need to be kept apart, and they should be cleaned and disinfected at least once a month (Hemsworth and Pizer 2006).

6.6. EDUCATION AND TRAINING

- It is necessary to educate farmers and animal handlers about zoonosis. Programs for training farmers and livestock handlers in zoonotic disease transmission and management are required (Chowdhury et al. 2018).

6.7. COLLABORATION

- The execution of practical operations and surveillance among the human, animal, and environmental sectors is needed for the prevention and control of developing and re-emerging illnesses, including zoonosis (Rahman et al., 2020).

7. CONCLUSION

Active and widespread zoonosis surveillance and monitoring using cutting-edge methods like molecular epidemiology tools and satellite-based remote sensing systems. It is crucial to implement food safety and cleanliness. It is also essential to store food in the right location and at the right temperature, as well as cook meals at the right temperature. To maintain excellent health for all, the One Health approach is crucial. People should try the best strategy to prevent infections acquired through contact with animals is to fully wash their hands with soap and water after interaction with animals or their habitats. To prevent infections from spreading to populations of humans and animals, pet owners must carefully follow biosecurity procedures: Animal pens should be fenced, Keep pet areas apart from your family's residence, Distinguish animal areas from water and food sources for people, Limit the interaction of visitors with animals. Prior to entering and exiting animal areas, make sure all non-disposable equipment is cleansed and sterile. Personal protective equipment includes things like masks, goggles, gloves gown or apron should be worn when tending to sick animals. It is essential to maintain the security of infectious laboratories in order to stop the unintended spread of zoonotic illnesses and bioterrorism.

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Factors Influencing the Emergence and Re-emergence of Zoonotic Infectious Diseases in Livestock and Human Populations

23

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ABSTRACT

The emergence of zoonotic infectious diseases poses a significant threat to human and animal health. Understanding the factors influencing the emergence of these diseases is crucial for effective prevention and control strategies. Livestock populations act as reservoirs for zoonotic pathogens, circulating silently and potentially infecting humans. Disease transmission, pathogenesis, and genetic diversity within and across the livestock and human populations play a significant role in disease susceptibility, thus increasing the risk of disease emergence. These factors also hinder disease surveillance, control measures, and timely interventions, allowing disease to spread among different geographical regions. The deviations in human and animal behavior, habitat, ecology, vector biology, pathogen adaptability, use of antibiotics, livestock farming, production systems, food safety, malnutrition, urbanization, deforestation, and climate contribute to the emergence of highly infectious diseases. In addition, wildlife animals also serve as a reservoir of zoonotic pathogens which cause newly emerging and reemerging zoonotic diseases. Therefore, understanding and addressing these factors is essential for effective prevention and adaptation of control measures to mitigate the high risk of zoonotic disease emergence, re-emergence, transmission, and spreading in livestock and human populations.

Keywords: zoonosis, disease transmission, pathogen adaptation, surveillance, prevention

CITATION

Usmani MW, Rizvi F, Shakir MZ, Mahmood N, Numan M, Abdullah RM, Tahir J, Shafiq MS, and Hameed HA, 2023. Factors influencing the emergence and re-emergence of zoonotic infectious diseases in livestock and human populations. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 316-326. https://doi.org/10.47278/book.zoon/2023.023

CHAPTER HISTORY Received: 21-Feb-2023 Revised: 25-July-2023 Accepted: 05-Aug-2023

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1. INTRODUCTION

An emerging zoonosis is one that has recently been identified or evolved in recent past and still prevailing more in terms of its geographic, host, or vector ranges (Alvi et al. 2023a). Over the past 70 years, about 250 zoonoses have been reported as emerging and re-emerging spreading over the globe with more intensity than previous (de Thoisy et al. 2014). The animals being as reservoirs for newly emerging and re-emerging zoonotic diseases transmit to human populations, play a crucial role in the dynamics of disease morphology, pathogenesis, overflow, and amplification (Usmani et al. 2022). There are multiple factors which affect the transmission and occurrence of zoonotic infectious diseases from animal population to human beings. Furthermore, these factors also have significance in disease transmission within livestock (Craddock and Hinchliffe 2015). First, the close contact between humans and livestock, particularly in intensive farming systems, increases the opportunities for disease transmission because livestock populations serve as reservoirs for zoonotic pathogens, even without apparent signs of disease. Second, genetic diversity within livestock populations affects disease susceptibility, with reduced diversity increasing the risk of disease emergence (Fig. 1).

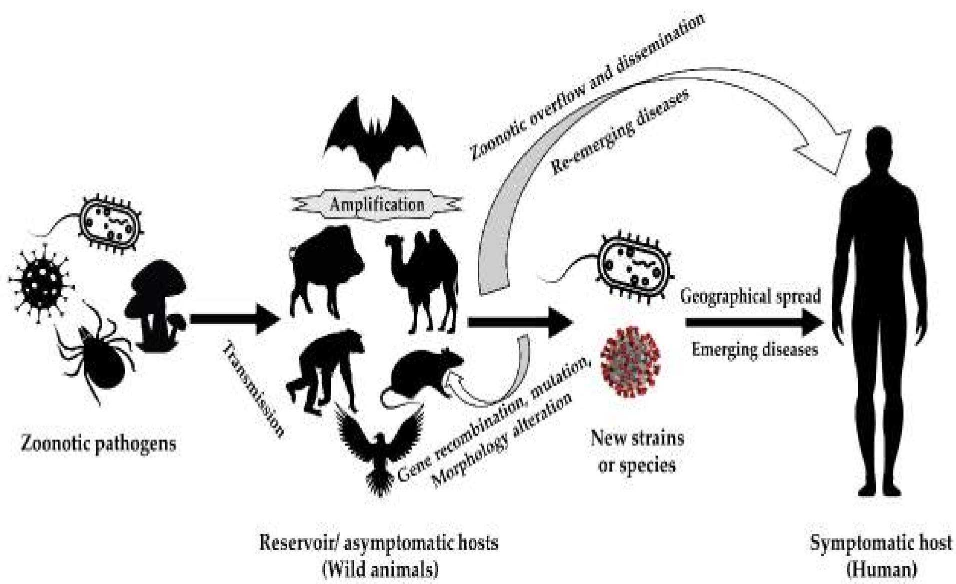

Fig. 1: Transmission of zoonotic pathogens and emergence of infectious diseases in animals and human populations (Rahman et al. 2020)

2. IMPACT ON GLOBAL SOCIO-ECONOMIC AND PUBLIC HEALTH

The emergence and re-emergence of zoonotic diseases has great impact on global socio-economic and public health. A total of 132 diseases have been declared as emerging zoonotic infectious diseases out of 175 recognized emerging diseases (Alvi et al. 2022). The most important emerging zoonotic diseases are avian influenza (AI), bovine spongiform encephalopathy (BSE), Ebola, rotavirus, West Nile (WN) fever, canine leptospirosis, cat scratch disease, MRSA infection, SFTS (severe fever with thrombocytopenia syndrome), MERS (Middle East respiratory syndrome), SARS (severe acute respiratory syndrome), and the most recent COVID-19 (coronavirus disease 2019). These zoonotic diseases account for almost 60.3% of all new diseases and about 71.8% of them are derived from wildlife animals (Mosnier et al. 2020).
On the other hand, many regions of the world have declared rabies, brucellosis, Japanese encephalitis, tuberculosis (TB) special emphasis on *Mycobacterium bovis*, and Schistosoma japonica infection as zoonotic (Civitello et al. 2015). Recently, a *bunyavirus* belonging to the *Bunyaviridae* family causes the potentially fatal infection known as SFTS, characterized by abrupt onset of fever, thrombocytopenia, and leukopenia.

The signs and symptoms of this infection are quite similar to hemorrhagic fever. Under extreme circumstances, this infection can lead to a multi-organ failure, which kills almost 6-30% of patients. In May 2007, this disease was first reported in central and northeast China, transferred by Ixodid tick (*Haemaphysalis longicornis*) and mostly affects the people working at and nearby the mountains (Bolatti et al. 2020). The animals in the endemic regions develop antibodies that are antigen specific i.e., against severe fever with thrombocytopenia syndrome (SETS) virus. Typically, this disease spreads horizontally i.e., direct interaction with animals or vectors. Later, SFTS-like clinical indication, similar to bunyavirus-associated disease was reported in the USA, Japan, and South Korea. These findings have led to the disease being classified as an emergent zoonotic infection in several regions of the world (Binetruy et al. 2020).
In 2012, Middle East Respiratory Syndrome (MERS) was first reported in Saudi Arabia in camels and is an emerging viral zoonotic infection that affects humans (Chaisiri et al. 2017). The MERS coronavirus (MERS-CoV) is the causative agent of this infection and significantly causes high fatality rates, lowers production performance, and has public health significance. This disease has about 60% morbidity and 7-14% mortality rates in humans, although it has no signs and symptoms in the infected dromedaries. However, the dromedaries which had the infection showed mild respiratory symptoms. There is evidence that MERS-CoV can cause serious infection in the lower respiratory tract of animals (Saldanha et al. 2020).

3. ROLE OF KEY FACTORS IN THE EMERGENCE OF INFECTIOUS ZOONOTIC DISEASES

The emergence of zoonotic diseases in livestock and human populations can be influenced by various factors which can be broadly categorized as biological, ecological, and socio-economic factors. The interaction of human, animal, and environment associated factors in the transmission and spreading of infectious zoonotic diseases in one heath perspective has been described in Fig. 2. However, these factors are further classified and the key factors that may contribute significantly to the emergence of zoonotic infectious diseases are discussed below:

4. ECOLOGICAL CHANGES

Human-derived changes such as deforestation, agriculture expansion, and urbanization to ecosystems have led to the alteration of habitats and increased the interactions between wildlife, livestock, and human population (Fong 2017). This interaction created a favorable condition for the transmission of zoonotic diseases, altered the disease transmission dynamics, fragmentation, distribution and behavior of human, livestock, and wildlife populations. These changes brought them into closer contact, facilitated the transmission of pathogens between different species across the different geographical regions (García-Pena et al. 2016).

5. CLIMATE CHANGE

Global climate change influenced the distribution of disease, especially the prevalence of vector-borne diseases and their biological and mechanical vectors i.e., mosquitoes, ticks, and flies. It also led to changes in the distribution and behavior of human, wildlife, and livestock populations, increasing the likelihood of disease transmission (Barry et al. 2018). This climate change badly altered the distribution and behavior of zoonotic pathogens, their hosts i.e., animals and insects such as mosquitoes and ticks. These hosts and vectors' geographic ranges increased and shifted towards warm and humid temperate regions exposing them to new populations of humans and animals (Alvi et al. 2020). This increase in temperature favors the circumstances for disease-carrying vector reproduction and survival. For instance, the rise in temperature favors mosquitoes to spread diseases such as malaria, dengue fever, and the Zika virus (ZIKV) and alters

Fig. 2: Interaction of human, animal, and environment associated factors in the acceleration of infectious zoonotic diseases in One heath perspective (Messenger et al. 2014).

the dynamics of zoonotic pathogen transmission (Imran et al. 2023). At high temperature, shorter incubation periods and quicker transmission can result in disease outbreaks more quickly at higher intensity. This may lead to disease transmission at higher magnitude and perhaps even more severe outbreaks. Both host's and pathogens' physiological and behavioral characteristics can be altered by climate change. This may alter the host and pathogen interaction, thereby altering the prevalence, severity, and patterns of disease transmission (Petersen et al. 2016).

6. GENETIC DIVERSITY

The microbes, especially viruses and bacteria evolved through mutation and recombination, resulting in the development of new and more virulent strains. These new virulent strains infect multiple hosts which include humans and animals more severely than previous (Bhatt et al. 2013). This genetic variation within livestock populations can also influence disease susceptibility. Reduction in genetic diversity results from selective breeding for specific traits can make animals more susceptible to certain diseases. This also increases the likelihood of disease occurrence and spread within livestock populations (de Thoisy et al. 2014). A population's genetic homogeneity, though, may also make some diseases more contagious in animals. In a population with low genetic variety, a single virus can quickly spread throughout the community, raising the danger of zoonotic transmission (Ioos et al. 2014).

7. PATHOGEN RESERVOIRS

Livestock populations act as reservoirs for various pathogens that can cause zoonotic infectious diseases. These pathogens may circulate silently within animal populations without causing apparent disease in the animals, but they can still be transmitted to humans and cause infections (Alvi et al. 2023b). Animals in close proximity to one another, shedding and spreading pathogenic organisms in the environment are greater sources of infections to humans and their feces due to intensive farming techniques. As a result, there is a greater chance that viruses will be released into the environment and might infect people who come into touch with polluted surfaces, water, or air (Binetruy et al. 2020). More than a billion people are suffering from zoonotic infectious diseases, and more than 60% fatalities are being reported in humans and domestic or wild animals each year. According to estimates, zoonoses account for 75% of newly emerging infectious diseases. There is a large variety of terrestrial and aquatic vertebrate animals that can spread a wide range of microbial infections to people either directly or indirectly (Usmani et al. 2022). A wide variety of microorganisms, including rickettsiae and mycobacteria, viruses, fungi, parasites (including protozoa, metazoans, and helminths), and prions are included in the vast range of infectious agents. Animals can spread infectious diseases to people through a number of different routes, including the fecal-oral route with foodborne zoonoses, accidentally contaminated drinking water, unwashed hands, direct contact with or without bites or scratches, indirectly through a variety of vectors [mosquitoes, sandflies, fleas, and ticks], and incidentally by environmental contamination with animal pathogens, such as aerosol of dried infected animal excrement (Imran et al. 2023).

8. ANTIMICROBIAL RESISTANCE

The overuse and misuse of antimicrobials in both human and animal medicine contributes to the development of resistant pathogens, which can be more difficult to treat and control. The overuse of antibiotics in livestock farming can contribute to the emergence of drug-resistant pathogens. To slow down the emergence of antibiotic resistance, safe and judicious use of antibiotics must be implemented in veterinary and human medical procedures. Regular monitoring of antibiotic-resistant bacteria in humans and animals can help to identify the growing patterns of resistance and developing effective control measures (Plowright et al. 2017; Mosnier et al. 2020). In addition, the One Health strategy also collaborates the human, animal, and environment and playing positively in identifying and managing the development of antibiotic resistance microbes (AMR) at the human-animal-environment interface (Blaizot et al. 2020). This one-health is also making possible to lessen the selection pressure for antibiotics by promoting the use of organic and sustainable therapeutic agents that will definitely decrease the overuse of antibiotics which will ultimately slow down the spread of AMR and improve the humans and animals' health status (Mosnier et al. 2020).

9. INTENSIVE LIVESTOCK FARMING PRACTICES

Basically, a high-density and monoculture livestock farming practice can facilitate the rapid spread of infectious diseases among animals. Such kind of systems often have poor biosecurity measures and high-stress levels for animals, which can compromise their immune systems and production performance as well as making them more susceptible to infections. Specific breeds of animals with desired productivity traits are frequently preferred in intensive farming, and they are frequently stuffed together in small quarters of intensive husbandry (Cascio et al. 2011). Such conditions i.e., over-crowding, stress, poor biosafety, and unhygienic environment weaken the immune system of animal, leaving them more prone to disease. Under these circumstances, there is a higher chance of spreading and proliferation of zoonotic pathogens from animals to human beings. Moreover, when animals are fed on animal and plants byproducts, this may also expose them to various toxins present in these products. This could spread zoonotic infections and introduce new microbial pathogens to the community of humans and animals (Craddock and Hinchliffe 2015).

10. INADEQUATE DISEASE SURVEILLANCE AND MONITORING SYSTEM

Lacking rapid and accurate tools for the detection and reporting of emerging infectious diseases can delay the proper identification and effective prophylactic measures against to zoonotic disease outbreaks, allowing them to spread quickly and widely (Usmani et al. 2022). Early and accurate detection of pathogens is essential to limit the spread of outbreaks in a wide geographical region. Due to limited diagnostic facilities, unavailability of skilled personnel and poor healthcare infrastructure, zoonotic diseases may go unreported or get the wrong diagnosis. Lack of precise data on disease prevalence and distribution, the effective control initiatives are also being hampered regularly (Cascio et al. 2011).

11. SOCIOECONOMIC FACTORS

Socioeconomic factors, such as poverty, limited access to healthcare, and inadequate veterinary services, can impact disease emergence and spread. These factors can hinder disease surveillance, control measures, and timely interventions, allowing disease outbreaks. Among these factors, the alterations in human and animal behavior, habitat, ecology, vector biology, pathogen adaptability, farming practices, livestock production systems, food safety, urbanization, deforestation, and global warming facilitating the emergence and transmission of zoonotic diseases (Cipolla et al. 2015). Additionally, certain behaviors and cultural practices i.e., consumption or use of animals in traditional medicine, can increase the risk of exposure to zoonotic pathogens. Poor sanitation and hygiene practices in both human and animal population can facilitate the transmission and persistence of zoonotic infectious pathogens. Moreover, poverty, malnutrition, and poor healthcare infrastructure can also exacerbate the emergence and spread of zoonotic diseases by limiting the access to healthcare, disrupting disease control efforts, and increasing vulnerability to infections (Cassadou et al. 2014: Wood et al. 2016).

12. GLOBAL TRADE AND TRAVEL

Increased movement of humans, animals, and animal products across borders can introduce new pathogens to previously unexposed populations. The live animal trade, in particular, can facilitate the spread of zoonotic diseases. The movement of livestock, either within a country or across international borders, can contribute to the spread of diseases. Trade in live animals, animal products, and the movement of people associated with livestock farming can introduce pathogens into new areas and increase the risk of disease transmission (de Thoisy et al. 2010; Hoen et al. 2018).

13. CHANGES IN LAND USE AND AGRICULTURE PRACTICES

Alterations in land use, such as the expansion of agricultural land or changes in farming practices, can affect the interaction between livestock, wildlife, and humans (Wangdi et al. 2015). Encroachment into wildlife habitats or the conversion of forests into agricultural land can bring livestock and humans into closer contact with wildlife, increasing the chances of exposure to new pathogens. Livestock animals often live in close proximity to humans, increasing the opportunities for disease transmission. Intensive farming practices, such as factory farming, can lead to high population densities of animals, making it easier for diseases to spread within and between herds (Civitello et al. 2015).

14. WILD ANIMALS AND RE-EMERGING ZOONOSES

The disruption of the ecological interactions among the one-health components due to globalization, habitat degradation, climatic change, species extinction, and biodiversity loss eventually results in the formation of zoonotic infections and alterations in how they are transmitted. Mammals, reptiles, birds, fish, amphibians, and other wild animals are reservoirs for zoonotic illnesses that can be transmitted to humans or other animal hosts (Roux et al. 2013). It is concerning that wild animals are involved in the epidemiology and spread of zoonotic illnesses. The type of pathogen implicated and environmental factors like temperature, humidity, and rainfall affect the patterns of transmission of wildlife zoonoses (Chaisiri et al. 2017). These viruses' patterns of transmission among wild animals, domestic animals, and people determine when and if they first appear and reappear.

The following factors have an impact on these processes: (1) the rapid increase in the human population; (2) the consumption of wild meat (such as bush meat); (3) the increased exposure of humans to animals and animal products; (4) the careless handling and transportation of wildlife carcasses; (5) wildlife farming; (6) the ease of domestic and international travel; and (7) variations in agricultural methods. There is significant human-to-wild animal pathogen transfer in developing and reemerging diseases. The majority of human diseases are contracted from wild animals either directly or with the use of a vector, as in the cases of lyssaviruses, hantaviruses, the Nipah virus, the West Nile (WN) virus, and the agents that cause leptospirosis and ehrlichiosis. Human-to-human transmission is a major factor in the spread of illnesses such the coronavirus, Ebola virus, and HIV (Bolatti et al. 2020).

15. ROLE OF POPULATION MOVEMENTS IN ZOONOTIC DISEASES EMERGENCE AND TRANSMISSION

The BAM concept's M component, which refers to population mobility, international travel, and trade globalization, also points to these factors as important factors for the rapid spread of viruses (Bhatt et al. 2013). The probability of new epidemics is clearly influenced by climate change and environmental destruction. They have moved people, animals, insects, food, plants, and vectors that are ever more linked to the transcontinental persistence of germs (Stanaway et al. 2016). When it comes to microbial infections, examples of rapid worldwide growth were historically uncommon, but as more people and money have moved around the world, barricades between the species and ecosystems have gradually crumbled, cumulative the prevalence, geographic spread, and host ranges of numerous new communicable illnesses (Ioos et al. 2014).

Local population shifts brought on by migratory patterns, the cross-border pendulum, or periodic mobility (Saldanha et al. 2020) may also have amplification effects on these emerging diseases, or at the very least make it more difficult to contain and eradicate them. Along with this immigration, informal living has grown significantly, which encourages the direct and/or indirect communication of many dangerous illnesses (Wangdi et al. 2015). In addition to the challenging economic situation i.e., 45% of the total population lives below the poverty level, 20% lack adequate access to drinking water, and the number of unemployed individuals is over 22%, these features all contribute to the high rate of immigration (Stanaway et al. 2016). Examples of illnesses that infected visitors can bring into geographically vulnerable locations where capable mosquitoes or arthropod vectors are present include vector-borne infections. Through the occurrence of epidemics, dengue fever, zika, chikungunya and yellow fever (YF) illnesses, whose distribution has increased in risk areas, have demonstrated different impacts to this vibrant process in recent decades (Epelboin et al. 2016; Mosnier et al. 2020).

The most substantial virus spread by mosquitoes to people is believed to be dengue fever. Due to the significant public health burden associated with these outbreaks, surveillance mechanisms have been strengthened, allowing us to clearly show that a serotype's resurgence was caused by imported human cases (Cassadou et al. 2014). For example, during the 2012–2013 DENV-2 pandemic, the detection of cases with scientific verification rapidly decreased to sporadic levels before disappearing completely after September 2016. In January 2019, two epidemiologically unrelated dengue fever cases were discovered, one of which was introduced from the French West Indies (Petersen et al. 2016). Late in April, the epidemiological investigation conducted in Kourou revealed the finding of a second DENV-2 case, this one imported from South America; the examination also showed a secondary case, the first local case found in the area since 2016. A few weeks later, an outbreak started, most likely in response to the discovery of a DENV-1 case in Cayenne that had been brought in from the French West Indies. Between January 2019 and April 2020, the region experienced over 1000 cases in two separate epidemic outbreaks linked to these two serotypes, providing insight into the spread of viral circulation (Hoen et al. 2018).

CHIKV has caused numerous significant outbreaks in Asia, Africa, and the Pacific Islands since it was originally discovered in Tanzania in the early 1950s. The discovery of autochthonous cases in Saint Martin, a French overseas territory, in December 2013 sparked the first known case of CHIKV transmission in the Americas. Within nine months, CHIKV had spread rapidly throughout the Caribbean, the Americas, including French Guiana (Cassadou et al. 2014). Particularly, a small number of nearby acquired CHIKV infections were recorded in February 2014. Prior to a significant epidemic in Yap, Federated States of Micronesia, in 2007, and a subsequent one in French Polynesia in 2013, ZIKV was regarded as an emerging virus with few rare cases identified in Africa and Asia (Ioos et al. 2014). ZIKV then carried on disseminating across the Pacific region until making an early 2015 appearance in South America. Due to the virus' quick spread over 50 other countries and territories in the Americas after its first discovery in Brazil in May 2015, it attracted interest from around the world (Hoen et al. 2018; Petersen et al. 2016).

16. IMPACT OF ANIMAL SPECIES COMMUNITIES AND VECTOR-BORNE ZOONOTIC DISEASES

How animal species involved in the disease cycle respond to environmental changes is one crucial consideration. The expansion of more generalist host and vector species may be aided by changes in the distribution of natural resources, the extinction or loss of more specialized, weaker host and vector species, and the simplification of ecological niches. Many illnesses depend on a small number of efficient reservoir and vector species, even though many other species may act as hosts, especially under conditions of ecological disequilibrium (Wangdi et al. 2015). To conceptualize the potential impacts of biodiversity, change on the transmission of zoonotic illnesses, the "dilution effect hypothesis" was utilized. Because the existence of unfit hosts serves as an epidemiological dead end or delays the disease agent cycle, more biodiversity should normally prevent the spread of infectious illnesses. This concept attracted a lot of interest, but it also drew critiques that the relationship between biodiversity and disease was peculiar because alternative mechanisms might instead cause disease transmission to become amplified with greater biodiversity (Epelboin et al. 2016; Mosnier et al. 2020).

Understanding these factors and implementing appropriate preventive measures, such as improved biosecurity, surveillance, and responsible antibiotic use, are essential for mitigating the risk of zoonotic disease emergence in livestock populations. It's critical to understand that interactions between people, animals, and the environment play a role in the genesis of zoonotic illnesses, which is a complicated and multifaceted process. The likelihood of zoonotic disease onset in cattle populations can be reduced by being aware of these factors and putting the right preventive measures in place, such as enhanced biosecurity, surveillance, and responsible antibiotic use. We must better understand the local contexts and factors that may contribute to disease onset and spread, even though our local societies are now dealing with significant global changes. Only then can we prioritize local resilience in future national and international agendas. Knowledge gaps suggest that future efforts are needed in the following areas:

17. INCREASE IN ACTIVE GLOBAL DISEASE SURVEILLANCE

Commenting on whether disease incidence is changing as a function of environmental circumstances is challenging due to the absence of exact understanding of present disease incidence rates. To give epidemiological research a baseline, incidence statistics are required. Additionally, these data will be helpful for confirming forecasting models. Since these data are challenging to collect, especially in remote areas, a centralized computer database must be established to make it easier for researchers to share these data.

18. CONTINUATION OF EPIDEMIOLOGICAL RESEARCH INTO ASSOCIATIONS BETWEEN CLIMATIC FACTORS AND INFECTIOUS DISEASES

Research is required to demonstrate persistent trends across many populations and geographical locations in order to make a causal connection between patterns of infectious disease and climate change. The most effective way to do this is to use robust study designs that sufficiently account for social and environmental variables. In order to increase the depth of knowledge, multidisciplinary collaboration between experts such as epidemiologists, climatologists, and ecologists is crucial, as is international collaboration among academics. Entomologists, epidemiologists, and climatologists must collaborate to research the relationships between shifting vector habitats, disease patterns, and climatic conditions, as in the case of a thorough study of mosquito-borne diseases. Policymakers can use epidemiological statistics to inform the development of preventive measures.

19. IMPROVEMENTS IN PUBLIC HEALTH INFRASTRUCTURE

Programs for preventive and control, emergency response, and public health training are some of them. It is important to have a better grasp of both the population's ability to respond to expected climate change health effects and the ability of individuals to adapt to those outcomes.

20. CONCLUSION

As this analysis's conclusion has demonstrated the local factors that may favor the spread of new infections that are currently emerging and reemerging in the future include human demography, unfavorable health conditions, and landscape modification as a result of human activities like resource extraction and agricultural growth. In order to better understand the local conditions that lead to sickness production and more effectively improve healthcare systems, we also invite other research consortiums around the world to revisit and adapt the same kind of examination of local vs. global elements. Environmental factors, such as changes in land use, climate change, and habitat fragmentation, can alter the dynamics of disease transmission between livestock and wildlife. Livestock trade and movement facilitate the spread of diseases across regions and countries. The use of antibiotics in livestock farming contributes to the emergence of drug-resistant pathogens, posing challenges for treatment. Socioeconomic factors, including poverty and limited access to healthcare, impact disease surveillance and control efforts.

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Transmission Dynamics of Zoonotic Diseases from Forest to Cities

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ABSTRACT

Zoonotic diseases, characterized by their transmission from animals to humans, present a pervasive threat to global public health. The zoonotic diseases, ranging from viral to bacterial and parasitic, present a major threat globally. Wildlife, acting as reservoirs for many pathogens, plays a pivotal role in interspecies transmission. Various zoonotic diseases, such as Ebola Virus Disease, Nipah Virus Infection, Hantavirus Pulmonary Syndrome, and others, have been traced back to wildlife origins. Biodiversity, human-wildlife interactions, and the impact of habitat loss and urbanization emerge as critical factors shaping the spread of zoonoses. The drivers of zoonotic disease transmission from forests to cities are multifaceted, involving both ecological and anthropogenic factors. Ecological factors include biodiversity, species interactions, human-wildlife interactions, and habitat loss, while anthropogenic factors encompass urbanization, wildlife trade, consumption, and climate change. These factors contribute to the spillover of pathogens from wildlife to humans, increasing the risk of disease transmission. The implications of wildlife zoonosis for public health underscore the need for proactive measures, including a one-health approach, effective communication, and targeted interventions. The strain on healthcare systems in underdeveloped countries and the difficulty of tracking zoonotic infections in urban and forested regions are acknowledged. In conclusion; interdisciplinary collaborations, research on ecological dynamics, socio-cultural factors, and genetic evolution of pathogens are identified as key areas for advancing our understanding of zoonotic disease transmission. Ultimately, the integration of evidence-based policies and actions is essential to protect public health and mitigate the impact of zoonotic diseases originating from forests on urban populations.

CITATION

Latif M, Ashraf H, Ahsan MF, Rehman A, Sharif NT, Ahmad MN, Sannan MA, Saad M and Salman M, 2023. Transmission dynamics of zoonotic diseases from forest to cities. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 327-337. https://doi.org/10.47278/book.zoon/2023.024

CHAPTER HISTORY Received: 12-Jan-2023 Revised: 21-Jun-2023 Accepted: 14-Nov-2023

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1. INTRODUCTION

The word "zoonoses" comes from the Greek words "zoon" (animal) and "noson" (disease). Zoonotic disease is an ailment, disease, or infection that spontaneously spreads from vertebrate animals to human beings (Rehman et al. 2020). These diseases may be bacterial, parasitic, viral and fungal that are of major threat to public health. Zoonotic diseases that had caused significant morbidity and mortality include Malaria, Ebola virus, Plague, Yellow Fever, Nipah virus, Hendra Virus, SARS Corona Virus and Avian Influenza virus etc. (Daszak et al. 2007; Dong and Soong 2021). The diseases may be transmitted either directly or via vector from one species to another. Ticks, flies, bugs, cockroaches, fleas and sandflies are the best vectors that are capable of transmitting the pathogen to domestic animals or human beings (Bueno-Mari et al. 2015). An understanding of transmission dynamics is crucial for effective prevention, preparedness, and control interventions (Webster et al. 2017). The significant impact on public health in developed and underdeveloped countries due to zoonosis is because of the range and adaptability of vectors to different kinds of pathogens and the difficulty in applying effective control programs (Bueno-Mari et al. 2015). Due to increased human-wildlife interaction brought on by population expansion, agriculture, and urbanization, infectious pathogens can more easily spread to new hosts and ecosystems, which can lead to the development of dangerous relationships (Cupertino et al. 2020). This chapter aims to explore the transmission dynamics of zoonotic diseases from wildlife to cities, shedding light on the factors influencing their spread, the pathways of transmission, and the implications for public health. Moreover, this chapter provides valuable insights into the mechanisms by which zoonotic diseases emerge and disseminate, enabling us to develop proactive measures to mitigate their impact.

2. ZOONOTIC DISEASES AND THEIR WILDLIFE ORIGIN

Wildlife has been playing a significant role in the transmission of infectious diseases to humans resulting in life-threatening conditions (González-Barrio 2022). The zoonotic diseases in humans are mainly linked to their exposure to mammalian wildlife. These mammals harbor an abundant number of pathogens (Van Brussel and Holmes 2022). This interaction between wildlife, livestock, and humans leads to the interspecies transmission of infectious agents. Forest ecosystems harbor a rich diversity of wildlife, providing ample opportunities for the spillover of zoonotic pathogens to humans with or without vector involvement. Numerous zoonotic diseases have originated from forests and impacted human populations worldwide (González-Barrio 2022). Some of the zoonotic diseases that originate from the forests include Ebola Virus disease, Lyme disease, Hantavirus pulmonary syndrome, Nipah virus, Leptospirosis and Monkeypox etc. The origin of different diseases is mentioned in Table 1. Wildlife plays a significant role as reservoirs or carriers of zoonotic pathogens. Many animal species, including mammals, birds, reptiles, and insects, can harbor these pathogens without experiencing significant health effects by themselves (Rehman et al. 2020). These reservoir species act as natural hosts, allowing the pathogens to persist and circulate within their populations (Begon 2008). However, when humans come into contact with infected wildlife or their bodily fluids, the risk of zoonotic disease transmission increases (Tarantola et al. 2006).

3. DRIVERS OF ZOONOTIC DISEASE TRANSMISSION FROM FOREST TO CITIES

Two types of factors play a critical role as the drivers of zoonotic disease transmission from forest to cities i.e., ecological and anthropogenic factors.

3.1. ECOLOGICAL FACTORS

Pathogen and host ecology are related to the transmission of the majority of zoonotic diseases. These factors influence the transmission dynamics of zoonotic diseases (Slingenbergh et al. 2004). These factors include;

Table 1: Zoonotic Diseases and their reservoir host

No.	Zoonotic Diseases	Reservoir Host	Reference
1	Ebola Virus Disease	Fruit bats	Gryseels et al. 2017
2	Nipah Virus Infection	Fruit bats	Hauser et al. 2021
3	Hantavirus Pulmonary Syndrome	Rodents (e.g., deer mice)	Calderon et al. 1999
4	Lyme Disease	American Robins	Richter et al. 2000
5	Plague	Rodents (e.g., rats)	Prentice and Rahalison 2007
6	Rabies	Bats, raccoons, and dogs	Rupprecht et al. 2002
7	Leptospirosis	Rodent (*Rattus norvegicus*)	Nally et al. 2011
8	Hendra Virus Infection	Fruit bats	Ashraf et al. 2023
9	West Nile Virus Infection	Birds	Reed et al. 2003
10	Q Fever	Domestic animals	Porter et al. 2011
11	Tularemia	Lagomorphs and rodents	Luque-Larena et al. 2017
12	Brucellosis	Livestock	Haque et al. 2011
13	Monkeypox	Squirrel and Gambian Rat	Walker 2022
14	Leishmaniasis	Dogs, rodents, mammals	Quinnell and Courtenay 2009
16	Psittacosis (Parrot Fever)	Psittacine Pet Birds	Beeckman and Vanrompay 2009
17	Toxoplasmosis	Wild boar (*Sus scrofa*)	Reiterová et al. 2016
18	Trichinellosis	Red Fox and Wild Boar	Hurníková et al. 2006
19	Avian Influenza	Aquatic Waterfowl	Latif et al. 2023
20	Chikungunya	Primates and mosquitoes	Latif et al. 2023

3.1.1. BIODIVERSITY AND SPECIES INTERACTION

Pathogens or infectious agents are similarly shared with each other through specie interaction as in human beings. These pathogens are transmitted through bodily fluids such as blood, urine, and saliva (Keesing and Ostfeld 2021). High levels of biodiversity and a wide variety of animal species interacting within forest ecosystems are distinguishing features. According to McMohan et al. (2018), the intricacy of these relationships can affect the spread of zoonotic diseases. Increased biodiversity increases the risk of acquiring new infections and encourages the spread of those pathogens (van Langevelde et al. 2020). The loss in biodiversity is threatening human health by increasing the incidence of zoonotic diseases (Ostfeld 2009). This leads to a smaller number of competent hosts and the pathogen spreads better and more rapidly (van Langevelde et al. 2020). Large-bodied species with slower life histories are more likely to disappear when biodiversity is lost in ecological groups, whereas smaller-bodied species with faster life histories often become more prevalent (Keesing and Ostfeld 2021). For example, the presence of reservoir host species and their interactions with vectors or intermediate hosts can affect the circulation and spread of pathogens (Otranto et al. 2009).

3.1.2. HUMAN-WILDLIFE INTERACTION

Human and wildlife interact with each other, particularly in forests which can be detrimental as it plays a crucial role in zoonotic disease transmission (Soulsbury and White 2016). Hunting and cooking of wildlife by humans carries a major risk of zoonotic transmission. Building logging paths also results in division of habitat because the degradation of the forest edges along the roads reduces animal mobility across forest areas. Infected animals or their body fluids might come into intimate contact with people via activities including hunting, eating bush meat, trading wildlife, and ecotourism, increasing the risk of disease transmission (Wolfe et al. 2005; Keesing and Ostfeld 2021;). The other activities include encroachment into natural habitats, including forest clearing for agriculture or settlements, further intensifying human-wildlife interactions and the potential for zoonotic disease spillover (Despommier et al. 2006).

3.1.3. HABITAT LOSS AND FRAGMENTATION

Deforestation and habitat fragmentation are significant ecological drivers that are recognized as threat to biodiversity and can facilitate zoonotic disease transmission (Pérez-Rodríguez et al. 2018). As natural habitats are converted for agriculture, infrastructure development, or urbanization, human activities come into closer contact with wildlife, increasing the likelihood of disease spillover. Fragmentation of forests can also lead to changes in wildlife populations, behavior, and ecological dynamics, influencing the disease transmission patterns (Ferreira et al. 2021).

3.2. ANTHROPOGENIC FACTORS

Different factors include urbanization and encroachment, wildlife trade and consumption, and climate change that affect the transmission of zoonotic diseases. Rapid urbanization and expansion of cities often involve encroachment into nearby forested areas. This proximity increases the likelihood of zoonotic disease transmission, as humans come into contact with wildlife reservoirs and vectors (Soulsbury and White 2016). Urbanization also creates new habitats and conditions favorable for disease vectors, such as mosquitoes, leading to the establishment of urban transmission cycles (Alirol et al. 2011). The trade of wildlife, both legal and illegal, can contribute to zoonotic disease transmission. This includes the trade of live animals, animal products, and bushmeat. Through the interaction of livestock wild animals, and people during the processes of extraction, consumption, and commerce, zoonotic diseases are disseminated (Bezerra-Santos et al. 2021). Wildlife markets and consumption of bushmeat, particularly in urban areas, pose risks of introducing zoonotic pathogens to human populations (Wolfe et al. 2005). Improper handling, processing, or preparation of wildlife products can also facilitate disease transmission (Newell et al. 2010). Climate change can influence zoonotic disease transmission dynamics. Alterations in temperature, rainfall patterns, and ecological conditions can impact the distribution, behavior, and abundance of disease vectors and reservoir hosts (Gage et al. 2008). Changes in vector-borne disease transmission, such as those carried by mosquitoes or ticks, have been observed in response to climate variability, affecting disease risk in both forested and urban environments (Ogden 2018).

4. PATHWAYS OF TRANSMISSION

The transmission pathways are important for targeted disease surveillance and mitigating zoonotic diseases through proper prevention and control (Loh et al. 2015). There are different pathways involved in the transmission of zoonotic diseases from wildlife to human beings (Fig. 1).
These pathways include;

4.1. DIRECT TRANSMISSION

4.1.1. CONTACT WITH INFECTED ANIMALS

Direct contact with infected animals, both domestic and wild, is a common pathway of zoonotic disease transmission. This can occur through skin-to-skin contact, scratches, and animal bites. Physical contact with infected animals or their contact with body fluids such as blood, saliva, urine, organs, and tissues can facilitate the transfer of infectious agents from animals to humans (Loh et al. 2015).

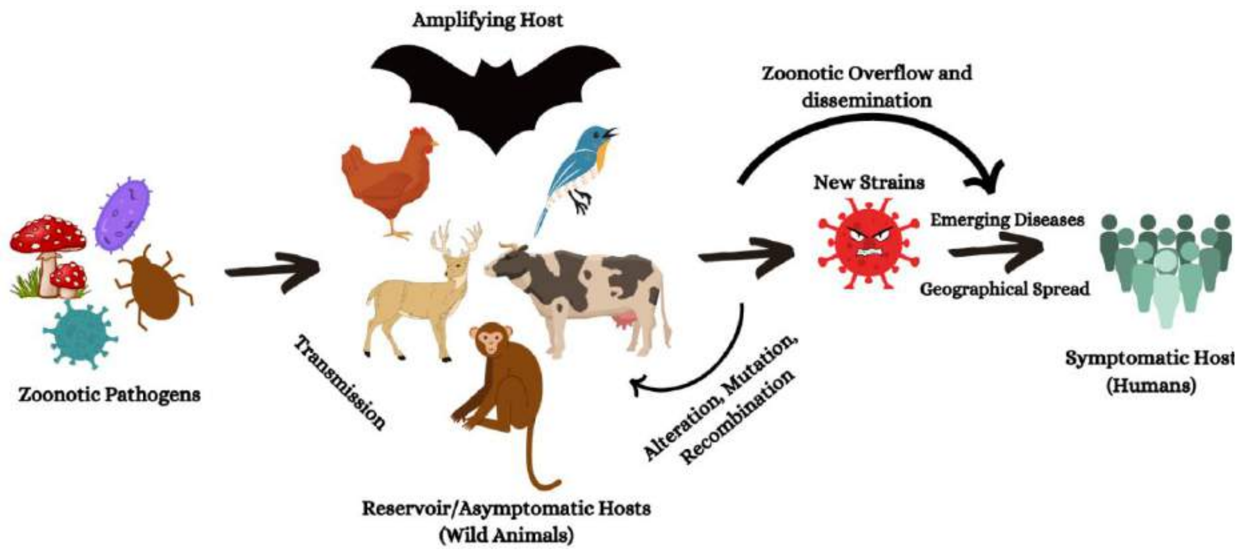

Fig. 1*:* Transmission of Zoonotic Pathogen from Reservoir Host to Humans.

4.1.2. CONSUMPTION OF BUSH MEAT

The utilization of wild animals for food, from cane rats to gorillas, is referred as bushmeat. It is another direct pathway/anthropogenic factor of zoonotic disease transmission. Hunting, slaughtering, and preparing wild animals might expose people to infectious organisms that are present in the animal tissues, blood, or secretions in areas where bush meat is consumed. The bushmeat may include viruses, bacteria, and parasites that are potentially harmful for the animals and humans (Karesh and Noble 2009).

4.2. INDIRECT TRANSMISSION

4.2.1. VECTOR-BORNE TRANSMISSION

Zoonotic diseases can be transmitted indirectly through arthropod vectors, such as mosquitoes, ticks, fleas, or sandflies (Dantas-Torres and Otranto 2016). These vectors are capable of taking up diseases from infected animals in forests and then spread them to people in urban or peri-urban regions. (Rizzoli et al. 2014). Mosquito-borne diseases like chikungunya virus, and tick-borne diseases like Lyme disease, are examples of zoonotic diseases that rely on vector-borne transmission (Richter et al. 2000; Latif et al. 2023).

4.2.2. ENVIRONMENTAL CONTAMINATION

Indirect transmission can also occur through environmental contamination. Infected animal feces, contaminated water sources, or contaminated soil can serve as reservoirs of zoonotic pathogens. Humans can contract the diseases by coming into contact with these contaminated environments or through the ingestion of contaminated food or water (Rees et al. 2021).

4.3. CROSS-SPECIES TRANSMISSION EVENTS

Cross-species transmission, in which infections are transferred from animals to humans, is a common feature of zoonotic illnesses. Genetic changes can result in cross-species transmission, enabling the pathogen to infect and adapt to a new host (Parrish et al. 2008). These events can occur as a result of contact with domestic animals that have been exposed to zoonotic infections or during close encounters between people and wildlife in wooded areas (Bradley and Altizer, 2007).

5. DISEASE SURVEILLANCE AND DETECTION

Surveillance is a system that performs multitudinous health functions. Data is integrated, processed, and then different control measures are made in accordance with the specific outbreak. However, surveillance plays a role in case detection where the prime objective is disease eradication (Robertson et al. 2010). Accurate data is required for this program. Any kind of fictitious data will lead to less veridicality resulting in compromised surveillance (Robertson et al. 1994).

5.1. IMPORTANCE OF EARLY DETECTION AND MONITORING

Early detection of viral emergence may reduce the impact of many zoonotic diseases by effective prevention and control measures (Bisson et al. 2015). Time series analysis method is applied for detection of many zoonotic diseases that are prevailing from forests to human residential areas (Hashimoto et al. 2000). Moreover, diseases or infections are detected by mortality and morbidity of wild and domestic animals, but due to lack of efficacious system and encyclopedic surveillance, these are detected too late to knock off the pathogen and its sequential impingement, it has on the human population (Bisson et al. 2015).

5.2. APPROACH FOR EARLY DETECTION

Humans are the dead-end hosts in the majority of zoonotic diseases. Pathogen changes its variants, stains, and forms to make its successful transmission from humans to humans and animals to humans (Heeney 2006). However, animals act as sentinels of zoonotic illness. Animals can be used as an early diagnostic tool of different emerging zoonotic diseases because humans and animals interact in the same environment, clinical signs may develop prior to humans so we can interpret based on manifestations, and animals and humans reciprocate to pathogens analogously. For example, dead cows affected with West Nile virus were reported in New York, and the animals were correlating with humans, so it indicates that humans are at higher risk because of their zoonotic impact (Gubernot et al. 2008). Some pathogens change their hosts by adapting themselves accordingly i.e., in case of measles and influenza, but it was also observed that pathogens did not infect humans for so long from a non-human reservoir host (Heeney 2006).

5.3. STRATEGIES FOR IMPROVED DISEASE SURVEILLANCE IN FOREST AND URBAN SETTINGS

Major tactics are made and practiced for improved disease surveillance in forest and urban settings which include; Protection, Avoidance, Host resistance, Therapy, Integrated disease management, Eradication, and Exclusion. Forests are managed by successful surveys, monitoring system and understanding the infection biology (Edmonds 2013).

6. IMPLICATIONS OF WILDLIFE ZOONOSIS FOR PUBLIC HEALTH

Zoonotic diseases originating from forests can pose significant threats to public health when they spill over into urban areas (White and Razgour 2020). The urban areas create vast interface between livestock, human, and wildlife thus acting as critical point for transmission and increases the risk of disease prevalence. In underdeveloped countries, zoonotic diseases can pose a burden on the healthcare system. This can strain the capacity of healthcare systems, especially in areas with limited resources (Shaheen 2022). Additionally, it is difficult to identify and keep track of zoonotic infections in both urban and rural settings. Forested regions have weak monitoring systems, which makes it challenging to detect and report illness outbreaks. The variety of diseases and the intricate dynamics of transmission make monitoring operations challenging in urban environments. For successful management and prevention, outbreaks must be quickly identified and responded (Morner et al. 2002).

7. CASE STUDIES

There are certain case studies that highlight the specific examples of zoonotic diseases that are transmitted from wildlife to cities:

7.1. NIPAH VIRUS OUTBREAK IN MALAYSIA (1998-1999)

The Nipah virus outbreak in Malaysia resulted in severe respiratory illness and encephalitis in humans with high mortality rate. The reservoir host of Nipah Virus is fruit bats of *Pteropid* species. Pigs were believed to be the dead-end host. The virus was transmitted between humans and from dogs to humans (Islam et al. 2023). This outbreak began among the pig farmers and spread to other regions in which pigs were reared. In this outbreak, 265 number of human cases were reported with 105 number of deaths. The case fatality rate recorded was 39.6% (Ambat et al. 2019).

7.2. EBOLA VIRUS OUTBREAK IN WEST AFRICA (2013-2016)

The virus is thought to have originated in fruit bats, and humans were exposed to it by handling and consuming bushmeat as well as through contact with sick animals. Person-to-person transmission helped the illness grow even further, increasing mortality rates and taxing healthcare infrastructure. The epidemic made it clear how crucial it is to monitor the situation, act quickly, and include the community in zoonotic disease control. The case-fatality rate recorded in this outbreak was 45.5% (Ohimain et al. 2021).

7.3. HANTAVIRUS OUTBREAKS IN AMERICAS DURING 1997-2017

Hantavirus pulmonary syndrome (HPS) is a severe respiratory illness transmitted mainly by rodents (MacNeil et al. 2011). Hantavirus belong to genus *Orthohantavirus*. It causes hantavirus pulmonary syndrome (HPS). The major transmission pathway that pathogenic hantaviruses are transferred from rodents to people is by aerosolized excreta. HPS mortality rates in South America ranged from 35% to 50% (Ferro et al. 2020).

7.4. RIFT VALLEY FEVER OUTBREAK IN SUDAN (2007)

RVF is caused by genus *Phlebovirus* belonging to *Bunyaviridae* family (Hassan et al. 2014). It is mainly a mosquito-borne disease that is mainly transmitted by the bites of mosquitos and exposure to bodily fluids of infected animals. In Sudan, 747 human cases were confirmed with 230 deaths leaving behind

the case fatality of 30.8%. Unfortunately, no case was reported/demonstrated among the livestock (Hassan et al. 2011).
There is a need for proactive surveillance, a one-health approach, effective communication, and targeted interventions to prevent, detect, and control zoonotic diseases that can be transmitted from forests to cities (Morner et al. 2002; Hassan et al. 2014).

8. FUTURE DIRECTIONS AND RESEARCH NEEDS

The majority of zoonotic diseases originate from the transmission of pathogens from animals to humans. As zoonotic diseases continue to pose threats to public health, it is crucial to monitor and study emerging infectious diseases originating from forests (Hughes et al. 2010). Research efforts in the field of zoonotic diseases should prioritize several key areas including the identification of high-risk areas, predicting disease impact, and implementing one-health surveillance approaches (Wolfe et al. 2005; Hassan et al. 2014; Beard et al. 2018). Addressing the complexities of zoonotic disease transmission requires interdisciplinary research collaborations (King et al. 2004). Key research areas should include studying ecological dynamics, behavioral and socio-cultural factors, and genetic and pathogen evolution (Wilcox and Gubler 2005).
Understanding and reducing the dangers associated with zoonotic illnesses that are spread from forests to cities depends on these study directions. We may increase our understanding of zoonotic disease transmission patterns and improve our capacity to prevent, identify, and respond to outbreaks by focusing research efforts on the identification of high-risk regions, forecasting disease impact, and establishing one-health surveillance (Saylors et al. 2021). The development of evidence-based policies and actions to protect the public's health and lessen the effects of zoonotic illnesses originating from forests on urban populations will be facilitated by these study directions (Wood et al. 2012).

9. CONCLUSION

There are considerable difficulties and consequences for public health associated with the dynamics of zoonotic disease transfer from forests to towns. Urban human populations can become infected with viruses from animal reservoirs, which can cause outbreaks that tax healthcare systems and jeopardize community safety. To successfully reduce the dangers associated with these illnesses, it is essential to comprehend the routes of transmission, the significance of surveillance and detection, and the consequences for public health. Public health is greatly affected by zoonotic infections that spread from woods to towns. To guarantee successful disease control, they need proactive measures including outbreak management and response, public awareness and education programs, and the adoption of a One Health concept. Regulations on the trade in wildlife, land use practices, food safety, and public health initiatives are just a few of the policy implications and regulatory measures that are crucial for avoiding and controlling zoonotic illnesses. Future-focused research must give top priority to important topics including the effect of developing zoonotic diseases, multidisciplinary research possibilities, and the use of technology in disease prevention and diagnosis. We can better understand how zoonotic diseases spread, increase readiness, and create efficient risk-reduction plans by identifying high-risk locations, forecasting disease impact, and putting one-health surveillance systems into practice. We can lessen the effect of zoonotic diseases on public health and promote a healthier and safer cohabitation between people, wildlife, and the environment by integrating information, improving monitoring systems, raising public awareness, and putting evidence-based initiatives into practice.

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Relationship between Zoonotic Diseases and Food Safety

25

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ABSTRACT

Food safety is a critical global issue impacting economies and human health, with zoonotic diseases posing significant threats. Comprising approximately 60% of all infectious diseases affecting humans, zoonotic diseases significantly add to the burden of infectious diseases worldwide. Limited resources and insufficient healthcare systems intensify the issues resulting from the economic consequences, particularly in developing countries. The food supply chain, which includes primary production, processing, distribution, and consumption, is crucial to the spread of zoonosis. Animals often serve as sources of zoonotic diseases, and various stages of the food chain can facilitate their transmission. The genesis and spread of zoonotic diseases within the food supply chain are facilitated by changes in the environment, globalization, altered food consumption patterns, and socioeconomic factors. To reduce risks, a number of preventive measures have been put in place, including traceability programs, regulatory frameworks, Hazard Analysis and Critical Control Points (HACCP), Good Manufacturing Practices (GMPs), Good Agricultural Practices (GAPs), and GAPs. A number of outbreaks highlight the significance of appropriate food safety procedures at every point in the food supply chain to avert these kinds of occurrences. To treat zoonotic diseases, a One Health approach—which acknowledges the interdependence of human, animal, and environmental health—is crucial. Integrated surveillance systems and cooperative efforts are essential for early detection, risk assessment, and management. Effective methods for disease prevention and control are made possible by the systematic gathering and sharing of data. To reduce the incidence and effects of zoonotic diseases, it is essential to comprehend the variables that contribute to zoonosis and to put thorough food safety procedures in place. Continuous research, robust surveillance systems, and education campaigns are vital for sustaining global efforts to combat zoonotic diseases and ensure food safety in the future.

CITATION

Latif M, Danish W, Waheed M, Sattar M, Ali M, Sudheer N, Zahra M and Mehmood M, 2023. Relationship between zoonotic diseases and food safety. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 338-347. https://doi.org/10.47278/book.zoon/2023.025

CHAPTER HISTORY Received: 18-March-2023 Revised: 20-June-2023 Accepted: 28-July-2023

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1. INTRODUCTION

In recent years, the intersection between human health, animal health, and the environment has garnered increased attention due to the emergence of infectious diseases that cross species barriers (Bartlow et al. 2021). Zoonosis is the term used to describe infectious illnesses that may spread from animals to people through direct or indirect contact. These include bacteria, protozoa, fungus, and viruses (Rahman et al. 2020). Zoonosis has grown to be a serious problem on a global level, endangering food security, socioeconomic stability, and public health (Tirado et al. 2010). Zoonoses, such as the COVID-19 and the H1N1 influenza pandemic, have caused some of the most severe epidemics and pandemics in history (Piret and Boivin 2021). A multifaceted concept, food safety works to protect public health by making sure that food items are suitable for intake by humans. It involves the application of proper handling, preparation, and storage practices throughout the entire food supply chain, from production and processing to distribution and consumption (Raspor and Jevšnik 2008). The goal of food safety is to stop foodborne diseases brought on by bacteria, chemicals and physical hazards (Gizaw 2019). The food production cycle is somehow connected to zoonosis. As a result, many zoonotic diseases use food as an essential transport medium (Wielinga and Schulundt 2013). Many zoonotic diseases have their origins in animals, particularly livestock and wildlife, and can be transmitted to humans through the consumption of contaminated food products. The connection between zoonosis and food safety is critical because health of food animal is intrinsically related to safe food production and human health (Collins and Wall 2004).

This chapter gives a thorough analysis of the connection between zoonosis and food safety. It tries to clarify the routes by which zoonotic illnesses are transferred via the food chain and their potential impact on human health by synthesizing current literature, research findings, and case studies. The vital role that food safety practices and regulations play in avoiding and reducing the spread of zoonotic diseases will be further examined, along with the challenges and inadequacies of the existing system and suggested remedies. The need for a One Health strategy is also emphasized, with a focus on how the human health, veterinary, and environmental sectors can work together to combat zoonotic illnesses.

1. FOOD SAFETY AS A GLOBAL ISSUE

Food safety is a crucial worldwide issue that has an impact on both the economy and human health (Negri 2009). Global public health is greatly impacted by zoonotic infections, which spread from animals to humans. Serious infections, ranging from minor gastrointestinal symptoms to life-threatening problems, can be brought on by these diseases. In addition to their negative health effects, zoonotic illnesses can have significant negative economic effects, especially in underdeveloped nations. Food safety affect the human health by increasing the disease burden. Zoonotic diseases account for a substantial portion of global infectious disease burden (Rahman et al. 2020). The World Health Organisation (WHO) estimates that zoonotic illnesses account for around 60% of all infectious diseases that affect humans. These illnesses have the potential to spread globally and cause major morbidity and death through outbreaks, epidemics, and even pandemics (WHO 2014). Food safety has an influence on the economy as well since zoonotic disease outbreaks can have negative effects on commerce and tourism as well as productivity loss and higher healthcare expenditures. The financial impact is particularly severe in underdeveloped nations, where a lack of resources and a substandard healthcare system make it difficult to prevent and treat diseases (McElwain and Thumbi 2017).

Fig. 1*:* Four Steps to Food Safety

2. ROLE OF FOOD SUPPLY CHAIN IN ZOONOSIS

The practices, processes and circumstances required to guarantee that food is safe for consumption and free from contaminants are referred as food safety. There are four food safety processes as shown in Fig. 1 (CDC 2020).

Throughout the whole chain of food production, processing, distribution, and preparation, hazards are needed to be prevented, controlled, and mitigated. Reduced risk of foodborne infections and assurance that food is healthful, nourishing, and safe to eat are the two main objectives of food safety (Borchers et al. 2010).

The food supply chain connects farmers and consumers. It prepares food for human consumption by bringing it from farm to fork. The production, preparation, distribution, and consumption of food all fall under the umbrella of the food chain (Panghal et al. 2018). It involves various stages, including primary production (farming or fishing), processing, transportation, retailing, and ultimately, consumer consumption. Every stage of the food chain has the potential to transmit zoonotic diseases (Calvo-Porral et al. 2017). Animals frequently serve as the source of zoonotic diseases, which may be spread to people by direct contact, ingestion, inhalation, injection with infected material, or exposure to contaminated animal products. Influenza, brucellosis, salmonellosis, and other diseases can be transmitted to humans via various routes in the food chain (Shaheen 2022). Many foods, such as fruits and vegetables, serve as vehicles for the spread of infectious organisms to people. Consumption of raw or undercooked animal products, such as meat, poultry, seafood, and dairy, is particularly hazardous for the spread of zoonotic diseases. Fruits and vegetables can also get contaminated when they come into contact with animal faeces or polluted irrigation water. This contamination occurs where there is limited knowledge about supply chain contamination (Berger et al. 2010). Animal farming methods are also important in the spread of zoonotic diseases. Intensive agricultural practices, in which animals are confined in close housing, can foster the spread of infectious pathogens (Pesavento and Murphy 2014). Furthermore, the use of antimicrobial drugs in the livestock industry might contribute to the development of antimicrobial resistance, complicating treatment and management of zoonotic infections (Aarestrup 2005).

3. FACTORS CONTRIBUTING TO THE EMERGENCE OF ZOONOSIS IN THE FOOD SUPPLY CHAIN

There are several factors that contribute to the emergence and spread of zoonotic diseases in the food chain. These factors include:

3.1. ENVIRONMENTAL FACTORS

Increased human-wildlife interactions may result from changes in land use, deforestation, and encroachment on natural ecosystems. This contact facilitates the spread of zoonotic infections by opening up isolated areas and introducing more vectors and reservoirs to the new hosts. The distribution and behavior of disease vectors and reservoirs can potentially be affected by environmental degradation and climate change (Muehlenbein 2013).

3.1.1. GLOBALIZATION AND TRADE

Urbanization, population growth, and market forces have led to the global movement of food, including contaminated food. Due to more effective delivery systems, fresh goods are now available all year round. These modifications have helped foodborne illnesses to become more prevalent. The international trade in livestock, animal goods, and food items might hasten the global spread of zoonotic diseases. The interconnectedness of food supply chains increases the likelihood of disease transmission (Broglia and Kapel 2011). For instance, *Cyclospora cayetanensis*, a parasite causing gastroenteritis, gained recognition in the 1990s after an outbreak linked to imported Guatemalan raspberries (Almeria et al. 2019).

3.1.2. CHANGES IN FOOD CONSUMPTION PATTERNS

Dietary selection and preparation procedures are greatly influenced by customs, traditions, cultural beliefs, and dietary preferences, which can in turn increase the risk of acquiring foodborne illnesses. As a result, the availability of a wide range of food alternatives from other countries has increased the risk of exposure to infectious pathogens. Factors such as the consumption of raw or undercooked foods, the popularity of street food and takeaways, and the growing interest in healthy and ready-to-eat products also contribute to the risk of foodborne infections (Broglia and Kapel 2011).

3.1.3. SOCIOECONOMIC FACTORS

Lack of access to safe water and poor food safety infrastructure in some areas can worsen the spread of zoonotic illnesses. Inadequate sanitation facilities foster an environment where faecal contamination of water sources and food is more likely to occur. (Todd 2014).
Understanding these factors and their interactions is crucial for developing preventive measures and interventions to minimize the occurrence and impact of zoonotic diseases in the food chain.

4. FOOD SAFETY MEASURES AND ZOONOTIC DISEASE PREVENTION

The lack of food safety measures in industrial systems contributes to the spread of many diseases, including the swine flu and Ebola. In order to stop the spread of zoonotic diseases and safeguard public health, it is crucial that food safety regulations are upheld in food systems. For the purpose of avoiding outbreaks, reducing the burden of illness, and sustaining public trust in the food supply, it is essential to ensure the safety of food items along the whole food supply chain (Aiyar and Pingali 2020). Some of food safety practices and regulations that have been established to mitigate the risks are as follows:

4.1. GOOD AGRICULTURAL PRACTICES (GAPs)

It is crucial to protecting the health of consumers. Integrated pest management (IPM) and integrated crop management (ICM) are used to enhance farming practices. The guidelines and requirements for safe and sustainable agricultural production are also included, with an emphasis on good farm management, cleanliness, and the control of potential hazards (Akkaya et al. 2005).

4.2. GOOD MANUFACTURING PRACTICES (GMPs)

The cornerstone of the integrated management system is GMP. GMPs are a set of uniform policies and processes that guarantee the secure production, handling, and processing of food items. These procedures are intended to reduce the possibility of contamination, uphold product quality, and guarantee customer safety. The design and upkeep of facilities, staff health and safety, sanitation procedures, equipment calibration and maintenance, record-keeping, and quality control are only a few of the components of food manufacturing that are covered by GMPs. Compliance with GMPs is essential to meet regulatory requirements and maintain high standards of food safety (Blanchfield 2005).

4.3. HAZARD ANALYSIS AND CRITICAL CONTROL POINTS (HACCP)

These are a series of internationally recognized recommendations for managing food-borne infections. It is a crucial component of food safety management procedures that may be used at any point in the food supply chain. It is a methodical, scientific approach to manage food safety. The goal of HACCP is to recognize, assess, and manage any risks that could arise throughout the manufacturing, process, handling, and distribution of food (Fig. 2). In addition to lowering the risk of foodborne diseases and assuring the manufacture of safe and high-quality food products, it offers a systematic framework for recognizing and mitigating risks across the food chain (Kafetzopoulos et al. 2013; Wallace and Mortimore 2016).

Fig. 2: 7 Principles of HACCP

4.4. TRACEABILITY SYSTEMS

With the use of traceability, producers and consumers may now be linked, resulting in safer food supply. Traceability is the ability to use recorded identifications to gain access to any or all information about the item under consideration across its entire life cycle (Olsen and Borit 2018). This system tries to track and gather data on various items as they move through the supply chain. This approach makes it possible to quickly identify and recall items that could be contaminated (Dabbene and Gay 2011).

4.5. REGULATORY FRAMEWORKS

In order to assure compliance and enforcement, there are a number of national and international rules that establish standards for food safety, labelling, and inspection (Omojokun 2013). Regional regulations in Pakistan are provided by the Punjab Food Authority Act of 2011 and the KPK Food Authority Act of 2014. According to the ISO (International Organization of Standardization), Codex Alimentarius Commission, and World Health Organization, food standards are harmonized globally (Ibrahim et al. 2021).

The prevention of zoonotic disease supports a diversified approach at each stage of the food chain, from farm-level preventative measures through retail and food service practices (Mardones et al. 2020). To lessen the danger of zoonotic diseases in animal populations, farm-level solutions include applying biosecurity practices, such as vaccination campaigns, illness monitoring, and appropriate waste management (Robertson 2020). Additionally, high hygiene standards are followed throughout food preparation, storage, and delivery to reduce the possibility of food contamination. The danger of transmission of zoonotic infections to humans can also be reduced and minimized by following food safety regulations in restaurants, food institutions, and retail stores (Trienekens and Zuurbier 2008).

5. ONE HEALTH APPROACH TO ZOONOSIS AND FOOD SAFETY

The One Health approach recognizes the interconnectedness of human, animal, and environmental health and emphasizes the need for collaborative efforts to address zoonotic diseases and ensure food safety. Understanding the interdependencies and interactions between these three domains is essential for effective disease prevention and control strategies. To improve health through food safety, there is a need for increased awareness among consumers, producers, and governmental agencies (Garcia et al. 2020). The One-Health approach involves improved communication and collaboration among different disciplines including human health, veterinary medicine, and environmental management (Lammie and Hughes 2016). One-health dissolves the boundaries between the sectors and all relevant stakeholders are involved in the management of health problems (Bordier et al. 2020). Collaborative initiatives facilitate the identification and implementation of effective control measures, such as integrated disease surveillance systems, joint investigations of outbreaks, and the development of shared protocols and guidelines for disease management (WHO 2019).

The systemic collection, validation, analysis, and interpretation of data and dissemination of collected information come under the umbrella of one-health surveillance. Surveillance systems are critical components of the One Health approach to zoonotic disease control. Early detection of zoonotic diseases is crucial for prompt response and intervention to prevent further spread. Integrated surveillance systems enable the early identification of emerging zoonotic diseases, facilitate risk assessments, and guide the implementation of targeted control measures (Stärk et al. 2015). A collaborative approach is necessary to undertake a risk assessment. Risk assessment and management strategies form the cornerstone of the One Health approach to zoonosis and food safety. Risk assessment involves identifying and evaluating potential hazards, assessing their likelihood of occurrence, and estimating the associated consequences. Risk management strategies focus on implementing measures to mitigate and control identified risks (Liu et al. 2013). This includes interventions aimed at reducing exposure to zoonotic pathogens, enhancing biosecurity measures, improving food safety practices, and promoting awareness and education among stakeholders (Murphy et al. 2017).

6. NOTABLE OUTBREAKS

There are certain outbreaks that illustrate the range of pathogens and food products involved, emphasizing the importance of proper food safety practices at all stages of the food supply chain to prevent the occurrence of such incidents and safeguard public health as shown in Table 1;

Table 1: Notable Outbreaks involving the food products contamination

No.	Pathogen	Food Product Involved	Outbreak Year	Reference
1.	E. coli O157:H7	contaminated spinach	2006	Gelting et al. 2011
2.	Salmonella	contaminated peanut butter	2008-2009	Medus et al. 2009
3.	Listeriosis	contaminated cantaloupes	2011	Laksanalamai et al. 2012
4.	Campylobacter	raw milk consumption	-	Kenyon et al. 2020
5.	Hepatitis-A	contaminated green onions	2003	Chancellor et al. 2006
6.	E. coli O104:H4	contaminated sprouts	2011	Grad et al. 2012
7.	Listeriosis	contaminated ice cream products	2015	Chen et al. 2015
8.	Salmonella	contaminated papayas	-	Whitney et al. 2021
9.	Norovirus	contaminated oysters	2010	Westrell et al. 2010
10.	Shiga toxin-producing E. coli	contaminated ground beef	-	Butt et al. 2021
11.	Cyclospora	contaminated produce, such as lettuce and cilantro	-	Hadjilouka and Tsaltas 2020
12.	Salmonella	contaminated pet food	2006-07	CDC 2008
13.	Hepatitis A	contaminated frozen berries	-	Tavoschi et al. 2015
14.	Clostridium perfringens	improperly stored and reheated foods	-	Wittry et al. 2022
15.	Staphylococcus aureus	contaminated food prepared by infected food handlers	-	Kadariya et al. 2014
16.	Listeriosis	contaminated cheese products	-	McIntyre et al. 2015

These case studies highlight the need for continuous improvement in food safety practices which include:

6.1. ENHANCED HYGIENE PROTOCOLS

Rigorous adherence to good manufacturing practices (GMPs) and standard operating procedures (SOPs) for cleaning, sanitization and personal hygiene can significantly reduce the risk of contamination in food processing environments (Blanchfield 2005).

6.2. ROBUST CONTROL MEASURES

Implementation of hazard analysis and critical control points (HACCP) systems can help identify potential hazards and establish preventive measures at critical stages of food production, processing, and distribution (Wallace and Mortimore 2016).

6.3. STRENGTHENED SURVEILLANCE AND MONITORING

Implementation of comprehensive surveillance systems, including routine testing and inspections, can facilitate early detection of contamination and prompt intervention to prevent the spread of zoonotic pathogens (Stärk et al. 2015).

6.4. EDUCATION AND AWARENESS

Educating consumers, food handlers, and producers about the risks associated with zoonotic diseases and the importance of proper food safety practices can help prevent outbreaks and promote responsible food handling and consumption (Trienekens and Zuurbier 2008).

7. CONCLUSION

The connection between zoonotic illnesses and food safety is, therefore, a complicated and vitally essential problem. The investigation of notable zoonotic disease outbreaks connected to problems with food safety has exposed the disastrous repercussions that can occur when food safety procedures go wrong. Through the analysis of these outbreaks, identified various factors have been identified that contribute to their occurrence, such as inadequate hygiene practices, insufficient control measures, and limited surveillance and monitoring. To safeguard the public's health and to ensure the security of the food supply and handle the difficult problems brought on by newly developing zoonotic illnesses, it is crucial to comprehend the connection between zoonosis and food safety. We can make substantial progress in avoiding zoonotic infections, enhancing food safety, and ensuring the welfare of both humans and animals by adopting a multidisciplinary strategy that involves collaboration between the human health, veterinary, and environmental sectors. Continued research, robust surveillance systems, and ongoing education and awareness campaigns are vital for maintaining and improving global efforts to combat zoonotic diseases and ensure food safety in the future.

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Policies to Control Zoonotic Disease Transmission in Pakistan

26

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ABSTRACT

Globally, zoonotic diseases are an emerging threat and the Pakistani government is conducting public education campaigns to raise awareness of zoonotic diseases and how to prevent them. One Health approach is a synergistic attempt between public, animal and environmental health professionals to prevent, detect, and control infectious diseases. The Pakistani government is formulating a One Health Strategic Plan to preclude, observe, and respond to infectious disease eruptions in Pakistan. This plan will include a focus on zoonotic diseases. The government has developed National One Health Strategic Framework to address zoonotic diseases comprehensively. For disease surveillance AI tools should be introduced for plans such as the "One Health" system tracing and analysis with resourcing toolkit. Food-borne infections are caused by various pathogens that are fatal from a safety point of view like Listeria spp., Campylobacter spp., Salmonella spp., Toxoplasma gondii, and Norovirus are prevalent in Pakistan. Safe meat for the end consumer demands that standard parameters are implemented from crop production to animal rearing handling slaughtering, designing, and storage. Close affiliation and climax of humans and their pets and livestock is directly related to the transmission of zoonotic pathogens. In Pakistan, food is usually sold in the streets by vendors under unhygienic conditions. Additionally, hygiene maintenance, food safety and handling awareness in the natives is poor. Awareness campaigns have been launched to educate the public about zoonotic diseases, their transmission routes, and preventive measures. The ZDCP is a collaborative initiative between the Ministry of National Health Services and the Food and Agriculture Organization (FAO) of the United Nations for coordination and regulations. Pakistan has a significantly legal model to endorse and implement the technical sector objectives of the IHR and the Global Health Security Agenda at the country level. Strategic planning is crucial to ensure cost-effective quality maintained and safe services for health managers. The government is taking the best initiatives to control zoonotic disease in the zone. However, some new policies are under their way.

Keywords: Zoonoses, One Health, Zoonoses Policies, Food Safety, Policies in Pakistan.

CITATION

Saleem F, Faraz A, Irtaza A, Ishaq HM, Ilyas MF, Khalid RH, Soomro KA, Sufiyan A, Ashraf M and Ghazali MH, 2023. Policies to control zoonotic disease transmission in Pakistan. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 348-360. https://doi.org/10.47278/book.zoon/2023.026

CHAPTER HISTORY Received: 23-March-2023 Revised: 20-June-2023 Accepted: 28-Aug-2023

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1. INTRODUCTION

Globally, zoonotic diseases are an emerging threat to the economy and sustainability of human life. Every year, millions of people lose their lives because of zoonotic disease (Belay et al. 2017). Pakistan is facing severe issues on this. Various policies should be taken to avoid disease transmission in humans. The One Health approach is a synergistic attempt between public, animal and environmental health professionals to prevent, detect, and control infectious diseases that can spread between living beings. This approach is essential for controlling zoonotic diseases in Pakistan, as it allows for a comprehensive and coordinated response to these diseases. One of the most efficient ways to prevent zoonotic diseases is vaccination. The Pakistani government has a number of vaccination programs in place for livestock, including programs for rabies, brucellosis, and anthrax. These programs have been successful in reducing the incidence of these diseases in livestock, which has helped to reduce the risk of transmission to humans. Improved sanitation is another essential way to prevent zoonotic disease transmission (Yasmeen et al. 2022). This includes improving hygiene practices in livestock production and handling, as well as improving sanitation in food markets and other areas where people and animals come into close contact. Public education is also important for preventing zoonotic disease transmission. This includes educating people about the risks of zoonotic diseases, how to avoid them, and what to do if they think they have been exposed to a zoonotic disease. The Pakistani government has established a single-domain health hub at the Pakistan National Institute of Health (NIH). This hub will endorse a synergistic and coordinated approach between all living beings and their surroundings on infectious zoonotic diseases. The Pakistani government is implementing vaccination programs for livestock to prevent the spread of zoonotic diseases. The Pakistani government is formulating a One Health Strategic Plan to preclude, observe and respond to infectious disease eruptions in Pakistan. This plan will include a focus on zoonotic diseases. The Pakistani government is working to improve sanitation in livestock production and handling, as well as in food markets and other areas where people and animals come into close contact. The Pakistani government is conducting public education campaigns to raise awareness of zoonotic diseases and how to prevent them. The Government of Pakistan has adopted the One Health notion to look at zoonotic diseases comprehensively. The National One Health Strategic Framework aims to integrate public, animal, and environmental health sectors to prevent, observe, and respond to zoonotic disease outbreaks. The ZDCP is a collaborative initiative between the Ministry of National Health Services, Regulations, and Coordination and the Food and Agriculture Organization (FAO) of the United Nations. It focuses on strengthening surveillance, diagnosis, and control of priority zoonotic diseases such as rabies, brucellosis, and avian influenza. Efforts have been made to enhance disease surveillance systems across the country. This includes strengthening veterinary and public health laboratories, developing early warning systems for disease outbreaks, and improving reporting mechanisms to ensure timely detection and response to zoonotic diseases (Khan and Jaspal 2017). Vaccination campaigns have been conducted to control specific zoonotic diseases. For example, to prevent rabies transmission, the government has initiated mass dog vaccination programs in high-risk areas and promoted public awareness about responsible pet ownership and the importance of rabies vaccination. The government has worked on enhancing veterinary services, including training and capacity building for veterinarians, promoting biosecurity measures in livestock farms and markets, and improving animal health management practices. These measures aim to cut down zoonotic disease transmission from animals to mankind. Awareness campaigns have been launched to educate the public about zoonotic diseases, their transmission routes, and preventive measures. These campaigns include public service messages, educational materials, and workshops targeting both urban and rural populations. Protecting and conserving natural ecosystems and wildlife habitats are crucial for preventing zoonotic disease outbreaks. The government has taken steps to strengthen environmental conservation efforts, including the establishment of protected areas and regulations to control illegal wildlife trade. Pakistan actively participates in international collaborations and partnerships to address zoonotic diseases. This includes working with organizations like the World Health Organization (WHO), FAO, and the World Organization for Animal Health (OIE) to share knowledge, resources, and best practices in disease control and prevention (Khalil et al. 2017).

An important task that is performed by the state system and especially by the health care system to control zoonoses is strategic planning. It is predetermined, logical and compact, allowing public health associations to concentrate on a point and sustainability of the future. It improves the management's consciousness of foreign threats, forces and organization. Strategic planning is therefore a crucial task that should be done before making policy against any zoonotic disease. It consists of various steps that should be carried out. Haphazard arrangements are often catastrophic. Long-term planning should be done to rule out zoonoses completely.

2. ONE HEALTH STRATEGY

One Health is an integrated, multidimensional, and transdisciplinary path putting their efforts from regional to global level with a vision to obtain optimal health consequences by realizing the linked connection between mankind, animals, plants, and their conjugated environment. Zoonotic diseases are infectious diseases that are transmitted from land-living domestic animals to humanity and are a root cause of rising infectious diseases. Nearly >60% of the pathogens that infect humans are zoonotic in nature. Zoonosis is dominant in Ethiopia, Nigeria, Tanzania, and India. (Jones et al. 2008).

Various environmental factors are deeply involved in disease progression. Neglecting ecological factor leads to a significant impact on biological risks. Regarding ecological factors, a global climatic change may result in increased dominancy of common disease vectors, i.e., ticks and mosquitoes, together with a surge in climax already inhabited, in the number of disease vectors. Wild and game animals are currently presenting an elevated risk of transmission of non-domestic animal diseases to domestic animals and to agricultural settlements. Therefore, agricultural workers are more prone to this risk. These infections have a strong relation with climatic change associated zoonosis like the tick-borne encephalitis virus (TBEV) group of *encephalitis, Lyme borreliosis* and *Coxiella burnetii,* the agent of Q fever, infections and anaplasmoses (Lindgren and Gustafson 2001).

Studies enlighten close and reciprocal actions of fruit-eating bats with humankind. These bats are a source of zoonotic pathogens and are carriers of lethal diseases including rabies in the Indian subcontinent (Ahmed et al. 2023).

Previously in Pakistan, there has been no research carried out to determine the role of fruit-eating bats in spreading rabies virus known as lyssavirus. On survey-based results bat should not be given less importance in zoonoses strategy making and should not be overlooked in any national rabies surveillance planning or committee. Keeping in view that associated animals as a main predator of alive and dead bats, will provide valuable information for looking into the rabies cycle and it will result as fruitful in saving life of mankind and animals. Mountains and plains residential background as compared to provincial (Punjab and KPK) are markedly associated with the rate of bat-human interaction. (Ahmed et al. 2023).

The One Health approach is a synergistic attempt between public, animal and environmental health professionals to prevent, detect, and control infectious diseases that can spread between living beings. This approach is essential for controlling zoonotic diseases in Pakistan, as it allows for a comprehensive and coordinated response to these diseases.

3. DEVELOPING A ONE-HEALTH STRATEGIC PLAN

The Pakistani government is formulating a One Health Strategic Plan to preclude, observe, and respond to infectious disease eruptions in Pakistan. This plan will include a focus on zoonotic diseases. Environmental change has disturbed one health concept. Population increase has resulted in huge atmospheric carbon emissions and has risen global warming that has interrupted normal lifestyles and biome. Urban socialization has hastened the coordinated interaction of humans with animals such as pigs, squirrels, foxes, mice and jackals. These are probative conditions for the expression and out-growth of zoonotic diseases (Sleeman et al. 2019).

Cutting down of forests and the loss of ecosystem diverseness, intensity of temperature, melting of glaciers due to global warming, air pollution from burning of crop remnants and coal combustion, over-population, declined eatables production and high humidity and temperature index due to urbanization resulted in havoc on the ecosystem. These circumstances lead to favorable conditions for survival and the explosion of the zoonotic pathogen (El-Sayed and Kamel 2020; Majeed and Munir 2020).

In Pakistan, the primary source of contamination and disease spreading in the surrounding is poor management of infectious waste at a large scale. There should be categorical waste separation on base of hazardous chemicals disposable items pulps leather in hospitals and industries. These waste products act as the primary source of acute respiratory pathogens, hepatitis A and E and intestinal pathogens. (Rab et al. 1997; Qasim et al. 2014). Factory, domestic animal farms, hospitals and household disposal waste can combine with natural disasters such as tornados, and tsunami to pollute drinking water supplies (Daud et al. 2017).

The government of Pakistan has developed National One Health Strategic Framework to address zoonotic diseases comprehensively. The National One Health Strategic Framework aims to integrate public health, animal health, and environmental health sectors to prevent, observe, and show a quick response to zoonotic disease outbreaks (Fig. 1).

4. SURVEILLANCE OF DISEASE OUTBREAKS

Improved Disease surveillance and reporting is significant. Efforts have been made to enhance disease surveillance systems across the country. This includes strengthening veterinary and public health laboratories, developing early warning systems for disease outbreaks, and improving reporting mechanisms to ensure timely detection and response to zoonotic diseases. Epidemiological surveillance is crucial to estimating linked risk factor that is majorly accountable for the perseverance and explosion of disease. Public health management regulations is responsible for this surveillance. Usually, we consider hospital-based surveillance data and it shows a high prevalence of numerous zoonotic diseases. Clinicians, epidemiologists, and specialists in veterinary medicine, and public and environmental health could be brought together on a single platform to regulate policies that turn to disease perseverance. Formulating basic awareness seminars and vaccination programs for the guidance of the population or community is need of hour. AI tools should be introduced for plans such as the “One Health” system tracing and analysis with resourcing toolkit. (Breslin et al. 2017; Brown and Nading 2019; Iqbal et al. 2020a).

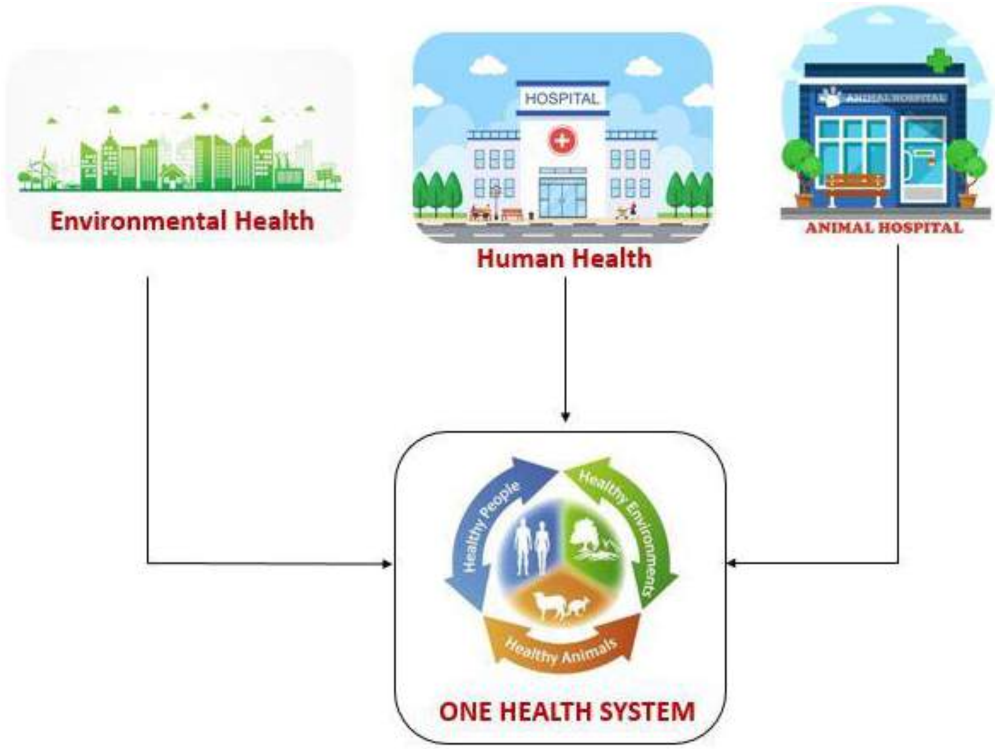

Fig. 1: Public, Animal and Environmental Health under umbrella of One Health System

5. FOOD SAFETY AND ANIMAL HEALTH

Food-borne infections are caused by various pathogens that are fatal from a safety point of view like *Listeria* spp., *Campylobacter* spp., *Salmonella* spp., *Toxoplasma gondii,* and Norovirus are prevalent in Pakistan (Nisar et al. 2018).

Pakistan is one of the highest producers of protein sources like milk and halal meat in the world and the quality of these products is often up to the mark. Therefore, negligence and ignoring biosecurity measures during animal handling, milking, slaughtering, and processing results in diseases such as brucellosis and bovine TB initiating their progression at the farm level (Claeys et al. 2013).

Pasteurization is the most successful and convenient method for increasing milk storage life and for implementing standard milk production. Antibiotic residues as well as pathogens and other contaminants in milk can be easily screened using Raman spectroscopic techniques. Nowadays various antibiotic milk testing kits like Twin-Sensor, and Bio-easy are available for quick results. Dairy companies like Nestle Engro etc. mostly use these mainly. Raw milk or untreated milk contains infectious pathogen, while pasteurization extends the shelf life of the milk. Therefore, the latest and hygienic milk production and processing techniques must be enforced on a small-town basis to control milk-related zoonoses (He et al. 2019).

6. MEAT IS A LEADING SOURCE

A vital source of protein that is consumed all over the world is meat. Inappropriate meat processing results in the spread of food-borne illnesses such as Bovine Spongiform Encephalopathy (BSE), hepatitis, and typhoid has been linked (Ozawa 2003; Javed 2016), and sanitation cleanliness and hygiene standard operating procedure for farm and abattoir sanitation plays a vital role for quality and healthy meat production. Environmental and public health practitioners have an essential role in meat safety and ensuring a hygienic environment. Meat and food inspections are also necessary for exporting labeled meat, and it's easy to enforce screening technologies like ELISA, and PCR for meat screening (Iqbal et al. 2020b). All these cautions and safety procedures also pave a way to organic food production (Akbar et al. 2019) Safe meat for the end consumer demands that standard parameters are implemented from crop production to animal rearing handling slaughtering, designing, and storage. (Ishaq et al. 2021) Salmonella species in raw chicken are of prime importance in Pakistan with a prevalence of 22-30%. Recent research showed that 25.5% contamination of Salmonella in fresh and 21.8% in processed chicken meat. (Dufrenne et al. 2001).

Salmonella was isolated 89% of various fresh chickens and 68% of frozen chicken products, in the Netherlands, Dallal et al. (2009) investigated 62.7% in Tehran, Zhu et al. (2014) detected Salmonella 28.3% from fresh and 33.5% from stored poultry.

Previously various studies in different cities of Pakistan have reported 30% Salmonella prevalence in poultry in Faisalabad (Akhtar et al. 2010), 69.70% in Kashmir (Mir et al. 2010) and it has been seen that there is a 38% contamination rate in poultry meat in local markets of Sindh province (Soomro et al. 2010).

7. OVER-CROWDING

Close affiliation and climax of humans and their pets and livestock is directly related to the transmission of zoonotic pathogens (Suk et al. 2014), and places where animals and humans share common living areas in most villages are at high risk (Owczarczak-Garstecka 2018) and those with inadequate sanitation facilities (Warraich et al. 2011). Congested housing and overcrowding of people affect a pathogen's capability to infect immune-compromised hosts (Hammer et al. 2018). Improvement in hygiene and cleanliness and enforcement policies like preventing overcrowding physical distance and maintaining hygiene and sanitation in local food markets will reduce the risk of zoonotic disease transmission.

8. HYGIENE PRACTICES IN FOOD RESERVOIR AND WATER SAFETY

Food-borne zoonoses are typically caused by contaminated food reservoir and water consumption leads to food borne zoonoses because hundreds of zoonotic microbes reside in the intestinal tract of halal meat source animals and pose a contamination hazard from animal rearing at the farm to meat cooking in your kitchen. Food is a basic necessity for living that's why food safety is a top concern for global public health (Gizaw 2019) and hyper-active strategies should be advised to overcome and reduce the spread of these diseases as well. (Ishaq et al. 2021). Raw food and food products handling and storage play a crucial role in overcoming the spread of food-borne diseases. In Pakistan, food is usually sold in the streets by vendors under unhygienic conditions. Additionally, hygiene maintenance, food safety and handling awareness in the natives is poor (Ma et al. 2019). These factors increase the risk of zoonotic diseases such as the major pathogens Salmonella, Campylobacter, Listeria, *E. coli* O157:H7, *Bacillus cereus* and Clostridium (Samad et al. 2018).

The purity of water is one of the utmost requirements for enjoying a healthy life. (Pandey 2006) Consumption of contaminated water by animals and humans can result in interaction with pathogens and pollutants resulting in GIT, psychological, and reproductive anomalies (Lee and Murphy 2020). Urbanization, industrial waste pollution, global warming, and garbage dumping in deep pits have polluted water resources in Pakistan and contributed towards environmental changes (Pandey 2006). Roughly about 2.2 billion people are consuming unsafe and harmful drinking water globally (World Health Organization 2017).

According to a survey only 20% of the population in Pakistan has access to nontoxic drinking water. (Daud et al. 2017) Pakistan is ranked 80th out of 122 countries in the context of drinkable water quality standards. If we don't pay heed towards improved water quality and we don't address the issues then we are going to confront a 60% drinkable due to the mixing of community, sewerage, and industrial waste without treatment. (Ilyas et al. 2019). In 2020, 410+ schools were thoroughly analyzed and a water test was run in Pakistan to determine the water quality and >49% of the tested samples were polluted with highly pathogenic microorganisms (Altaf Hussain et al. 2020). Another research reported a high contamination level of potable water in the Sibi district, Baluchistan with fluoride and arsenic (Chandio et al. 2020).

9. PUBLIC AWARENESS AND EDUCATION

Awareness campaigns have been launched to educate the public about zoonotic diseases, their transmission routes, and preventive measures. These campaigns include public service messages, educational materials, and workshops targeting both urban and rural populations. Our basic vision should be to make the people aware of the public about their health and wellness. Major hurdles in implementing Pakistan's health security that should be overcome are food insecurity, poverty, illiteracy overcrowding, and malnourishment, vaccination not reporting the disease timely, unhygienic sanitary treatment measures and consuming contaminated water. In 2002, three hundred attorneys from thirty-five countries discussed elevating awareness and rendering basic knowledge through seminars related to social threats and their effects on human and environmental health. (Ahmed and Shaikh 2011).

10. ZOONOTIC DISEASE CONTROL PROGRAM (ZDCP)

The ZDCP is a collaborative initiative between the Ministry of National Health Services and the Food and Agriculture Organization (FAO) of the United Nations for coordination and regulations. It focuses on strengthening surveillance, diagnosis, and control of priority zoonotic diseases such as rabies, brucellosis, and avian influenza. Vaccination campaigns have been conducted to control specific zoonotic diseases (Jost et al. 2007) For example, to prevent rabies transmission, the government has initiated mass dog vaccination programs in high-risk areas and promoted public awareness about responsible pet ownership and the importance of rabies vaccination.

11. STRENGTHENING VETERINARY SERVICES

The government has worked on enhancing veterinary services, including training and capacity building for veterinarians, promoting biosecurity measures in livestock farms and markets, and improving animal health management practices. These measures aim to cut down disease transmission from animals to humans. The need of an hour is to upgrade legal infrastructure to improve veterinary services in the country. Already working body has pointed out many flaws and deficient areas. A suitable and authoritative body should be established that reviews provincial and federal laws to improve regulations to control zoonoses (Erkyihun and Alemayehu 2022).

12. ANIMAL WELFARE

Animal welfare refers to the circumstances in which your domestic animal is from any stress and it should exhibit its natural behavior. Animals should be well fed and should be in a comfortable state. (Fraser et al. 2009).

13. INTERNATIONAL HEALTH REGULATIONS (IHR) COMPLIANCE

Pakistan is bound to follow the World Health Organization's International Health regulations and legal framework. This commitment includes strengthening the country's capacity for disease prevention, detection, and quick response to public health emergencies of international concern, which can include zoonotic disease outbreaks. Pakistan has a significantly legal model to endorse and implement the technical sector objectives of the IHR and the Global Health Security Agenda at the country level. Manage ports of entry for medicine, healthcare, health workers, food safety and more. Although some new legislation may be necessary, in general, the already legal running module provides a number of legal enhancements, such as basic laws and authoritative measures, which can help to comprehend necessary legal basis for the implementation of IHR, eliminating the need for parliamentary approval - the Time Process and a strong effort Legal basis for IHR coordination derives from the 1973 constitution and its amendments, which include coordination strategy between the various branches of government and working rules that define the duties and obligations of each concerned body. This legal framework is an example of best practice for countries to coordinate IHR. With the presence of significant changes to the Constitution since 1973, the government structure since IHR (2005), and the presence of several related laws in the national and provincial legal framework, there are inevitably some gaps, contradictions and directions for national reform. Provincial law provisions for IHR to secure an inclusive legal model, best practice is to direct a statutory and regulatory judgment to find specified domains for betterment (WHO 2017).

14. INFRA STRUCTURE DEVELOPMENT

Efforts have been made to enhance the skills and knowledge of healthcare professionals, veterinarians, and other relevant stakeholders through training programs and capacity-building initiatives. This enables them to effectively diagnose, treat, and prevent zoonotic diseases and strengthens the overall response to outbreaks. Following are some capacitance and infrastructure development plans that should be implemented in order to have control over zoonotic diseases and to avoid their emergence: At the national level there should be an appropriate communication structure to regulate control activities. Consider a one health triad and there should be veterinary, public health and environment sectors on the single and coordinated platform with a multidimensional strong cabinet or some mirror body which should take the necessary measures to control disease progression and develop a monitoring system (Ghai et al. 2022)

Governmental and political support is necessary to emphasize the economic burden of zoonoses, with comparative analysis including cost–benefit and cost–effectiveness analysis of control strategies. It should be done at the regional level. Build a strengthening partnership. with animal and human health organizations such as OIE, FAO, relevant pharmaceutical companies and interested nongovernmental organizations such as the World Society for the Protection of Animals (WSPA). Their collaborations should pay heed and develop various programs at the community level and support operational research in control and prevention (WHO 2017).

15. MANAGEMENTAL CONTROL AT SMALL SCALE

Many managemental gaps that are not addressed are familiar sources of zoonotic disease transmission. Improper washing of utensils that are placed near the shed and the laborer's interacting with animals after feeding or after touching forget to wash their hands with soap and

this is also a main source of transmission. On commercial dairy farms and farms in rural areas, most of the people lack awareness. They don't vaccinate their animals and they lack dipping or spraying practices, neglecting deworming of animals and contact with feces will cause intestinal parasitic infections. The whole staff at the farm is at high risk. Animal caretakers and abattoir workers commonly encounter ectoparasites and infested tissue so safety measures should be taken like the use of gloves, gumboots, aprons and proper sanitization. Outbreaks of Crimean-Congo Hemorrhagic fever in Pakistan are considered to be linked with bad management, especially in tick-infested cattle (Awan et al. 2014).
At small-scale farm, shearing is an important task that is commonly accomplished in summer. The shearing persons do not use a mask or cover his face to avoid inhalation of infected air. Minor skin rupture and wounds during skin removal is often ignored or remain as it is that's actually is big source of transmission of blood-borne infections (Abbas et al. 2014).

16. STRATEGIC PLANNING

An important task that is performed by the state system and especially by the health care system to control zoonoses is strategic planning. It is planned, logical and compact, allowing public health foundations to keep an eye on relevant tasks and sustainability of the future. That's why, strategic planning is crucial to ensure cost-effective quality maintained and safe services for health managers. It will enhance the management's basic concepts of external threats, forces and organization. Clarified policy is essential to control and reduce zoonotic diseases. For controlling and preventing of disease countries should use suitable strategic planning and pursue annual objectives (Nantima et al. 2019).
Generally, three steps are involved in strategic planning as mentioned in Fig. 2.

16.1. STRATEGY DEVELOPMENT

Strategy plays an important role in which the concerned body achieves its main objectives. Firstly, these strategies are required to be developed for zoonotic diseases. Internal and external resources are assessed to review the health system and zoonotic disease. It aids in looking for pros and cons and the deficiencies of a system that might pose a risk to public safety (Ghanbari et al. 2021).

Fig. 2: Steps involved in strategic planning

16.2. STRATEGY IMPLEMENTATION

After the development of suitable strategies related to zoonoses next step is implementation. In the second phase of strategy implementation, the planned plan must be implemented through negotiation and cooperation with all resources related to the stages of zoonotic diseases, including prevention, control and treatment. Financial resources, enough workforce, and equipment are required for the efficient implementation of strategies. (Ghanbari et al. 2021).

16.3. STRATEGY EVALUATION

Implemented planning should be analyzed to assess the progress and efficiency of the strategy. This way health workers would be well aware of the ways to achieve goals and to rectify the issues. The only option left behind to have full control to deal with issues is evaluation and control programs. Eventually by these strategies' tasks would be accomplished (Ghanbari et al. 2021).

16.4. SHORT AND LONG-TERM GOALS

The conceptual difference between time-limiting (short term) and long-lasting (long term) goals can also assist us in getting our objectives achieved of a health system. Pinpoint apprehension of the present scenario and the prowess to have an eagle-eye view for the future perspective is likely not to be understood without considering the difference between time-limiting and long-lasting goals. A long-term goal usually decides the well beingness of community health in upcoming years and these are integrally technical. On the other hand, short-term goals are faster to achieve and are easily approachable. (Bailey 2019) In materializing short- and long-term goals, focus should be kept on the following characters to be them put in a nutshell:

16.5. SPECIFIC

In health systems, objectives are required to be specific and all ambiguities should be removed but highlighted points should be focused on a specified matter like zoonotic diseases with clear motive.

16.6. MEASURABLE

Analyzing the extent of goal achievement depends on their measurability. If strategic planning is up to mark it will assist in ensuring quality set points. In this way outcome of overall health systems in the context to zoonoses can be calibrated, and stake holders for policy making along with health care managers could understand their progress.

16.7. ACHIEVABLE

Suitable analysis of workforce, fiscal responsibilities, and apparatus should be conducted in a better way to check for the achievability of concerned goals. Feasibility and being able to operate are vital points that are to be checked to keep your project achievable (Sadeghifar et al. 2015).

16.8. TIMELY RESOURCES AND FACILITIES

The probability of achieving any goal depends on considering these finite limitations. The experience of diseases such as SARS, Avian Influenza, and COVID-19 showed that in most of the states, there was inadequate awareness about their basic facilities and resources; that's why the disease progressed (Spallina 2004).

17. CONCLUSION

The government is taking the best initiatives to control zoonotic disease in the zone. However, some new policies are under their way. One health program is the need of hour where animal health, human health and the environment are under one umbrella. This approach is essential for controlling zoonotic diseases worldwide, as it allows for a comprehensive and coordinated response to these diseases. The World Organization for Animals, the World Health Organization, the Food and Agriculture Organization of the United Nations, and Health have all developed policies and guidelines to help countries to control zoonotic disease transmission.

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Zoonosis in the Food Chain

27

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ABSTRACT

This book chapter examines the complex relationship between the worldwide food supply chain and the transmission of diseases, with a particular emphasis on zoonotic pathogens. During the latter part of the 20th century, there was a significant growth in global interdependence due to the movement of people and goods across borders. This resulted in a higher risk of the worldwide spread of biological threats. Globally, outbreaks of foodborne diseases have extensive social and economic consequences, impacting food consumption patterns and behavior. The chapter explores foodborne pathogens, classifying diseases caused by bacteria, viruses, and parasites. The chapter delineates the origins of zoonotic infections, with particular emphasis on manure, animal feed, and milk as noteworthy contributors. Manure presents a significant hazard of contaminating crops and pastures. Animal feed can act as a reservoir for zoonotic infections. The popularity of consuming raw milk is increasing; however, it poses health hazards due to the presence of potentially harmful microbes. Proposed are mitigation measures to effectively manage zoonotic illnesses within the food chain. These measures encompass international cooperation, monitoring, and timely identification; embracing a holistic approach to health; advocating for public awareness; enforcing strict protocols to prevent the spread of disease on farms, implementing responsible antibiotic usage; ensuring cleanliness and sanitation in food production; enforcing stringent food safety regulations; and implementing effective strategies for wildlife management. To Conclude, the chapter highlights the urgent requirement for a comprehensive and cooperative strategy to reduce the dangers linked to zoonotic pathogens in the worldwide food supply network. It stresses the significance of international collaboration, research, and proactive actions to guarantee the safety and welfare of both animals and humans.

Keywords: Zoonotic pathogens, Foodborne diseases, Global food supply, Biosecurity, Mitigation strategies, One Health approach, Antibiotic control, Manure contamination, Food safety, International collaboration

CITATION

Nadeem A, Nasrullah T, Nasir A, Nazar MW, Hussain A, Iqbal MU, Jabbar MH, Talib T, Khan R and Rehman A, 2023. Zoonosis in the Food Chain. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 361-373. https://doi.org/10.47278/book.zoon/2023.027

CHAPTER HISTORY	Received:	27-Jan-2023	Revised:	13-May-2023	Accepted:	03-Aug-2023

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1. INTRODUCTION

GLOBAL FOOD SUPPLY AND DISEASE SPREAD

During the latter half of the 20th century, the globalized political economy witnessed a notable social, political, and economic interdependence rise (Cork and Checkley 2011). The swift cross-border movement of individuals, goods, and other commodities primarily drove this phenomenon. One of the outcomes resulting from the escalation of trade, travel, and migration is the increasing potential for the widespread transmission of biological and other dangers across different countries (Smith and Kelly 2008). The increasing interconnectedness of global populations has facilitated the rapid spread of novel and emerging diseases, making their containment and management challenging. The rise of global trade commodities and the emergence of transnational corporations (TNCs) have coincided with a surge in foodborne illnesses across national borders (King et al. 2004).

Worldwide foodborne disease outbreaks have significant social and economic consequences, influencing food and behavioral patterns (Quested et al. 2010). Over the last few decades, industrialized nations' foodborne disease reporting systems have improved a lot. Food safety awareness has increased due to improved pathogen detection and the ability to trace diseases to specific food products (Wilcock et al. 2004). Furthermore, novel infections have emerged that align with the evolving food supply, a rise in the population of individuals with increased vulnerability to foodborne illnesses, and a more comprehensive range of food preparation methods and dietary preferences. The circumstances mentioned above have presented several difficulties for veterinarians, and organizations focusing on public health (Lusk and McCluskey 2018). In addition to these modifications, the global economy has enabled rapid transportation of consumable food items, hence augmenting the likelihood of novel populations being subjected to foodborne infections commonly found in remote regions of the globe (Gargiulo et al. 2022). Biosecurity and pathogens should be checked on the farm where food production starts (Youssef et al. 2021).

From production to packaging, food can be contaminated before it reaches consumers. Advanced food processing facilities are vast and consolidated compared to modest family-run operations that supply food locally. Consolidation of the food-producing sector has been driven by economic forces in many countries (Cardwell et al. 2016).

The increasing prevalence of middle-class households in numerous nations has led to a growing preference for takeaway food (Burgoine et al. 2014). There is a correlation between this phenomenon and a rise in foodborne illnesses, particularly in fast-food establishments and restaurants that exhibit inadequate food handling practices and hygiene. Certain countries are experiencing a rise in the elderly population due to decreasing birth and death rates. Consequently, a significant portion of this demographic has pre-existing medical conditions. Advancements in medical treatments have contributed to the increased life expectancy of infants, pregnant women, individuals with compromised immune systems, and aging populations. Healthcare professionals should be knowledgeable about the potential risks related to feedstuffs and adhere to safe meal preparation methods (Kelly and Marshak 2009).

2. FOOD PATHOGENS

2.1. BACTERIAL DISEASES

Foodborne pathogens refer to microorganisms that have the potential to induce illness when ingested along with food. The predominant causative agents in question are bacteria, although they may also encompass viral, parasitic, and fungal entities. Locality, food preparation, poor hygiene, limited access to clean water, and lack of community education are primary epidemiological factors (Allard et al. 2018). The following are several often-observed bacterial foodborne diseases (Table 1).

L. monocytogenes is a Gram-positive facultative pathogen that can cause severe problems in pregnant women, infants, the elderly, and immune-compromised individuals. The disease is categorized into high, medium, and low-risk foods. Non-pathogenic *E.coli* is categorized into serotypes according to the presence of virulence genes (Wilcox 2018). Vero toxic *E. coli* (VTEC) is a bacterial group that can lead to multiple human diseases, such as gastroenteritis, dysentery, urinary tract infections, sepsis, pneumonia, and meningitis (Karmali et al., 2003). Salmonella, a Gram-negative bacterium, is frequently present in the gastrointestinal tracts of reptiles, birds, wildlife, farm animals, and humans. *Salmonella enterica* serovar *Choleraesuis, Salmonella dublin, Choleraesuis,* and *Arizonae* are frequently implicated in foodborne salmonella outbreaks in Europe (Dos Santos et al. 2019).

Table 1: Various bacteria, their contamination sources, and associated symptoms.

Bacteria	Source of Contamination	Symptoms	References
Escherichia (*E.*) *coli* (many variants)	Meats and vegetables washed in contaminated water	Gastroenteritis, significant systemic signs	(Orth et al. 2008)
Campylobacter spp.	Contaminated meats	Gastroenteritis, fever, and other systemic signs	(Hermans et al. 2012)
Brucella spp.	Milk and milk products from infected ruminants	Undulant fever, body and headaches which may become chronic	(El-Diasty et al. 2018)
Vibrio spp.	Contaminated water and food, shellfish and salads	Gastroenteritis, fever, vomiting	(Baker-Austin et al. 2018)
Salmonella spp.	Meats and vegetables rinsed in contaminated water	Gastroenteritis, fever, and other systemic signs	(Hurley et al. 2014)
Listeria monocytogenes	Contaminated shellfish, chilled meats, and salads	Gastroenteritis with other systemic signs	(Stavru et al. 2011)
Staphylococcus aureus	Food contaminated with toxin	Gastroenteritis may have other systemic signs	(Haag et al. 2019)
Shigella	Contaminated food; primates and humans the key hosts	Gastroenteritis with blood in feces	(Jennison and Verma 2004)
Mycobacterium avium paratuberculosis	Contaminated milk	Bowel disease and Crohn's disease	(Kennedy and Benedictus 2001)
Bacillus cereus	Reheated food, especially rice	Gastroenteritis	(Bottone 2010)
Yersinia enterocolitica	Contaminated meats	Gastroenteritis with other systemic signs	(Galindo et al. 2011)
Clostridium perfringens	Insufficiently cooked meat or reheated food	Gastroenteritis with other systemic signs	(Freedman et al. 2016)
Leptospira – various serovars	Humans are typically infected through direct contact with infected animals' urine or contaminated food or water consumption	Variable including diarrhea, fever, vomiting, myalgia, abdominal pain, and jaundice	(Zuerner et al. 2009)
Mycobacterium bovis	Contaminated milk	Lymph gland enlargement and localized or systemic signs	(Phillips et al. 2003)
Clostridium difficile	Contaminated ground beef, pork or turkey	Mild gastrointestinal signs associated with toxin	(Vonberg et al. 2008)
Yersinia pseudotuberculosis	Contaminated meat and vegetation	Gastroenteritis, appendicitis and systemic signs	(Galindo et al. 2011)
Coxiella burnetii	Contaminated milk products	Fever, systemic signs such as nausea, headache, and myalgia	(Kazar 2005)

Campylobacter spp. is a significant cause of human foodborne illness, accounting for 14.2% of reported cases from 1998 to 2002 in the United States (Bhunia 2018). The primary reservoirs for Campylobacter spp. include leporids, birds, ovine, canines, bovines, poultry, and domestic pets. Risk assessments have been employed to identify the origin of human infections, and it has been found that contaminated chicken meat is the primary source of foodborne *Campylobacter jejuni* infection. *Yersinia enterocolitica* is a zoonotic ailment caused by *Coxiella burnetii*, which is frequently present in the gastrointestinal tract of both healthy and diseased birds and mammals. It causes approximately 87,000 cases of gastroenteritis each year (Riahi et al. 2021). Yersinia is categorized into five groups according to their pathogenicity, ecological factors, and geographical distribution. Although the disease typically resolves on its own, there have been rare instances where septicemia and mortality have been documented. The prevention of Yersinia necessitates the purification of dairy products and thorough gastronomic of meat, particularly pork (Tauxe 2019).

Q fever, also known as "query fever," is a globally prevalent zoonotic disease caused by *Coxiella burnetii* (Angelakis and Raoult, 2010). The primary mode of infection in humans is through the inhalation of aerosols that contain dried placenta, secretions, and feces from infected livestock. Q fever primarily affects individuals in occupational fields such as farming, abattoir work, veterinary practice, and laboratory work (Clark et al. 2018).

Common symptoms of brucellosis include profuse sweating, splenomegaly, cough, and pleuritic chest pain. Gastrointestinal symptoms encompass reduced appetite, nausea, vomiting, diarrhea, and constipation (Dadar et al. 2019). Symptoms typically last for a duration of 2 to 4 weeks and resolve without the need for intervention. Brucella spp., such as *B. melitensis*, pose a food security concern in Mediterranean areas (Aliyev et al. 2022). Standardized animal health and public health programs are more prevalent in certain countries (Antunes et al. 2020).

2.2. VIRAL DISEASES

Foodborne viral diseases can have long-lasting persistence in the environment, facilitating transmission to susceptible hosts (Velebit et al. 2019). The primary modes of transmission for the most prevalent human viruses are through water contamination, consumption of contaminated drinking water, ingestion of shellfish, and consumption of fresh fruits and vegetables. Zoonotic viruses may be transmitted through meat that is infected or contaminated. In the United States, the majority (66.6%) of foodborne illnesses are caused by viruses, while *Salmonella* and *Campylobacter* account for 9.7% and 14.2%, respectively (Fleet et al. 2000). Some human viral pathogens which are recently discovered, may have originated from animals, and there is still limited understanding of the epidemiology of these viruses. The presence of water and foodborne viruses, such as Enteroviruses, Adenoviruses, Hepatitis Ab, Hepatitis E, Astroviruses, Rotaviruses, and Norwalk-like viruses (noroviruses), may result in the development of gastroenteritis and systemic symptoms (Table 2).

Enteroviruses constitute a collection of viruses that are commonly disseminated by water sources that have been contaminated, as well as through the ingestion of food that has been tainted. The microbes can induce gastroenteritis, a condition marked by inflammation of the gastrointestinal tract that manifests through symptoms such as diarrhea, vomiting, and abdominal pain. Moreover, Enteroviruses can induce systemic symptoms, consequently impacting several organs and systems inside the human body. Adenoviruses, akin to Enteroviruses, have the potential to be transferred via water that has been contaminated, hence leading to the manifestation of gastroenteritis. In certain instances, patients may also manifest respiratory symptoms, such as wheezing or respiratory infection, alongside gastrointestinal problems. This virus can be transmitted by ingesting water and food that has been infected, with a specific focus on crustaceans. This pathological state gives rise to hepatic inflammation, resulting in the clinical

manifestation known as hepatitis. The manifestation of the illness may occur without jaundice, a condition distinguished by the coloring of the skin and eyes. The primary mode of transmission for Hepatitis E is through the ingestion of contaminated food, with a particular emphasis on the intake of raw pig and deer meat. Hepatitis E induces a clinical presentation resembling Hepatitis A, though with a notable absence of jaundice in many cases (Koopmans et al. 2002).
Astroviruses spread via ingesting water and food that has been infected, with a particular emphasis on crustaceans. The incidence of gastroenteritis is attributed to the causal agents, which manifest symptoms such as diarrhea accompanied by mucus, vomiting, and a reduced appetite, sometimes referred to as anorexia. Rotaviruses possess the ability to be transmitted via water and food that have been polluted. Noroviruses are commonly linked to gastroenteritis, especially in young infants, and present with vomiting symptoms and diarrhea episodes. The subject of discussion pertains to Norwalk-like viruses, which are alternatively referred to as noroviruses. Noroviruses are mainly spread via ingesting contaminated water and food. These are widely recognized for their inclination to induce gastroenteritis outbreaks in settings characterized by limited space or high population density, such as cruise ships and healthcare institutions.

Table 2: Various Viruses, their contamination sources, and associated symptoms

Virus	Transmission Route	Symptoms	References
Enteroviruses	Contaminated water	Gastroenteritis and systemic signs	(Sinclair and Omar 2022)
Norwalk-like viruses (noroviruses)	Contaminated water and food, including shellfish	Gastroenteritis with vomiting, diarrhea, and abdominal pain	(Marks et al., 2000)
Hepatitis A-B	Contaminated water and food	Hepatitis with or without jaundice	(Maddrey 2000)
Astroviruses	Contaminated water and food, including shellfish	Gastroenteritis with watery diarrhea, vomiting and anorexia	(Kurtz and Lee 2007)
Hepatitis E	Contaminated food, including pork and venison	Hepatitis, often without jaundice	(Krawczynski et al. 2000)
Rotaviruses	Contaminated water and food	Gastroenteritis with vomiting and diarrhea	(Cook et al. 2004)
Adenoviruses	Contaminated water	Gastroenteritis may have respiratory signs	(Lynch III and Kajon 2021)

The infection elicits symptoms characterized by severe emesis, episodes of diarrhea, and abdominal discomfort (Iturriza-Gomara and O'Brien, 2016).

2.3. PARASITIC DISEASES

Including over three hundred species of parasitic helminth and more than seventy species of protozoans, parasitic diseases transmitted through food pose a significant threat to human health (Torgerson et al. 2014). Parasites have had a symbiotic relationship with humans, and they are typically transmitted through food and water. The mode of environmental transmission plays a crucial role in the epidemiology of numerous protozoa and helminths, making the epidemiology of parasitic diseases complex (Chávez-Ruvalcaba et al. 2021). Important environmental factors include appropriate humidity, temperature, food and water availability, and favorable soil and vegetation. The capacity of parasites to generate multiple infectious stages and their environmental resilience pose a significant threat to human health and regulatory agencies. Geographic variations in the prevalence of parasites in the food supply are influenced by the consumption of fresh or undercooked foods (Torgerson et al. 2015).
Human or animal excreta frequently contaminates freshwater sources with protozoa. In addition, they are present on fruits and vegetables rinsed in contaminated water (Fayer et al. 2004). Some protozoa are also transmissible via direct contact with or consumption of fresh meat. The clinical pathology of human

protozoan diseases is influenced by several variables, such as the level of exposure, parasite virulence, host immunity, and the presence of concurrent infections caused by bacteria, viruses, and other protozoa (Omarova et al. 2018). As a large proportion of the population has been unprotected to Toxoplasma cysts, but only a minority exhibit obvious symptoms of contamination, the clinical presentation of these individuals differs considerably. Foodborne infections such as Giardiasis, Cryptosporidiosis, Cyclosporiasis, Sarcocystosis, and Amebiasis can cause severe gastrointestinal complications. Giardia cysts are found in surface water and the feces of fauna, whereas *Cryptosporidium parvum* is typically found in cider, unpasteurized milk, and contaminated wastewater (Fletcher et al. 2012). *C. cayetensis* is endemic in a variety of developing countries and is transmitted via the fecal-oral route. Sarcocystis is a significant human pathogen, observed predominantly in Asia with few reported cases. *Entamoeba* (*E.*) *histolytica* is a significant agent in the etiology of gastroenteritis pathogens in tropical and subtropical regions, as well as a notable human pathogen (Mortimer and Chadee 2010). *E. histolytica* is another important source of mortality in humans, affecting approximately 50 million people worldwide. Annually, between 40,000 to 100,000 fatalities are attributed to this infection's complications. It is recommended to cook completely wild game meat and pork. Trichinellosis and Diphtheria are just a few of the health, social, and economic concerns of parasites. Trichinellosis is a parasitic infection caused by the consumption of raw or undercooked flesh containing the larvae of Trichinella and its related species. Commonly, both wild carnivores and domestic dogs are infected. Meat can be cooked properly or frozen at -15°C or lower for at least 20 days to prevent contamination (Zhou et al. 2008).

The cestodes capable of infecting humans encompass *Taenia solium, Taenia saginata, Diphyllobothrium latum, Hymenolepis nana, Echinococcus granulosus, and Echinococcus multilocularis*. The global distribution of *T. saginata* encompasses several regions, yet there is a notable disparity in the prevalence of human infection, with poorer countries exhibiting greater rates (Dorny et al. 2009).

The canine parasite *Diphyllobothrium latum* can infect both humans and animals through its transmission via crustaceans and freshwater fish (Amissah-Reynolds et al. 2016). The parasite is transmitted to humans through the consumption of raw fish, but it frequently does not cause any symptoms in humans or other primary hosts. The hydatid cyst caused by *Echinococcus spp*., is a parasitic organism that primarily infects canines. However, it can also infect humans and other animals that inadvertently consume tapeworm eggs present in the feces of the host. Cysticercosis is caused by two primary cestodes: *E. granulosus*, which leads to the development of "cystic" ailment, and *E. multilocularis*, which bases "alveolar" ailment (Chhabra and Singla 2009). The estimated occurrence of *D. latum* infection in the United States is no more than 0.5%. However, recent epidemics have been linked to the accessibility of fresh salmon and the consumption of raw fish (Fried and Abruzzi 2010). Flukes exhibit a life cycle that necessitates the involvement of one or two intermediate hosts. Foodborne trematodes infection pose a growing public health concern in Southeast Asia and the Western Pacific region. Human fascioliasis is a significant emerging disease primarily transmitted through the ingestion of infectious forms found in plants, particularly watercress. Fish borne Zoonotic Trematodes (FZT) can pose significant health risks to humans, particularly when transmitted through the consumption of raw or undercooked fish that have been cultivated on fish farms (Toledo et al. 2012).

To prevent human infection, it is imperative to implement effective educational initiatives, conduct thorough testing of beef and pork products, adhere to proper cooking techniques, and promote hygiene habits.

3. SOURCE OF ZOONOTIC PATHOGENS

The common sources of zoonotic pathogens have been shown in Fig. 1.

3.1. MANURE

Manure, a mixture of livestock excreta and bedding materials, is a significant source of contamination for crops and pastures. Diseases that are connected with organisms that can be contracted through manure primarily spread through the fecal-oral pathway and present as gastrointestinal illnesses. More than 100 zoonotic pathogens have been documented to impact humans by entering the food chain (Khan et al. 2020). Despite the considerable array of zoonotic pathogens that possess the capacity to induce illness in human beings, the overwhelming majority of diseases can be attributed to a limited number of species. Manure can contaminate water sources accessed by humans through leaching, runoff, and thawing snow. This contaminated water contains pathogenic microorganisms, which can lead to human morbidity (Chen et al. 2018). Control measures can be implemented at various stages of animal and plant production to prevent zoonotic infections transmitted through feces (Ghasemzadeh and Namazi 2015). These measures should reduce the pathogen burden within the host animal, which can reduce productivity. Preventing environmental contamination mitigates the potential for reinfection of livestock and human diseases resulting from the transmission of plant or waterborne pathogens. Fertilizer management systems,

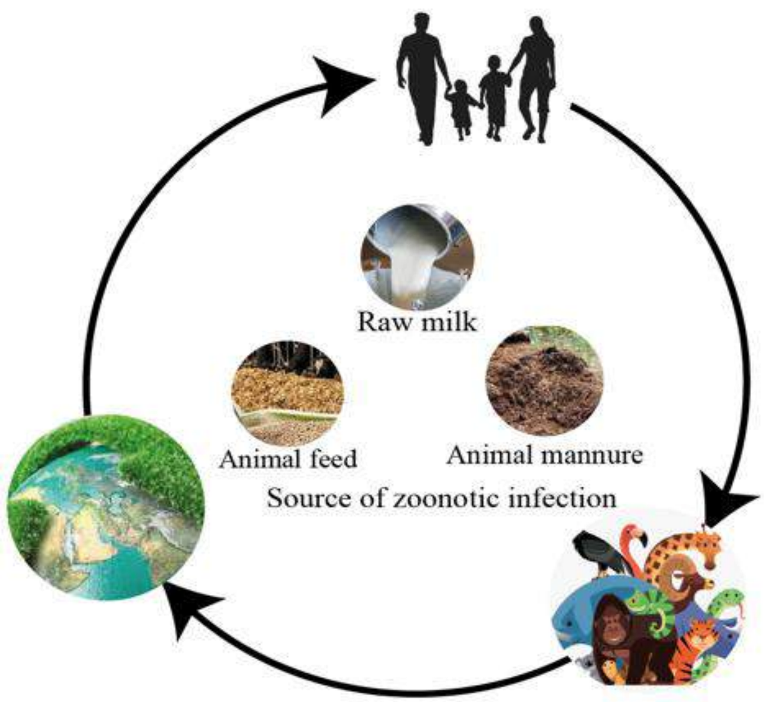

Fig. 1: Common sources of zoonotic pathogens.

including composting and various treatment methods such as physical, chemical, and biological approaches, have the potential to mitigate environmental pollution. Applying appropriate irrigation and soil management techniques can mitigate the potential for contamination in fruit and vegetable crops. Food processors should adopt risk mitigation measures to minimize the likelihood of fecal contamination in their products (Bosch et al. 2018).

3.2. ANIMAL FEED

The feed industry plays a crucial role in the agricultural supply chain and sustainability by providing essential ingredients, including forage, grains, meals, fats, oils, minerals, vitamins, and by-products, sourced from developing countries. However, it also possesses the capacity to isolate, intensify, and recycle zoonotic pathogens, while redistributing significant amounts of heavy metals and other potentially harmful substances. (Martinez et al. 2009). Feed production in developed countries is estimated to be around 420 million tons annually, indicating significant growth and complexity in the industry.

Feed ingredient contamination poses a greater risk compared to other risks, and animal feedstuff serves as a notable reservoir of zoonotic etiologies, including Salmonella spp., which can endure in arid conditions. Oilseeds, animal feed, cooked plants, and feed mills are common sources of this substance (Gaggìa et al. 2010). The heat treatment employed in animal protein feeds effectively eliminates the organism, but subsequent meals become contaminated following the heating process. *Salmonella* can persist on greasy surfaces and floors, become airborne in factory dust, and subsequently contaminate flour during the cooling process. *E. coli* O157:H7 and *Salmonella* are frequently present in compound feed mills (Davis et al. 2003).Feed decontamination is a significant issue in the European Union (EU) due to the requirement that all feed must undergo testing for *Salmonella* and be confirmed negative before being transported to farms (Okojie and Isah 2014). The feed industry in Europe does not consider the presence of *Salmonella* in feed to pose a substantial risk to human health. The EU has implemented a ban on the use of subtherapeutic antibiotics in animal feed, reflecting the complexity surrounding the use of antibiotics in this context. The administration of residual drugs in animal feed can come up with the emergence of drug resistance and a decline in antibiotic-susceptible pathogens (Heinzerling 2012). In North America, the utilization of antibiotics in livestock production is primarily motivated by economic advantages and improved operational effectiveness. The cessation of using antibiotics as growth promoters may result in increased antibiotic usage for treating animals, which could lead to a higher incidence of clinical conditions in livestock and poultry.

3.3. MILK

The consumption of unprocessed, unpasteurized milk has increased significantly. Raw milk's growing prevalence can be attributed to its improved nutritional value, enhanced flavor, potential health welfare, rising petition for inherent and raw foodstuffs, and the desire for personal autonomy. However, it is essential to recognize that additional extensive scientific evidence is necessary to support these claims completely (Angulo et al. 2009). Milk and dairy products are essential to a healthy diet, but consuming them unpasteurized can pose health risks due to potentially hazardous microorganisms. People continue to consume raw milk despite the well-documented presence of numerous microorganisms, some of which have been linked to human illness. In the context of allowing the sale of raw milk, it is essential to establish safeguards against the potential risks associated with raw milk consumption and its derivatives. Establishing regulatory standards, such as microbiological criteria, for unprocessed milk intended for human consumption is one method for addressing this issue. Additionally, implementation of whole milk labeling requirements could be considered (Papademas and Bintsis 2010).

Furthermore, it is possible to enhance hygienic practices during the milking process and implement educational programs targeting both producers and consumers. Implementing on-farm pre- and post-harvest control techniques is crucial for effectively reducing microbial contamination in raw milk, which in turn contributes to overall pathogen control (Oliveira et al. 2011). The International Dairy Foods Association and the National Federation of Dairy Producers endorse a legal requirement for all establishments producing raw or unpasteurized dairy products for human consumption to be registered with the United States Food and Drug Administration (FDA). Furthermore, these facilities must adhere to food safety regulations, similar to other establishments engaged in the production of dairy products.

Liability is a significant aspect that merits attention from both raw milk manufacturers and consumers. Dairy manufacturers must possess comprehensive knowledge regarding the potential risks and legal responsibilities associated with the distribution of raw milk to consumers. Customers getting un-processed milk must acknowledge the vital hazards and limited legal protections in case of illness caused by consuming contaminated raw milk infection. Until comprehensive investigations are carried out, the most effective approach to mitigate the risk of foodborne illnesses related to raw milk is to refrain from consuming un-processed milk and dairy harvests through un-processed milk.

Through consistent measures, the safety and purity of dairy products are ensured from the farm to the processing plant. Transforming low-quality un-processed milk into a higher-quality milk product is likely simpler. Dairy producers must implement production practices to reduce mastitis and microbial contamination in bulk milk to meet stringent raw milk quality standards (Lemma et al. 2018). Reducing raw milk contamination, implementing effective management practices, and establishing mastitis control strategies can aid dairy producers in achieving significant objectives. This. It is essential to recognize that using these techniques does not eliminate the possibility of pathogens in raw milk and the associated dangers of milk-borne illnesses (Zeinhom and Abdel-Latef 2014).

4. MITIGATION STRATEGIES

The effective management of zoonotic diseases on a global scale necessitates a high degree of international collaboration. Promoting international collaboration in disease surveillance and response endeavors mitigates cross-border transmission and enhances the effectiveness of coordinated outbreak responses (Jebara 2004).

Within the food chain context, diverse tactics for mitigating zoonotic diseases exist, which encompass a range of interventions designed to impede the transfer of infectious ailments from animals to people. The significance of surveillance and timely detection in identifying possible threats at an early stage must be considered. This includes implementing a complete surveillance system aimed at monitoring zoonotic illnesses in animals and installing reporting procedures that facilitate the identification of unusual disease patterns in both animal and human populations. The allocation of resources towards research and testing facilities plays a crucial role in expediting the detection of emerging zoonotic infections, thereby enabling a proactive approach to addressing these threats.

Adopting a One Health approach is essential to successfully treat zoonotic illnesses inside the food chain (Rossow et al. 2020). The facilitation of collaboration between the human health, veterinary, and environmental sectors is crucial in fostering the development of complete solutions. The exchange of information and collaboration across pertinent authorities and groups enhances a cohesive and efficient response (Webster et al. 2016). Education and public knowledge play a vital role in mitigating zoonotic dangers. Raising consumer awareness of zoonotic diseases and the importance of proper food handling and cooking techniques can contribute to mitigating disease transmission. Furthermore, increasing awareness among healthcare workers expedites the process of identifying and reporting suspected cases of zoonotic diseases (Monath et al. 2010).

To avoid introducing and spreading infectious pathogens, farms, and animal production facilities must adopt and enforce rigorous biosecurity protocols. It is imperative to limit access exclusively to individuals who have been granted authorization while ensuring regular animal health monitoring. The prompt implementation of isolating and treating unwell animals further diminishes the probability of disease spread (Collins and Wall 2004).

Antibiotic control practices are essential in mitigating zoonotic diseases within the food chain. Promoting safe antibiotic usage in animals is crucial in mitigating the transmission of antibiotic-resistant microorganisms to humans. In contrast, promoting non-antibiotic interventions, such as probiotics and vaccines, safeguards animal health by mitigating the emergence and proliferation of antibiotic resistance (Gwenzi et al. 2022).

Ensuring stringent levels of cleanliness and sanitation are upheld throughout the food production process is of utmost importance. This entails implementing rigorous hygienic measures during the processing and handling of animal products to mitigate the risk of contamination. The use of routine cleaning and sanitation practices for equipment and facilities in slaughterhouses, processing plants, and vehicles further mitigates the potential for cross-contamination (Lam et al. 2013). The implementation of rigorous food safety rules is crucial to mitigate the risk of zoonotic infections. Implementing routine inspections and audits in food production facilities significantly ensures compliance with safety regulations. The implementation of traceability systems for monitoring the provenance of food products facilitates prompt recalls in the event of outbreaks, effectively mitigating the transmission of zoonotic illnesses.

Preventing zoonotic illnesses necessitates implementing effective wildlife management strategies, given that numerous viruses have their origins in wildlife populations. Implementing policies aimed at managing and controlling zoonotic diseases in wildlife and monitoring and regulating wildlife trade and migration can contribute to the mitigation of disease transmission to human populations (Shiferaw et al. 2017).

CONCLUSION

The allocation of resources toward research and innovation is pivotal in advancing efficient solutions for preventing and controlling zoonotic diseases. The comprehension of the ecological aspects and transmission routes of zoonotic diseases plays a crucial role in formulating and implementing precise therapies. Furthermore, assisting in advancing novel diagnostic instruments, vaccines, and treatments enhances our ability to address zoonotic illnesses efficiently, safeguarding the well-being of animals and humans across the entire food production process.

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Diagnostic Tools for Zoonotic Infections

28

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ABSTRACT

The recent growth of infectious diseases stemming from zoonotic origins has placed a significant global burden on both morbidity and mortality. Additionally it has generated substantial economic challenges. The complexity and dynamism of the resurgence and epidemiology of zoonoses are shaped by diverse factors which can be broadly classified into human-related, pathogen-related and climate related parameters. The diagnosis of animal diseases serves a dual role as both the origin and solution to various ailments. It is instrumental in managing and preventing diseases, playing a crucial part in overall disease control. Therefore, the imperative for the development of veterinary diagnostic tools becomes apparent, ensuring comprehensive animal welfare and effective monitoring of disease spread. Here we discussed various molecular and non-molecular diagnostic methods for zoonotic infections. These diverse approaches include viral metagenomics, clinical recognition, standard labortary assessments, and labortary tests. By examining recent advancements in diagnostic methodologies, this chapter aims to underscore the importance of ongoing research and innovation in the field of zoonotic disease diagnostics for enhanced public health preparedness and intervention strategies.

Key words: Disease management, Diagnostic, Zoonotic, Viral metagenomics, Clinical tests, PCR, DNA fingerprinting, DNA based composition, Radioimunoassay.

CITATION

Batool T, Toqir S, Naz K, Sajjad A, Saeed A, Aslam MA, Younas F, Nawaz M, Mehnaz S and Fatima T, 2023. Diagnostic tools for zoonotic infections. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 374-387. https://doi.org/10.47278/book.zoon/2023.028

CHAPTER HISTORY Received: 25-Jan-2023 Revised: 27-May-2023 Accepted: 21-June-2023

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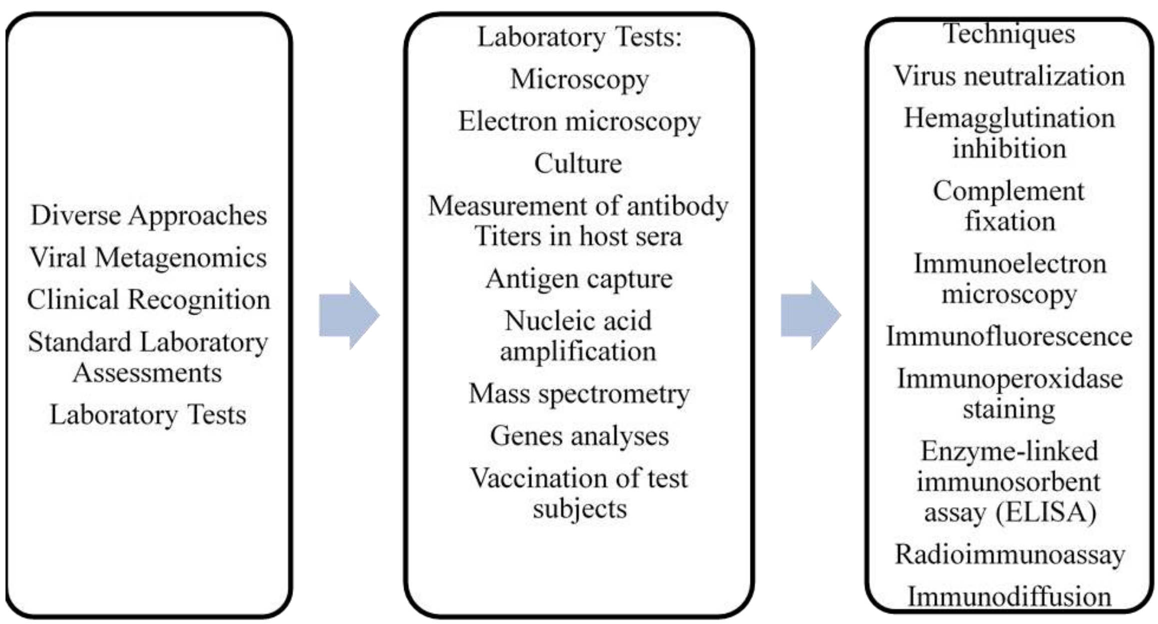
1. INTRODUCTION

Some unidentified and mysterious illnesses with no proper treatment have been observed all over the globe (He et al. 2020; Smolarz et al. 2021; Shafaati and Zandi 2022). Table 1 shows rapid diagnosis for molecular and non-molecular zoonotic infections.

Furthermore, such diseases are unique to specific regions of the world and have spread to new ones (Malki et al. 2020). Therefore, we need to be able to spot emerging diseases and determine its cause (Connolly et al. 2021).

Table 1: Rapid diagnosis for molecular and non-molecular zoonotic infections**.**

Molecular diagnostic methods	Non-molecular diagnostic methods
• Polymerase chain reaction (PCR)	• Cultures
• Hybridization	• Beta-Glucan Assay
• Metagenomics	• CAGTA Assay
• Gene probing	• Histopathology
• DNA Fingerprinting	• Glutomannan assay
• rRNA sequencing	• Serological Tests (Antigen tests, Antibody tests)
• DNA Base composition	
• Electron Microscope	• Optical microscope
• Mass Spectrometry	
• Restriction Endonuclease and Oligonucleotide Fingerprinting	



2. DIVERSE APPROACHES

The technique that incorporates simultaneous and diverse approaches is the most promising for evaluating novel diseases (Basith et al. 2020).

2.1. VIRAL METAGENOMICS

A culture-independent method called viral metagenomics is used to examine all viral genetic populations in biological material (Sommers et al. 2021). This methodology becomes a powerful tool for identifying new and emerging viruses, considering that animals remain a reservoir for the virus that can cause zoonosis. Less than 1% of bacterial hosts have been cultivated, so it is difficult to identify and measure the dynamics of the viral population in the environment (Zhang et al. 2022). On the whole, these restrictions can be overcome by metagenomics investigation of uncultured viral communities, which can also offer insights into the makeup and organization of environmental viral communities.

2.2. CLINICAL RECOGNITION

An immediate individual or group recognizes a disorder that does not share traits with any other recognized condition (Shah et al. 2020). It could be an illness with a recently identified or previously documented ailment with an atypical presentation. As a result, it is advantageous to alert hospital infectious disease specialists, emergency room physicians, and other combatants to the potential for a novel disease or one that has not previously been observed in the region (Sami et al. 2021).

2.3. STANDARD LABORATORY ASSESSMENTS

It could be an illness with a recently identified or previously documented ailment with an atypical presentation. Therefore, it is advantageous to alert hospitals for novel disease specialists, emergency room physicians, and other combatants to the potential for a novel disease or one not previously observed in the region to encourage such recognition.

2.4. EPIDEMIOLOGY STUDIES

The epidemiological field is a scientific, systematic, and analytical study of the frequency, distribution, and origins of medical symptoms and events in particular groups (such as communities, schools, cities, regions, nations, and the world) (Luca et al. 2022).
The investigations may shed light on the new condition's distribution, the race, age, and sex of vulnerable people, the immune response of those who are resilient and those who are potential animal vectors or recipients, the lubricating period, and the mode of transmission (Belbasis and Bellou 2018).

2.5. LABORATORY TESTS

All conceivable laboratory tests need to be performed when an indication of a new and significant disease is indicated. These exams comprise of:

- Microscopy
- Electron microscopy
- Culture
- Measurement of antibodies serum
- Antigen capture assays
- Nucleic acid amplifications
- Mass spectrometer
- Genes Measurements
- Vaccination of test subjects

2.6. MICROSCOPY

A microscope can be used for a variety of things, depending on its type. While some are utilized in instructional settings, others are appropriate for biological purposes (DeVree et al. 2021).

Light microscopy can be performed quickly, but precision depends on the equipment's quality and the microscopist's competence. The ability of doctors to employ microscopy for diagnosis outside of an accredited laboratory is frequently constrained by regulations. To differentiate between invasive illness and surface colonization—a distinction that is difficult to make using culture methods—microscopic inspection of tissue may be necessary (Richert-Poggeler et al. 2019).

3. MICROSCOPY USING ELECTRONS AND IMMUNOELECTRON MICROSCOPY

These techniques are best suited for quickly detecting viral isolates from cell cultures and actual specimens (Madanayake et al. 2023). Electron microscopy only allows for family-level identification, whereas immunoelectron microscopy with a suitable, particular antibody may allow for the creation of finer differences (Gulati et al. 2019).

4. CULTURE

Culture is the development of microorganisms located in a nutrient-rich either liquid or solid medium; more organisms make identification easier. Antimicrobial susceptibility testing is also made more accessible by culture (Namdari et al. 2019).

5. IMMUNOLOGIC TESTS

The antigens are used to search for pathogen-specific antibodies in the patient's samples. Detection antibody for a pathogen's antigen in the patient's samples. Although there are different protocols for handling specimens, they should normally be chilled or frozen if testing needs to be postponed to avoid bacterial contamination proliferation (Normann et al. 2020). There are numerous techniques used or put forth for the cultivation-independent characterization of infectious pathogens (Gilboa et al. 2020; Preena et al. 2020). Through the use of molecular pathogen discovery techniques, new pathogens connected to both acute and chronic illnesses have been discovered during the past ten years (Belizario et al. 2021).

6. LIMITATIONS

6.1. THE PATHOGEN'S HOST RANGE

A pathogen once exclusive to dogs, swine, or cats now threatens human life (Tomori and Oluwayelu 2023).

6.2. MODIFICATION OF TISSUE TROPISM

A virus that in the past only occasionally caused moderate enteritis now frequently causes severe myocarditis and severe encephalitis (Shieh 2022).

6.3. IMMUNE EVASION

Large DNA viruses with many genes that help them escape or manipulate the host's immunity include orthopox viruses (Verdonck et al. 2022). These genes could undergo mutations that alter the virus's host range. Mutations can cause viruses of all sizes, including RNA viruses, to switch species. Additionally, some

RNA fragments are capable of recombining to create new variations that are immune-evading for both humans and the animals that serve as their reservoirs (Ma et al. 2019).

6.4. ENVIRONMENTAL EFFECTS

Human beings' activities include constructing routes across the bush and moving animals or vectors (Mishra et al. 2021).

6.5. ZOONOSES WITHOUT A VECTOR

Pathologists can now identify the root cause of dying more quickly than ever before and frequently when it would have been impossible in the past, using techniques like polymerase chain reaction (PCR) testing, in situ hybridization, and immunohistochemistry (Sledzinskaet al. 2021).

Table 2: Main categories of tests used to determine an accurate diagnosis of a viral outbreak in an animal

Taxonomy	Techniques	Examples	References
Family (genus)	• Complement Fixation • Electron Microscopy • Cytopathology	GBV-A, a virus from the family Flaviviridae, is found in wild monkeys, whereas GBV-B, from the genus Hepacivirus, is found in infected tamarins. Pegivirus is the name of the fourth genus in the Flaviviridae GBV-D and GBV-C family observed in bats, rodents, horses, and pigs	(Koonin et al. 2021)
Species (types)	Neutralization	Brown bats' Eptesicus fuscus and Myotis lucifugus were examined for the presence of the rabies virus and antibodies that can neutralize it.	(Gold et al. 2020)
Subtype	Kinetic neutralization Monoclonal antibody serology	Tembusu virus (TMUV), a new flavivirus that is developing in ducks, was neutralized by an antibody response in 2010. Influenza-neutralizing antibodies A virus and the effectiveness of their preventative measures in mice	(Lv et al. 2019)
Variant	• Restriction Endonuclease • Oligonucleotide fingerprint • Nucleic acid hybridization	Dromedaries with MERS-CoV Infection variant detection are detected and in pregnant white-tailed deer, SARS-CoV-2 and its alpha form were found and also in Norway rats. Endonuclease fragments were used to find the *bla*CTX-M-15 and *bla*CTX-M-1 (CTX-M ESBL gene variants) in Escherichia coli isolates and animal faeces	(Lado et al. 2021; Cool et al. 2022; Higgins et al. 2023)
Mutant (including by point mutation)	Nucleic acid sequencing	Asiatic lions in India were infected with the SARS-CoV-II Delta mutation	(Karikalan et al. 2022)

7. VIRAL DIAGNOSIS

There are three main categories of tests used to determine an accurate diagnosis of a viral outbreak in an animal:

1. Characterization and isolation of the causative virus.
2. Measurement and detection of antibodies.
3. Direct demonstration of viral nucleic acids, viral antigens, virions, or in tissues, secretions and excretions.

There are numerous interesting diagnostic tests employing nanomaterials that are focused on the chemicals that cause animal diseases, but many of them have not yet reached a balance between specificity, sensitivity, cost-effectiveness, and repeatability. (Ramakrishnan et al. 2021). Table 2 shows main categories of tests used to determine an accurate diagnosis of a viral outbreak.

7.1. SPECIMEN PREPARATION FOR INOCULATION

Once the material has arrived at the laboratory, it should be handled and immunized as soon as feasible. If delays of more than a day are anticipated, the specimen may be frozen. Swabs are treated by rotating them in the vessel of transport and applying significant pressure to the container's side to release the substance (MacDonald et al. 2022). The excrement is dispersed using a vortex mixer. Tissue samples are meticulously cut with scissors and homogenized in a glass or mechanical homogenizer.

Table 3: The main serological methods in diagnostic virology.

Techniques of choice	Working Principle	Examples	References
Virus Neutralization	Antibody prevents cytopathology, protects animals, or decreases plaques by neutralizing the virion's infectivity.	Antibodies against the West Nile virus were discovered in wild birds from Southern Spain. Virus-neutralizing antibodies and related variables against rabies in the immunized domestic dogs of Kathmandu Valley, Nepal.	(Ferraguti et al. 2016) (Rimal et al. 2020)
Hemagglutination Inhibition	Antibody suppresses the hemagglutination of viruses.	In Kerman, Iran's southeast, dogs were used in an experiment to test for the avian H_9N_2 influenza virus's ability to hemagglutinate.	(Saberi et al. 2019)
Complement Fixation	Complement is bound by the antigen-antibody complex, rendering it effective to lyse hemolysis-sensitive sheep red blood cells.	Complement fixation test for detection of specific antibodies against bovine brucellosis in chosen peasant association in Guto Gida district, East Wollega Zone, Oromia Ethiopia	(Tosisa et al. 2020).
Immunoelectron Microscopy	Electron microscopy can reveal virions that have aggregated into antibodies.	After a single dose of immunization, immunoelectron microscopy-based immunogenicity of a recombinant VSV-vectored SARS-CoV vaccine generated strong protection in rhesus monkeys.	(Shan et al. 2022)
Immunofluorescence	The fluorescent antibody binds to subcellular antigens and fluoresces under ultraviolet light microscopy.	To investigate the seroprevalence of *Bartonella henselae* in Egyptian cats and people, an immunofluorescent test was performed	(Sayed et al. 2022)
Immunoperoxidase Staining	The intracellular antigen is recognized by the peroxidase-labeled antibody, and upon the addition of substrate, colored precipitate results.	*Brucella melitensis* in experimentally infected foetuses is diagnosed by immuno-peroxidase staining in the liver of the foetus.	(Mazlan et al. 2021)
ELISA (Enzyme-linked immunosorbent assay)	The reaction causes the substrate to change colour when an antibody or antigen that has been enzyme-labeled binds to it.	To find antibodies against *Toxoplasma gondii* in a cohort of hunting dogs, researchers used an ELISA with the modified agglutination test (MAT)	(Bellatreche et al. 2022)
Radioimmunoassay	An antigen or antibody that has been radiolabeled binds to it, such as when it is connected to the solid phase.	The ELISA test was developed based on radioimmunoassay to test samples from potentially infected animals.	(Broussard 2020)
Immunodiffusion	In a gel, soluble antigens and antibodies precipitate in clear lines.	Agar gel immunodiffusion assay for the diagnosis of canine brucellosis using Brucella ovis antigen	(Bolotin et al. 2022)

Membrane filters with an average pore diameter of 0.45m filter out contaminating microorganisms before inoculation. Then mycoplasmas can pass through these kinds of filters. The suspension needs to be refiltered using 0.22m filters to get rid of mycoplasmas after the virus has been successfully isolated and grown to a significant titer. Faeces and tissue homogenates should be diluted by at least a factor of 10 before being centrifuged at 1000g for 15 minutes to produce a filterable supernate. The virus concentration is believed to be very low, so a high dosage of antibiotics may be chosen for filtration (Diaz-Linan et al. 2021).

7.2. UTILIZING SEROLOGY TO IDENTIFY VIRAL ISOLATES

The main serological methods used to identify various viruses have been enlisted in Table 3.

7.3. COMPLEMENT FIXATION

Indirect diagnostic tests with great sensitivity like the complement fixation test (CFT) have a lot of false-positive outcomes (Elschner et al. 2021).
Inactivated serum samples are diluted twice in Complement fixation test (CFT) buffer and combined with CFT antigen and complement hemolytic units. Sera, complement, and antigen are combined in the plates and left to interact overnight at 4°C. This allows the complement to be fixed.
The plates are then incubated for 45 minutes at 37°C with a 2% suspension, then centrifuged for 5 minutes at 600g, and then the process is repeated. Samples exhibiting 25-75% hemolysis are regarded as suspicious, samples showing 100% hemolysis in a dilution are classified as negative. The classification of all suspicious test results is affirmative (Elschner et al. 2019).
Complement fixation can be utilized to classify an isolate and perform initial screening on it. Essentially a slightly streamlined version of the complement fixation of complement fixation test, the immune-adherence hemagglutination test is currently employed more commonly to identify antibodies than antigens (Coombs 2012).

7.4. HEMAGGLUTINATION AND INHIBITION OF HEMAGGLUTINATION

Numerous viral families' virions attach to red blood cells to hemagglutinate them. Hemagglutination is suppressed if antibodies and viruses are combined before the inclusion of red blood cells (Cho et al. 2022). Dissociating the virions using detergents can boost the hemagglutination level of some viruses, such as the canine distemper virus (Suarez et al. 2020). Antisera may need to be prepared to get rid of hemagglutination inhibitors that aren't specific. Test for determining the titer of antibodies to viral hemagglutinin by inhibiting hemagglutination. In titers, dilutions are stated as reciprocals (Spackman and Sitaras 2020).

8. METHODOLOGY

1. Periodate is applied to the sera, which is subsequently subjected to heat at 56°C for a half-hour to inactivate non-specific hemagglutination inhibitors.
2. After that, the sera are diluted in microtiter wells. The appropriate viral strain is then injected with hemagglutinating units into each well. Each well receives 0.05 ml of red blood cells following a 30-minute room temperature incubation period (Chivukula et al. 2021; Zhang et al. 2022).
3. Hemagglutination has been prevented where there is enough antibody to coat the virions, and as a result, at the bottom of the well, the erythrocytes condense to form a button (Saegerman et al. 2021).

Erythrocytes get agglutinated by the virus when there is insufficient antibody present. For example, the horse lacked any antibodies that could have blocked the hemagglutinin-inducing effects of this particular influenza virus strain. The first dose of the vaccine resulted in some antibody production, and the second dose induced a booster response (Drozdz et al. 2020).

8.1. NEUTRALIZATION OF VIRUS

A unique antibody may neutralize a virus's infectiousness through several different processes. To get rid of general viral inhibitors. The serum first needs to be inactivated by being heated at 56°C for 30 minutes (Cuevas et al. 2022). Suitable cell cultures are infected with serum-virus combinations. Afterward, they are allowed to develop until the virus-only controls show cytopathic effects by reducing a virus's ability to infect, an antibody shields cells against viral annihilation (Amanat et al. 2020).

8.2. RESTRICTION ENDONUCLEASE AND OLIGONUCLEOTIDE FINGERPRINTING

For the majority of routine diagnostic purposes, even to the level just mentioned, it is often not necessary to isolate antigenically. However, there are circumstances in which going further to identify differences between variants or subtypes within a particular serotype could provide viral epidemiological data. Similarly, viral DNA can be isolated from infected cells or virions, and the fragments can then be separated using agarose gel electrophoresis after being cut with properly chosen restriction endonucleases (Guo et al. 2022).

Ethidium bromide per silver staining is required to obtain restriction endonuclease fragment patterns, which are frequently referred to as fingerprints. All dsDNA virus families have found a use for methodology, particularly referred to as fingerprints. All dsDNA virus families have found use for the methodology, particularly in epidemiology research but also in pathogenesis research. These methods' resolution allows us to distinguish different isolates of the same viral species, even if they did not all come from the same epizootic, depending on the viral family. Minor amounts of genetic drift, which are typically not reflected in serological differences, can occasionally be detected using this technique (Laudermilch and Chandran 2021).

8.3. ELECTRON MICROSCOPY FOR THE DIRECT DETECTION OF VIRIONS

Electron microscopes are used for quick viral diagnosis. Negative staining techniques and understanding the concentration of virions are crucial for accuracy. Technology in the medical field is constantly advancing. This method can diagnose viral skin disease using vesicular fluid, scrapings, or scabs. It can also be used for accurate diagnosis in cell culture (Hopfer et al. 2021).

8.4. IMMUNOELECTRON MICROSCOPY

It is a technique that uses immune serum to increase the susceptibility of electron microscopic techniques. After mixing the sample with the antibody for an overnight period, the sample is typically cleared by low-speed centrifugation.

The immune complexes are subsequently centrifuged at a low speed to form pellets, which are then negatively stained. The antibody used could be a mixture of these antibodies, serum from an old animal that is hyperimmune to many viruses, or type-specific monoclonal or polyclonal antibodies (Zhang et al. 2022).

8.5. DIRECT IDENTIFICATION OF VIRAL ANTIGENS

These techniques rely on the direct interaction of viral particles, or antigens, with specific antibodies that have been prelabeled in some way to quickly identify the interaction, in situ in tissues, excretions, or secretions. The labeling techniques used—are immunoperoxidase staining and radioimmunoassay.
The labeling methods are divided into four categories: radioimmunoassay, immunoperoxidase staining, immunofluorescence, and ELISA. Viral antigens can also be identified using two proven serological techniques, precipitation and complement fixation (Bassani-Sternberg et al. 2016).

8.6. IMMUNOFLUORESCENCE

Immunofluorescence is a method of unique significance in the quick identification of viral infections due to its specificity, speed, relative simplicity, and sensitivity (Zhang et al. 2022).
The classic instance of immunofluorescence is the diagnosis of rabies, for which immunofluorescence has been recognized as diagnostic for more than 20 years (Chiebao et al. 2019).

9. STAINING WITH IMMUNOPEROXIDASE

An alternate approach involves using an enzyme-labeled antibody to locate and detect viral antigens in infected cells. The process results in a pore-durable, non-fading, and anatomically clearer preparation than immunofluorescence, and it uses less expensive equipment. Similar steps and ideas apply to immunofluorescence (Burrell et al. 2017).
The conjugated antibody, bound to the antigen through a direct or indirect procedure, is detected by adding a substrate suited for the specific enzyme. In the case of peroxidase, this is H_2O_2 coupled with a benzidine derivative. Endogenous peroxidase, which is found in many tissue cells, especially leukocytes, causes false positive results, which is a drawback of the method. By using a diligent approach and proper controls, this issue can be avoided (Arshad et al. 2022).

9.1. RADIOIMMUNOASSAY

A radioactive element, most frequently 125I, serves as the label in radioimmunoassay. The technique is incredibly sensitive, allowing the detection of viral antigens at low concentrations ranging from 10–12M. There are numerous radioimmunoassay techniques available. The principles are the same for both direct and indirect approaches as for immunofluorescent staining.
In the most basic configuration, a sample that might contain a virus or viral antigen is allowed to attach to the bound antibody, washed, and then an antiviral antibody is measured in a gamma counter after additional washing (Burrell et al. 2017).
A more popular approach is indirect radio-immunoassays, which include a second layer of 125I-labelled anti-IgG as an indicator antibody in place of the detection antibody. Different animal species must be used to generate the antiviral antibodies that make up the capture and detection antibodies (Inoue et al. 2010).

9.2. DIRECT ISOLATION OF LEPTOSPIRES FROM CLINICAL SAMPLES

A common method for identifying Leptospira directly from clinical samples is dark-field microscopy (DFM). Early detection of leptospires in bacterial infections is crucial. The direct fluorescent antibody (DFM) is highly sensitive for detecting leptospires in both blood and CSF, with a sensitivity rate of 64.7%. DFM is a good way to diagnose the early stages of an illness, with high sensitivity in identifying leptospires in blood and CSF. A skilled specialist is needed and 100 fields on each slide must be studied to deem it negative. As the illness progresses, DFM's sensitivity may decrease.

9.3. LEPTOSPIRES' CULTURE

A Bunsen burner will be used to aseptically add blood samples dropwise to the semi-solid medium that has been prepared. Within 24 hours, the sample-containing medium will be switched over to the liquid media. Every day for three months, each tube will be examined for the development of leptospires, and after every 2-3 weeks, they will be routinely switched to a new medium. The media developed by Stuart, Korthoff, and Fletcher is also utilized for culture. Although cultivation is the most common method of detection, its application for routine isolation is debatable because it requires a longer period for development, with a gestation period of 6–20 hours (Hornsby et al. 2020).

9.4. SEROLOGICAL METHODS

The serum of people who have contracted Leptospira can be tested using a variety of serological assays for antibodies against the parasite. We can detect IgG and IgM antibodies with MAT and ELISA- based test kits, and a wide variety of commercial fast diagnostic card tests that are already on the market (Trozzi et al. 2023).

9.5. MOLECULAR TECHNIQUES

Molecular methods can quickly and accurately diagnose infections, including leptospires, in medical or environmental samples (Girones et al. 2010).

9.6. POLYMERASE CHAIN REACTION (PCR)

Due to its specificity, sensitivity, and capacity to identify even the smallest amounts of nucleic acid particles. PCR is the best way to identify infections. Quantitative PCR is better than MAT or culture for quick and reliable results (Wood et al. 2019). This finding has important implications for medical and epidemiological analyses of this worldwide neglected disease. Leptospira is also detected using a variety of PCR techniques, including nested PCR, randomly primed PCR, etc. The drawbacks of PCR are similar to those of other diagnostic techniques and include complex lab requirements, degradation, false-positive results, initial validation, etc. These problems necessitate highly competent and trained personnel as well as a significant financial commitment (Hoorfar et al. 2004).

9.7. QUANTITATIVE PCR

PCR techniques detect Leptospira, but have limitations such as specialized equipment, sample degradation, and false positives. qPCR (real-time PCR) is preferred for accurate results in a short time by monitoring the DNA amplification rate. To evaluate disease severity, bacterial DNA amount and density must be assessed, often through targeting the LipL32 gene. qPCR is a reliable method for the early detection of Leptospirosis but is Challenging to implement in low-resource labs due to the required skilled personnel and expensive equipment (Ruijter et al. 2021).

9.8. IMMUNOCAPTURE-POLYMERASE CHAIN REACTION

New techniques have been developed to quickly identify leptospires from clinical samples, including the immunocapture-polymerase chain reaction methods created in 2018 using ELISA and PCR. A combination of molecular and serological methods is important for an accurate diagnosis of leptospires. The IC-PCR technique is a powerful tool that rapidly identifies leptospires and provides crucial information about specific serovars or serogroups present. This study shows it to be more accurate than traditional PCR methods (Jian et al. 2020).

9.9. OTHER MOLECULAR METHODS

Other molecular methods such as RAPD (random amplified polymorphic DNA), nucleic acid probe techniques, DNA-DNA hybridization, REA (restriction enzyme analysis), fingerprinting, PFGE (pulsed-field gel electrophoresis), etc., are available in highly developed laboratory settings. They support research into and comprehension of genetic diversity and genomic diversity profiles.
Several diagnostic techniques are available to detect and diagnose Leptospirosis, including ELA (IgM-Enzyme Immunoassay), MCAT (microcapsule agglutination test, LEPTO Dipstick, macroscopic SAT, IHA (indirect haemagglutination assay), and LEPTO Dri-dot. However, these rapid tests are less sensitive and specific than IgM rapid and immunochromatography techniques, despite the availability of several serological rapid tests.

CONCLUSION

Our ability to diagnose the cause of the disease is greatly improved by following all the stages consistently and sequentially. This method not only increases the scientific knowledge base but also helps zoo employees conduct retrospective studies and aids other researchers with the new database. It also enhances the ability of the zoological community to recognize disease trends and enables researchers to identify diseases that pose a threat to captive and wild animals.

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Molecular Techniques Used for Diagnosis of Zoonotic Diseases

29

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ABSTRACT

Zoonotic diseases are described as diseases that are transmitted between animals and humans through direct or indirect contact or by any other route. Many microorganisms causing recently identified zoonotic infections in humans were initially detected in animals (specifically, wildlife) or products of animal origin. Dogs and cats are the most common pets which can disseminate zoonotic diseases. Rabies, ringworms, Campylobacteriosis, Salmonellosis, and Leptospirosis are the most common diseases that can spread through dogs. All domesticated animals, including poultry, have the potential to harbor germs that cause food-borne diseases. Around 90% of bacteria-related food-borne infections are caused by Salmonella spp. and Campylobacter spp. Molecular biology methods are increasingly being used in small animal veterinary care to diagnose infectious diseases. Understanding of infectious disease agents has improved because of techniques like polymerase chain reaction (PCR), Real-time PCR, Restriction fragment length polymorphism (RFLP), ELISA and CRISPR-CAS. Approximately 50% of bacterial and 87% of viral genomes have been identified so far by different molecular techniques. To subtype organisms beyond phenotypic categories, genotyping techniques such as PFGE, RAPD, REP-PCR, and AFLP are especially applied. As DNA is the starting material, these molecular biology techniques are often frequently referred to as "DNA fingerprinting." In addition to epidemiology, these techniques are also employed in forensic medicine and evolutionary biology research. Compared to phenotyping procedures, genotyping techniques frequently offer better discriminating power. Another way to identify genomic sequences from various microbial communities is through metagenomics. Over the last few decades, metagenomics-based methodologies have been developed to assess, analyze, and utilize biodiversity across a wide range of various environmental niches. Metagenomics has helped characterize the microbiomes in many samples, such as the gastrointestinal tract of various creatures (e.g., feline, canine, human, mouse, and chicken), in addition to the discoveries of viral genomes. As technology continues to evolve, the integration of molecular diagnostics into routine surveillance and healthcare systems holds promise for more effective prevention and control of zoonotic diseases, ultimately safeguarding both humans and animals.

Keywords: Zoonosis, One-Health, RT-PCR, Metagenomics, CRISPR-CAS, Genotyping, Phenotyping.

CITATION

Rana T, Sarwar A, Mahmood A, Batool N, Shamim R, Gul S, Arshad I, Iftikhar F, Ali A and Sarwar F, 2023. Molecular Techniques Used for Diagnosis of Zoonotic Diseases. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 388-399. https://doi.org/10.47278/book.zoon/2023.029

CHAPTER HISTORY Received: 07-Jan-2023 Revised: 28-July-2023 Accepted: 13-Aug-2023

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1. INTRODUCTION

1.1. ZOONOTIC DISEASES: AN OVERVIEW

Zoonotic diseases are described as diseases that are being transmitted between animals and humans through either direct, indirect contact or by any other route. Many of the microorganisms causing recently identified zoonotic infections in humans were initially detected in animals (specifically, wildlife) or products of animal origin (Van Eeden 2014). Understanding the extra-human reservoirs of these viruses is still essential for figuring out the epidemiology of these zoonotic diseases and potential prophylactic measures. The biological characteristics of the pathogen determine whether it will develop to transmit from person to person. The formation of new diseases can be seen as an evolutionary reaction to the environmental conditions (Gluckman et al. 2007).

Changes brought on by anthropogenic factors include modifications in using agricultural techniques, or, as well as climate change. In order to characterize infectious agents, several methodologies are employed (Ugochukwu et al. 2022). These can be broken down into methods based on direct analysis of microbial protein sequences. Fig. 1 highlights the role of wild animals in transmission and amplification of zoonotic agents.

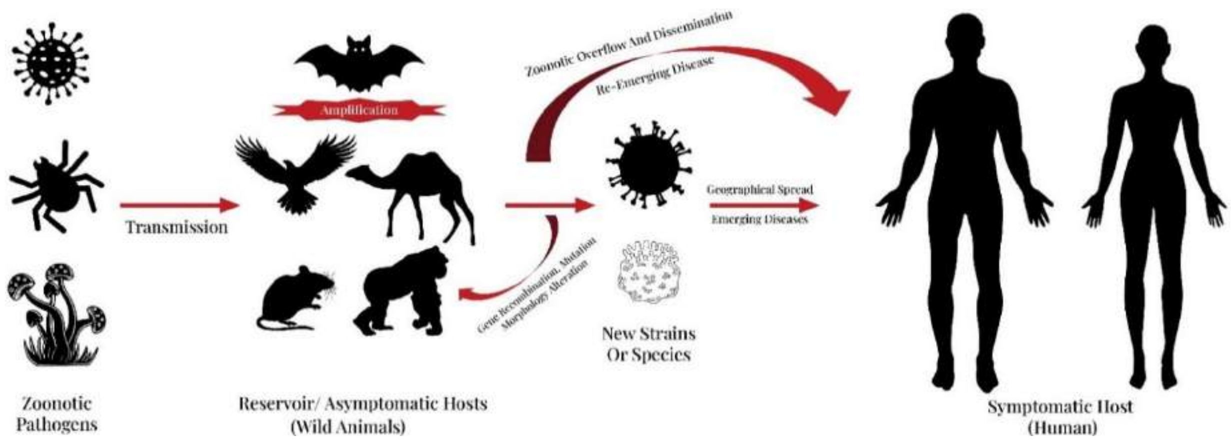

Fig 1: The involvement of the wild animals in the transmission and amplification of etiological agents of emerging and re- emerging zoonosis (Mehmood et al. 2023).

Molecular biology methods are increasingly being used in small animal veterinary care to diagnose infectious diseases. Understanding of infectious disease agents has improved because of techniques like polymerase chain reaction (PCR), Real time PCR, Restriction fragment length polymorphism (RFLP), many of which were created initially for research objectives only. As a result, the diagnostic characterization of these quantitative assays was quickly understood, among these, some are now used to screen for infections in pets and domestic animals (Sellon 2003). Molecular biology approaches rely on the biochemical properties of nucleic acids, which are further determined by their sequencing patterns. The capacity of nucleic acid sequences to bind to one another and produce double-stranded nucleic acid moieties, or denaturation, is influenced by the nucleotide makeup of nucleic acids (Sellon 2003). Denaturation is the separation of the DNA's two identical strands. The sequence of nucleotides also affects the characteristics of hybridization and determines how susceptible nucleic acids are to be "cut" by restriction enzymes at a particular place in the nucleic acids (Toccafondi 2022).

1.2. IMPORTANT ZOONOTIC DISEASES AND THEIR TRANSMISSION

1.2.1. PET ASSOCIATED TRANSMISSION

Dogs are the most common pets around which can disseminate zoonotic disease. Rabies, ringworms, Campylobacteriosis, Salmonellosis and Leptospirosis are the most common diseases which can spread through dogs. The rabies virus is associated with an infectious viral agent, and the rabies is communicated by the bite or scratch of an infected animal, usually a dog or a bat.
Cats are also associated with the spread of zoonotic diseases like Toxoplasmosis, Round worm and ring worm infections and Cat Scratch disease. Cat-scratch disease is caused by the infection of *Bartonella henselae*. Although the illness is mostly spread from cat to cat, but sometimes can also be spread by fleas and ticks, which can ultimately infect humans.

1.3. BIRD ASSOCIATED TRANSMISSION

The illness, which are mostly spread by infected birds to people through contact, are caused by the Psittacosis also called parrot fever and avian influenza virus and its several variants. Both in established and emerging nations, populations of birds like canaries, finches, sparrows, parrots, and parakeets are growing and these zoonotic diseases are being more prevalent. The majority of zoonotic viruses, which transmit by direct contact and arthropods, are also capable of being carried by these game and ornamental birds. The chickenpox virus, the Newcastle disease virus, *Coxiella burnetii, Coxiella psittaci, Salmonella spp, Listeria monocytogenes, Erysipelothrix rhusiopathiae, and Mycobacterium spp*. are some infectious agents that are present.

1.4. FOOD-ASSOCIATED ZOONOTIC DISEASES

The zoonosis that occurs through the consumption of undercooked meat, improperly boiled milk, and the handling of infected animals without proper protection or taking precautionary measures are included in food-borne zoonosis. *Salmonella spp*. *(Salmonella enterica serovar Enteritidis), Campylobacter spp., Shiga toxin-producing Escherichia coli (STEC)*, and hepatitis E virus are typical food-associated zoonotic diseases. 90% of bacteria-related food-borne infections are caused by *Salmonella spp*. and *Campylobacter spp.* All domesticated animals, including poultry, have the potential to harbor germs that cause food-borne diseases.

1.5. ENVIRONMENT-ASSOCIATED ZOONOTIC DISEASES

The coronavirus illness (COVID-19) produced by the severe acute respiratory syndrome coronavirus 2 (*SARS-CoV-2*) has affected humanity and has a huge impact on human existence worldwide. This zoonotic pandemic seems to be the worst disease epidemic recently (Mishra et al. 2021). The expanding human population and anthropogenic activities, which are also closely connected to the current and other recent zoonotic disease epidemics, have terribly harmed the ecosystem. Although the causes of zoonotic pandemics vary, most contributing environmental factors include fragmentation of the living environment, deforestation of habitat, loss of biodiversity, intensive livestock farming, unchecked urbanization, pollution increase, drastic changes in climate, and the trade and consumption of bush meat are among the main factors that contribute to their emergence and spread (Perera 2021).

As seen in the *West Nile virus* (WNV) in North America, where an adaptive mutation resulting in temperature variability efficiently propagates the virus at elevated temperatures. The climate-driven changes such as precipitation, dust, ozone disruption and temperature may bring genetic instability in the evolutionary structure of viruses (Kruse et al. 2004). Studying MERS-CoV revealed that between April and August, 56.1% of positive cases occurred, and that conditions that were favorable to the virus' survivability included high temperatures, high UV indices, moderate wind speeds, and low relative humidity (Altamimi and Ahmed 2020).
It was discovered that, in the instance of H5N1 transmission, environmental parameters like temperature, relative humidity, and wind speed altered migratory bird behavior, increasing avian flu outbreaks in particular locations of Egypt (Allan 2017).

1.6. WILDLIFE ASSOCIATED ZOONOSIS

Dermatophytosis, sometimes known as "ringworm," is a fungal skin disorder that causes scaly, circular areas of hair loss in both humans and animals (Lunestad et al. 2007).
External parasites like fleas, ticks, lice, and mites can occasionally be spread by handling infected bedding or being near an infected animal. Leptospirosis and tularemia, which are bacterial diseases that plague mice and rabbits in the wild, are sporadic infections that wild predators who hunt or drink contaminated water may occasionally get (Lunestad et al. 2007).

1.7. WATER ASSOCIATED ZOONOTIC DISEASES

Many protozoan and helminth parasites are transmitted through the environment, with water, soil, and food playing a particularly important role. In addition to being substantial contributors to protozoan waterborne infections, *Cryptosporidium spp.* and *Giardia spp.* are major causes of diarrheal sickness in humans globally. Examples of zoonosis that spread through watery channels include *SARS, E. coli* O157:H7, and *Salmonella* (Blancou 2003).
In areas with water scarcity, overhead and subsurface storage tanks are crucial and a mandatory way of water storage. Water is kept in overhead tanks and pumped from the tanks into residences as needed to guarantee a constant residential supply. The growth of *N. fowleri* amebae in tap water and water from mosques may have been aided by water storage in tanks. Summertime temperatures can exceed 44°C, which raises the water temperature in the above tanks. We discovered water with temperatures as high as 34°C, which may help *N. fowleri* amebae grow into infectious forms. The cause of infection, *N. fowleri* multiplication in storage tanks, is most likely explained by slime, filth, and high ambient temperatures (Yoder et al. 2012).

1.8. COMMONLY USED MOLECULAR ASSAYS FOR DETECTING INFECTIOUS AGENTS

Some important and commonly used purely molecular or partially molecular methods are mentioned below.

1.9. PCR (POLYMERASE CHAIN REACTION)

PCR and RT-PCR are the molecular diagnostic methods most frequently employed to identify infectious diseases (Mullis and Faloona 1987). The PCR is used to identify DNA initially, making it particularly helpful for detecting infectious agents that employ DNA as their main genetic component to detect infectious agents, including bacteria and viruses (Fig. 2). In case of these viruses, RNA could be used as their major genetic material and cannot be recognized by end-point PCR. For this purpose, reverse transcription (RT) can be used to create a copy of the infectious agent's DNA, which is called cDNA (Mullis 1990). Reverse transcriptase encourages the development of a DNA molecule from an RNA template, in contrast to transcription, which typically creates messenger RNA from a DNA template. The entire process is known as RT-PCR. A PCR may be performed after the creation of cDNA (Condron et al. 2013).

1.10. RESTRICTION FRAGMENT LENGTH POLYMORPHISM (RFLP)

Restriction sites provide restriction enzymes with the ability to "cut" DNA. Because DNA nucleotide sequences specify the restriction site that is "fetched" by a certain restriction enzyme, each restriction enzyme detects and cuts at a unique nucleotide sequence (Miller et al. 1994). For a given restriction enzyme, which is used to cut DNA, several restriction sites may exist inside a specific DNA segment from a certain human or organism. It is a known fact that when restriction enzymes are employed to cut DNA that has been obtained from an organism and that part of DNA is then placed and visualized via gel electrophoresis. Differences in fragment lengths, or polymorphisms, are caused by differences in DNA sequence between the restriction sites. Variations in the restriction fragment lengths during gel electrophoresis influence the migratory properties of the fragments, allowing comparison between species (Huang et al. 2015). The more restriction enzymes that are employed to cut a certain DNA sample, the more patterns there may be to investigate. Restriction fragment length polymorphisms (RFLP) are frequently unique to certain individuals or populations of closely related species, which is why RFLP

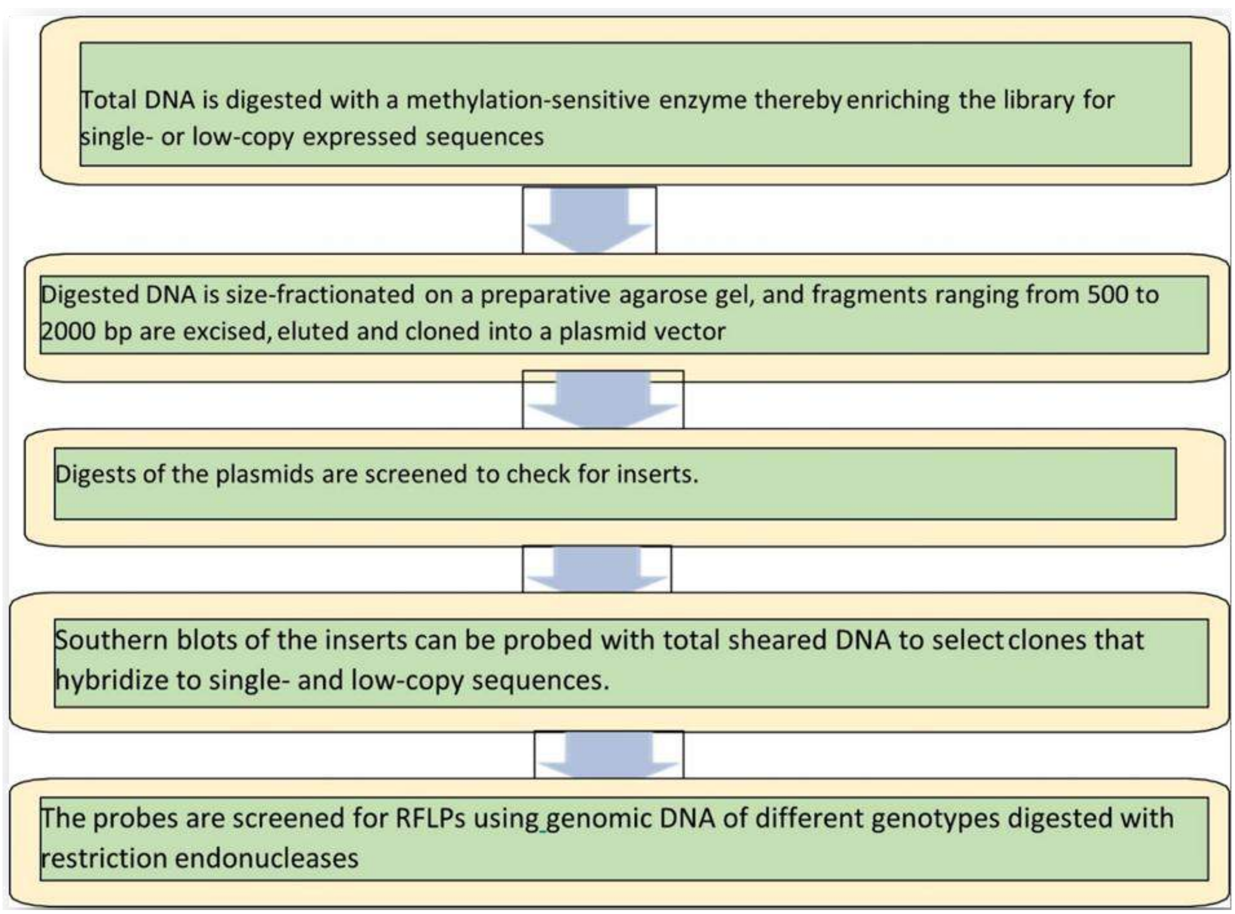

Fig 2: The step-by-step process of the Polymerase Chain Reaction.

analysis is sometime also known as "DNA fingerprinting" (Allen et al. 1990). Comparing variations between an unknown and known pattern can help identify novel or distinct organisms linked to the identified agent (Masiga and Turner 2004). RFLP analysis can be used to precisely identify the amplicon produced by the PCR-based techniques (Alevizos et al. 2001). However, RFLPs have been proven to be less effective as a solo diagnostic technique for detecting infectious illnesses in small animals when compared to PCR-based testing. RFLP is a very effective tool for detecting how closely related or distantly related pathogenic organisms are in a particular animal or group of animals (Walter et al. 2012). The presence of different pathogens in populations, or in the case of chronic illnesses, even within the same person, maybe discernible when RFLP patterns are compared. *Bartonella henselae* variations were found in cats with chronic infection using RFLP analysis; this discovery may point to a possible source of persistent infection (Huang et al. 2015). Genome mapping, forensics, paternity testing, genetic disease diagnosis, and variation analysis are common uses for RFLP probes.

1.11. ELISA (ENZYME-LINKED IMMUNOSORBENT ASSAY)

The catalysis capabilities of enzymes are used in enzyme immunoassays (EIAs) to identify and measure immunological responses. Clinical research makes use of the heterogeneous EIA method known as the enzyme-linked immunosorbent test (ELISA) (Aydin 2015). In this kind of assay, a reaction component is covalently or nonspecifically attached to the surface of a solid phase, such a microtiter well. The separation of bound and free-labeled reactants is made easier by this connection (Alhajj and Farhana 2023).

Adding a little quantity of sample or calibrator containing the target antigen (Ag) and letting it interact with a solid-phase antibody (Ab) is the most common application of the ELISA method. After washing, an enzyme-labeled antibody is added to make a solid-phase Ab-Ag-Ab enzyme "sandwich". Specific antibodies in a sample may also be evaluated using an ELISA technique, which binds an antigen rather than an antibody to a solid phase. The second reagent is an antibody that has been enzyme- labeled and is specific to the analyte (Shah and Maghsoudlou 2016). ELISA methods have also been extensively used to identify virus- and autoantigen-specific antibodies in serum or whole blood.

A 96-well polystyrene plate with a protein-binding layer is the most typical form used for ELISA testing (Alhajj and Farhana 2023). The test requires a substrate or chromogen, analyte or antigen, coating antibody or antigen, buffer, washing, and primary and/or secondary detection antibodies, depending on the kind of ELISA to be performed (Baker 1995). An antibody that binds to the target protein with precision is used for the primary detection. A secondary detection antibody connects an enzyme-conjugated primary antibody to an enzyme-conjugated primary antibody (Alhajj and Farhana 2023). Four main general steps are performed in an ELISA immunoassay. (i) Coating (with either antigen or antibody). (ii) Blocking (typically with the addition of bovine serum albumin (iii) Detection. (iv) Final reading of detected antigen or antibody.

1.12. CRISPR-CAS

Approximately 50% of bacterial and 87% of archaeal genomes have so far been identified by different molecular techniques (Cui et al. 2017). In 1987, researchers found the repetitive 29-nt and 32-nt regions in the *E. coli* genome. In 2005, it was discovered that the CRISPR-Cas system is a component of an adaptive immune system in bacteria or archaea (Mojica et al. 2005). After the first invasion by the invader, the host cell memorizes the genetic composition of alien species by integrating small amounts of the invader's foreign gene into its own genome. Some diagnostic techniques based on the CRISPR-Cas system only use the binding qualities of the target's sequence without depending on the subsequent cleavage activity, despite the fact that the primary goal of the CRISPR-Cas system is to cleave the target gene while also searching for a target based on the target's sequence (Guk et al. 2017). The majority of these techniques employ deactivated Cas9 (dCas9) proteins, which are proteins that have lost the capacity to break dsDNA due to two amino acid changes (Guk et al. 2017). The CRISPR-Cas system has developed into an exciting and effective diagnostic tool by using both the sequence-specific target binding and cleavage and the target-specific trans-cleavage. The trans-cleavage activity makes the CRISPR-Cas complex more appealing and improves detection sensitivity since it may attach to a target several times. Since the CRISPR-Cas system primarily targets nucleic acids, several nucleic acids associated with diseases have been successfully discovered and analyzed. These include methylation DNA, mRNA, miRNA, SNPs, and genomic DNA.

1.13. DETECTION OF DISEASES CAUSED BY MAJOR ZOONOTIC AND LIVESTOCK PATHOGENS: GENOTYPING METHODS

In order to subtype organisms beyond phenotypic categories, genotyping techniques are especially applied. As DNA is the starting material, these molecular biology techniques are often frequently referred to as "DNA fingerprinting." In addition to epidemiology, these techniques are also employed in forensic medicine and evolutionary biology research. Compared to phenotyping procedures, genotyping techniques frequently offer better discriminating power. These methods are also anticipated to have improved throughput, repeatability, and type ability, albeit, in some circumstances, these expectations might not always be met (Tasie and Gebreyes 2020). Amplification, restriction digestion, hybridization, and/or sequencing are some of the main molecular technologies that are frequently combined in genotyping procedures. Certain genotyping techniques are applied to zoonotic and animal illnesses. A list of the most popular techniques in veterinary medicine may be found. Each genotyping technique has distinct properties depending on the size of the genome it may be applied to, the primary molecular approaches it uses, the complexity level, and other elements (Tasie and Gebreyes 2020).

1.14. PFGE

PFGE, a macro restriction genotyping method that has been available since 1984, is one of the most widely used methods for detecting bacteria linked with cattle, particularly foodborne diseases (Schwartz and Cantor 1984). This technique was initially used to describe the fungal *Saccharomyces cerevisiae*. The basic idea behind this technique is to use a rare-cutter restriction endonuclease to perform restriction digestion on an intact genome.

1.15. RAPD (Randomly amplified polymorphic DNA)

Another genotyping technique that is often used in research on zoonotic diseases and cattle is (RAPD), also known as randomly primed PCR. The approach was initially explained in 1990 (Williams et al. 1990). As its name suggests, RAPD aims to amplify random targets located throughout an organism's DNA. Even without prior knowledge of the nucleic acid sequence of the organism being researched, this method may be used very easily. This technique is among the least expensive to set up in laboratories and is straightforward to teach (Williams et al. 1990).

1.16. REP- PCR

Comparatively less commonly used than the methods mentioned above, repetitive palindromic PCR (REP-PCR) is a subtyping approach, based on recognition of repetitive elements found in a variety of eukaryotic and prokaryotic genomes. REP-PCR was initially reported as a technique used in infectious disease research based on repetitive elements published in 1984 (Williams et al. 1990).

1.17. AFLP

This method has been used to map the genomes of eukaryotic organisms. A modified version of the AFLP has been used in several infectious disease research with relevance to food safety and zoonotic risk. The AFLP test works by amplifying genomic regions that have been digested by two restriction enzymes, one common cutter (commonly MseI) and one unusual cutter (often EcoRI).

Therefore, this method may be used to amplify a random fraction of DNA fragments that are characteristic of the genome (Tasie and Gebreyes 2020). The most recent addition to the genotyping techniques currently gaining popularity for epidemiologic research is whole-genome sequencing (WGS). The technique is only sometimes utilized in highly developed nations and only in situations of high value food-borne illness outbreaks for trade enforcement and other regulatory objectives, therefore its utility in veterinary epidemiology is still in its infancy (Tasie and Gebreyes 2020). These applications may be seen, for instance, in the investigation into the *Salmonella serovar Bareilly* outbreaks in two states of the United States that were linked to scraped tuna imported from India (Riess et al. 2016) and the *E. coli* O104:H4 epidemic in Germany (Schiebahn et al. 2015).

1.18. VIRAL ZOONOTIC DISEASES: MOLECULAR DIAGNOSIS

1.18.1. INFLUENZA VIRUS

To ascertain if the influenza A virus is present in the samples or not, preliminary influenza screening tests are carried out. Depending on the animal species being tested, specific H and N subtyping is carried out if a test for the type A influenza virus is positive. All samples that test positive for the type A influenza virus undergo testing for the H5 and H7 subtypes of the influenza virus, which can evolve into viruses that are particularly lethal in poultry. The OIE-approved avian influenza reference laboratories, such as the National Veterinary Service Laboratories of the USDA conduct confirmation testing on those H5- or H7-positive sample (Tasie and Gebreyes 2020).

A common technique for identifying influenza is (RRT-PCR), which focuses on the (M) gene, is a virus. The positive samples are subsequently subjected to the H5 and H7 tests and a few RRT-PCRs for selected N subtypes. Additionally, partial genome sequencing and/or WGS are used as confirmatory testing. To compare with previously identified HPAI virus sequences, the H protein gene is often partly sequenced first. If the genetic sequence matches one, the sample is assumed to contain an established HPAI virus and is sent to the OIE. Thanks to recent developments in sequencing technology, epidemiologic surveillance typically employs WGS in combination with phylogenetic analysis (Tasie and Gebreyes 2020).

1.19. HPAI VIRUS (HIGHLY PATHOGENIC AVIAN INFLUENZA VIRUS)

For advanced examination of influenza virus, phylogenetic analysis based on partial- or full-genome sequencing is now the method of choice. As the two main surface proteins, H and N, control the pathogenicity, responsiveness to vaccination, and zoonotic potential of avian influenza viruses in addition to other crucial characteristics (Suh et al. 1999). As a result, the H gene and, to a lesser extent, the N gene, have received the greatest focus throughout sequencing. However, more full-genome sequencing is being done as a result of recent developments in sequencing technology, a decline in sequencing costs, and the comparatively modest size of viral genomes (approximately 14,000 nucleotides) (Wu et al. 2011). Comprehension of the adaptability or interspecies transmission of the H5N1 virus has increased thanks to genetic research of particular amino acid changes in the viral genome (Kanekiyo et al. 2013). Editing the viral genome became possible with the development of the influenza virus's reverse genetics system, which produces a virus from a full-length cDNA copy of the viral genome.

1.20. IBDV (INFECTIOUS BURSAL DISEASE VIRUS)

IBDV has two double-stranded RNA genomic sections (Dobos et al. 1979). Young chicks' immune systems are weakened when this virus infects them (Giambrone et al. 1978). Despite the fact that there are two known serotypes, only serotype 1 can be dangerous. It is essential to create a molecular diagnostic test that can only identify viruses of serotype 1 as a result. Additionally, (Ismail et al. 1990) has shown that immunizing hens against just one antigenic subtype of serotype 1 viruses fully protects them from immunizing against a second antigenic subtype. It is known that the hypervariable sequence region of the capsid surface protein VP2 controls the antigenic subtype of IBDV. By amplifying the VP2 variable region using RT-PCR, these viruses can be found.

1.21. TICK-BORNE DISEASES: MOLECULAR DIAGNOSIS

Zoonotic and veterinary diseases caused by ticks pose a severe hazard to the health of humans and/or animals (Merle et al. 2014). Domestic dogs, or *Canis familiaris*, are maintained as pets all over the world and cohabitate with people in homes where they serve as hosts for diseased ticks that could be taken inside (Sellon 2003). These ticks might be dangerous to our health if a child, an elderly person, or anyone with compromised immune system is attacked (Dantas-Torres and Otranto 2014). In order to prevent and manage zoonotic disorders, it is essential to study neglected zoonotic diseases in companion dogs and the vectors that spread infections. This is because dogs are often considered to be "sentinels" for diseases that may affect humans in an endemic environment (Cardoso et al. 2016). The tick-borne diseases *brucellosis, rickettsiosis, anaplasmosis,* and ehrlichiosis are all thought to be re-emerging around the globe and are all caused by various species of the genus *Brucella* and certain members of the order *Rickettsiales (Rickettsia, Anaplasma, and Ehrlichia)*, (Zintl et al. 2003). There have been at least 13 new human infections linked to Rickettsiales that have been transmitted by ticks in mainland China during the past 30 years. Since its first description, *Anaplasma ovis* has been found in China and other countries (Song et al. 2018).

A. ovis has previously been found in ticks or blood samples from cattle and wild animals (Wang et al. 2020). Only *Rh. turanicus* from pet dogs were used in this investigation to screen for A. ovis, and all other blood samples from pet dogs came back negative. The prospect that ticks, dogs, and even people might get A. ovis is raised by a report that an isolate from a stray dog in Henan was shown to be highly similar to the strain discovered in a human in Cyprus (Cui et al. 2017).

1.22. EMERGING MOLECULAR DIAGNOSTIC TECHNIQUES

1.22.1. METAGENOMICS

Another way to identify genomic sequences from various microbial communities is through metagenomics. These techniques have been used for research and diagnostic purposes. Over the last few decades, metagenomics-based methodologies have been developed in an effort to assess, analyze, and

utilize biodiversity across a wide range of various environmental niches (Karesh et al. 2012). Even with diagnostic capabilities, metagenomics methods have grown in prominence in clinical trials. Through the isolation of microorganisms and the acquisition of axenic cultures, conventional diagnostic (cultivation-dependent techniques) detects pathogen species, strains, and serotypes of interest in independent colonies (Karesh et al. 2012). Because of this, metagenomics is used to study microbiomes and viromes, which cannot be cultivated in a laboratory setting. This enables diagnostic analysis of pathogen bacteria using culture-independent approaches (Quiroz-Castañeda et al. 2018).
The first crucial stage in the metagenomics study is the extraction of high-quality DNA. When studying microbiomes and virome from human or animal samples, a significant amount of human or animal DNA is frequently recovered (Quiroz-Castañeda et al. 2018). This method was initially created to analyze the microbial genomes found in environmental samples, but in the last 10 years, its use has been expanded to characterize novel infections that affect both humans and animals. Additionally, metagenomics has been utilized to describe microbiomes and virome from various tissues and organisms and has a significant influence on public health (Quiroz-Castañeda et al. 2018).
Studies on zoonotic illnesses and animal microbiota are becoming more common thanks to metagenomics and high-throughput sequencing methods. Since cloning techniques are not necessary, these methods produce millions of short sequences reads (about 150 pb) and make analysis easier. To explain the diversity and dynamics of bacterial, viral, and fungal species in tissues and samples taken from various animals, metagenomics is a potent and valuable approach (Gereffi and Sturgeon 2013). Metagenomics has helped characterize the microbiomes in many samples, such as the gastrointestinal tract of various creatures (e.g., feline, canine, human, mouse, and chicken), in addition to the discoveries of viral genomes. These investigations have identified taxonomic groups with zoonotic potential.

1.23. LAMP (LOOP-MEDIATED ISOTHERMAL AMPLIFICATION)

The LAMP method is based on traditional PCR, but unlike that method, it uses a DNA polymerase with high strand displacement activity, four primers that recognize six to eight distinct regions of the target DNA, and results in a stem-loop structure of the DNA that makes it easier to repeat rounds of amplification. By using a DNA-binding dye, such as SYBR green, (Gereffi and Sturgeon 2013) one may identify the release of pyrophosphate that occurs after the synthesis of the target DNA stem-loop. LAMP is more sensitive than traditional PCR since it can produce up to 109 copies of products in less than an hour (Rule et al. 2021).

1.24. NASBA AND TMA (NUCLEIC ACID SEQUENCE-BASED AMPLIFICATION)

Unlike PCR, isothermal amplification techniques like NASBA and TMA often use a variety of mRNAs as the target sequence. These methods are the industry standard for gonorrhea and chlamydial infection diagnosis. Another isothermal amplification technique is HDA, (Gerace et al. 2022) which divides dsDNA into two single strands that can be used as a template for fresh DNA synthesis.

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Disease Biography Advances and Constraints Using Ecological Niche Modelling

30

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ABSTACT

Ecological Niche Modelling (ENM) has emerged as a powerful tool in understanding the dynamics of disease spread and providing valuable insights into disease biographies. This innovative approach integrates ecological and geographical data to model the environmental conditions suitable for the existence and transmission of pathogens. The application of ENM in disease research has yielded significant advances in our comprehension of disease patterns, facilitating better preparedness and response strategies. One notable advance lies in the ability of ENM to predict the geographical distribution of disease vectors and reservoirs, aiding in the identification of high-risk areas for transmission. This predictive capacity is crucial for public health interventions, enabling targeted surveillance, timely resource allocation, and effective preventive measures. Additionally, ENM contributes to our understanding of how environmental factors, such as climate change and land use, influence disease dynamics, allowing for adaptive strategies to mitigate potential outbreaks. However, despite its considerable contributions, ENM faces certain constraints. Limitations arise from the reliance on accurate and comprehensive ecological data, which may be challenging to obtain, especially in resource-limited regions. Model uncertainties, the dynamic nature of ecosystems, and the complex interplay of various factors influencing disease transmission further contribute to the challenges. In conclusion, Disease Biography Advances and Constraints Using Ecological Niche Modelling highlight the pivotal role of ENM in enhancing our understanding of disease ecology. While it provides invaluable insights for disease management and control, addressing data limitations and refining models will be essential to harness the full potential of this approach in combating emerging and re-emerging infectious diseases.

Keywords: Disease biography, Ecology, Environment, Niche, Public health.

CITATION

Ijaz M, Bhatti FE, Liaqat C, Rizvi SBH, Fatima N, Tariq S, Tahira S, Khan R, Rehman A and Jabbar A, 2023. Disease Biography Advances and Constraints Using Ecological Niche Modelling. In: Khan A, Abbas RZ, Hassan MF, Aguilar-Marcelino L, Saeed NM and Mohsin M (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 400-410. https://doi.org/10.47278/book.zoon/2023.030

CHAPTER HISTORY Received: 07-Jan-2023 Revised: 09-May-2023 Accepted: 15-June-2023

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1. INTRODUCTION

Epidemiology, the study of disease prevalence and its factors in communities, has contributed substantially to improvements in public health. Traditional epidemiological methods, however, could ignore how complex and unique diseases are. A revolutionary approach, called as "disease biography," has recently developed as a new paradigm in epidemiology. Its goal is to revolutionize our understanding of illnesses by evaluating their dynamic and individual trajectories over the time. This chapter examines the fundamental ideas and implications of disease biography, emphasizing how it has the potential to transform an epidemiological study and enhance patient outcomes (Cooter and Stein 2013).

1.1. PRINCIPLES OF DISEASE BIOGRAPHY

1.1.1. LONGITUDINAL PERSPECTIVE

Disease biographies emphasize the value of longitudinal studies that track people over time in order to capture how diseases change over time. Researchers learn a great deal about the complexity of disease dynamics by examining the onset, progression, and outcomes of an illness over the course of a person's life (Burton-Jeangros et al. 2015).

1.1.2. MULTIFACTORIAL APPROACH

The paradigm acknowledges that a wide range of variables, including as genetic predisposition, lifestyle decisions, environmental exposures, and social determinants of health, have an impact on diseases. The intrinsic variety in disease manifestation is accounted for by disease biography by incorporating these various characteristics into analysis.

1.1.3. LIFE COURSE PERSPECTIVE

In disease biography, a life course perspective is essential because it recognizes that experiences and exposures throughout the formative stages of life might affect future health trajectories. Childhood exposures and prenatal variables, for example, can have long-lasting effects on disease risk and prognosis (Colman and Ataullahjan 2010).

1.2. PERSONALIZED MEDICINE AND PREVENTION

1.2.1. PRECISION MEDICINE

The concept of personalized medicine, in which treatments and interventions are adapted to the unique characteristics of each patient, is consistent with disease biography. Clinicians can design targeted medicines with increased efficacy and fewer side effects by taking into account each patient's particular disease biography (Kulkova et al. 2023).

1.2.2. PREVENTIVE STRATEGIES

Personalized preventive measures can also be influenced by knowing a person's disease biography. Public health interventions can be created to successfully slow the onset or course of disease by identifying early risk factors and high-risk times (Kulkova et al. 2023).

1.3. CHALLENGES AND FUTURE DIRECTIONS

1.3.1. DATA INTEGRATION

Implementing disease biography necessitates combining several data sources, including genetic data, socioeconomic characteristics, environmental data, and electronic health records. Realizing the full potential of this paradigm presents problems to create comprehensive data infrastructure and safe sharing platforms (Gligorijević and Pržulj 2015).

1.3.2. ETHICAL CONSIDERATIONS

In particular, data privacy and informed consent require careful consideration in longitudinal investigations. In disease biography research, balancing the advantages of individualized insights with potential hazards is crucial.

1.3.3. INTERDISCIPLINARY COLLABORATION

Collaboration between epidemiologists, doctors, geneticists, bio-statisticians, and social scientists are essential to the success of disease biographies. Innovative approaches and holistic viewpoints can result from an interdisciplinary approach (Bendowska and Baum 2023).

2. ECOLOGICAL NICHE OF PARASITES FROM DISEASE REPORTS TO DISEASE MAPS

The term "ecological niche" describes a species' place and function in its environment, including its interactions with other creatures and the physical conditions needed for it to thrive and procreate. Because they depend on their host for food and dwell inside or on them, parasites have distinct ecological niches (Poulin and Morand 2000).

2.1. PARASITIC DISEASE REPORTS

In order to estimate the number of illnesses, complications, and deaths for ten helminth diseases and toxoplasmosis, the researchers combined data from national estimates of foodborne diseases, systematic reviews (studies that identify all the research on a topic using predefined criteria), national surveillance programs, and other sources. They also calculated the total and regional disability adjusted life years (DALYs) for each condition. A disease's burden is measured by DALYs, which are the disease-related losses of one year of full health due to premature death or disability. In 2010, these illnesses collectively resulted in 48.4 million cases of sickness, 59,724 fatalities, and 8.78 million DALYs. According to the study, contaminated food was responsible for 48% of these parasitic illness cases, which resulted in 6.64 million DALYs. Ascaris infection and toxoplasmosis (12.3 million and 10.3 million cases, respectively) were the most widespread parasite infections transmitted by food. The biggest disease loads were caused by foodborne cysticercosis, trematodes infection, and toxoplasmosis, and the Western Pacific and African regions had the highest burdens of foodborne parasite disease (Torgerson et al. 2015).

2.2. IDENTIFY PARASITIC DISEASES

The history of parasitic disorders today primarily focuses on attempting to comprehend the circumstances that led to the discovery of parasites and their subsequent accusation in the etiology of the disease. Only a few of the most significant parasites, those that cause disease and produce recognizable signs and symptoms, can be discussed in this article (Table 1) diseases and their parasites, while other parasitic infections are briefly described in the chapter (Cox 2004).

2.3. EVOLUTIONARY ECOLOGY OF PARASITES

In many animal lineages, parasites have independently evolved, and they currently make up a sizeable fraction of the diversity of life. In addition to having a profound influence on people and other creatures, they have recently emerged as a potent model system for the study of ecology and evolution,

Table 1: DISEASES AND THEIR PARASITES.

Disease	Parasite
Malaria	Plasmodium spp.
Amoebiasis	Entamoeba histolytica
Sleeping sickness	Trypanosoma brucei gambiense and T.b.rhodesiense
Chagas' disease	Trypanosoma cruzi
Schistosomiasis	Schistosoma spp.
Hookworm	Ancylostoma duodenale and Necator americanus
Lymphatic filariasis	Wuchereria spp, Brugia spp
Loiasis	Loa loa
Onchocerciasis	Onchocerca volvulus
Guinea worm disease	Dracunculus medinensis
Larval cestodiasis	Taenia spp, Echinococcus granulosus

with applications in the field of disease prevention. Robert Poulin offers an evolutionary ecologist's perspective on the biology of parasites in this edition of his influential earlier work, which has been extensively edited and updated. With information from scales ranging from the characteristics of individual parasites to the dynamics of parasite populations and the structure of parasite communities, he presents a thorough synthesis of parasite evolutionary ecology. In order to gain a deeper knowledge of why parasites behave the way they do and give an evolutionary framework for the study of parasite biology, Evolutionary Ecology of Parasites combines theory with practical evidence. The book is a perfect teaching resource for advanced courses on the topic because it provides an up-to-date synthesis of the field. It will also be a priceless resource for researchers looking to advance our understanding of parasite ecology and evolution because it points towards promising directions and establishes a research agenda (Poulin 2011).

3. CURRENT METHODS FOR DISEASE MAPPING

3.1. DISEASE MAPPING

A disease map illustrates and analyzes patterns and risk factors associated with disease distribution. It aids in prevention and management by providing insight into strategies, resource allocation, and interventions.

It enhances public health research and surveillance by detecting outbreaks, monitoring trends, and assessing disparities. Providing insights to make effective decisions is one of the most important functions of disease mapping in policy-making, which facilitates targeted interventions in areas with a high disease burden by allocating resources to those areas. It helps to control and prevent diseases by understanding the geographic distribution of diseases. Disease mapping is an essential tool in public health, aiding in understanding, managing, and mitigating the impact of diseases (Andrew and Lawson 2001).
In this chapter, we will look at the most popular methods of current disease mapping, along with their applications in public health research and interventions. In the area of veterinary epidemiology, model-based geo-statistics and Bayesian techniques are helpful when point data have been acquired using the right study design. In order to examine the risk of dog parasite infection in the city of Naples, 2004–2005, we make use of an example of epidemiological surveillance on urban settings where a two-stage sampling strategy with first stage transects is implemented. To forecast the continuous risk surface of parasite infection on the research region, we did Bayesian kriging and specified Bayesian Gaussian spatial exponential models. We contrasted the findings with the proportion of positive specimens by transect obtained by using hierarchical Bayesian models to areal data. The models' findings agreed with one another, and the Bayesian geostatistical method worked better at spotting places where zoonotic parasitic illnesses can spread. Larger danger areas were generally found along city borders where domestic dogs and wild dogs coexisted and there were less human or municipal barriers (Biggeri et al. 2006).

3.2. METHODS OF DISEASE MAPPING

3.2.1. SPATIAL AGGREGATION

In disease mapping, spatial aggregation is a technique that groups cases or health-related occurrences into geographical units like counties, states, or postal codes in order to analyse disease occurrence. Spatial aggregation enables comparisons and the discovery of disease trends by compiling disease data at various geographical scales (Wakefield 2007; Jeffery et al. 2014). For example, suppose a study aims to understand the prevalence of infectious disease across various states of a country. Researchers can visualize and compare disease burden by averaging the number of cases reported in each state, highlighting areas with a greater incidence or prevalence.

3.2.2. KERNEL DENSITY ESTIMATION

The effective disease mapping methodology known as kernel density estimation makes use of statistical methods to calculate the spatial distribution of disease cases based on their geographic coordinates. It produces a continuous surface that depicts the density of disease occurrences, enabling the detection of regions with dense populations of cases, often known as disease hotspots (Cai et al. 2012). For example, think of a study that looks at the prevalence of a disease spread by mosquitoes in a particular area. By compiling the geographic coordinates of disease cases, kernel density estimation can create a smooth density surface that depicts regions with a high density of cases, indicating probable hotspots where the disease is more frequent.

3.2.3. CLUSTER DETECTION

Cluster detection is a disease mapping technique that locates statistically significant clusters of disease cases. In order to locate regional clusters and identify epidemics, it analyses observed and anticipated case counts in a specified geographic area (Aamodt et al. 2006). For instance, take a study on the prevalence of cancer in a specific area. With the use of cluster identification, scientists may pinpoint regions where the observed number of cancer cases is noticeably greater than predicted. To learn about probable risk factors or environmental exposures causing the greater disease incidence, more research can be done on these identified clusters. In order to address the heightened cancer risk in those particular places, this knowledge supports targeted public health interventions, resource allocation, and surveillance efforts.

3.2.4. GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

Geographical information systems (GIS) combine spatial data with information about diseases to allow for sophisticated analysis and visualisation. GIS investigates relationships and risk variables by superimposing disease data on spatial layers like demographics, environment, or medical facilities. For example, in a study on the distribution of a vector-borne disease, GIS can overlay disease cases onto a map showing the locations of mosquito breeding sites, climate data, and human population density. By visually analyzing this spatial context, researchers can identify areas where high disease prevalence coincides with specific environmental conditions or population characteristics. This information helps in understanding the underlying determinants of disease patterns (Murad and Khashoggi 2020).

3.2.5. BAYESIAN DISEASE MAPPING

Bayesian Disease Mapping is an advanced method in disease mapping that employs Bayesian statistical techniques to estimate disease rates or prevalence at unobserved locations. This method produces more reliable estimates, particularly when data are scarce, by combining disease data with prior knowledge and assumptions (MacNab 2022). For example, it can be used in a study on the prevalence of a rare disease to estimate disease rates in areas with sparse data by combining existing data from nearby regions with previous knowledge of disease patterns. Bayesian approaches produce detailed disease risk maps that show regions with a higher or lower disease burden by taking spatial interdependence and the estimation process' uncertainty into account.

3.2.6. CHOROPLETH MAPPING

Using colour shading or patterns over different geographic areas, choropleth mapping visually depicts disease rates or prevalence. It helps to identify high-risk regions and trends. For example, a choropleth map can employ colour gradients to depict differing rates in different regions of a cancer incidence research. Lighter colours signify lower disease rates, while darker shades imply greater rates. This makes it easier to identify regions in need of targeted interventions (Andrienko et al. 2001).

3.2.7. SPATIO-TEMPORAL MAPPING

Spatio-temporal mapping techniques, such as spatio-temporal clustering or spatio-temporal regression models, are used to analyze disease patterns over both space and time (Coly et al. 2015). The analysis of influenza epidemics across various regions and seasons is an example of spatio-temporal mapping. Researchers can locate regions with shifting sickness rates, spot persistent clusters, and monitor the spread and development of the illness by analysing data on influenza cases over a number of years. Table 2 shows the summary of disease mapping methods with examples.

4. ENVIRONMENTAL VARIABLES USED IN ECOLOGICAL NICHE MODELING

Ecological niche modeling (ENM) is a crucial tool for understanding zoonotic diseases and forecasting species distribution. Researchers can discover disease hotspots and evaluate disease dynamics by using ENM to map potential habitats for species. The increasing number of interactions at the animal-human interface is affecting the emergence and spread of zoonoses worldwide. Protecting human health requires an understanding of zoonotic illnesses in relation to environmental changes. ENM improves our capacity to foresee and control zoonotic outbreaks by examining the interdependence of ecosystems and human-animal interactions.

Understanding the environmental variables is crucial for ecological niche modelling. Environmental variables are factors in the environment that impact the presence and distribution of species. They can be abiotic, such as temperature and precipitation, which affect the physical conditions of an area. Biotic variables, like vegetation and soil, are influenced by living organisms. Evaluating these variables are the main key in predicting the distribution of zoonotic diseases.

4.1. KEY ENVIRONMENTAL VARIABLES IN ECOLOGICAL NICHE MODELING

Key Environmental Variables in ecological niche modeling play a vital role in understanding zoonotic diseases. Temperature, a primary variable, influences species distribution by shaping their physiological tolerances.

Table 2: Summary of Disease Mapping Methods.

Method	Description	Example
Spatial Aggregation	Grouping disease cases into geographical units (counties, states, etc.) to analyze disease occurrence trends (Wakefield 2007; Jeffery et al. 2014).	Understanding infectious disease prevalence across different states in a country (Wakefield 2007; Jeffery et al. 2014).
Kernel Density Estimation	Statistical method estimating the spatial distribution of disease cases based on geographic coordinates (Cai et al. 2012).	Identifying hotspots of a mosquito-borne disease in a specific area (Cai et al. 2012).
Cluster Detection	Technique identifying statistically significant clusters of disease cases (Aamodt et al. 2006).	Identifying regions with significantly higher cancer cases than expected in a specific area (Aamodt et al. 2006).
Geographical Information Systems (GIS)	Integration of spatial data with disease information for analysis and visualization (Murad and Khashoggi 2020).	Overlaying disease cases on a map with mosquito breeding sites and population density (Murad and Khashoggi 2020).
Bayesian Disease Mapping	Bayesian statistical method estimating disease rates or prevalence at unobserved locations (MacNab 2022).	Estimating disease rates in areas with sparse data for a rare disease (MacNab 2022).
Choropleth Mapping	Visual representation of disease rates or prevalence using color shading or patterns (Andrienko et al. 2001).	Depicting varying cancer incidence rates in different regions through color gradients (Andrienko et al. 2001).
Spatio-temporal Mapping	Analyzing disease patterns over space and time using clustering or regression models (Coly et al. 2015).	Studying influenza outbreaks across regions and seasons to monitor spread and progression of the disease (Coly et al. 2015).

Seasonal changes affect migration patterns of disease vectors, impacting disease spread. For example, rising temperatures due to climate change may expand the range of disease-carrying mosquitoes, leading to the spread of vector-borne diseases like malaria and dengue fever (Rupasinghe et al. 2022).

Precipitation affects water availability, influencing habitats and subsequently the occurrence of zoonotic pathogens. For instance, heavy rainfall can create breeding sites for disease vectors, increasing the risk of outbreaks. Land Cover/Land Use types determine the availability of suitable habitats for both disease reservoirs and vectors. Deforestation can alter the ecosystem, bringing humans into closer contact with wild animals, potentially leading to spillover events. For instance, the destruction of forests in Southeast Asia has been linked to the emergence of zoonotic diseases like Nipah virus (Chua et al. 2002).

Altitude affects temperature, thereby influencing zoonotic disease patterns. For example, high-altitude regions may have a reduced prevalence of certain diseases due to lower temperatures and altered ecological conditions.

Soil Type impacts the survival and transmission of zoonotic agents. Certain pathogens thrive in specific soil environments. For instance, soil-transmitted helminths find suitable conditions in moist and warm soils, leading to human infection through contact or ingestion.

Human Disturbance, such as urbanization and agricultural expansion, can modify environments, increasing disease exposure and transmission. For example, encroachment of human settlements into wildlife habitats can lead to increased contact with disease reservoirs, as observed with the spread of Ebola in Africa (Pigott et al. 2016).

Understanding and incorporating these key environmental variables into ecological niche modeling allows researchers to predict disease hotspots, identify high-risk areas, and implement targeted interventions to prevent and control zoonotic diseases.

Scientists utilize Geographic Information Systems (GIS) and remote sensing technologies to acquire spatial information, such as temperature, precipitation, land cover, and altitude. Statistical algorithms are then employed to analyze the data, identifying correlations between environmental variables and zoonotic disease occurrences, aiding in disease prediction and prevention strategies.

4.2. CASE STUDIES

In a study titled "Ecological Niche Modeling of Hantavirus Pulmonary Syndrome in the Southwestern United States," researchers utilized ecological niche modeling to understand the dynamics of hantavirus pulmonary syndrome (HPS) transmission. They found that variables like temperature, precipitation, and vegetation type were critical in predicting disease hotspots. By analyzing these factors, they identified specific regions with a high likelihood of HPS occurrence, aiding in targeted surveillance and preventive measures(Gongóra-Biachi et al. 1999).

In another article "Predicting the Geographical Distribution of Lassa Fever Virus," researchers applied ecological niche modeling to understand Lassa fever dynamics. They identified variables such as temperature, land cover, and proximity to water bodies as critical factors for disease transmission. The study highlighted specific regions in West Africa with suitable environmental conditions for the virus, helping public health authorities focus on prevention and control strategies(Vieth et al. 2007).

Ecological niche modeling has significant implications for zoonotic disease research and control. It allows predicting disease emergence and implementing preventive measures. Future research should focus on integrating climate change scenarios and enhancing data collection methods to improve modeling accuracy and enhance disease preparedness.

5. PARASITE, VECTOR, RESERVOIR: WHAT TO MODEL IN THE DISEASE SYSTEM?

The nature of diseases brought on by unknown or inadequately figured out parasites, such as the Marburg and Ebola viruses, can be better understood through ecological niche modelling (Peterson et al. 2004). The most qualified species to serve as a parasite's repository may need to be identified (e.g., competitor repositories for Tanapox infection in tropical Africa; Monroe et al. 2014), or researchers may need to provide potential vector species within a framework for the disease with obscure vectors (e.g., up-andcomer vectors for Chagas illness in Brazil) (Gurgel-Gonçalves et al. 2012). Thus, the use of parasites, vectors, or reservoir occurrences can be used to calibrate ecological niche models. As they provide a comprehensive overview of the illness system (referred to as "black-box models" in ecological niche modelling), reports of human or animal diseases could also be used for modelling (Peterson 2007).

Once the ecological niche of a parasite has been identified, this knowledge can be used to predict potential habitats for the parasite in the future or outside of its current distribution. Today, spatial epidemiology is using this method, which Peterson and Vieglais first outlined and patent-protected in 2001, to pinpoint possible epidemic hotspots (Peterson et al. 2004). The idea that a parasite's ecological niche will remain stable throughout time underlies the use of it to locate new potential locations for expansion. Simply put, the ecological niche will not change. According to empirical data the ecological niche will remain constant. As a matter of fact, it is accepted that a parasite's specialty does not vary despite virulence variations among strains. For instance, Toxoplasma gondii strains may become more virulent after encountering animals, but the abiotic niche still exists. At large scales, abiotic alterations to ecological niches are uncommon (Soberón and Peterson 2011).

Ecological niche models typically predict that illnesses including cholera (Escobar et al. 2015), leishmaniasis, and malaria would spread more widely under the current trends in climate change. Future study should focus on how parasites conform to novel ecological circumstances and changes in virulence. Experimental investigations spanning a lengthy parasite generational period, greater than "human" time, are required to comprehend Evolution of the parasite niche and modifications to environmental tolerance. Given some taxa's rapid generation times, such investigations might be possible (e.g., bacteria). Risk regions in simulations of ecological niches can be thought of as places with environmental factors that favor the existence of the parasite either its reservoirs or its vectors. When defining risk in terms of the environment, local scale factors might be added as a supplement. Since the "disease-transmission risk" or "parasite-exposure risk" theories are strongly encouraged, even in communities where the parasite is common, disease per se may not exist (i.e., asymptomatic hosts), while the word "disease risk" implies exposure, infection, and symptomatology. For the simple reason that recently discovered parasites might not be harmful, recent parasite discoveries should not be interpreted as a pathogen report. (e.g., Bai et al. 2011). In the same way, the presence of a parasite inside an arthropod does not necessarily mean that the arthropod acts as a vector for the spread of the illness. However, due to similarities (i.e., taxonomical, morphological, behavioral) with known pathogens or vectors in both circumstances, risk may be "assumed" in terms of the probability that the parasite or arthropod may participate in a disease system. Reports on the risk of developing diseases also contain noise. Emergent infections may have gone unnoticed in the past but may now surface because of social factors such as increased monitoring efforts, improved diagnostic techniques, or the introduction influx of a fresh, weak population into the parasite's habitat. In such case, danger was not considered even though the population was always at risk of infection. In conclusion, the term risk needs to be defined in every study because it depends on the context and because its presumptions and characteristics vary depending on the population of interest (Monroe et al. 2014).

Risk may be generalized to mean "No people, no risk" in the context of public health, for instance. Environmental conditions that support the existence of the parasite, either its reservoirs or its vectors are referred to as risk zones in ecological niche models. When defining risk in terms of the environment, local scale factors might be added as a supplement. Since disease per se may not exist in populations where the parasite is abundant (i.e., asymptomatic hosts), we highly recommend the use of the "disease-transmission risk" or "parasite-exposure risk" notions. The term "disease risk" implies exposure, infection, and symptomatology. For the simple reason that recently discovered parasites might not be harmful, recently discovered parasites should not be regarded as a reliable report of a pathogen (Bai et al. 2011). In the same way, arthropod does not necessarily act as a vector for the disease when a parasite is present inside of it. However, in both cases, risk may be "assumed" in terms of the possibility that the parasite or arthropod may take part in a disease system because of similarity (i.e., taxonomical, morphological, behavioural) with identified pathogens or carriers.

Reports on the risk of developing diseases also contain noise. Emergent infections may have gone unnoticed in the past but may now surface because of social factors such as increased monitoring efforts, improved diagnostic techniques, or the introduction influx of a fresh, weak population into the parasite's habitat. In this case, danger was not considered even though the population was always at risk of infection. (Gurgel-Gonçalves et al. 2012).

6. CONCLUSION

Disease biography represents a revolutionary shift in epidemiology, emphasizing the unique, changing, and complex nature of diseases over time. By adopting a longitudinal, multivariate, and life course approach, this paradigm has the potential to transform healthcare practices and public health regulations. Embracing personalized medicine and prevention, disease biography can lead to more effective therapies, improved patient outcomes, and a healthier global community. However, challenges like data integration, ethical considerations, and interdisciplinary collaboration must be addressed for widespread adoption. With continuous research and dedication, disease biography can advance epidemiology towards a more patient-focused and impactful future.

Disease mapping methods like spatial aggregation, kernel density estimation, cluster detection, GIS, Bayesian disease mapping, and choropleth mapping enhance our understanding of disease distribution and inform targeted interventions. They reveal patterns, hotspots, and risk factors, guiding resource allocation and public health strategies. Disease mapping plays a vital role in evidence-based decision-making and improving our understanding of disease dynamics.

In conclusion, ecological niche modeling (ENM) is a powerful tool for understanding and combating zoonotic diseases. It helps predict disease hotspots and identify potential reservoirs, crucial for safeguarding human health amidst increasing human-animal interactions. By integrating climate change scenarios and enhancing data collection, ENM enhances disease preparedness and guides proactive measures. This research provides valuable insights into disease ecology, enabling effective protection of human and animal populations in a changing world. In conclusion, every study must define risk since it varies depending on the setting and because of its presumptions and characteristics vary depending on the population of interest. Risk may be generalized to mean "No people, no risk" in the context of public health.

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Illegal Wildlife Trade and Emergence of New Zoonotic Diseases

31

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ABSTRACT

Illegal wildlife trade is defined as illegal activities including illicit trade, smuggling, poaching, and capturing of protected wildlife species. Illegal wildlife trade (IWT) is one of the common causes of the transmission of zoonotic diseases and also causes economical losses. The products of the illegal wildlife trades can be used as fashion, exotic pets, medicine, and food. Illegal wildlife trade brings wildlife species or their products close to humans and increases the chances for spillover of zoonotic infections. Theses zoonotic infection can be transmitted through hunting, capturing, and consuming wildlife products. During 2021-2022, the outbreak of SARS-CoV-2, also known as COVID-19, causes huge losses. Although the exact origin of the virus is still unknown, many studies suggested that the source of virus transmission exists in the Wuhan wet market (Wuhan seafood market), where bats and other wild animals are closed for sale of the live animal and their products. Similarly, investigations showed that the outbreak of the Ebola virus in 2014 occurred due to consumption of wildlife bushmeat. Thus, to avoid the spillover of zoonotic diseases with IWT strict action should be taken to lower the IWT, which is only possible by improving the documentation methods, improving the transport sectors, discouraging corporate gifting, and taking the help of armed forces at free trade and economic zone. Furthermore, the scientific community should address the general public about the complications associated with IWT and develop innovative methods of digital surveillance.

Key words: Wildlife trade, Illegal, Zoonotic diseases, Surveillance, Ebola virus.

CITATION

Javed Z, Ahmad MZ, Sohoo MUR, Bukhsh A, Sial AUR, Rehman SUR and Zafar MA, 2023. Illegal wildlife trade and emergence of new zoonotic diseases. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 411-422. https://doi.org/10.47278/book.zoon/2023.031

CHAPTER HISTORY Received: 19-April-2023 Revised: 20-June-2023 Accepted: 20-Aug-2023

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1. INTRODUCTION

In May 1998, the US Fish and Wildlife Services and US Customs Service completed Operation Jungle Trade, exposing the illegal trade and smuggling of birds and other wildlife animals. The operation was conducted in the US and other commonwealth countries, including New Zealand, Australia, South Africa, Costa Rica, and other well-developed countries. This operation illustrates illegal wildlife trade throughout the globe (Zimmerman 2003). Unfortunately, the black-market trade of wildlife and wildlife products is widespread in developing countries and developed countries (as exposed by Operation Jungle Trade). Several studies have proved that billions of wildlife species are killed or captured for the legal and illegal wildlife trade. The major purpose of wildlife bartering is to produce goods and services. Human consumes wild animal products in several forms, including medicines, fabrics, meat products, etc. Wildlife birds can also be captured as pets because of their beauty (Dutton et al. 2013; Wyatt et al. 2022).

Climate change, poverty, and human activities, including deforestation and illegal wildlife trade, are the most potential threats to global health and risk factors for emerging infectious diseases. Almost one-quarter of the deaths are caused by infectious diseases, and nearly 60% of these can spread from animal to human (zoonotic diseases). Most zoonotic diseases (71.8%) enter the human community by direct contact with the wildlife animal or by consuming the products of the wildlife. In simple words, the wildlife trade is a potential threat to the spread of Emerging Infectious Diseases (Jones et al. 2008). Multiple examples explain the illegal wildlife trade as a gateway to zoonotic Emerging Infectious diseases (EID) and their devastating effects on the economy and public health. SARS, Ebola, influenza H5N1, and even SARS-CoV-2 have close links with the illegal wildlife trade (Kan et al. 2005). Similarly, many studies link the emergence of HIV infection with the consumption of non-human primates. Before further discussion, let's explain what illegal trade and emerging infectious diseases are.

1.1. ILLEGAL WILDLIFE TRADE

Illegal wildlife trade (IWT) is one of the most serious green or environmental crimes that are defined as "illegal activities including illicit trade, smuggling, poaching, and capturing of the protected wildlife species (flora and fauna) or their products for some financial benefits." Illegal trade is the fourth most common illegal activity and the cause of several zoonotic infections (Wyatt 2009; Mozer and Prost 2023). IWT not only causes the transmission of zoonotic diseases but also causes substantial economic losses by affecting livestock and harming the ecosystem. According to a study, 4 million live birds, 350 million tropical fish, and nearly 40,000 primates are traded throughout the globe annually. The daily flow of these animals in the trading center involves direct contact with humans and dozens of other species, increasing the chances of spreading infectious diseases from animals to humans (Karesh et al. 2005).

1.2. EMERGING INFECTIOUS DISEASES

Emerging Infectious Diseases (EID) are defined as infectious diseases that newly appeared in the population or a rapid increase in already existing diseases. In the past few decades, novel pathogens have affected the human population, and most of these infections are zoonotic. Globalization, environmental changes, and illegal trade have increased the interaction between animals and humans, ultimately leading to the emergence of highly infectious pathogens. IWT acts as a major gateway for the spread of the EID and poses a severe threat to public health, the environment, and economic stability (Rush et al. 2021). IWT acts as a major gateway for the spread of EID and poses a severe threat to public health, the environment, and economic stability.

National Institute of Allergy and Infectious Diseases (NIAID) categorizes the EID into three major groups.

1.2.1. GROUP-A

It includes all pathogens that pose the highest risks to a country's national security and public health. The most common zoonotic diseases in this group include Filoviruses (Ebola viruses) and Anthrax.

1.2.2. GROUP-B

This group includes pathogens that result in moderate morbidity and low mortality rates. Common diseases in this group include brucellosis, glanders, and Psittacosis.

1.2.3. GROUP-C

This group includes emerging pathogens that could have devastating effects in the future. Common examples include Nipah and Hendra viruses, Rabies viruses, and Prions (McArthur 2019).

1.3. SCOPE OF IWT

Unfortunately, there is very limited data available that highlights the global estimate of the species and quantities involved in the IWT. However, IWT is most commonly found in African or developing countries where criminal groups are commonly found and have poor legislation to control IWT. Increased legal wildlife trade is another common factor that facilitates criminal groups to move or sell animals from one country to another. Normally, the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) estimates the global trade of wildlife species. According to CITES, the wildlife trade is a complex process that includes live wildlife species and their products. Tigers, rhinos, elephants, more fantastic apes, and rodents are the most common victims of the IWT (Avis 2017).

According to TRAFFIC Europe, the total legal wildlife trade in 2005 was worth U.S.$22.8 billion. On the other hand, the illegal trade was one-third of the legal trade and was worth U.S.$7.6 to U.S.$8.3 billion. However, according to CITES, this data is not reliable, and illegal trade is more than the estimated values (Engler and Parry-Jones 2007).

Illegal trade is increasing rapidly, and income from the IWT and poaching are considered among the top sources of illegal wealth. Because of the clandestine nature of the IWT, estimating the total number of wildlife traded illegally is very difficult (Weru 2016).

2. IWT MARKET

According to UNODC (United Nations Office on Drugs and Crime), there are five major sectors of the wildlife trade. When illegal wildlife is traded in these sectors, it not only leads to wildlife extinction but also has devastating effects on public health (Korenblik al. 2016).

1. Fashion
2. Exotic pets
3. Medicine
4. Food
5. Decoration, accessories, and jewelry

2.1. FASHION

Wildlife products are used in several fashion items, including fur, leather, purses, and shoes. The consumers of these products can knowingly and unknowingly be consumers of the IWT. Usually, items are prepared by properly processing wildlife products, reducing the chances of zoonotic diseases. However, in IWT, wildlife is roughly processed or transported in unhygienic conditions, which can result in the transmission of pathogens from the products to humans (Mozer and Prost 2023).

2.2. EXOTIC PETS

An exotic pet is any wild animal that isn't normally domesticated, kept, or traded for entertainment. Exotic pet keeping involves birds, reptiles, and to a lesser extent, mammals. The exotic pet trade is a large sector of the IWT and a significant source of hundreds of zoonotic diseases (Mozer and Prost 2023). According to a study, 68% of parrots that are kept at home are illegally traded (Berkunsky et al. 2017). The emergence of lyssaviruses from pet bats, ringworm infections from African pygmy hedgehogs, and salmonellosis from reptiles indicate the importance of exotic pets as a source of zoonotic diseases that have affected humans (Chomel et al. 2007).

2.3. MEDICINE

Several wildlife products are being used to treat, diagnose, and prevent mental and physical illnesses. Usually, traditional medicines are also named according to their origin, such as Traditional Chinese Medicine or Asian traditional medicines, but they are consumed worldwide. According to a study, almost 500 animal species, 50,000 plants, and 700 fungal species are used as medicine globally (Organization 2013). Most of the wildlife species used in traditional medicines are imported illegally, but due to the extinction of many wildlife species, illegal trade is becoming more common. Sparganosis infections from the consumption of medicine made from snakes and frogs is the most common example of infectious disease that has spread by consumption of medicinal products (Wang et al. 2014).

2.4. FOOD

A vast proportion of illegally traded wildlife is consumed as food. Food from wildlife can be further categorized as traditional, luxury, and medicinal food. Although after COVID-19, bushmeat consumption is lowered, many wildlife animals and other species are illegally traded for their meat, especially in Africa (Travis et al. 2011). The increase in bushmeat consumption in the last two decades, especially before COVID-19, resulted in several novel zoonotic diseases. Wildlife can be a reserve host to several zoonotic diseases, e.g., rodents are the reserve host of the monkeypox virus. Consuming the meat of these wild reservoirs can result in zoonotic disease spillover (Wolfe et al. 2005).

2.5. DECORATION, ACCESSORIES, AND JEWELRY

Decoration, accessories, and jewelry are other essential sectors of the IWT. Illegal hunting trophies like antlers, jewelry made from turtle shells, and furniture (elephant footstools) are a few important examples. Ivory is the most common wildlife product that is illegally traded between countries and is most commonly used for decoration (Gao and Clark 2014).

3. HOW DO ZOONOTIC PATHOGENS SPILLOVER FROM IWT?

Wildlife trade is a multi-million-dollar business and worth $6 billion U.S. dollars annually (Warchol 2017). Wildlife trade, both legal and illegal, brings wildlife species close to humans and increases the chances for

spillover of zoonotic infection. Wildlife species contact hunters, marketers, and consumers throughout the trade route. In the case of the legal trade method, most wildlife species and their products are treated with specific SOPs, reducing the chance of infectious zoonotic diseases. However, in the case of IWT, the people involved in the trade are unaware of the zoonotic diseases that threaten the whole community (Hilderink and de Winter 2021).
The risk factors associated with the spillover of zoonotic infection through IWT are divided into four phases.

3.1. PHASE-1 HUNTING, CAPTURING, OR BUTCHERING

Hunting or capturing wildlife is the first phase of the illegal wildlife trade. Hunting techniques have tremendously improved due to advancements in hunting equipment. Hunting or capturing wildlife increases the chances of zoonotic spillover in two ways:

1. Direct contact with the animal's body fluid (e.g., blood), contaminated soil, and water. For example, monkeypox can spread through direct contact with the body fluid of the infected or reservoir host.
2. Hunting and capturing involve direct contact with the animal, increasing the risk of bites and scratches, which can result in an exchange of bodily fluid or infectious agents.

Similarly, butchering also increases the chance of pathogen exposure. Butchers may obtain cuts or injuries that can result in contact with the infected body fluid or pathogens and spread of the disease within the community. HIV, Ebola, and monkeypox are a few most important zoonotic diseases that are thought to be spread by butchering non-human primates (Hilderink and de Winter 2021).

3.2. PHASE-2 TRANSPORTATION

Wildlife traffickers rely on logistics to smuggle contraband by land, air, and sea carriers. The international transport of wildlife plays a crucial role in the global spread of zoonotic pathogens. Transportation of non-live wildlife material lacks proper preservation or proper product cleaning, increasing the chances of food-borne diseases. Similarly, most of the pathogens of zoonotic potential, such as Anthrax, are resistant to environmental changes and cause the spread of the disease to the area where products are imported and consumed (Bengis 1997). However, most of the IWT involves smuggling live wildlife animals, including exotic pets, laboratory animals, and zoo animals. These animals can cause zoonotic spillover by cross-species spillover and the release of the vector. During pre-housing and transportation animals are kept with unnaturally grouped animals at high densities, increasing the flow of pathogens from the reservoir host to other species and possibly spilling over to humans through consumption or direct contact with the infected or reservoir host (Pavlin et al. 2009). Similarly, vectors such as fleas and mosquitoes can be accidentally imported with wildlife, increasing the risk of vector-borne diseases. In countries where an animal health certificate is not required, illegally imported wildlife, possibly carrying novel zoonotic pathogens, can spread the infection to the livestock and put the lives of people at risk (Van Roon et al. 2019).

3.3. PHASE-3 SALE

Informal networks usually perform the sale of IWT products and need to be documented, which increases the spread of new and emerging zoonotic diseases within the human population. History witnesses to several diseases, such as SARS and Avian influenza that spread through the consumption of wildlife meat and direct exposure to illegally traded wild animals (Hilderink and de Winter 2021). The live butchering of the animal is another common risk factor that can increase the spread of zoonotic diseases. Both wild and domestic scavengers consume the remnants and waste of the butchered animal and can act as a reservoir host for novel zoonotic pathogens. The illegal trade of these reservoir hosts increases the risk of zoonotic disease spillover. Similarly, keeping wildlife animals in unhygienic and stressful conditions can increase cross-species disease transmission (Karesh et al. 2005).

3.4. CONSUMPTION AND USE OF WILDLIFE PRODUCTS

The demand for both live and non-live wildlife products has dramatically increased over the past few years. Humans consume wildlife products for several purposes, such as meat, fashion, etc. But most wildlife animals are kept in the zoo and houses as pets. According to a study, Central Africa and the Amazon basin consume nearly 67–164 million kilograms of bushmeat. Thus, the increasing demand for wildlife products encourages IWT, exposure of wildlife to humans, and increases the risk of zoonotic diseases. Consuming fresh bushmeat increases the chances of several viral zoonotic diseases, such as hepatitis and retroviruses. Similarly, the emergence of the HIV and Ebola viruses have close links with the consumption of non-human primates. (Kurpiers et al. 2016).

Increasing illegal wildlife use for medical, ornamental, and apparel can also cause the spread of novel zoonotic pathogens; for example, in the history spread of sparganosis infections from the consumption of medicine made from snakes and frogs (Wang et al. 2014).

Keeping the Illegally traded wildlife as a pet or zoo animal can also spread severe parasitic and viral zoonotic infections. The spread of monkeypox and lyssavirus from pet bats and prairie dogs are the two most common examples (Fooks et al. 2003; Guarner et al. 2004). Infected pets and zoo animals can bring zoonotic pathogens to the caretakers, and biting these infected animals can transmit zoonotic diseases (Fig. 1).

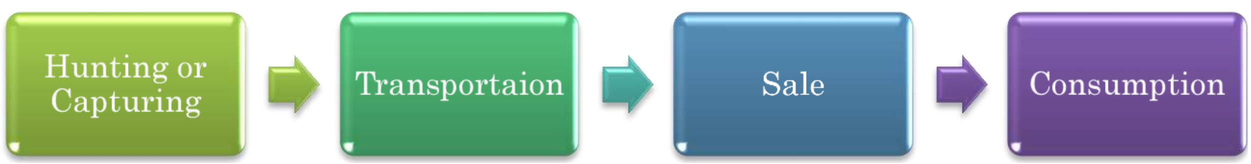

Fig. 1: Zoo animal misuse chain.

4. HISTORY OF HEALTH RISKS ASSOCIATED WITH IWT

The global health crisis originating from the national and international wildlife trade is not novel; over the past two decades, several zoonotic diseases from the live and wet wildlife market have originated. According to a study, the wet market is one of the major sources of creating novel zoonotic diseases. When cages are placed on top of one another, the chances of pathogen transmission increase, sometimes leading to mutation, especially when more than one reservoir host is involved. The meat of illegally traded exotic birds, such as penguins, is rarely inspected, which can affect public health directly and indirectly (by passing pathogens to another wild bird or animal) (Aguirre et al. 2020).

In history, several examples show the devastating effects of the IWT. Zoonotic diseases spread from the IWT affect public health and have led to huge economic losses worldwide.

During 2021-2022, the outbreak of SARS-CoV-2, also known as COVID-19, causes huge losses. Although the exact origin of the virus is still unknown, many studies suggest that the source of virus transmission exists in the Wuhan wet market, where bats and other wild animals are closed for sale of the live animal and their products (Su 2020).

4.1. EBOLA VIRUS OUTBREAK

The Ebola virus outbreak in 2014 was another devastating outbreak faced by West Africa. According to a study, the Ebolavirus outbreak caused more mortalities than all previous emerging viral diseases combined (Judson et al. 2015). Ebolavirus has been isolated from several wildlife animals, including rodents, bats, non-human primates, and duikers. Most of these wildlife animals are used for bushmeat. The Ebolavirus outbreak between 2001 and 2003 was mainly found in people involved in illegally handling the carcasses of gorillas, chimpanzees, and duikers (Mann et al. 2015). The Ebola virus also opens a debate about the illegal trade of wild plants that can transmit the virus to humans indirectly. For example, research has proved that the virus can be transmitted to humans by consuming the fruit eaten by infected bats (Leroy et al. 2007).
The introduction of ectoparasites through IWT also results in the spread of several important zoonotic diseases (Fig. 2). Usually, ectoparasites, especially ticks, are reservoir hosts of several important zoonotic pathogens. For example, Rickettsia spp. and Ehrlichia spp. are found in ticks, parasitizing exotic reptiles and amphibians (Andoh et al. 2015). Unfortunately, very little data is available that highlights the disease risks posed by hundreds of millions of animals traded globally each year. However, few countries implement adequate regulatory measures to quantify the disease risk of pathogen transmission with traded wildlife animals. Still, there is a need for some steps at the international level to minimize zoonotic pathogen pollution (Rosen and Smith 2010).
A few important viral, bacterial, and parasitic zoonotic diseases that emerged from the IWT are described below in table 1 (Bezerra-Santos et al. 2021):

Table 1: Spread of Zoonotic pathogens through wildlife products trade

Pathogens	Wildlife specie	Wildlife product	Type of Trade
Retroviruses (HIV)	Non-human Primates	Bushmeat	International
Herpes virus	Non-human Primates	Bushmeat	International
E. coli	Birds	Live animal, Bushmeat	International
Klebsiella Pneumonia	Birds	Live birds	National
Listeria monocytogenes	Pangolin, red hog	Bushmeat	International
Toxocara spp.	Raccoons	Live animals	National/International
Trichinella spp.	Black bear, grizzly bear	Meat products	International
Cryptosporidium spp.	Non-Human Primates	Live animals	National

5. GLOBAL RESPONSE TO IWT AND ZOONOTIC DISEASES

After the COVID-19 pandemic, the world took the illegal wildlife trade seriously. Many countries, especially China, focus on their policies to discourage the IWT. In April 2021, UNEP's Fifth Science Policy Forum For Biodiversity recommended some steps to prevent future pandemics. The most important recommendations include halting the unregulated use of land, making food systems nature-positive, and supporting ecosystem restoration. It was concluded that human health and nature's health are interlinked, and disturbances in nature can affect human health (King 2021). On 27-31 July 2020, IPBES conducted a workshop participated by 20 experts from all over the world in Germany on Biodiversity and Ecosystems Services. To prevent the transmission of zoonotic diseases, blaming wildlife or domestic animals is distracting. Most of the destruction is caused by human activities, including hunting, deforestation, and consuming wildlife meat and products. Experts only focus on the post-pandemic strategies and never consider on the key factors responsible for the pandemic. Identifying the potential geographical sites of the IWT and environmental and socioeconomic changes is essential for the prevention of future pandemics. Combining the efforts of the health professional, environmental expert, and veterinarian can help government bodies develop a multi-sectoral policy and practice strategy. (Daszak et al. 2020).
Some important steps the international bodies took from 2015 to 2019 are described in the Table 2:

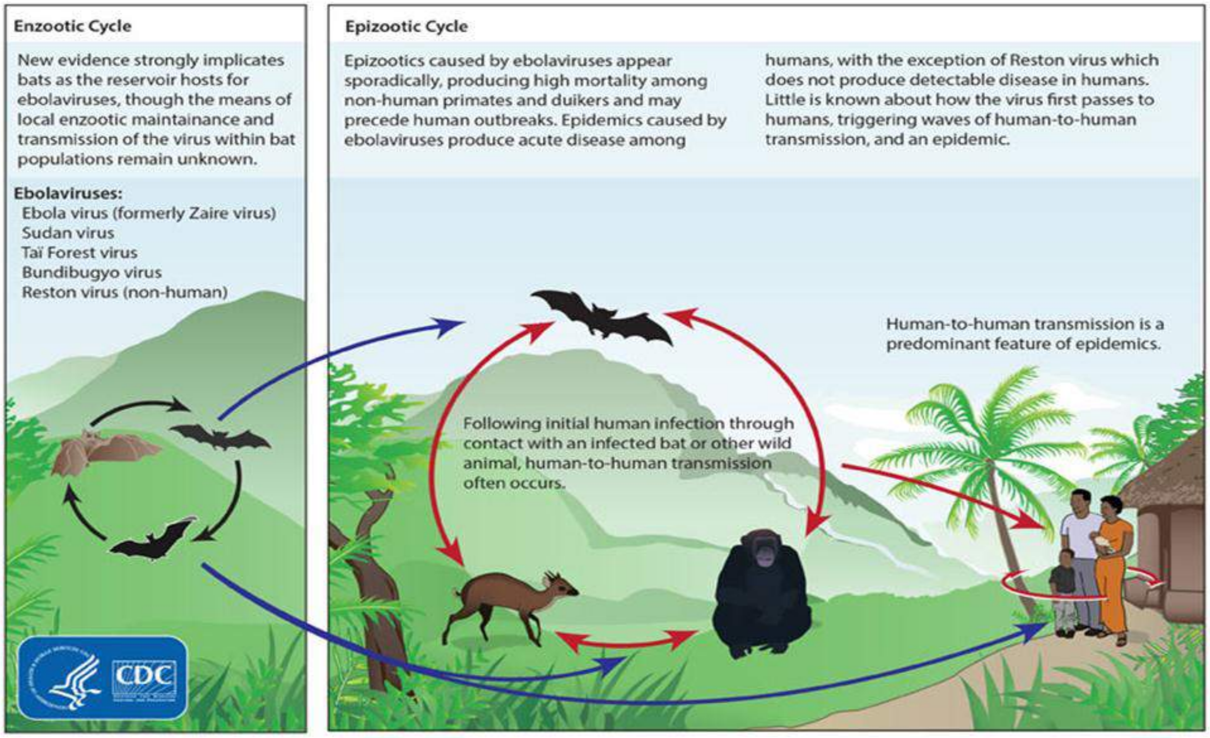

Fig. 2: Cycle of the ebolavirus showing transmission of disease from wildlife to human.

Table 2: Important steps the international bodies took from 2015 to 2019.

Year	Important Steps for IWT Prevention
2015	• The United Nations General Assembly Passed Resolution on Tracking Illicit Trafficking in Wildlife.
	• Passed Resolution on Tackling Illicit Trafficking in Wildlife.
	• Discourage the IWT facilitated by political bodies.
	• The African Union adopted strategies to combat illegal wildlife corruption.
2016	The European Union
	● Provide an action plan against wildlife trafficking to tackle the illegal wildlife trade.
	● Support to take the initiatives to address the risks associated with wildlife corruption at national and international forums.
	CITES
	● CITES resolution 17.6 encourages preventing, detecting, and countering wildlife corruption.
2017	G-20 Summit
	● The twelfth meeting of the G-20 summit in Hamburg includes several points including a strong pledge to address the corruption associated with illegal wildlife trade. The declaration includes a strong commitment to "intensify our fight against IWT and wildlife products.
	● Concluded that IWT can destroy biodiversity, and the economy, and act as a greater risk for public health.
2019	● UNGA passed several resolutions, similar to 2015, to address the IWT in September 2019.

6. CHALLENGES TO CONTROL IWT

Illegal wildlife trade is usually perceived as a low-risk but high-profit generating business that involves targeting specific species due to their high monetary value. Government and international policy makers can lower IWT by building a stronger understanding of the factors that facilitate the IWT. Some important challenges that national and international bodies can face to control IWT are discussed below:

6.1. DOCUMENTATION FRAUD

Documentation fraud is one of the most important challenges that facilitates IWT. One of the most important examples of documentation fraud is the export of illegal trade of the apes from Guinea by using fraudulent CITES export permits between 2009 to 2011. The head of the CITES management was removed from the office and arrested due to involvement in fraudulent actions (Ammann et al. 2013).
The corrupt use of illegal paperwork to facilitate the IWT and illegal hunting is very common in developing countries. When illegally traded wildlife is traded with false paperwork, it leads to several problems, including the transmission of zoonotic pathogens from one animal to another and ultimately to humans (Zain 2020).

6.2. TRANSPORT SECTOR COMPLICITY

Corruption at the transport hub is one of the most important factors that facilitates the IWT. An assessment conducted by the CITES in Kenya confirmed that corruption and illegal cooperation between government officials and the transportation industry are key drivers for illegal trade and poaching of elephants and rhinos. Due to corrupt government officials in developing countries, their cooperation with other private organizations is increasing day by day (Zain 2020).

6.3. FREE TRADE AND ECONOMIC ZONE

Many free trade and economic zones are being used by illegal wildlife traders. An important example of a free economic zone is "The Golden Triangle Special Economic Zone," which is situated at the border of Myanmar and China. This free economic zone is a major route for IWT due to relaxed Customs regimes. Trade through free economic and trade zones is not subjected to customs control which allows illegal wildlife traders to enter the neighboring country without a customs clearance document (Krishnasamy et al. 2018).

6.4. CORPORATE GIFTING

One of the most important but least studied factors that contribute to illegal hunting and IWT is corporate gifting. For example, Rhino horns are more expensive gifts that are usually offered to political officials and other socioeconomic elites in many developing countries (Milliken et al. 2012).

7. FUTURE INTERVENTIONS

After the emergence of COVID-19 and monkeypox infection, illegal hunting and wildlife trading have attracted the attention of international organizations. According to the United Nations Environment Program, combating the IWT and hunting demands diverse strategies, including campaigns to lower the demand for wildlife products, increase surveillance, and an increase in poverty not only facilitates people to hunt illegally but also use of these people by organized wildlife smugglers. Thus, to reduce the IWT and other environmental crimes, it is important to improve the quality of life and alleviate poverty (Duffy et al. 2016).

7.1. AWARENESS ABOUT CONSEQUENCES OF IWT

Most of the people involved in the IWT are usually illiterate and lack awareness or knowledge of the risk factors associated with the IWT and zoonotic spillover. Unfortunately, most of the strategies to combat

IWT are focused on regulation and enforcement, but this is not sufficient. Campaigns to reduce the consumption of illegally traded wildlife products are essential. International and national organizations should focus on generating awareness among poor traders and wildlife product consumers about the zoonotic diseases that can spread or have spread due to IWT. Awareness and educational campaigns need strong social and political support. Thus, it is essential to involve the local communities and other stakeholders during the planning phase to maximize the chances of success in the campaign (Fukushima et al. 2021).

7.2. DIGITAL SURVEILLANCE

Not only is the truly global scale of the illegal wildlife trade unknown but also regional and local levels of wildlife trade are difficult to assess. Quantifying the illegal wildlife trade can be a difficult task, thus there is more need to facilitate digital surveillance. Digital surveillance of the IWT can also provide insight into the zoonotic diseases spillover and early detection of these diseases. Currently, many organizations have introduced several digital applications to digitally assess the IWT throughout the globe. For example, The HealthMap Wildlife Trade website provides IWT reports from official and unofficial sources. Similarly, WWF and TRAFFIC, have successfully created the Law Enforcement Management Information System (LEMIS) tracker that plots official data and flows of wildlife products seized upon entry into the United States.

7.3. POTENTIAL POLICIES

The devastating effects of COVID-19 increase the need for potential policies to combat zoonotic disease spillover due to IWT and other green crimes. Unfortunately, due to deforestation and other illegal activities worldwide, their human-animal interaction has increased ultimately leading to the emergence of several novel zoonotic diseases. Thus, significant steps should be taken to ensure this type of pandemic is prevented in the future. There is more need for the Global Enforcement Cooperation to address the IWT and consumption of illegally traded wildlife products. Similarly, proper SOPs should be designed for the wet market to avoid the spread of zoonotic pathogens. Awareness should be generated about the risk factors associated with the consumption of wildlife meat (Aguirre et al. 2020).

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Zoonotic Diseases Causing Abortion in Humans

32

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ABSTRACT

Zoonotic diseases are contagious diseases that are transmitted from animals to humans. Among these zoonotic diseases, some are associated with potential losses of pregnancy in pregnant women. A variety of pathogens cause emerging infections which are zoonotic in nature. Travelling facilities across the globe have given rise to the spread of these pathogens. Humans' intervention in distant places has caused the development of contact with zoonotic infections. Although, thorough research of rare outbreaks can be difficult, the knowledge of emerging pathogens and their effect on women is accumulating. That's why zoonotic infections should be considered a serious challenge as they are persistent risk for human populations. Brucellosis, Leptospira, and Rift Valley Fever are important agents of abortion in humans, they also induce abortion in animals. Brucellosis is considered to be the cause of abortion around the globe, and it remains mostly undiagnosed in both humans and animals thus leading to extreme losses. Studying the relation of this disease with pregnancy loss has the potential to help in the reduction of it reproductive stress. Despite the availability of effective vaccine drugs, pregnant women are at possible risk of infection from zoonotic infections. These zoonotic diseases can be prevented by adopting certain practices like maintaining biosecurity, education of public through awareness campaigns, and encouraging people to learn the hazards of zoonotic diseases. Government should initiate programs to develop vaccines against zoonotic infections.

Key words: zoonotic, abortion, infection, pathogens, humans

CITATION

Ahsan M, Wasif M, Mehak M, Zeeshan M, Gul Z, Afzal I, Khalid I, Umair M, Rehman F and Farooq A, 2023. Zoonotic diseases causing abortion in humans. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 423-434. https://doi.org/10.47278/book.zoon/2023.032

CHAPTER HISTORY Received: 12-March-2023 Revised: 23-May-2023 Accepted: 10-Sep-2023

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1. INTRODUCTION

Animals, Humans, and the Environment are vital in the spread and emergence of many infectious diseases (Thompson and Kutz 2019). Infectious diseases affecting humans mostly have an animal basis. The "Asia Pacific Strategy for emerging diseases, 2010" states that approximately 60% of human potential infections are zoonotic, and above 70% come from wildlife animals (WHO 2010). The recently originated diseases in humans in the last years are predominantly animal-borne and have a clear association with animal-based foods (Slingenbergh 2013). Abortion is the delivery of an immature fetus, live or dead, earlier than normal gestation length due to the failure of processes that control gestation. If gestation terminates before organ development, it is early embryonic mortality. If a fetus is born dead after reaching full maturity, it is called a stillbirth (Gelaye et al. 2014). Infectious causes of abortion include viral, fungal, protozoal, and bacterial infections. Non-infectious causes include physical, chemical and nutritional factors. The most familiar cause of abortion in humans is infectious agents (Pretzer 2008).

Zoonosis poses a severe public health threat to humans, sometimes proving lethal. Around the world, 13 zoonoses were most dreadful on poor livestock individuals in third-world countries and resulted in about 2.4 billion cases of illness each year with their hazardous effects on people's health (Grace et al. 2012). Zoonotic pathogens can be transferred from animals to humans directly or indirectly (Mortimer 2019). Toxoplasmosis is believed to be one of the most infections which causes abortion in pregnant women around the globe. About 1/3 of people possess antibodies against *T. gondii.* The possible route of infection transmission is through the placenta, resulting in encephalitis, mental dysfunction, and vision loss in birth-affected children. The intermediate and dead-end hosts of sarcosporidiosis are humans, but no lethal effects are exhibited by it. However, one case of abortion due to *Trypanosoma evansi* has been documented (Shaapan 2016). A common cause is eating or tasting uncooked meat or meat products and handling cat litter (Shaapan 2016).

Brucellosis is a zoonotic disease present throughout the world. Reproductive stress in humans and animals can be reduced by understanding the association of this infection with abortion. Brucellosis has an abortion rate of 11.8% in humans. Thus, brucellosis is a direct cause of abortions in human communities. There is a manifestation that brucellosis is becoming an increasing cause of abortion in domestic ruminants (Ntirandekura et al. 2018). Abortive infections pose serious health threats to humans (Walder et al. 2005). Pelvic inflammatory infection by *C. abortus* in pregnant women proliferates in the epithelium of the trophoblast (Pospischil 2002).

Hospitalization with critical care is sometimes required if a pregnant woman is infected and indirect contact by living in the neighborhood of a farm affected with enzootic abortion has also been reported. For women from rural places, a complete history is required when brought in a hospital emergency with developing an influenza-like illness, and doctors should provide proper attention (Meijer et al. 2004). Adequate care is required in case of human infection with C. abortus, but timely detection, lab confirmation, and proper treatment can cut short abortion and other effects in pregnant women (Pichon et al. 2020).

2. ORIGIN OF ZOONOTIC DISEASES INDUCING ABORTION

Arthropods are one of the most potential vectors of zoonoses due to their high adaptation, evolution to various pathogens, and hurdles in applying for proper eradication programs. Fleas, ticks, flies, and bugs are significant vectors for transmission, but the most critical human disease vectors are mosquitoes, while in domestic animals, ticks are important vectors (Bueno-Marí et al. 2015). Zoonotic infections in humans are acquired mainly by infections caused by viruses, bacteria, protozoa, and arthropods. These infections may lead to intense and lethal medical conditions in seriously infected humans. Interaction between

livestock and wild animals and among cats, dogs, and humans serves as a pillar for zoonoses. Humans are accidentally infected in endemic areas, where environmental conditions enhance the vector spread and animal populations behave as reservoirs. Climate, vectors, temperature, and humidity are important parameters to understand zoonoses' development. Around 60% of human infections are of zoonotic basis, and 75% of newly emerging pathogens originate from animals (Morchón et al. 2021).
Many emerging infections in humans are the result of pathogens that comes from animals and animal products. A vast range of animals which may be wild or domestic, serve as a reservoir for these pathogens. Adequate eradication and control have become challenging due to the wide variety of reservoirs (Meslin et al. 2000). Progressive deforestation and agricultural land use for city development result in ecological changes that modify the disease epidemiology. Man-vector contact resulting from changes in the habitats of wild species poses a threat to public health. In the last twenty years, many ignored infections have re-evolved with wide distribution (Pavani 2014).

3. SERO-EPIDEMIOLOGY OF ABORTIFACIENT ZOONOTIC PATHOGENS IN HUMANS

Cross-sectional studies suggest the prevalence of closely related diseases like Brucellosis and Q-fever in cattle, humans, and sheep. Particularly, ungulates are believed to adopt more than 300 pathogens on a zoonotic basis. Many new infections are zoonotic (Cleaveland et al. 2001). There is a need to study these diseases in populations where there are chances of their stability. Multidisciplinary teams should work together on these infectious diseases. Some zoonoses are significant bacterial infections that cause a wide range of clinical conditions. Additionally, they infect people who eat contaminated products derived from milk (Haydon et al. 2002). In healthy animals, infection by T.gondii has been seen with an occurrence of 0 to 47 percent across countries (Bisson et al. 2000). Various problems, including reproductive issues like miscarriage and maceration, have been inflicted by this pathogen (Szeredi and Bacsadi 2002).
There is evidence of individuals facing simultaneous infections with *T. gondii* and *C. abortus*, which may present a complicated examination (Sharma et al. 2003). It is known that research models have a seroepidemiological nature fact that there was no separation of pathogens conducted. There is a fact that T.gondii is involved in miscarriage. The cat population on the farm must be controlled to reduce financial losses and health threats, especially in pregnant women. There should be awareness about the possible modes of transmission of this pathogen. Animal shelters may help to limit cat populations away from farms (Borde et al. 2006). Diagnosis of zoonotic infections is dependent on serological procedures, which are inexpensive and easily available (McDermott et al. 2013). Bovine brucellosis has prevalence of o to 68% (Godfroid et al. 2019).

4. ETIOLOGY

Infectious and non-infectious causes are general causes of abortions (Fig. 1). The presence of abnormal chromosomes in one or both partners can induce abortion. Chromosomal aberrations are the main causative agents of abortion (Suzumori and Sugiura-Ogasawara 2010). In humans, insufficient progesterone secretion is an important cause of early and late abortions (Kaur and Gupta 2016).

4.1. LYME DISEASE

Spirochete belonging to the *borrelia burgdoferi* sensu lato complex is responsible for Lyme disease. This infection is mainly known as Lyme Disease in North America, while it is called Lyme Borreliosis or Borreliosis in Europe and some other countries. Bite from an Ixodid tick is the source of Lyme disease transmission. These species differ by geographical location (Trevisan et al. 2021).

4.2. BRUCELLOSIS

Genus Brucella is responsible for this zoonotic infection (Kaltungo et al. 2014).
It is a serious health problem in many countries with high incidence in humans and animals. Drivers of disease transmission are unpasteurized milk items, contact with the affected population and aerosol spread. Its prevalence is different in different regions, with the most reported cases in places with increasing animal populations and lack of health awareness among people, which lead to human infections and financial losses (Asrie et al. 2023). Studies suggest that consumption of raw milk can be the source of transmission to humans. It occurs more frequently than toxoplasmosis and Q fever (Fig. 2) (Ahmad et al. 2020).

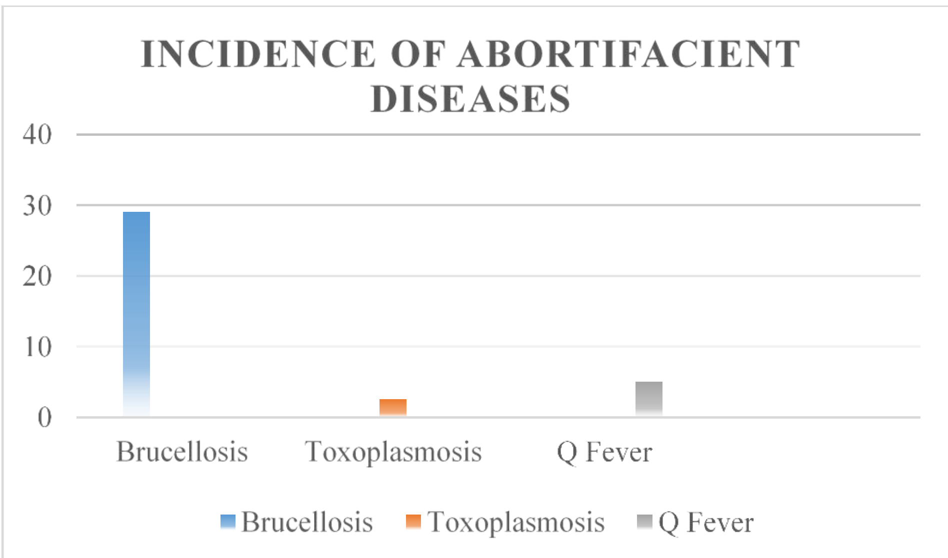

Fig. 1: Occurrence rate of abortifacient infections

4.3. TOXOPLASMOSIS

Toxoplasma gondii can lead to fetal death. Other problems caused by *T. gondii* include loss of eyesight, mental abnormality, and other health problems. These health problems may not be evident until twenty or thirty years of life (Jones et al. 2003).

4.4. SARCOSPORIDIOSIS

is caused by a wide range of *Sarcocystis* species (Barbosa et al. 2009). These are protozoan species, intracellular in nature, and their life cycle depends on prey-predator interaction. In the intermediate host, their asexual stages develop. Sarcocysts are ingested through meat consumption and their life cycle initiates in the host's intestine (Fayer 2004). Evaluation of cattle tissues proves that many are infected with sarcocyst (Van Knapen et al. 1987).

4.5. Q Fever

Q fever is responsible for long-term clinical conditions. Its causative factor is *Coxiella burneti. A broad clinical boundary is related to this infection. Q fever can cause a serious illness in humans, mostly in immunosuppressed patients and pregnant women (*Angelakis and Raoult 2010). The role played by Q fever in abortion is not known. A relationship exists between its serology and areas in which it is endemic

(Quijada et al. 2012). Very few reported cases exist due to contact as it is an occupational disease (Fig. 2) (Dupont et al. 1992).

5. FACTORS FACILITATING ZOONOTIC INFECTION

Pathogens that pose a severe threat to human health may have very little in common with identified zoonotic agents as they go through an intermediate stage before invading humans. The biological characteristics of pathogens determine man-to-man transmission. Various factors, like changes in the exposure pattern of humans, may support this transmission (Fig. 3). The evolution of disease can be expected as a response to environmental alterations, including urbanization and advanced agricultural methods (Slingenbergh et al. 2004). Zoonotic diseases are specifically crucial given evolving infections of humans as most of them have a zoonotic basis (Cleaveland et al. 2001).

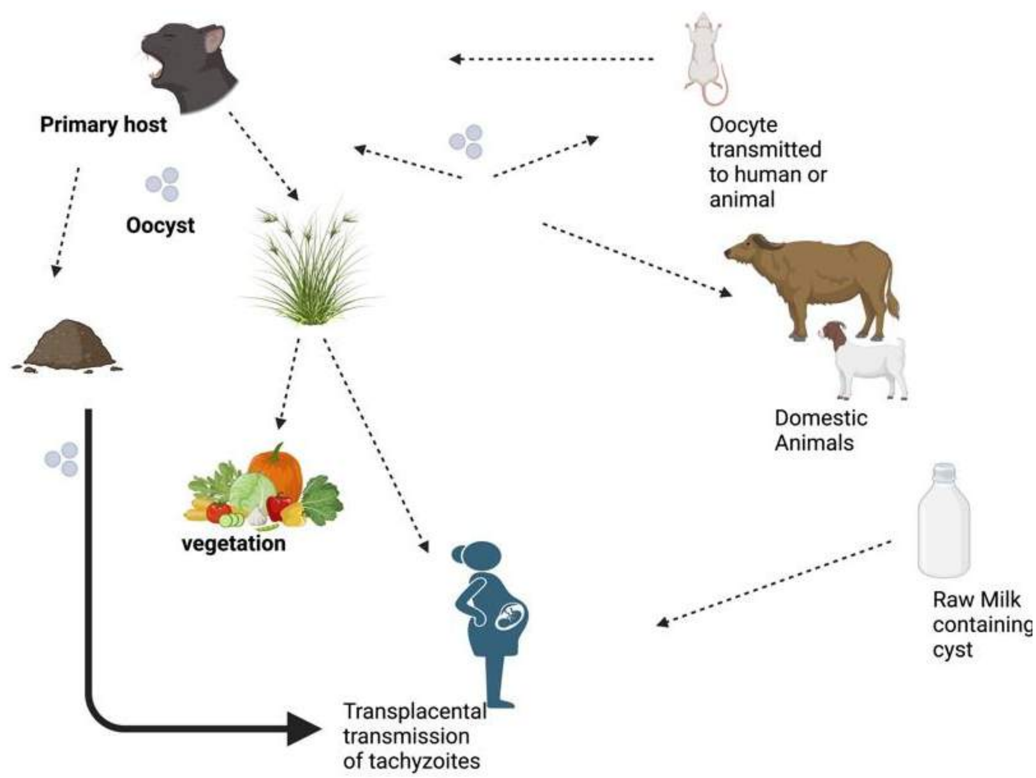

Fig. 3: Transmission routes for *T. gondii*

Human-animal interaction is complex, and it is affected by changes in climate and other natural factors. Geo-climatic variations primarily influence zoonotic disease transmission. Tourism, travel, and trade are major human factors responsible for triggering the spread. Pathogen adaption to conditions is one of the causes of the re-emergence of zoonotic diseases. All these things contribute to causing infections like Lyme disease and West Nile Fever which are direct threats to public health (Naicker 2011).

The cause of severe epidemics is an animal-human relationship (Cutler et al. 2010). Zoonotic infections are considered as the ones transmitted from animals to humans and are not well transmitted among humans (Kotton 2010). Changes in reservoir and carrier dynamics alter the climatic change of zoonotic diseases. The temporal and spatial distribution of infections is affected by environmental variation (Lafferty 2009).

Pathogen populations may be increased by increased food and crops resulting from increased rainfall. Flood risk is also responsible for disease transmission (Mac Kenzie et al. 1994).

To employ methods to reduce the spread of zoonotic pathogens, it is important to study the causes that accompany the spread of pathogens from animals to humans (Ellwanger and Chies 2021). The relationship between humans and animals is enhanced by certain activities like consuming meat and meat-derived products (Kurpiers et al. 2016).

Wild animals and products derived from them serve as a food source and are sold in markets. These markets are a source of increased contact between humans and animals. Zoonotic species can be transmitted easily via contact in places where various animals are kept in closed boundaries. Possible sources of spread are blood, meat, air, etc. (Brown 2004; Aguirre et al. 2020).

Numerous zoonotic and vector-borne agents affect humans due to the ability of an infectious agent to cross the species barrier (Vorou et al. 2007). There are multiple causes of disease emergence in humans, but the main factors are the increase in population and international trade. The movement of different animal species and terrorism contribute to the emergence of human infections (Brown 2004).

6. PATHOGENESIS OF ZOONOTIC DISEASES

Zoonotic diseases can pose serious public health concerns and cause disruptions of various systems in humans. One of the most lethal diseases is brucellosis, which causes fever, arthritis, endocarditis, etc. (Paixão et al. 2009). Brucella infection is capable of replication in phagocytic cells and trophoblasts as well. This capability comprises a short combination of a vacuole with a lysosome. After this, an association develops between the vacuole and the endoplasmic reticulum (Starr et al. 2008). Another health threat for pregnant women is Coxiellosis which induces miscarriage in humans and other reproductive problems. This can also lead to economic losses. Wide documentation of cases is rare in countries in which it is dominant. Moreover, the pathogen remains mostly ignored. It is not seen as a problem of attention by funding agencies (Sahu et al. 2021).

Chlamydia Abortus shows different development cycles, and the details about its invasion and release are not thoroughly elaborated (Van Lent et al. 2012). It is proven that chlamydia uses a needle-like apparatus to inject the proteins across the host's cell membranes (Stephens et al. 1998). The ability of zoonotic diseases to co-occur with other infections is a therapeutic barrier. This results in difficulty in probing the diseases, and the administration of many medicines can harm a particular individual (Rodríguez et al. 2014).

7. PUBLIC HEALTH IMPACT OF ABORTIONS

For the last 50 years, abortion has been considered as a critical public health problem by the World Health Assembly. Induced abortions can be performed safely if the staff is well-trained and properly equipped. WHO-recommended procedures should be considered while performing induced abortions. It is a national and global health imperative to address the complications of unsafe abortion that negatively impact individuals and society. Public health cost-effective interventions such as using effective contraception, providing legal and safe abortion, and sexual education can be crucial in preventing every abortion disability and death. Due to some factors, including prevailing stigma, lack of political commitment, poor socio-economic status, and restrictive legal regulations, safe abortions pursue to be a serious complication of public health. Education of policymakers, legislators, and the public at large about the harmful consequences of confining abortion policies, laws, and regulations are the responsibilities of health professionals in a society (Fathalla 2020).

8. SOCIAL IMPACTS OF ABORTIONS

Science and technology development plays a vital role in medicine and health care because it incorporates new concepts, products, techniques, and ideas to tackle health problems. Intensive diffusion of prenatal ultrasound can create new problems for pregnant women and their families and society in managing malformations of the fetus. This is because of very strict legislation on induced abortion (Novaes 2000). The stigma of abortion is poorly theorized, although it is widely acknowledged. The social production of abortion stigma is highly local. However, the media promotes the abortion stigma. It is neither essential nor natural but depends upon inequalities and disparities for its development (Kumar et al. 2009).

9. PREVENTION AND CONTROL STRATEGIES

Since the beginning of recorded history, abortion, typically with an increased risk of fatal impacts, has been considered a reality in women's life. Advancements in the medical field, including strategies for safe abortion and reliable methods of family planning, increasing gender and reproduction-related evolution in human rights, eradicated the need for unsafe abortion until the last century. The context of women's lives is crucial but, unfortunately, ignored. When national human rights laws, including life and health, are violated, regional and international human rights instruments are cited. Most maternal deaths due to abortion could be managed by addressing and ensuring human rights globally (Shaw 2010).

9.1. Eradication of Abortive Infections

Respiratory and genital tract infections, including infectious rhinotracheitis (IBR), balanoposthitis (IBP), infectious pustular vulvovaginitis (IPV), and abortion are caused by bovine herpesvirus type 1 (BoHV-1) which is a zoonotic virus. The virus never eradicates from an infected host despite of immune response but develops lifetime latency and can be activated at intervals of time. It has been a long era since Europe's fighting against BoHV-1 infections, but only a few countries have successfully achieved eradication against IBR. Woefully, the vaccinations are only caretaking and of limited value. The significant risks, the high costs, and the undesirable quality of tools require several considerations to keep forward against such plans of managing and eradicating the virus. Eradication or controlling viruses like IBR in animals requires better vaccines, tools, and companion tests. It would be a more beneficial task to gather viral stains from many countries collaboratively and include them in newly established clustering libraries (Ackermann et al. 2006).

9.2. Developing New Antimicrobials and Control Options

In placental mammals, the adaptive immune system has evolved to tolerate the fetus in the womb. It is a very rare event that the adaptive immune responses reject the fetus. Usually, the inflammation in the placenta leads to abortion. Feto-maternal status depends on the innate immune system and microbial infections in the womb (Kanellopoulos-Langevin et al. 2003). During evaluation in placental mammals, there are two opposing selective pressures. The first one is that specie's ability to eradicate pathogens demonstrates its survival. The second one is the ability to protect the fetuses from rejection by immune systems (Jiang and Vacchio 1999). It is not an evidence-based statement that the maternal adaptive immune system rejects the semi-allogeneic fetus just as the allogenic graft might be rejected. Unlike this, it is indicated by experimental evidence that the maternal adaptive immune system recognizes the fetal alloantigens. However, the tolerance for specific maternal B and T cells is induced by this recognition, just like the antigen-receptor transgenic models (Aït-Azzouzene et al. 1998).

9.3. Education and Awareness Programs

From the moment of conception, a fetus is considered a person. Abortion and miscarriage are two different things. Miscarriage is much deadlier than abortion, resulting in 89% of pregnancies. It means that miscarriage, a particularly very early miscarriage that leads to a dilemma is the biggest public health crisis of our time (Berg 2017).

9.4. Using Proper Treatment Methods

In developing countries, incomplete abortions contribute to maternal morbidity and mortality. Three ways to manage incomplete abortions can be surgically, expectantly, and with misoprostol. For many years, surgical methods' standard of care, safety, and effectiveness has been well established and provides good medical care. Expectant management is effective but not more than surgical methods because it is often neither an immediate treatment nor much desirable to women and some attendants. Misoprostol is gaining attention worldwide as a management tool for incomplete abortion because it is a more feasible, cost-friendly uterine evacuation method and a revolutionary and easy-to-use treatment (Blum et al. 2007).

10. FUTURE PERSPECTIVES AND RESEARCH GOALS

Up to 20% of the recognized pregnancies are affected by spontaneous abortion. It is the loss of a pregnancy before 20 weeks without any outside intervention. Spontaneous abortion can be categorized as missed abortion, complete abortion, incomplete abortion, septic abortion, and recurrent spontaneous abortion. Despite other testing needed during ectopic pregnancies, ultrasonography is a helpful diagnostic tool. Besides other factors, approximately 50% of abortions are due to chromosomal abnormalities. Surgical evacuation of the uterus is a traditional treatment and is considered best for unstable patients. Intravaginal misoprostol is a medical therapy with a great success rate of up to 80%. Medical staff should also consider the psychological issues of the women and their attendants. Usually, women are on a brick of anxiety and depression for up to 1 year. Counseling should be given to the affected women targeting the grief process, guilt feeling, and coping with family and friends (Griebel et al. 2005). Traditional treatments for abortion include curettage and dilatation, while another surgical procedure is manual vacuum aspiration (Scroggins et al. 2000).

10.1. Preventive Approaches

Pills are one of the well-known contraceptive methods for managing abortion and its complications. The effectiveness depends upon the use of the pills, whether they are used perfectly or typically. The first one is considered more effective (Trussell and Wynn 2008). Providing safe services for pregnancy termination also plays a vital role in safe abortion with minimal complications (Selassie 1995). When needed, the most advanced technologies and equipment should be used to complete the uterine evacuation. It is considered the provision of subtle quality of postabortion care (Tunçalp et al. 2010).

10.2. Innovative Methodologies to Combat Abortion Complications

Abortion is supposed to be a very important social justice and public health problem worldwide. Unsafe abortions lead the way to causing maternal mortalities. Young and poor women are greatly at risk for their lives and health when undergoing abortion. In comparison with other ailments and health complications, abortion has more economic costs. Access to legal and safe abortion fits antiquely into the prevailing agenda. Structural social and economic equity-friendly policies should be developed (Lamas 2007).

10.3. Public Awareness

Family education and medicine training is the basic tool and strategy for ensuring the safety of abortion. Trained staff and physicians as positive interventions can play a very vital role in managing and minimizing the complications of abortion (Summit et al. 2020), as abortion is a common and simple medical procedure (Berer 2005).

11. CONCLUSION

Abortions are one of the most traumatic experiences faced by pregnant women. Various unsanitary practices enhance the spread of diseases from animals to humans. People having food animals kept near their homes are vulnerable to zoonotic diseases. Consumption of contaminated and raw food of animal origin is the leading cause of zoonoses. Among these zoonotic infections, some are very harmful to human beings. Lack of awareness is also an essential factor leading to increased disease spread. Pregnant women, if not conscious of the possible dangers of certain infections during pregnancy, can fall prey to multiple complications in the form of miscarriage, mummification, or other reproductive system diseases. These abortions can be prevented if proper hygienic practices are observed, and complete medical support is provided in case of infection.

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Personal Accessories as a Carrier for Zoonotic Disease

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ABSTRACT

Healthcare workers are vital for public health, but they can get sick and unintentionally spread infections among patients. Microorganisms can enter healthcare settings through items like laptops, lab coats, money, keys, drinks, phone accessories, and medical tools. Healthcare workers can unknowingly pass infections between patients by using various objects and accessories. For example, female healthcare workers are advised to clean their handbags daily and avoid fabric purses. White coats can also spread contamination, so there are suggestions to limit their use in non-clinical areas. Zoonotic diseases, which transfer from animals to humans, are a growing concern. Diseases like Anthrax, Rabies, Tuberculosis, Salmonellosis, Campylobacteriosis, and Leptospirosis pose health risks. Preventing zoonotic diseases involves vaccination programs, such as immunizing dogs against Rabies. Vaccinating animals is crucial to protect public health and prevent the spread of these diseases. To address the risks of zoonotic diseases, collaboration between public health veterinarians and other stakeholders is necessary for effective prevention and management.

Key words: Personal Accessories, zoonotic diseases, Vaccination, Public health Healthcare workers.

CITATION

Ashraf R, Kauser R, Murtaza G, Zaidi B, Naeem Q, Nasar DSJ, Nasar AB, Fasiullah, Hammadullah, Illyas A and Rehan M, 2023. Personal Accessories as a Carrier for Zoonotic Disease. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 435-446. https://doi.org/10.47278/book.zoon/2023.033

CHAPTER HISTORY Received: 25-Feb-2023 Revised: 18-May-2023 Accepted: 14-Aug-2023

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1. INTRODUCTION

Healthcare workers play a vital role in preserving public health, although they are not immune to falling ill themselves. In some cases, they inadvertently contribute to the transmission of illnesses between patients (Belay et al. 2017). Micro-organisms can be introduced into healthcare settings through the use of various inorganic objects by healthcare personnel, increasing their susceptibility to infection and facilitating the spread of infections among patients (Braam et al. 2021). Commonly used items such as laptops, lab coats, currency notes, keys, canned beverages, mobile phone accessories, and medical instruments from healthcare environments can be sources of infection (Spoorthy et al. 2020). Additionally, healthcare workers can inadvertently spread infections within hospitals from one patient to another through various accessories and objects (Danzmann et al. 2013). For instance, it is recommended that female healthcare workers wash their handbags daily and avoid using fabric purses (Tedder et al. 1995). Moreover, white coats have been identified as potential sources of cross-contamination, leading to suggestions for their prohibition in non-clinical areas such as study spaces and eating areas (Rahman et al. 2020).

Moreover, the emergence of diseases that are transmitted from animals to humans has become a growing concern (Atlas 2012). Notably, major zoonotic diseases, including Anthrax, Rabies, Tuberculosis, Salmonellosis, Campylobacteriosis, and Leptospirosis, have raised significant health risks (Keck et al. 2018). Among these, Anthrax has been observed to cause clinical epidemics in both humans and cattle, leading to multiple cases of infection and mortality (Chakraborty et al. 2012; Han et al. 2017). Furthermore, zoonotic diseases like Rotavirus pose global threats to mammals and birds (Samad 2011), impacting the health and production rates of farm animals (Nelson 1999). The effects of zoonoses include not only the direct consequences of illness but also financial losses, damage to the reputation of workers, and the implementation of control measures (Zhang et al. 2016; Ostfeld et al. 2004).

Efforts to prevent zoonotic diseases often involve vaccination programs, such as those for Rabies, which include regular immunization of dogs (Hasanov et al. 2018; Vial et al. 2006). Vaccination of animals serves as a crucial strategy in safeguarding public health and preventing the transmission of zoonosis and foodborne illnesses (Hafez 2020). Given the potential risks associated with zoonotic diseases, collaboration between public health veterinarians and other stakeholders is imperative for effective disease prevention and management (McGee 2003).

2. THE PURSES AS A SOURCE OF TRANSMITTING ZOONOTIC DISEASE

Purses have long been regarded as prized possessions in many households (Aruga et al. 2021). Beyond just carrying cash, people use handbags to store various valuable items, devices, debit cards, car accessories, and receipts (Mittal et al. 2022). Typically, handbags are not regularly cleaned and are often used for extended periods, potentially serving as agents for the spread of infections (Strong et al. 2017). Individuals' bags can become carriers of infections within communities. In healthcare settings, the handbags of medical workers have been found to harbor bacteria (Brownlie 2006). Studies have shown that approximately 96% of handbags in community settings are contaminated with microorganisms, a higher rate than the 69.2% contamination rate found in handbags in pharmaceutical settings. Previous research has indicated that the interiors of women's purses and wallets are also teeming with microorganisms. Several studies have reported bacterial colonization on currency notes during circulation (Lusher et al. 2017).

Various types of bacteria such as Staphylococcus, Enterococcus, E. coli, Pseudomonas, and Micrococcus have been isolated from these handbags, highlighting the presence of both cooperative and opportunistic pathogenic organisms (Owusu-Kwarteng et al. 2020). The attachment and persistence of microorganisms may be facilitated by the surface environment. Uneven and textured materials increase the surface area and create concealed spots that can aid microbial attachment, in contrast to smooth surfaces. Additionally, pathogens tend to adhere more readily to textured materials compared to smooth ones (Nash et al. 2015).

3. THE WHITE COAT AS A SOURCE OF TRANSMITTING ZOONOTIC DISEASE

Traditionally, the white coat is regarded as a symbol of honor and dignity within the medical profession, serving as personal protective equipment (PPE) for healthcare workers to safeguard against skin irregularities and patient contact (Willemsen et al. 2019). Studies have suggested that infectious microorganisms, including drug-resistant bacteria such as Erysipelothrix rhusiopathiae, can persist on white coats, potentially leading to skin infections (Zachary and McGavin 2017). It has been found that bacteria can survive on the fabric of white coats, including materials like linen, polyester, or cotton, for approximately 20 to 80 days (Todd et al. 2010). Another study identified the sleeves and pockets of white coats as the areas most heavily contaminated. Therefore, medical professionals should purchase new white coats annually and have at least two in rotation (Willemsen et al. 2019).

It is crucial to encourage healthcare workers to wash their white coats daily. Inadequate hand hygiene practices significantly contribute to the contamination of white coats, especially as these garments frequently come into contact with patients during medical duties (Burgess 2021). Thus, it is imperative to emphasize the importance of thorough handwashing before and after patient interaction. Furthermore, the promotion of alternatives to white coats, such as the widespread use of protective gowns, should be encouraged (Kraus et al. 2018).

4. MOBILE PHONES AS A SOURCE OF TRANSMITTING ZOONOTIC DISEASE

Mobile phones play an integral role in communication among doctors and other healthcare workers (HCWs) in hospitals, where hospital-associated infections (HAI) are common (Stempliuk et al. 2014). The hands of healthcare workers are a significant factor in the transmission of hospital-associated infections, and cell phones, which are often not regularly cleaned and frequently come into contact with patients during or after examinations, can serve as a medium for the spread of healthcare-associated infections (HAIs) (Ulger et al. 2015). Approximately one-fourth of cell phones belonging to healthcare workers are contaminated with hidden pathogens. Microorganisms commonly found on our skin thrive and multiply in warm environments, making cell phones an ideal breeding ground for these microorganisms, particularly as they are often kept close and easily transported in bags and pockets (Chiappelli et al. 2015). Simple precautions, such as proper hand hygiene practices and regular disinfection of cell phones using ethanol, can help reduce the risk of healthcare-associated infections caused by these devices (Gunning 2014).

5. FACE MASKS AS A SOURCE OF TRANSMITTING ZOONOTIC DISEASE

Many zoonotic diseases can spread through the inhalation of droplets, and healthcare workers are instructed to use personal protective equipment (PPE) when treating patients affected by these diseases (Stawicki et al. 2020). PPE includes gloves, face shields, and masks. However, prolonged use of masks can lead to physical and mental strain, potentially reducing performance efficiency (Khan 2022). Work effectiveness tends to decrease over time with the use of face masks compared to when they are not used. Additionally, the duration of work is often shortened when utilizing face masks and PPE (Kähler and Hain 2020).

Long-term use of face masks can lead to various adverse physical effects such as headaches, breathing difficulties, skin irritation, and pressure ulcers, as well as impaired perception (Laurie 1983). It can also interfere with vision, neural impulses, and homeostasis (Glenn 1985). Headaches associated with long-term face mask usage are linked to factors like increased carbon dioxide levels (hypercapnia) and decreased oxygen levels (hypoxemia) (Böing et al. 2015). Tight straps and pressure on facial nerves can contribute to headaches (BIEKMAN 1950). Factors such as sleep deprivation, irregular meal times, and high-stress levels can also contribute to headaches in healthcare workers who wear face masks for extended periods (Rasmussen et al. 2020). Face masks with tight straps can impede proper breathing and result in increased carbon dioxide levels (CO_2) known as hypercapnia (McDonell 2015). Additionally, the accumulation of CO_2 between the mask and the face can lead to respiratory distress and breathing difficulties. Symptoms of hypoxemia, such as chest discomfort and hyperventilation, can also be observed in healthcare workers who wear masks for extended periods (Fried 1993).

6. MEDICAL INSTRUMENTS AS A SOURCE OF TRANSMITTING ZOONOTIC DISEASE

Clinical instruments commonly used by physicians, such as sphygmomanometers and stethoscopes, which are not regularly cleaned during routine clinical procedures, are potential sources of infection (Dancer 2014). Dental gloves, designed to protect the dental care team from being contaminated by the patient, are not always a foolproof method for preventing contamination (Illich 1975). The use of mobile phones by healthcare workers with covered hands in gloves is not uncommon, leading to an increased risk of spreading healthcare-associated infections (Wolfensohn 2008). However, the use of gloves does not eliminate the necessity for hand washing, as gloves themselves can become contaminated due to tears or other issues during use. Research suggests that prolonged glove usage, combined with the use of antiseptics, complex secretions, and ethanol, can compromise the integrity of the gloves. The American Dental Association recommends that hands be thoroughly cleaned with a bactericidal agent before and immediately after glove usage (Li et al. 2010).

7. BEVERAGES AND REFRESHMENT BOTTLES AS A SOURCE OF TRANSMITTING ZOONOTIC DISEASE

Indulging in chilled bottles of beverages and refreshments is a common practice among healthcare workers during their busy shifts, providing a sense of freshness and enjoyment (Rhys-Taylor 2010). However, many modern storage and retail food facilities often store these products alongside perishable items, potentially exposing them to unhygienic conditions before they reach the market (Higgins 2011). Rodents, commonly found in such storage areas, can serve as carriers of various diseases such as bubonic plague, epidemic louse-borne typhus, icterus (yellowing of the skin and whites of the eyes due to abnormal bile pigments in the blood), rat-bite fever, rabies, and microbial foodborne illnesses (Anstead 2020). Additionally, zoonotic diseases like hemorrhagic nephrosonephritis and epidemic hemorrhagic fever can be transmitted through the contaminated urine and excrement of rats (Forbes et al. 2012). Hemorrhagic nephrosonephritis, also known as Lancereaux-Mathieu-Weil Spirochetosis, has emerged as a significant epidemic disease characterized by spleen enlargement, kidney and liver deterioration, as well as severe bleeding or hemorrhage in the lungs (BARBERO et al. 1953). Raising awareness about these diseases through active informational campaigns is crucial to implementing preventive measures against them (Windahl et al. 2008).

8. AUTOMOBILE INTERIORS AS A SOURCE OF TRANSMITTING ZOONOTIC DISEASE

Automobiles are often a necessary means of transportation for many healthcare workers who frequently travel to and from hospitals or clinics to attend to calls and spend significant amounts of time in these settings (Dominelli 2021). *Staphylococcus epidermidis, S. aureus,* and *S. warnerii* are among the most commonly found microbes, as Staphylococci can easily adhere to commonly touched surfaces (Neela et al. 2019). It is plausible that the interiors of automobiles may serve as a reservoir for infectious staphylococci and play a significant role in the transmission of these bacteria to individuals. It is hypothesized that individuals constantly in contact with S. aureus may contract diseases, or those in contact with the S. aureus carrier may facilitate the storage of S. aureus on the surfaces of the automobile (Gresham et al. 2000). Coating the driver's seat with 10% silver ion preservatives can be an effective measure to eliminate the presence of these infectious microorganisms collected from these areas (Subhan et al. 2021).

9. ZOONOTIC DISEASES

Zoonotic diseases can inherently be transmitted between animals and humans as shown in Fig. 1 (Bridge et al. 2011). Recent epidemics, such as viral hemorrhagic fever, anorexia, and beriberi, have underscored the significant impact of these diseases on human health (Kuhn et al. 2003). Their rise is linked to global trade, human migration, and environmental degradation (Boguslavsky et al. 2022).

10. BACTERIAL ZOONOSIS

10.1. ESCHERICHIA COLI

Escherichia coli is a common bacterium that belongs to the family Enterobacteriaceae (Blood 1995). While it is typically commensal in both humans and animals and verocytotoxin-producing strains of E. coli can cause distinct illnesses in humans such as dysentery, Enterohemorrhagic Escherichia Coli-Associated Colitis, and diarrhea-associated (D+) hemolytic uremic syndrome, but do not generally cause noticeable diseases in animal hosts (Moatsou 2014).

10.2. LISTERIOSIS

Listeriosis is a bacterial infectious disease caused by Listeria monocytogenes (Schlech III 2000). The main source of the disease is contaminated food. It primarily affects older individuals, people with acquired immune deficiency syndrome (AIDS), and pregnant women, leading to miscarriages and premature births (Pradhan et al. 2023).

10.3. ANTHRAX

Bacillus anthrax, the pathogen responsible for anthrax, is a spore-forming gram-positive bacillus commonly found in the soil of endemic regions (Chikthimmah 2006). Anthrax is caused by toxins containing protective antigens, virulence factors, and edema factors (Lapointe et al. 2004). Genetic engineering, along with a potent single-domain antibody (sdAb) derived from llamas and nanobodies, has been tested in mice and has shown promising results in protecting them against anthrax (Steeland et al. 2016).

10.4. TUBERCULOSIS

Tuberculosis is an infectious disease that primarily affects the lungs and is caused by a type of bacteria (Long et al. 1999). It is caused by the bacterium known as Mycobacterium tuberculosis (Gobin 1996).

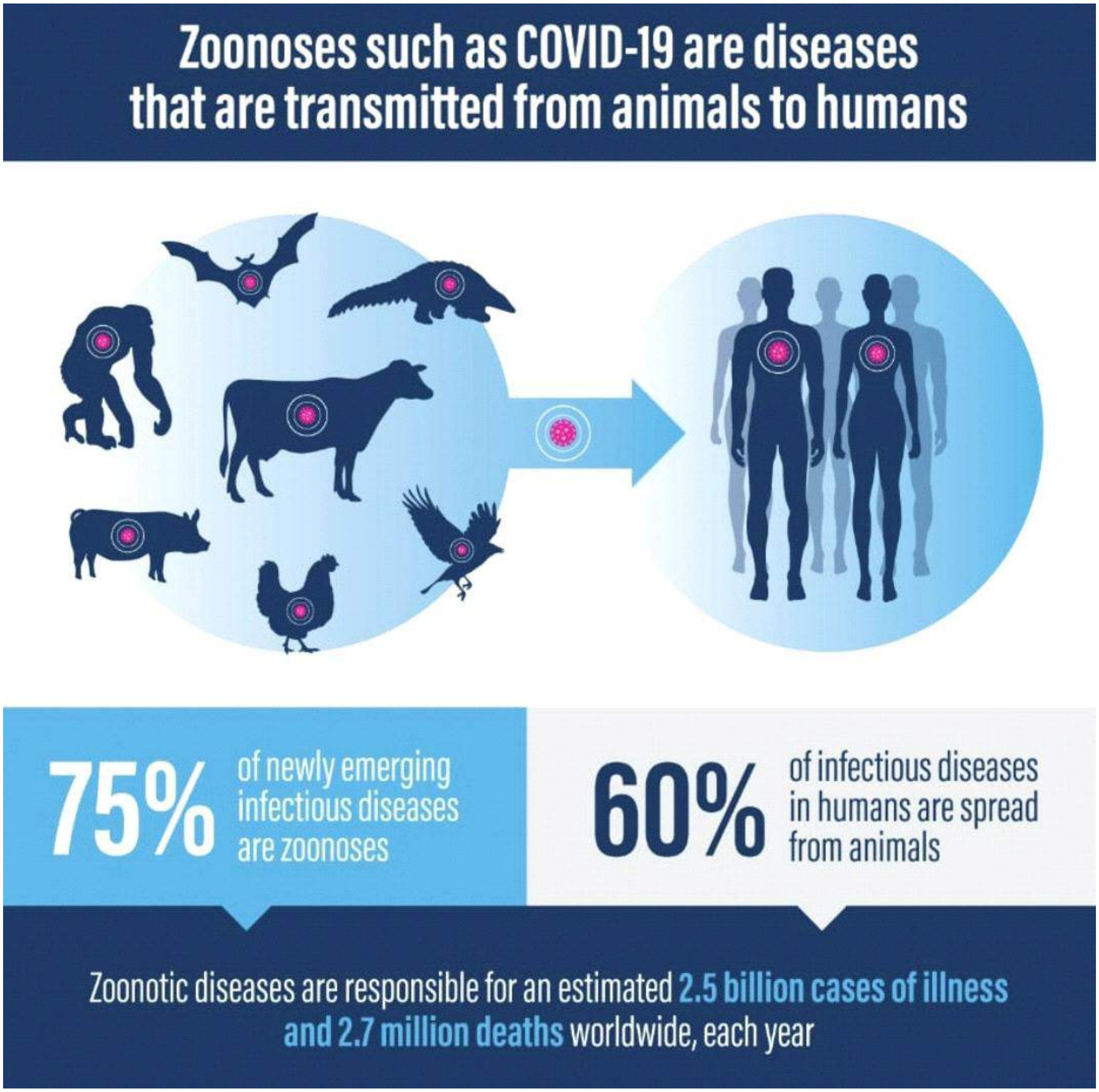

Fig. 1: Transmission of Zoonotic Diseases from Animals to Humans.

While the bacteria commonly target the lungs, tuberculosis can also affect other parts of the body such as the kidneys, brain, and spine. It spreads through the air when an infected person coughs, sneezes, or spits (Gupta 2020). Tuberculosis can be treated with medications such as Isoniazid, Pyrazinamide, and Rifampin (Aguilar Diaz et al. 2023).

10.5. CAMPYLOBACTERIOSIS

Campylobacteriosis is primarily caused by the bacterium Campylobacter jejuni (Hermans et al. 2012). Birds are commonly carriers of this bacterium without displaying any clinical signs, and it serves as a major source of foodborne illness, leading to symptoms similar to stomach flu in people worldwide. VHH, which binds to Campylobacter jejuni, has been isolated for its potential to improve thermal and hydrolytic stability, to inhibit the movement of Campylobacter jejuni through its flagella, thus potentially preventing or significantly reducing its colonization in the gut of birds (Levy 2013). These VHHs may have applications in both treatment and diagnostic tools (Funari et al. 2011).

10.6. VIRAL ZOONOSIS

10.6.1. INFLUENZA

Influenza A (H3N2), a member of the RNA family Orthomyxoviridae, consists of over 150 subtypes, distinguished by variations in the outer proteoglycans, Influenza hemagglutinin (HA), and neuraminidase (Krake 2013). IAV is diverse, including avian influenza, canine influenza, equine influenza, and human influenza. Several nanobodies specifically targeting influenza have shown heightened affinity against the amino acids Matrix protein 2-Influenza A virus and neuraminidase (Lukosaityte 2022).

10.7. FOOT AND MOUTH DISEASE

Foot and mouth disease is a highly contagious illness with the potential for transmission among susceptible animals (Paton et al. 2009). Effective vaccination can be employed for managing FMD outbreaks in FMD-free zones. Elevated levels of nanobodies targeting specific serotypes have been utilized in research by combining them with semiconductor nanocrystals and hydroxyl magnetic flux (Dubé et al. 2009; Chakravarty 2021).

10.8. RABIES

The rabies virus belongs to the group of negative-sense RNA viruses, within the family Rhabdoviridae, causing a fatal neurological disease known as rabies, which affects mammals (Suschak 2019). To reduce the impact of the rabies virus, the World Health Organization recommends administering the rabies vaccine along with local administration of human or equine rabies immunoglobulins in the event of severe bleeding wounds (Keshwara et al. 2019). In the case of intralingual rabies infection models in rats, the combined action of VHH and immunization has shown a symbiotic response in providing defense. However, the primary challenge in treating or managing rabies lies in the neurotropic nature of the rabies virus, making it difficult to access once it has entered the central nervous system (Kakooza-Mwesige et al. 2019). At this stage, only molecules capable of crossing the blood-brain barrier and penetrating nerve cells can effectively inhibit the infection (Moodley et al. 2015).

11. CONTROL OF ZOONOTIC DISEASES

Zoonosis poses a significant global health threat (Contini et al. 2020). Approximately 55-65% of human diseases are infectious, with about 80% of these being zoonotic (Spielman et al. 1985). Managing zoonotic diseases involves understanding the interactions between humans, animals, and the environment, necessitating coordinated efforts across various government sectors to implement effective control measures (Sallnow et al. 2022). Vigilant monitoring is crucial to prevent and control zoonotic diseases, enabling the timely detection of toxins, affected individuals, animals, carriers, and infectious areas, thus curbing their spread (Jerolmack 2008). This approach facilitates the adaptation of management strategies to tackle emerging and recurring diseases, improving both human and animal health outcomes, controlling diseases effectively, and reducing morbidity and mortality rates (Suckow et al., 2023). Various forms of surveillance can be employed for the control of zoonoses (Foreman et al. 2017)

• Microbial inspection is used to identify and differentiate various microbes (Benskin et al. 2009).

• Pre-symptomatic investigation aims to detect the presence of microbes in the blood plasma of both humans and animals by observing the immune response (Shurtleff 2015).

• Disease inspection helps to monitor disease trends through data analysis based on symptoms, although it may not always detect the presence of specific microbes (Jung et al. 2022).

• Threat inspection is utilized to identify potential points of transmission for disease spread (Benedict 2008). These control strategies may not fully address the intricate characteristics of certain chronic diseases (Cascio et al. 2011).

To prevent and manage epidemic diseases like zoonotic diseases, international organizations and observers have emphasized the interconnectedness of humans, animals, and the environment, introducing the concept of the One Health theory (Nierenberg 2005). This theory aims to comprehensively understand global health challenges. By promoting collaboration among veterinarians, paramedics, agronomists, virologists, ecologists, immunologists, and public health authorities, the One Health theory ensures holistic well-being for animals, humans, and the environment (Okello et al. 2014). The pet lovers and animal owners have to fallow the treatment and vaccination instruction mention in Fig. 2.

Fig. 2: Treatment and Vaccination Instruction for Animal Owners.

12. CONCLUSION

Healthcare workers' bags can carry germs, particularly for women who often place their bags on shelves and tables without cleaning them. It's crucial to clean bags, especially those made of fabric, daily. White coats, commonly worn in hospitals, can also spread germs and should be regularly washed and replaced every year. Mobile phones are another potential source of disease transmission, and regular cleaning of both phones and hands can help prevent the spread of germs. Similarly, drink cans should be cleaned before use, just like how we clean fruit baskets. Cars can also harbor germs, and using a silver ion coating can be effective in killing them. Scientists are currently researching nanoparticles as potential for the treatment of bacterial, viral and parasitic zoonotic diseases.

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Foodborne Pathogens in Poultry: A Public Health Concern

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ABSTRACT

Foodborne pathogens are one of the major risks in poultry meat industry due to its worldwide prevalence and public health significance. These infections, which come from the intestinal tracts of animals, contaminate chicken during processing and pose serious concerns when consumed. By identifying key control points and establishing safety thresholds, Hazard Analysis and Critical Control Points (HACCP) offer a systematic approach that is frequently used to manage these hazards across the food chain. However, different farm sizes and a lack of research provide challenges to the use of HACCP, particularly at the farm level, impeding its widespread acceptance. This chapter focus on these concerns that requires proactive measures within the meat sector. The use of antibiotics, especially gentamicin, successfully lowers the number of germs, but at high doses, it raises questions concerning fertility. Treatments like hydrogen peroxide and phenol dips show potential in reducing the number of bacteria in eggs. Reducing the spread of germs requires maintaining hygienic poultry facilities, strict disinfection procedures, and strong security measures. Using ingredients like sodium dodecyl sulphate, lactic acid, and citric acid throughout the meat processing process helps stop the spread of pathogens.

Multifaceted interventions are necessary to support poultry safety, even as HACCP standards and cleanliness measures do. Pre- and probiotics, organic acids, and essential oils can be used in conjunction with bacteriophages that target infections to potentially combat Salmonella and E. Coli. The goal of genetic engineering is to provide hens disease resistance. Germ transmission can be efficiently stopped by control techniques such as clean egg production, strict disinfection procedures, and avoiding semen contamination. To promote safer chicken production and reduce the significant hazards to the public's health presented by foodborne illnesses linked to the consumption of poultry, a comprehensive strategy incorporating HACCP principles, hygiene standards, antimicrobial treatments, and genetic interventions is essential. However, more study and coordinated work will be required to standardize and apply these controls to all aspects of chicken production.

Key words: Foodborne Pathogens, Salmonella, Campylobacter, Poultry Meat. HACCP, Antimicrobial Treatments

CITATION

Tahir MA, Park SH, Anwar MI, Bilal RM, Hussain K, Abbas A, Rehman A, Ghumman NZ, Muneeb M, Mushtaq F, Sugiharto S and Raza MA, 2023. Foodborne pathogens in poultry: a public health concern. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 447-458. https://doi.org/10.47278/book.zoon/2023.034

CHAPTER HISTORY Received: 12-June-2023 Revised: 07-Aug-2023 Accepted: 14-Nov-2023

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1. INTRODUCTION

Foodborne pathogens pose a significant threat to public health, causing millions of cases worldwide each year (Pal and Ayele 2020). Among the various sources of foodborne diseases, poultry meat stands out as a major concern due to its potential to harbor and transmit pathogenic bacteria such as *Campylobacter*, *Salmonella*, and pathogenic *Escherichia coli* (Zhao et al. 2001). These bacteria colonize the digestive tracts of animals, including those raised for human consumption, and can contaminate poultry meat at multiple stages of processing along the food supply chain.

The transmission of foodborne pathogens from poultry to humans occurs through various routes. One of the primary pathways is the consumption of contaminated meat. During the slaughter process, the removal of the gastrointestinal tracts (GIT) can lead to the cross-contamination of carcasses with *Campylobacter* and *Salmonella* (Rasschaert et al. 2008; Zhang et al. 2018). Additionally, improper handling, processing, or storage of poultry meat can contribute to the transmission of these pathogens as well. Poor hygienic practices of workers, inadequate storage conditions, and lack of preventive measures further increase the risk of microbial contamination, particularly in regions with limited resources (Hafez 1999).

Moreover, direct contact with live birds, such as handling or cleaning their coops, can also result in the transmission of foodborne pathogens to humans (Nichols et al. 2018). *Salmonella*, for instance, can colonize the intestinal tracts of live birds without causing noticeable symptoms, posing a risk to those in close contact. Furthermore, eggs from infected poultry can serve as a potential source of foodborne pathogens, either through contamination of the eggshell or the presence of the pathogen in the yolk or white (Isa 2023). Nevertheless, proper food handling, adherence to hygienic practices during food processing and cooking, and effective prevention measures can significantly reduce the risk of transmission.

The transfer of *Salmonella*, *Campylobacter*, and *E. coli* from poultry meat to humans poses a significant and ongoing public health threat. These three foodborne pathogens are commonly found in poultry and can cause a range of illnesses with varying degrees of severity (Zhao et al. 2001).

Salmonella transmission in humans can result in Salmonellosis, a gastrointestinal disease characterized by symptoms such as diarrhea, abdominal cramps, and fever. In severe cases, *Salmonella* infection can lead to hospitalization, especially in vulnerable populations, including young children and individuals with compromised immune systems (Wibisono et al. 2020). The potential for transmission is particularly high if poultry meat is not handled, stored, or cooked properly.

Similarly, *Campylobacter* is a leading cause of bacterial gastroenteritis worldwide, and poultry is a primary source of infection. Campylobacteriosis can result in diarrhea, abdominal pain, and fever. In some cases, the infection can lead to more severe complications such as Guillain-Barré syndrome (Acheson and Allos 2001). The transmission of *Campylobacter* to humans often occurs through the consumption of undercooked or cross-contaminated poultry meat.

E. coli, particularly certain strains such as toxin-producing *E. coli* can also pose a serious health risk when transmitted from poultry meat to humans. Infections with pathogenic *E. coli* can cause bloody diarrhea, abdominal cramps, and in some cases, progress to a severe condition called hemolytic uremic syndrome (HUS) which can lead to kidney failure (Stromberg et al. 2017). Poultry products contaminated with these strains can result in outbreaks of foodborne illnesses, underscoring the importance of preventing their transmission.

The public health threat associated with these foodborne pathogens from poultry meat to humans emphasizes the need for comprehensive control measures. These include strict adherence to food safety practices along the entire poultry production and supply chain, from farm to table. Proper cooking, storage, and handling of poultry meat are crucial to minimize the risk of infection. Additionally, robust surveillance, effective sanitation procedures, and appropriate vaccination strategies in poultry flocks can significantly reduce the prevalence of these pathogens (Dórea et al. 2010). By addressing the public health threat posed by these foodborne pathogens, we can protect individuals and communities from the debilitating effects of these infections and promote a safer food environment for all.

In this chapter, the transmission and control of foodborne pathogens in poultry is discussed. By understanding the routes of transmission and implementing effective control measures, we aim to enhance public health by reducing the incidence of foodborne illnesses associated with poultry consumption. Through comprehensive research and analysis, we explore various strategies to combat foodborne pathogens, highlighting the significance of good farming practices, vaccination, hygiene protocols, and other preventive measures. By combining these approaches, we can strive towards a safer and healthier poultry industry that safeguards consumer well-being.

2. FOODBORNE PATHOGEN TRANSMISSION

There are various ways that meat from animals or birds might spread foodborne diseases to people. Foodborne pathogens like *Campylobacter*, *Salmonella*, and pathogenic *E. coli* have colonized the digestive tracts of several wild and domestic animals, notably those produced for human consumption (Zhao et al. 2001). Along the whole food supply chain, these bacteria have the potential to contaminate food at many stages, including manufacturing, processing, distribution, retail marketing, and handling or preparation. According to several epidemiological studies, consuming foods obtained from animals is a significant risk factor for developing foodborne diseases (Petersen and James 1998).

Poultry is thought to be a major asymptomatic carrier of these pathogenic diseases. The removal of the GIT during slaughtering is one of the most significant causes of the cross-contamination of the carcass with *Campylobacter* and *Salmonella* (Mir et al. 2015). However, the predominant route of foodborne disease transmission from poultry to humans is through the ingestion of contaminated meat. The contamination can occur during slaughtering, processing, or storage of the meat (Hafez 1999). A study conducted in Africa discovered that poor hygienic practices of poultry meat handlers, as well as the sale of carcasses without cold storage or prevention from dust and flies, increased the risk of microbial contamination of meat, particularly with foodborne pathogens such as *Campylobacter* and *Salmonella* (Kagambèga et al. 2018). Moreover, factors like improper storage conditions, for example storage for prolonged period, also favors the microbial growth in meat and make it unsafe for human consumption (Taulo et al. 2008).

Furthermore, the transmission of foodborne pathogens from poultry to humans can take place in several other ways. For example, direct contact with live birds, such as handling them or cleaning their coops can also lead to transmission of foodborne pathogens to humans. This is particularly relevant for *Salmonella*, which can colonize the intestinal tract of live birds without causing any symptoms (Contreras et al. 2016). Moreover, in addition to meat, eggs from infected poultry can also be a source of foodborne pathogens.

This can occur when the eggshell is contaminated with pathogens or pathogens are present in the yolk or white (Pui et al. 2011). However, by proper food handling, good hygienic practices during food processing and cooking can help to reduce the transmission risk of these foodborne pathogens.

3. SIGNIFICANCE OF PUBLIC HEALTH

Each year the increasing food borne diseases are causing a huge economic and health losses around the globe. The WHO states that annually 30% of the population of developed nations suffers from food-borne illnesses and it is estimated that up to 2 million people die from these illnesses each year in developing nations (Abebe et al. 2020). Moreover, majority of the milk and meat associated foodborne illness effects about 10 to 30% population of the world annually (Grace et al. 2020). While, the causalities associated with foodborne infections result in harmful consequences on the health of individuals, resulting in conditions including cancer, immune system damage, and even death (Gibb et al. 2019).

The necessity for the meat sector to pro-actively handle food safety concerns that might harm the perception of dairy products is highlighted by growing public knowledge regarding the safety of food. Poultry meat producers must assess every step of their processing processes, including the procurement of raw meat to increase the food safety of their products (Boor 2001).

The necessity of implementing a system at the farm level to guarantee the safety of the meat is indicated by the importance of raw meat to the meat industry (Valeeva et al. 2005). The acknowledged significance of an integrated chain strategy to enhance food safety throughout the whole chain is another problem that places a lot of focus on the farm level (Valeeva et al. 2004).

Practices used in agricultural production, such as enhancing food safety, have been affected by the General Food Law. Farmers must use a range of control methods that might improve the safety of meat to satisfy the needs of the meat business and the requirements of European laws. It is crucial for farmers to discover cost-effective methods to improve food safety because such measures have a cost that is typically not covered by a higher product price (Communities 2000). The few studies that have been conducted to estimate the cost of making poultry products safe to consume mainly focus on the entire meat industry. At the farm level, only a small number of animal hygiene operations' costs have been calculated (Sakamoto 2007).

One of the largest concerns about their implementation at the farm level is how cost-effective the majority of controls are for improving the safety of the farm. There are very few studies that assist farmers in selecting the most cost-effective set of control measures to achieve a specific level of food safety (Cullor 1997). Farms have the greatest size diversity among other significant chain members, which is particularly true for research looking at dairy farms as players in the complete chain, while, the previous research has looked into the costs associated with improving food safety in meat processing industries (Dorn and Bachmann 2000).

4. MICROBIAL THREAT

Several diseases have either been newly characterized or linked to foodborne pathogen transmission in the recent 20 years. For instance, Pink hamburger consumption was positively associated with sporadic *E. coli* O157 cases in an American matched case-control study, according to (Kassenborg et al. 2004). Acute gastroenteritis following consumption of raw or undercooked shellfish, invasive septicemia following consumption of raw or undercooked shellfish, primarily oysters, and necrotizing wound infections following marine exposures and injuries have all been linked to the highly virulent Vibrio vulnificus organism (Hiransuthikul et al. 2005; Finkelstein and Oren 2011; Diaz 2014).

Listeria monocytogenes is a foodborne pathogen that may be found in a variety of foods (Ryser and Marth. 2007). The condition known as listeriosis, which can manifest as sporadic infections or disease outbreaks with a large mortality rate of 20-30% worldwide (Buchanan et al. 2017), is consequently caused by L. monocytogenes, a prominent foodborne pathogen. Depending on the patient's age, immune system, the quantity of ingested bacteria, and the strain's virulence characteristics, human infection can take one of three different forms: severe moderate invasive listeriosis, non-invasive febrile gastroenteritis. A total of 1,876 confirmed cases of invasive listeriosis in humans were reported in the member states of the European Union in 2020, with a notification rate of 0.42 cases per 100,000 people and 97.1% hospitalisations, according to the most recent common report from the European Food Safety Authority (EFSA) and the European Centre for Disease Prevention and Control (ECDC) (EFSA and ECDC 2021).
Chicken and raw milk are frequent causes of intermittent outbreaks of *Yersinia enterocolitica*, which causes diarrhea (Rahman et al. 2011). It is also commonly linked to undercooked pork (Fosse et al. 2008). Although more than 40 microorganisms are known to cause food poisoning, there are still many cases that need to be answered in terms of the causative organism(s) and the pathways of contamination. Another significant characteristic of these diseases is their tendency for fast epidemic spread, leading to a pandemic scale and for reasons that are occasionally yet unknown (Baines et al. 2005).

5. FOOD SAFETY STRATEGY

Hazard Analysis and Critical Control Points (HACCP) represents an approach to food safety. Systematically employing preventive strategies to safeguard both food products and consumers against potential chemical, physical, and biological hazards, or contaminants. Its application is primarily observed during production and post-production stages, ensuring the absence of contaminants that could compromise the safety of the end products. Moreover, it devises measures to mitigate contamination risks to a safe level (Motarjemi et al. 2023).
The main foundation of HACCP methods to food safety is a rigorous study of supply chain risk. Since it can be used to a variety of supply scenarios, it is very simple to implement and popular as the most often used safety management method. It enables the pre-planning of food safety measures for the intended prevention, control, and reduction of possible issues in a range of settings. As a result, it has completely changed how developed and developing nations handle food safety (especially in food production). Some people view HACCP as the "gold standard" method to regulate food safety (Woteki et al. 2004). According to claimed cost-effectiveness, the HACCP is also favored by many in the food business as the best safety solution. HACCP has generally been endorsed by the government and regulators as the most effective risk-based prevention-focused system, but mostly outside the farm gate.
The linkage between HACCP and food safety is integral, as the correct implementation of HACCP is imperative to ensure the safety of food. Consequently, HACCP's core objective revolves around hazard prevention rather than post-production hazard detection or presence inspection; it's fundamentally a preemptive strategy for upholding food safety (Awuchi et al. 2021; Morya et al. 2022).
The HACCP framework finds application across all phases of the food supply chain, spanning initial food preparation, production processes, and subsequent post-production handling, encompassing aspects like sourcing raw materials, production, packaging, storage, distribution, and more. Various regulatory bodies governing food safety in different countries mandate the obligatory adoption of distinct HACCP programs tailored to specific food categories, such as meat, juice, dairy items, infant formula, seafood, canned goods, and others. This requirement seeks to ensure comprehensive food safety, safeguard public health, and mitigate the occurrence of foodborne illnesses (Njunina 2022).

To minimize possible contamination by *Salmonella* and *Staphylococcus* in particular, HACCP was pioneered in space initiatives in the 1960s to prevent microbial contamination in food needed for extended space flight. The Pillsbury Company raised awareness of it among the public in 1971 at the National Conference of Food Production in the United States (Woteki et al. 2004). The Food and Drug Administration was prompted by a botulism outbreak in the USA caused by tainted canned soup. HACCP for safety management was endorsed by the National Academy of Sciences (NAS) in the USA in 1985, and the Codex Alimentarius Commission subsequently started using it more often globally. HACCP requirements must be implemented as a mandated system in meat and poultry slaughter facilities. Later, it was used in the production of fruit juice (Minor et al. 2017).

6. IMPLEMENTATION OF HACCP FOR FOOD SAFETY MANAGEMENT

The initial step is to initiate a hazard analysis, encompassing the development of a strategy to assess potential hazards to food safety. This requires the identification of preventive actions to manage these hazards effectively (Vu-Ngoc et al. 2018; Mureşan et al. 2020). A food safety hazard is defined as a tangible, biological, and/or chemical characteristic capable of rendering food unfit for consumption.

A critical control point (CCP) refers to any stage, process, or juncture within the production process where intervention is viable to avert or eradicate food safety risks, or at the very least, curtail them to an acceptable threshold. To establish a critical control point, the subsequent query proves valuable: during this preparation phase, is there potential for food contamination, or does the likelihood of contamination rise exist? (Mureşan et al. 2020; Maina et al. 2021).

The critical limit signifies the lowest or highest point to which a chemical, biological, or physical peril needs to be regulated at a critical control point (CCP) for the purpose of averting or eradicating the hazard, or, at the very least, diminishing it to a level deemed acceptable Supervision is essential to ensure that the process remains regulated at each critical control point (CCP). It might also be necessary to outline the monitoring procedures and their frequencies within the HACCP plan. Elements that could be considered when formulating monitoring prerequisites for CCPs comprise: the volume of products susceptible to adverse effects if a deviation arises at a critical control point; the permissible divergence from the critical limit (Lithuania 2020; Maina et al. 2021).

There are obvious indications that certain governments, such as Australia (Baines et al. 2005) and the European Union (EFSA and ECDC, 2021), view the implementation of whole chain HACCP, including primary production, as the preferred method to identify food hazards, preventing, and subsequently managing food risks. However, it should be noted that Australia and New Zealand have yet to implement required HACCP for primary production. Furthermore, the Deputy Head of Animal Nutrition, DG26 has stated that the political will to implement this in the EU appears to be under growing pressure. It is said that basic manufacturing will not be covered by HACCP. Regardless of where HACCP should start in the food chain, many countries believe that the food sector is ultimately responsible for adopting HACCP, with regulatory inspection serving at most as a means of consumer monitoring or supervision. Some governments, including those in the USA, are worried about food security because of potential terrorist operations (Azevedo 2003).

7. TREATMENT PROTOCOLS

During various handling phases, food is regularly contaminated with different pathogens. The contamination of foods by pathogens can result food poisoning which range from mild symptoms to more significant consequences. To the best of the world's knowledge, red meats, poultry, and seafood have been observed to be more likely to result in illness than fruits and vegetables (Noor 2019).

Symptomatic treatment may be used to alleviate symptoms like pain, fever, vomiting and diarrhea. In adults with uncomplicated acute diarrhea, symptomatic therapy with bismuth subsalicylate and loperamide may be taken into consideration (Riddle 2019). Despite the fact that loperamide drug is more efficient than that of bismuth subsalicylate; it may not be advised for patients suffering from hematochezia due to the possibility of invasive illness.

Antiemetics drugs can minimize the severity and symptoms of the illness and can avoid need for hospitalization in patients who have been diagnosed with substantial vomiting (Decamp et al. 2008). Numerous studies back the administration of one dosage of ondansetron to kids experiencing vomiting due to gastroenteritis (Ramsook et al. 2002). It is reasonable to use antiemetics in adults with gastroenteritis; however, there is a lack of information on potential side effects.

Oral rehydration therapy has been shown to be successful in treating diarrhea-related dehydration. Dehydration may be prevented and treated in individuals of all ages, according to research (Guerrant et al. 2001). World Health Organization and the American Academy of Pediatrics have released guidelines that advise using rehydration treatment for mild level to severe dehydration in newborns. A combination of electrolytes and carbohydrates are present in oral rehydration solutions. Sports drinks and soft drinks can make diarrhea worse since they have a high osmolality.

Empiric antibiotics can be used if the patient is suspected for having a foodborne illness and shows symptoms of a similar disease. Inappropriate use of empiric antibiotics may increase morbidity. The standard recommendation for empiric antibiotic therapy is fluoroquinolone or sulfamethoxazole/ trimethoprim in pediatrics. Traveler's diarrhea exists globally and can be caused mostly by E. coli; it is mostly treatable using ciprofloxacin. However, the use of azithromycin can be proven to be a better option when fluoroquinolone-resistance is present (Adachi et al. 2003).

Once the laboratory findings about stool culture, bacterial toxin and microscopy are available, specific and targeted antibiotic should be recommended. In older adults, neonates, and patients with impaired immune systems, the use of targeted antibiotic therapy may reduce the severity of disease and hence bacteremia can be prevented.

8. ONE HEALTH APPROACH

There are several foodborne pathogens that contaminate poultry, but *Salmonella*, *Campylobacter* and *E. coli* are commonly known pathogens. These disease-causing pathogens are often carried in the animal's intestine asymptomatically, but they can be passed into feces and transmit to other animals, products, or humans via vectors. These vectors include birds, vermin, insects, humans handling the animals, contaminated feed and water sources, and direct contact with droppings. Through a variety of interventions including the genetic selection of animals resistant to colonization, application of various treatment protocols to prevent vertical transmission of enteric pathogens, sanitation practices to minimize the risk of contamination on the farm, disinfection of transportation vehicles, elimination of pathogens contaminating the food and water sources, food additives that make it difficult for the pathogen to colonize, and biological treatments, the contamination with foodborne pathogens in poultry has been reduced (Doyle and Erickson 2006).

9. USE OF ANTIMICROBIALS

To reduce bacterial cell count, without having an adverse effect on fertility, several antibiotics can be effective including gentamicin. However, the concentration of specific antibiotics required to prevent bacterial growth can be harmful for fertility. To control pathogen contamination of chicks to be hatched, antimicrobial dips can be used to sanitize egg surfaces. *Salmonella* positive eggs can be treated with a single dip in the solution of hydrogen peroxide and phenol; however, three dips in the same solution could be more efficacious. The incidence of contamination with pathogens in poultry can be minimized by ensuring clean housing and proper disinfection of water supply lines and other utensils. Minimizing exposure of flocks to wild animals, restriction of traffic at farms, implementation of personal sanitation protocols and clean transport of equipment are the precautionary measures that can decrease the chances of pathogen attack. Decontamination treatment protocols can be applied on poultry transport containers, but they should be validated for their efficacy before use. Immersion of transport containers in water at 60 to 70°C temperature for 30 seconds is effective in reducing coliforms rather than using high pressure jet spray treatments (Ramesh et al. 2004).

Cross-contamination of chicken carcasses during poultry slaughter can happen because of insufficient disinfection and direct contact with infected tools. The usage of disinfectants is a popular method for lowering the danger of cross-contamination during meat processing. The disinfectants such as citric acid, lactic acid, and sodium dodecyl sulphate are tested for their efficacy against *Salmonella* and *Campylobacter* and proved highly effective, especially when used in combination (Bai et al. 2022).

10. GOOD MANAGEMENT PRACTICES

In addition to good farming and meat processing practices, strict adherence to HACCP principles, regular testing and monitoring, training of workers and consumer awareness can result in pathogen free poultry products and decreases the incidences related to foodborne infections. Strict biosecurity controls might prevent the disease from entering commercially raised flocks (Fraser Robert et al. 2010). Because *Campylobacter* is abundant in wild and domestic animals and the environment, it is critical to limit the contamination of chicken-raising units from such sources. Installing hygienic roadblocks between the outside and the inside, such as controlling farm personnel entry and strict hygienic routines such as hand washing and sanitizing, and changing boots and coveralls before entering, has been shown to be effective, but these barriers are frequently breached (Humphrey et al. 2007). Keeping optimal environmental conditions within the poultry house (air quality, temperature, or stocking density), as well as maintaining an excellent health status and implementing a novel vaccination strategy, reduce the danger of predisposing variables that often trigger E. coli infections (Barnes et al. 2008).

11. ROLE OF BACTERIOPHAGES IN FOOD SECURITY

Bacteriophages' primary role is to replicate bacteria by utilizing the genetic material and bacterial structures that they have introduced to create copies of themselves. Bacteriophages also connect to bacteria through surface receptors on the cell membrane. This permits the phage to invade the bacterial cell, causing the replication, transcription, and translation machinery to malfunction (Janez Nika and Catherine Loc-Carrillo 2013). Bacteriophages are, therefore, parasitic viruses that may be employed to target and destroy specific bacterial pathogens while leaving the surrounding microbiota unharmed. Phages have been proposed as potentially effective solutions for controlling foodborne pathogens such as *Campylobacter* (Moye Zachary et al. 2018).

12. USE OF PRO AND PREBIOTICS

However, the use of prebiotics and probiotics, such as complex polysaccharides and lactic acid bacteria strains, has shown some potential (Hariharan et al. 2004). The use of bacteriocin-producing bacteria (e.x.

Paenibacillus polymyxa) or bacteriocins has demonstrated certain potential and requires further investigation (Stern Norman et al. 2005). Probiotics and prebiotics have been shown to be effective against *E. coli* (Patterson and Burkholder 2003). Certain essential oils have also been shown to lower the amount of *E. coli* in the gut (Hammer et al. 1999). A study investigated the antibacterial activity of 16 essential oils against *E. coli* isolates derived from chicken and found that at least 5 oils had excellent activity (Ebani et al. 2018).

13. USE OF ORGANIC ACIDS

Acidifiers or organic acids can reduce the amount of *E. coli* by modifying the intestinal pH to limit the metabolism of intestinal pathogens, as well as by regulating the population of helpful bacteria (Khan and Javid 2016). Another study found that the use of a mixture of formic, acetic, and propionic acids helped to reduce the amount of *E. coli* that was resistant to the antibiotic's ampicillin, tetracycline, ciprofloxacin, and sulfamethoxazole. The risk of new hatched birds is significantly reduced by good hygienic practices in the hatchery. A basic step in reducing hatchery infections is to reject dirty eggs with a high number of coliforms on their outer shell. Spraying disinfectants over hatched eggs lowers *E. coli* contamination of the egg surface (Roth Nataliya et al. 2017).

14. GENETICISTS APPROACH

Genetic alterations were discovered in chicken after *S. Enteritidis* vaccination. To get genetic resistance against enteric pathogen infections, genetic lines have been suggested that targets genes to regulate the host's response to pathogens (Malek et al. 2004). The discovery of unique genetic procedures that regulate bacterial burden in the spleen and cecum, however, complicates this objective. *Salmonella* and *Campylobacter* have both been proved to transmit vertically from parent flocks to offspring. During semen collection, semen can be contaminated with debris, and insemination with this affected semen can transmit the pathogens in chicken and their eggs (Donoghue et al. 2004).

15. CONCLUSION

Foodborne pathogens can cause foodborne illness outbreaks in humans and pose serious threats to poultry. To stop and limit the spread of diseases along the production and processing chain, the poultry sector must put strict measures in place. To combat the spread of foodborne pathogens in chicken products, it is important to implement effective monitoring, sanitation, and hygiene procedures. To further ensure the protection and quality of chicken products before they reach consumers' plates, regular testing and adherence to food safety rules are essential. In order to remain abreast of changing foodborne risk factors, further research and breakthroughs in pathogen detection and mitigation techniques are required. The chicken business can greatly lower the occurrence of foodborne illnesses and protect public health by implementing proactive measures and remaining diligent in resolving food safety concerns.

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Impact of Zoonotic Diseases on Pregnant Women

35

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ABSTRACT

This chapter investigates the relationship between zoonotic diseases and pregnant women, addressing the complex implications for maternal and fetal health. The introductory section highlights the prevalence of interactions between animals and humans as well as the possible hazards associated with zoonoses. The chapter defines zoonotic diseases and provides examples of over 200 cases of various infections. A particular focus is placed on the modalities of transmission, emphasizing the intricacy of vector-borne transmission, foodborne routes, direct and indirect contact, and airborne distribution. With a focus on the possible effects of antibiotic usage in food-producing animals, antimicrobial resistance appears as a complicated concern in the prevention of zoonotic diseases. This study examines the increased vulnerability of expectant mothers to zoonotic diseases, considering the immunological modifications that occur throughout pregnancy. A significant aspect of this chapter is the in-depth analysis of specific zoonotic diseases, including Toxoplasmosis, Listeriosis, Q Fever, and Plague. These sections clarify the causative agents, modes of transmission, and the profound impact on pregnant women and their developing fetuses. Case studies give real-world context, emphasizing the challenges in diagnosis and implications for public health policies. The global incidence and trends of zoonotic diseases are scrutinized, with an emphasis on regional variations and emerging infectious threats. The prevalence of zoonoses in different geographical locations is discussed, considering the ecological conditions and human-animal interactions that contribute to disease spread. This chapter concludes by supporting a One Health approach, recognizing the link between human, animal, and environmental health. It underscores the importance of understanding physiological changes during pregnancy, the risks to the developing fetus, and the imperative of preventive measures. It also contributes to a holistic understanding of the complex dynamics of zoonotic diseases in pregnant women and underscores the global collaboration required for effective prevention and control.

Key words: Zoonosis, Zoonotic diseases, Pregnancy, Pregnant women, Fetus, Antimicrobial resistance, One Health, Physiology

CITATION

Rasheed M, Rasul A, Imran U, Ali M, Iqbal F, Gul M, Hussain M, Nasir MF, Abrar Awan HM, Maqsood MA and Gillani A, 2023. Impact of Zoonotic Diseases on Pregnant Women. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 459-469. https://doi.org/10.47278/book.zoon/2023.035

CHAPTER HISTORY Received: 10-Jan-2023 Revised: 25-July-2023 Accepted: 23-Aug-2023

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1. INTRODUCTION

Animals provide many benefits to humans. Many people interact with animals daily, both at home and in the outside environment. Millions of households have pets. Many people are connected to animal husbandry. Humans cannot avoid contact with animals as they are essential parts of their lives. However, animals can sometimes carry harmful germs that can spread to people and cause illness – these are known as zoonotic agents. They can cause many types of illnesses in people and animals, ranging from mild to serious illness and even death. Animals can sometimes seem healthy, but they carry germs and spread diseases in humans, depending on the zoonotic disease (Cross et al. 2019).
Infections that can spread spontaneously between animals and people are called zoonotic illnesses or zoonoses. There are almost 200 known zoonotic diseases. Various pathogens, including bacteria, viruses, parasites, and fungi can bring on these illnesses. Some examples of zoonotic disease include Rabies, Psittacosis, Blastomycosis, Histoplasmosis, Trichinosis, Coccidiomycosis, and many intestinal illnesses acquired from animals i.e., birds and reptiles transfer salmonella to humans. They pose serious health concerns to expectant mothers and their growing fetuses. To protect maternal and fetal health, it is essential to comprehend how zoonotic infections affect pregnant women (Chowdhury et al. 2021).

1.2. DEFINITION OF ZOONOTIC DISEASES

Zoonotic diseases are contagious illnesses that can be spread directly or indirectly from animals to people. These illnesses may be spread by several means, such as contact with sick animals, ingesting tainted food or water, or coming into contact with vectors like ticks and mosquitoes. Rabies, toxoplasmosis, brucellosis, and influenza are only a few examples of common zoonotic diseases. Some zoonotic diseases, i.e., Q fever, Anthrax, Brucellosis, and plague may fall in the category of Bioterrorism diseases. This is because there is some evidence of these diseases being used as bioweapons, depending on the ease of spread and severity of illness and death they can cause. Some diseases, for instance HIV, started as zoonosis but later mutated into human-only strains. Other zoonoses can cause repeated disease outbreaks, such as salmonellosis and Ebola virus disease.
Antimicrobial resistance is a complicated factor in the prevention and control of zoonoses. The use of antibiotics in animals breed for food raises the potential for drug-resistant strains of zoonotic pathogens capable of spreading quickly in humans and animals.
These diseases pose a serious threat to the public's health due to the variety of zoonotic infections and their modes of transmission. Due to physiological changes that can influence a woman's immune system and make her more susceptible to certain diseases during pregnancy, pregnant women are thought to be more sensitive to zoonotic infections.

1.3. IMPORTANCE OF STUDYING ZOONOTIC DISEASES IN PREGNANT WOMEN

For many reasons, it is crucial to research how zoonotic illnesses affect expectant mothers. First, pregnant women undergo special immunological changes throughout pregnancy that make them more prone to specific infections. Further, zoonotic illnesses can infect the growing fetus by breaching the placental barrier, resulting in unfavorable consequences such as congenital abnormalities, stillbirths, preterm births, or low birth weight (Aslan and Balaban 2020).

Many women, especially Asian and African women are not even aware of the zoonoses and their effect on their fetus due to the lack of education and poor medical system in these continents. Women doesn't undergo proper checkups during pregnancy. Due to this, many zoonoses that doesn't show any significant symptoms or even are asymptomatic, cause serious mental, physical, and physiological issues in the developing fetus and even cause death. As almost all zoonoses can be treated if detected at an early stage and both mother and fetus can be saved from long lasting damaging effects. It is necessary to research the cause, effects and the prevention and the treatments of zoonoses. This study will provide knowledge about the zoonoses, how they transfer to humans, how they pose serious threats to pregnant women and are fetal to their fetus, and how it is prevented and treated (Aslan and Balaban 2020).

Developing preventive measures and suitable medical interventions can be made easier by being aware of the hazards posed by zoonotic infections during pregnancy. Furthermore, early diagnosis of zoonotic illnesses in pregnant women and recognition of their symptoms might lead to better maternal and fetal health outcomes (Aslan and Balaban 2020).

1.4. OVERVIEW OF THE CHAPTERS STRUCTURE

This chapter is set up to give a thorough overview of how zoonotic illnesses affect expectant mothers. We will start by looking at specific zoonotic illnesses, such as toxoplasmosis, listeriosis, and Q fever, which seriously harm pregnant women. We will examine the causes, methods of transmission, potential effects on both the mother and the fetus for each condition, and its preventions and treatments.

The incidence and trends of zoonotic diseases in pregnant women worldwide will be examined, offering information on regional variances and newly developing infections. We will also talk about how important it is to take preventative steps, such as knowledge and good hygiene habits, to lessen the dangers connected to zoonotic illnesses during pregnancy.

Additionally, case studies will be included in this chapter to show actual instances of zoonotic infections in pregnant women and their results. In addition, the difficulties in diagnosing zoonotic infections that affect pregnant women and the ramifications for public health policy will be covered.

By the end of this chapter, readers will understand how zoonotic illnesses affect expectant mothers and the need for One Health strategy to address these issues successfully.

2. UNDERSTANDING THE ZOONOTIC DISEASE

2.1. DEFINITION AND EXAMPLE OF ZOONOTIC DISEASES

As was already noted, zoonotic diseases are infectious illnesses that can spread naturally between humans and animals. The word "zoonosis," which refers to the infection's animal origins, is derived from the Greek words "zoo" (animal) and "nosos" (disease).

These illnesses are caused by a wide variety of pathogens, including bacteria, viruses, parasites, and fungi, each with specific traits and modes of transmission. Zoonotic infections may impact many bodily systems and have clinical presentations that range from minor flu-like symptoms to serious, potentially fatal conditions.

2.1.1. EXAMPLES OF ZOONOTIC DISEASES INCLUDE

2.1.1.1. RABIES

A viral infection typically spreads to people through the bite of an infected animal, most frequently a dog, a bat, or other wild animal. Once symptoms manifest, rabies affects the central nervous system and is nearly invariably fatal.

2.1.2. TOXOPLASMOSIS

A warm-blooded animal infection brought on by the parasite Toxoplasma gondii that is frequently observed in cats. Humans become infected when they consume contaminated food or come into contact with infected cat feces. Because it can be passed on to the fetus during pregnancy, toxoplasmosis poses serious hazards.

2.1.3. AVIAN INFLUENZA (BIRD FLU)

A viral infection that mostly impacts birds, especially poultry. Rarely avian influenza viruses can translocate to humans, causing serious respiratory conditions and possibly igniting pandemic outbreaks.

2.1.4. BRUCELLOSIS

A bacterial infection spread to people by animals like sheep, goats, cattle, and pigs. The Brucella bacteria can enter the body by ingesting infected dairy products or through skin wounds.

2.2. MODES OF TRANSMISSION FROM ANIMALS TO HUMANS

Zoonotic diseases can be transmitted to humans through various routes, depending on the specific pathogen and its reservoir host. common modes of transmission include:

2.2.1. DIRECT CONTACT

direct physical contact with diseased animals or their bodily fluids, blood, saliva, mucus, urine, and feces that transfer to humans through contact with animals such as bites, scratches, or handling contaminated animals.

2.2.2. INDIRECT CONTENT

Contacts with contaminated objects or environments, such as contaminated water, soil, or surfaces. This has happened while roaming or living in the infected area or by handling contaminated objects. Pet baskets, chicken coops, aquariums, infected soil and pet water and food dishes can spread diseases to humans. Veterinary doctors, farmers and zoo workers are at high risk of developing zoonoses while handling animals or animals related objects. They can also transfer these diseases to other humans. Contaminated water resources through manure can also contain a wide variety of zoonotic parasites and therefore rise the risk of transferring it to humans.

2.2.3. VECTOR BORNE

Transmission through the bite of vectors like mosquitoes, ticks, or fleas that acquire the pathogen from infected animals and then pass it on to humans. Almost 17% of all infectious diseases are vector borne causing the death of more than 700000 people around the globe annually. Examples of vector borne diseases include yellow fever, malaria, dengue, zika virus transferred by mosquitos. Fleas can transfer plague and toxoplasmosis to humans and Lyme disease is transferred to human by ticks.

2.2.4. FOODBORNE TRANSMISSION

Ingestion of contaminated food products, especially undercooked meat, unpasteurized milk, or raw fuits and vegetables.

2.2.5. AIRBORNE TRANSMISSION

Inhalation of infectious particles (e.g., droplets or aerosols) expelled by infected animals or through close contact with their respiratory secretions.

2.3. COMMON SOURCES OF ZOONOTIC INFECTION

Certain animals act as primary reservoirs for zoonotic pathogens, and interactions with these animals or their by-products can lead to human infections. common sources of zoonotic infections include.

2.3.1. DOMESTIC ANIMALS

Pets like dogs and cats can transmit various zoonotic diseases to humans through bites, scratches, or exposure to their feces. Well known diseases transferred through dogs and cats are rabies, toxoplasmosis, scabies, and cat scratch disease.

2.3.2. LIVESTOCK

Animals raised for food production, such as cattle, pigs, and poultry, can be sources of zoonotic infections like Salmonella, E. coli, and brucellosis.

2.3.3. WILDLIFE

Wild animals, especially rodents, bats, and birds, can carry numerous zoonotic pathogens that pose risks to human health. Common among them are rabies and plague.

2.3.4. VECTOR

Mosquitoes, ticks, and fleas can act as vectors, transmitting zoonotic diseases from animals to humans. Among them are toxoplasmosis, Lyme disease, malaria, and dengue.

Understanding these modes of transmission and common sources of zoonotic infections is essential for preventing and controlling these diseases, especially in vulnerable populations such as pregnant women Mor and Cardenas 2010).

3. ZOONOTIC DISEASES AND PREGNANCY

Public health has been concerned about zoonotic illnesses, infections that can spread from animals to people. Due to physiological changes during pregnancy that can influence their immune systems and increase susceptibility to certain diseases, pregnant women are particularly vulnerable to zoonotic infections (Mor and

Cardenas 2010). Females generally manifest diseases differently than males because of the hormonal and anatomical factors. Social, cultural, and behavioral factors are also to be considered. For example, in many areas around the globe, women tend animal herds are more likely to get zoonoses like rift valley fever and Q fever. Likewise, women are more susceptible to get zoonoses who get pregnant after kidney transplantation. Zoonotic diseases are seen to be transferred from mother to fetus, if women get disease, it during pregnancy. West Nile virus encephalitis causes premature delivery with neonate having neurologic sequelae, which is transferred from mother to fetus. This zoonosis doesn't transfer through breast milk.

Toxoplasmosis, a zoonotic protozoal disease, cause of abortion of pregnant females, both humans and other animals worldwide. The infection may pass through the placenta and cause blindness, mental retardation, and encephalitis in a congenitally infected child. Cats and other felids are the only known host for this parasite. It transfers to humans by ingestion food or water contaminated by infected cat feces. Neosporosis, another zoonotic protozoal disease, causes abortion of both domestic and wild animals. Neosporosis hasn't been found to be transferred to humans.

Zoonoses pose serious threats to fetus when get transferred to mother and through mother to developing fetus. When left untreated cause severe infections during pregnancy that leads to mental retardation, low birth weight, preterm birth, learning problems and even fetal death. This review aims to investigate the susceptibility of pregnant women to infections, the physiological changes that affect susceptibility, and the dangers that zoonotic illnesses bring to the growing fetus.

3.1. VULNERABILITY OF PREGNANT WOMEN TO ZOONOSIS

Pregnancy causes special immunological condition in women that make them susceptible to infectious diseases. This the reason women are considered special population group. This concept creates a myth about pregnancy as a state of immunological weakness. But the studies show that pregnancy does not imply more susceptibility to infectious diseases, instead there is a modulation of the immune system which leads to differential responses depending on the stages of the pregnancy and on the microorganisms. Pregnant women are more susceptible to malarial infection during the first half of the pregnancy and the risk slowly drops during the second half.

Pregnancy puts the immune system through a complex process that involves immune system modification to stop the body from rejecting the growing fetus (Mor and Cardenas 2010). Pregnant women may be more susceptible to infections due to this modulation's potential reduction of immune responses to infectious pathogens. Progesterone and estrogen fluctuations during pregnancy also affect immunological responses, affecting how well the body can fight infections. Pregnancy-related physiological changes in the digestive and respiratory systems may also enhance an individual's susceptibility to infection (Smith and Mulvey 2018).

3.2. PHYSIOLOGICAL CHANGES DURING PREGNANCY THAT AFFECT SUSCEPTIBILITY

Dynamic physiological changes in the female body aid in the growth of the fetus. The heart pumps more blood to satisfy the needs of the fetus and placenta, increasing cardiac output, which may affect the movement of infectious pathogens through circulation (Smith and Mulvey 2018). The clearance of respiratory infections may be impacted by changes in lung function and ventilation brought on by the expanding uterus. Changes in renal function and hormonal changes may also impact the body's reaction to infections. Additionally, changes in the gut flora brought on by pregnancy may affect a person's susceptibility to gastrointestinal infections.

Due to these physiological changes, the pregnant mother becomes more susceptible towards certain infections caused by pathogens i.e., hepatitis E virus, malaria parasites, and influenza virus. All these

pathogens linked to zoonoses are known to pass from mother to fetus, causing significant health threats. Hepatitis E, a zoonotic disease, known to be transferred by eating undercooked meat of infected animals, cause more severe infections in pregnant women than non-pregnant women. Vertical transmission from mother to infant is also studied. It may cause fulminant hepatic failure and death in the patient. This severity of infections in pregnant women is known to be linked with hormonal changes especially progesterone and estrogen, during pregnancy that subsequently led to immunological changes (Smith and Mulvey 2018).
Stress is another factor that bring about physiological changes in pregnant women and indirectly affect the immunity of expected women. This increases the susceptibility towards infections. The relationship between stress and birth outcomes is unclear, but it may alter health behaviors such as sleeping pattern and eating. Sleeping and eating patterns are known to be linked with immune response and intensify the vulnerability of infections. Stress can also bring about hormonal imbalance, another factor in rising infections in pregnant women (Smith and Mulvey 2018).

3.3. RISKS TO THE DEVELOPING FETUS

Pregnant women who catch zoonotic illnesses run a severe risk to their growing fetus. Congenital infections and developmental abnormalities can result from certain zoonotic diseases that can pass through the placental barrier and directly infect the fetus (Liu et al. 2006). Preterm birth and low birth weight are risk factors for severe maternal sickness brought on by zoonotic infections and are linked to poor neonatal outcomes. Sometimes zoonotic infections can cause fetal death in utero, stillbirth, or neonatal death. Some zoonotic infections may have poor growth and development that affect the fetus's long-term health, manifesting later in life.
The placental outer membrane is made up of blastocysts, the specialized layer of cells called trophoblasts. Trophoblast is characterized by the regulation of blood and nutrient supply from mother to fetus. The permeable trophoblast plays a significant role in transferring infections from the mother to fetus. Toxoplasmosis, a systematic infection, during pregnancy can cause placental infections and affect the mother–child relationship. Placental membrane is specifically permeable towards Toxoplasma gondii. These zoonotic diseases then transfer from mother to fetus, causing serious health problems for the fetus i.e., mental retardations and even stillbirth. Infection in the later stage of pregnancy is asymptomatic but gives rise to neurological and retinal damage later in life. The severity of disease is also related to maternal immunosuppression commonly due to diseases like AID and diabetes and to some extent to placental damage. Clearly placenta plays a vital role in transmission and expression of infections in fetus.

4. ZOONOTIC DISEASES AFFECTING PREGNANT WOMEN

Zoonotic illnesses, or infections spread from animals to people, present serious hazards to expectant mothers and their growing fetuses. Toxoplasmosis, listeriosis, and Q fever are the three main zoonotic diseases this review of the literature analyses that afflict pregnant women. The review examines the causes, mechanisms of transmission, effects on expectant mothers and fetuses, and management techniques for pregnancy.

4.1. TOXOPLASMOSIS

4.1.1. CAUSATIVE AGENT AND TRANSMISSION THE PROTOZOAN PARASITE TOXOPLASMA GONDII

causes toxoplasmosis. Cats are the main hosts, excreting oocysts contaminating the soil and water. Humans can contract the virus by consuming oocysts from tainted food or water or by a mother's fetus vertically contracting it during pregnancy (Dubey 2010).

4.1.2. IMPACT ON PREGNANT WOMEN AND THE DEVELOPING FETUS

Pregnant women with toxoplasmosis may experience mild flu-like symptoms. If the infection is acquired while pregnant, it could seriously affect the fetus. Congenital toxoplasmosis can cause developmental defects in the baby, such as neurological deficits, visual issues, and other issues (McAuley et al. 2012).

4.1.3. PREVENTION AND MANAGEMENT DURING PREGNANCY

Avoiding contact with cat excrement, eating only properly prepared meat, and maintaining good hygiene are all preventive precautions. Additionally, pregnant women should refrain from gardening or handling dirt without gloves. Early detection and quick drug administration can help lower the chance of vertical transmission to the fetus (Holliman 2017).

4.2. LISTERIOSIS

4.2.1. CAUSATIVE AGENTS AND TRANSMISSION

The bacterium Listeria monocytogenes, which is frequently found in soil, water, and some animals, is what causes listeriosis. Consuming contaminated food, such as unpasteurized dairy products and ready-to-eat meals, is how the disease is transmitted to humans (Maertens de Noordhout et al. 2014).

4.2.2. IMPACT ON PREGNANT WOMEN AND THE DEVELOPING FETUS

Pregnant women with listeriosis may experience mild flu-like symptoms. The developing fetus, though, is more in danger from infection. Pregnancy-related infections have been linked to miscarriage, stillbirth, early birth, and serious newborn infections (Mylonakis et al. 2011).

4.2.3. PREVENTION AND MANAGEMENT DURING PREGNANCY

Avoiding high-risk foods, thoroughly cooking meat and eggs, and ensuring excellent food safety and cleanliness are all preventive actions. Pregnant women should consult a doctor immediately if they see any symptoms of listeriosis. Early detection and proper antibiotics can enhance maternal and fetal outcomes (Charlier et al. 2017).

4.3. Q FEVER

4.3.1. CAUSATIVE AGENTS AND TRANSMISSION

The bacterium Coxiella burnetii, which is frequently found in the placenta, labour fluids, and milk of infected animals, is what causes Q fever. Through direct contact with diseased animals or inhalation of polluted aerosols, the disease can be transmitted to people (Angelakis et al. 2014).

4.3.2. IMPACT ON PREGNANT WOMEN AND THE DEVELOPING FETUS

Q Flu-like symptoms might develop in pregnant women with a fever. However, infection during pregnancy may result in unfavourable consequences such as spontaneous abortion, stillbirth, and underweight babies (Anderson et al. 2013).

4.3.3. PREVENTION AND MANAGEMENT DURING PREGNANCY

Avoiding contact with diseased animals and their reproductive products and maintaining excellent cleanliness are preventive measures. Pregnant women should exercise caution while handling cattle and stay away from areas where Q Fever is known to be common. Pregnant women diagnosed with Q Fever can benefit from early diagnosis and appropriate antibiotic therapy (Porten et al. 2006).

4.4. PLAGUE

Plague is a life-threatening zoonotic disease caused by gram-negative bacteria called bacillus Yersinia pestis. The three most common forms of plague, i.e., septicemic, pneumonic, and bubonic are causing endemics in certain geographical areas and cause outbreaks worldwide. Plague is known as bioweapon worldwide, but its application on pregnant women as a war weapon is lacking evidence. Nowadays plague is being spread by infected fleas and rodents i.e., rats. Pregnant women having a plague can have adverse pregnancy outcomes. Evidence is available of this zoonotic disease to be transferred to fetus. Infection in pregnant women cause fetal tachycardia, spontaneous abortion, and fetal distress. More severe outcomes of plague infection in expected women cause birth defect in fetus, preterm birth, neonatal infections, and pregnancy loss.

5. GLOBAL INCIDENCE AND TRENDS OF ZOONOTIC DISEASES

Zoonotic illnesses, or infections that can be passed from animals to people have serious effects on global public health. Frequency and intensity of zoonoses is more in under developing countries than in developed countries. The reason behind this is poor health services, and poor sanitary conditions. In many under developing countries where livestock plays a significant role in the economy of the country, zoonoses are a common cause of infections in people. This is due to the reason; people are uneducated about the cause and effect of zoonotic diseases. Bad hygienic conditions in the area where livestock are being bred and poor handling of objects related to animals in the farms, households, and veterinary hospitals. Availability of proper veterinary aid to the animals in the zoos, farms, and households are also significant in the spread and transmission of zoonotic illnesses. Pregnant women are susceptible to infectious diseases including zoonotic infections. Many reasons for this rise in vulnerability include unawareness to zoonosis, bad hygiene, and non-availability of proper and on time medical aid.
Specifically focusing on the frequency of these illnesses in various countries and the effects of new zoonotic diseases on pregnant women, this literature review looks at the global incidence and trends of zoonotic diseases.

5.1. PREVALENCE OF ZOONOTIC DISEASES IN DIFFERENT REGIONS

Geographical location, ecological conditions, and human-animal interactions all play a role in the frequency of zoonotic illnesses spread throughout the world in many different places. Research studies and surveillance reports offer important insights into the prevalence and distribution of zoonotic illnesses in various geographic areas.
According to studies, some areas are more susceptible to particular zoonotic diseases because of their particular animal populations and environmental conditions. For instance, temperate regions with suitable vector habitats have higher prevalences of vector-borne zoonotic diseases like Lyme disease and the West Nile virus (Brisson et al. 2012; Medlock et al. 2013). On the other hand, areas where raising

livestock is common may see epidemics of zoonoses like brucellosis and Q fever (Dean et al. 2012; Di Nardo et al. 2018).

Zoonotic illnesses represent a significant burden in developing nations with frequent close encounters between humans and animals. Due to the close contact between people, domestic animals, and wildlife in these areas, neglected tropical zoonoses like rabies and leptospirosis are common (Hotez et al. 2014; Costa et al. 2015).

It is essential to understand the regional distribution of zoonotic diseases to develop targeted prevention and control methods and allocate funds for surveillance and research to lessen their influence on human and animal health.

5.2. EMERGING ZOONOTIC DISEASES AND THEIR IMPACT ON PREGNANT WOMEN

Emerging zoonotic diseases may be defined as infections that are new to a population or have existed but are fast growing in certain geographical ranges. Recent quickly growing zoonotic outbreaks include avian influenza, west Nile virus, and malaria. Emergence of zoonoses in pregnant women is of special concern. Studies show antibiotic resistance, organ transplantation, and certain immunosuppression diseases i.e., AIDS and diabetes. Pregnant women are more susceptible to emerging infectious diseases. In general, women manifest diseases differently than man because of hormonal and anatomical factors. The change in hormones and immune responses become more severe during pregnancy that make women to get infections more easily. Behavioral, social, and cultural factors are also to be considered in this regard. i.e., the women who tend animal herds are more likely to get rift valley fever and Q fever than the women linked to other professions. This shows that the emerging risks of zoonoses are linked to animal husbandry and agriculture. Cooperation should be developed between the owners and workers of farms and animals and the veterinarians to minimize the risks of the spread of zoonoses among the animals and transmission to humans.

Public health authorities are extremely concerned about newly discovered or re-emerging infections with the potential to spread zoonotic illnesses. Due to their altered immunological status and potential negative effects on the developing fetus i.e., mental retardation, low weight birth, stillbirth, preterm birth, and neonatal deaths, many disorders have the potential to affect pregnant women significantly.

The advent of zoonotic illnesses like the Ebola virus disease, Middle East Respiratory Syndrome (MERS), and severe acute respiratory syndrome (SARS) have brought attention to the threat that zoonotic viruses pose on a global scale (Zumla et al. 2016; Ng et al. 2016; Barry et al. 2017). These viruses can cause serious disease progression in pregnant women, resulting in unfavorable pregnancy outcomes like miscarriage, premature birth, and maternal mortality.

Zika virus, another emerging zoonotic disease, garnered attention for its association with congenital Zika syndrome, characterized by microcephaly and other neurological abnormalities in newborns (Rasmussen et al. 2016). Pregnant women infected with the Zika virus during pregnancy are at risk of vertical transmission to the fetus, resulting in devastating consequences for the developing brain and nervous system.

6. CONCLUSION

Wild birds become significant in spreading and re-emerging zoonoses like Lyme diseases and west Nile virus in different geographical locations. Birds' migration establishes a mechanism in spreading diseases. Birds cannot transmit Lyme disease directly, but they can play a major role as a disperser of tick carrying pathogen of Lyme disease. In the case of the west Nile virus, birds are the main amplifying host of the virus.

The effects of newly developing zoonotic illnesses on expectant mothers highlight the necessity of effective surveillance systems, early detection techniques, and quick reaction times. Monitoring and controlling emerging zoonoses is crucial to protect maternal and fetal health worldwide. This requires cooperation with infectious vulnerabilities, researchers, and healthcare professionals.

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Awareness and Community Engagement in Zoonotic Disease Management

36

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ABSTRACT

Zoonotic illnesses, which are transmitted from animals to people, constitute a huge worldwide health danger. A holistic strategy that goes beyond traditional medical procedures is required for effective management. This chapter investigates the critical role of public awareness campaigns and community participation in the control and prevention of zoonotic illnesses. This chapter demonstrates the interdependence of human, animal, and environmental health, emphasizing the importance of a collaborative and multidisciplinary framework. It dives into the numerous mechanisms by which zoonotic illnesses develop and spread, emphasizing the significance of proactive risk-mitigation techniques at the human-animal-environment interface. This chapter's major focus is the crucial importance of awareness in disease prevention. It assesses current community awareness strategies, spanning from old approaches to modern digital platforms, and analyses their influence on community comprehension and preparation. To maximise efficacy, the discussion emphasizes the importance of culturally sensitive and community-tailored campaigns. The ability of community-based participatory initiatives to improve early detection, facilitate fast intervention, and promote long-term behavioral change is being assessed. Strategies for overcoming these problems are highlighted, including the incorporation of local knowledge, the development of partnerships, and the use of technology to improve communication.

Key Words: Zoonosis, Community, Awareness, Zoonotic Disease Management.

CITATION

Waheed T, Ali K, Asad M, Baber ZU, Riaz A, Rasheed M, Arif A, Khanum S, Fatima T and Saleem M, 2023. Awareness and community engagement in zoonotic disease management. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 470-485. https://doi.org/10.47278/book.zoon/2023.036

CHAPTER HISTORY Received: 09-May-2023 Revised: 25-June-2023 Accepted: 12-Aug-2023

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1. INTRODUCTION

Humans, animals, and the environment all play a role in the origin and spread of various infectious diseases. The majority of infectious diseases that impact people are caused by animals. According to the "Asia Pacific strategy for emerging diseases: 2010" study, around 60% of emerging human infections are zoonotic in nature, with more than 70% of these viruses originating from wildlife species. In recent decades, newly emerging diseases in humans were of animal origin and were directly related with animal origin mealsThe term "Zoonosis" is derived from the Greek words "Zoon" (animal) and "nosos" (disease). The World Health Organisation (WHO) classifies zoonosis as any sort of illness that is naturally transmissible from vertebrate animals to people or from humans to animals. Approximately 61% of human pathogens are zoonotic. Zoonosis are a major public health risk and a direct human health hazard that can result in mortality. (Rahman et al. 2023). Infectious diseases that can be transmitted from animals to humans, known as zoonotic illnesses, pose a serious threat to global health. Understanding the risk factors and transmission mechanisms of zoonotic diseases is critical for preventative and control efforts. Risk factors such as a lack of piped water, intake of raw animal products, and occupational exposure to animals with diseases all contribute to the spread and persistence of zoonotic illnesses. (Gerken et al. 2023; Zakeri et al. 2023). Observational studies aid in the identification of modifiable risk factors and the development of responses (Jackson et al. 2023). These illnesses can be transmitted by a variety of means, including domestic animals, wildlife, and vectors, emphasizing the importance of comprehensive surveillance and control efforts. (Tomori and Oluwayelu 2023). To treat zoonotic neglected tropical illnesses, One Health approaches that integrate human, animal, and environmental health are critical (Taylor et al. 2023).

Agricultural landscapes and human-animal contact are essential in the spread of zoonotic diseases, and identifying high-risk individuals and places is crucial for targeted treatments (Klim et al. 2023). Factors including workplace exposure and wildlife rehabilitation activities raise the risk of zoonotic illnesses, highlighting the significance of preventive measures (Mathews et al. 2023). Zoonotic illnesses are caused by a diverse set of pathogens. Animals can transfer pathogens to humans either directly or indirectly. Direct zoonosis are diseases that are transmitted directly from animals to humans via media such as air. Avian influenza, a viral disease that spreads from animals to humans via droplets or fomites, is a classic example of a direct zoonosis. Infected animals can also directly transmit germs to humans through bites, as in the case of rabies, one of the worst zoonotic illnesses. Zoonotic diseases are categorized into numerous categories based on the ecology in which infections circulate. Some zoonosis, for example, are classed as synanthropic zoonosis or exoanthropic zoonosis. Synanthropic zoonosis, such as urban rabies and zoonotic ringworm, have an urban (domestic) cycle in domestic and synanthropic animals. Exoanthropic zoonosis, such as arboviroses, wildlife rabies, and Lyme disease, are typically accompanied by a sylvatic (feral and wild) cycle in natural foci outside of human settings. However, some zoonosis, such as yellow fever, Chagas disease, and dengue fever, can circulate in both urban and natural cycles. There are also certain zoonotic diseases that can be spread by arthropods, food, rodents, and those that are waterborne. (Rahman et al. 2023). Zoonosis are classified into bacterial zoonosis (such as anthrax, salmonellosis, tuberculosis, Lyme disease, brucellosis, and plague), viral zoonosis (such as rabies, acquired immune deficiency syndrome-AIDS, Ebola, and avian influenza), parasitic zoonosis (such as trichinosis, toxoplasmosis, trematodosis etc. (Rahman et al. 2023). Some Examples of Zoonosis are listed in Table 1.

2. UNDERSTANDING ZOONOTIC DISEASES: MODES OF TRANSMISSION, AND RISK FACTORS

2.1. MODE OF TRANSMISSION

Bacterial zoonosis can spread via a variety of channels, emphasizing the need to understand modes of transmission (Wilking et al. 2023). Community beliefs and awareness of zoonotic diseases can influence preventive and control efforts (Owiny et al. 2023). Monkeypox is a zoonotic disease that spreads through direct contact with infectious secretions from primates as well as person-to-person transmission (Tajudeen et al. 2023). Common mechanisms of transmission for intestinal pathogenic zoonotic diseases include fecal-oral transmission, contaminated food or water, and person-to-person contact (Capasso and Supuran 2023). Monkeypox, a zoonotic disease, has no definitive mechanism of transmission, but sexual contact may be a primary mode of infection (Hazra and Cherabie 2023). Personnel safeguards and staff training are critical for reducing zoonotic disease transmission in hospital settings (Fritz and Byers 2023).

3. RISK FACTORS ASSOCIATED WITH ZOONOTIC DISEASES

Because of their employment, wildlife rehabilitators in Australia are at a greater risk of contracting Q fever, a zoonotic disease (Mathews et al. 2023). Workers in slaughterhouses are at a high risk of contracting Q fever, underscoring the occupational risk connected with zoonotic infections (Zakeri et al. 2023). Human-animal contact rates and the danger of contact with possible zoonotic disease reservoirs can be influenced by agricultural landscapes (Klim et al. 2023). Infertility history is a risk factor for zoonotic abortive infections such as brucellosis and Q fever (Guesmi et al. 2023). Risk mapping in Cambodian goats using serologic surveillance revealed high-risk locations for zoonotic disease transmission (Siengsanan-Lamont et al. 2023). Many factors associated with the pets animals are mentioned in the Fig. 1.

Table 1: Examples of Zoonosis (Rahman et al. 2020)

Agent	Human Disease	Animal Disease	Animal Affected
Mumps virus	Mumps	Parotiditis	Humans
Hepatitis B virus	Hepatitis	Hepatitis	Nonhuman primates
Corynebacterium diphtheria	Diphtheria	Ulcers on teats, mastitis	Cattle
Staphylococcus aureus	None	Furunculosis, mastitis	Cattle
Streptococcus pyogenes	Pharyngitis, Scarlet fever	Mastitis	Cattle
Giardia lamblia	Gastroenteritis	None known	Beavers
Mycobacterium tuberculosis	Tuberculosis	Tuberculosis	Deer, Dogs, Elephants

4. IMPACT OF ZOONOTIC DISEASES IN HUMAN ANIMAL HEALTH AND OVERALL PUBLIC HEALTH

Zoonotic illnesses have a substantial impact on human health, livelihoods, and the environment. Urbanization and climate change both contribute to habitat degradation, resulting in the introduction of zoonotic species (Dubey et al. 2023). The severity of zoonotic illnesses in humans and animals, as well as their socioeconomic impact, emphasizes the need for prioritization and treatments. These diseases can have disastrous implications, harming both human and animal health and modifying disease landscapes (Tomori and Oluwayelu 2023). Understanding and treating the effects of zoonotic illnesses on human-animal-environment interactions requires One Health Strategy (Mubareka et al. 2023). The emergence and transmission of zoonotic diseases are influenced by human activities; land use, livestock practices, and climate change (Haruna et al. 2023). The establishment and spread of zoonotic diseases endanger both human and animal populations (Thukral et al. 2023). Surveillance systems prioritize zoonotic illnesses based on their impact on animal health, emphasizing the importance of collaboration (EFSA 2023). Human activities and the effects of climate change are among the root causes of developing viral zoonotic illnesses (Haruna et al. 2023). Zoonotic infections place a severe burden on public health worldwide, especially in India, with considerable livestock and public health consequences (Thukral et al. 2023). Urbanization and climate change aids the establishment and spread of zoonotic diseases, posing a

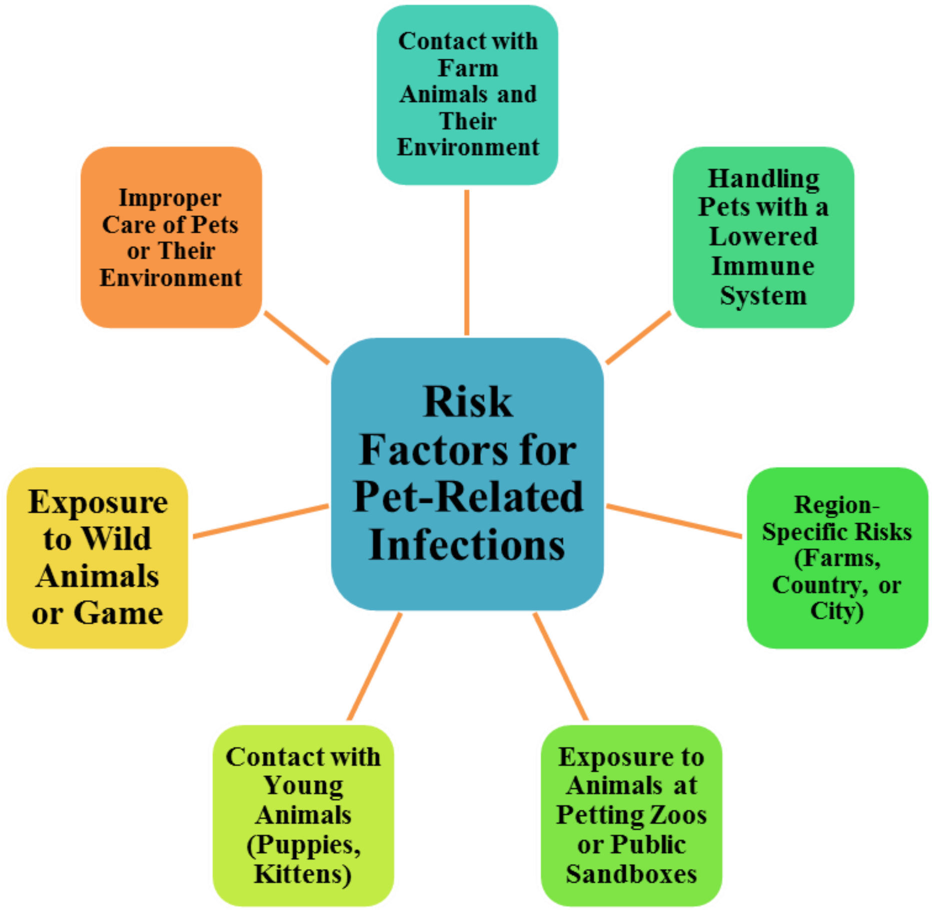

Fig. 1: Risk factors for Pet-related infections

hazard to human health (Dubey et al. 2023). Zoonotic infections have catastrophic consequences for human health, livelihoods, and economies, demanding the integration of zoonotic pathogen surveillance with public health surveillance (Tomori and Oluwayelu 2023). Neglected zoonotic diseases can occur in non-endemic countries, emphasizing the importance of proactive steps to fill knowledge gaps and protect public health (Youssef et al. 2023). Zoonotic and multi-species urbanization has numerous ramifications for human health and demand a rescaling of urban epidemiology (Gandy 2023).

5. HUMAN WILDLIFE INTERACTIONS &ZOONOTIC DISEASE

Several studies have shown that human-wildlife interactions play an important role in the transmission of zoonotic illnesses. Because of the possibility of zoonotic disease transmission and human concerns about cleanliness, the coexistence of humans and bats in urban areas causes a conflict (Davy et al. 2023). To handle these issues successfully, it's necessary to have mitigation measures. The likelihood of zoonotic disease spillover following animal exposure has been connected to global patterns of recorded human-wildlife interactions in areas of land-use change. (Jackson et al. 2023). Understanding the association between human-wildlife interactions and zoonotic diseases can aid in disease risk assessment and management. Synanthropic bats' roost selection in rural Kenya has consequences for human-wildlife conflict and zoonotic pathogen spread (Jackson et al. 2023). Furthermore, the involvement of wild animals in the transmission and amplification of etiological agents of emerging and re-emerging zoonosis is shown in the Fig. 2.

6. IMPORTANCE OF AWARENESS AND COMMUNITY ENGAGEMENT IN ZOONOTIC DISEASE MANAGEMENT

The dissemination of knowledge on the management of zoonotic diseases is crucial in averting and alleviating their impact on public health. According to studies, there is an urgent need to overcome knowledge gaps and improve public understanding of zoonotic illnesses (Youssef et al. 2023). For example, raising understanding that certain diseases, such as monkeypox, do not spread quickly among individuals can help debunk myths and minimize unneeded fear (Youssef et al. 2023). Understanding the disease burden of a country helps in management of different kind of zoonotic diseases so the Zoonotic disease burden of many countries is discussed in Table 2. Natural language processing techniques can help detect zoonotic awareness gaps and provide useful insights for enhancing disease prevention and control measures (Gonzalez 2023). Health specialists can modify educational campaigns and communication tactics to increase zoonotic disease awareness by analyzing public knowledge and views. Promoting the notion of One Health, which acknowledges the interdependence of human, animal, and environmental health, is critical in preventing zoonotic spillover occurrences. Raising public knowledge of One Health can help to reduce unsustainable behaviors that lead to the spread of zoonotic diseases and damage to the environment (Wu et al. 2023). Overall, boosting knowledge regarding zoonotic disease management is critical for illness prevention and control. We can improve preparedness, early detection, and effective response to zoonotic illnesses by raising the public's awareness, promoting One Health concepts, and prioritizing populations at greatest risk.

7. STRATEGIES FOR EFFECTIVELY COMMUNICATING ZOONOTIC DISEASE INFORMATION

Good communication about zoonotic illnesses is critical for public understanding and response. To combat both emerging and existing zoonotic illnesses, improved communication channels, policies, and data sharing procedures are required (Bansal et al. 2023). To combat both emerging and existing zoonotic illnesses, improved communication channels, policies, and data sharing procedures are required (Narayan et al. 2023).

7.1. UTILIZING DIFFERENT MEDIA; CHANNELS (PRINT, DIGITAL, SOCIAL MEDIA)

Effective zoonotic disease management requires the use of several media channels, including print, digital, and social media. During disease outbreaks, social media platforms such as Twitter play an important role in conveying public health messaging and fighting disinformation (Edinger et al. 2023). Television, radio, print, and internet media are also important for increasing public awareness and education regarding zoonotic illnesses (Pitakpon and Susilo 2023). The use of electronic and social media platforms speeds up the distribution of knowledge and aids in addressing the global challenges posed by zoonotic illnesses (Patil et al. 2023). However, it is critical to validate information and counteract the propagation of fake news through media channels (Hassina 2023). Integrating several media channels enables a comprehensive and interactive experience.

7.2. TAILORING MESSAGES FOR DIFFERENT TARGET AUDIENCES PUBLIC, SPECIFIC COMMUNITIES, HEALTHCARE PROFESSIONALS)

Messages must be tailored for diverse target audiences, such as the public, specialized communities, and healthcare professionals, in order to be effective in zoonotic disease management (Primeau et al. 2023). Messages that are customized are more relevant, engaging, and address the individual wants and

Table 2: Disease Burdens Associated with Zoonosis

Zoonotic Disease	Description	Common Sources	Symptoms	Precautions	References
Rabies	Viral infection affecting the nervous system and transmitted through animal bites.	Infected animals' bites and scratches (commonly dogs, bats, raccoons).	Fever, headache, agitation, confusion, hallucinations.	Avoid contact with stray or wild animals Vaccinate pets against rabies.	(Nejati et al. 2022)
Leptospirosis	Bacterial infection commonly spread through animal urine.	Contaminated water or soil (excretions from infected animals).	Fever, chills, muscle pain, jaundice, red eyes.	Avoid contact with potentially infected water sources Use protective clothing when handling animals or soil.	(Akash et al. 2023)
Lyme Disease	Bacterial infection transmitted through tick bites.	Tick bites (commonly carried by deer or mice).	Fever, headache, fatigue skin rash (bull's-eye pattern).	Wear insect repellent and protective clothing in tick-prone areas.	(Bernard et al. 2020)
Salmonellosis	Bacterial infection commonly spread through contaminated food.	Contaminated food or water (often from poultry, reptiles, and pets).	Diarrhea, abdominal cramps, nausea, vomiting.	Practice proper food handling and hygiene Wash hands after handling animals, food, or their waste.	(Teklemariam et al. 2023)
Brucellosis	Bacterial infection transmitted through animal contact.	Contact with infected animals or their products (e.g., milk).	Fever, joint pain, fatigue, muscle pain, night sweats.	Avoid consuming unpasteurized dairy products.Use protective gear when working with animals.	(Karunanayake et al. 2019)
Psittacosis	Bacterial infection commonly associated with birds.	Inhalation of infected bird droppings (especially parrots,pigeons, poultry).	Fever, chills, headache, Dry cough.	Avoid contact with infected birds. Keep pet birds in a clean environment.	(Kozuki et al. 2020)
Ringworm	Fungal infection transmitted through contact with infected.	Direct contact with infected animals, commonly cats, dogs, rodents.	Itchy, red, or scaly patches. Hair loss.	Avoid sharing personal items with infected animals. Seek veterinary care for infected pets.	(Karanja et al. 2019)
Toxoplasmosis	Parasitic infection commonly transmitted through cat feces.	Consuming undercooked contaminated meat (especially pork, lamb).	Fever, swollen lymph nodes, muscle pain.	Avoid contact with cat feces and infected animals. Practice good hygiene and proper food preparation.	(Tong et al. 2023)

problems of each audience (Shafie et al. 2023). Healthcare professionals require tailored information and treatment guidelines (Primeau et al. 2023), while community-specific messaging can improve intervention knowledge and acceptance (Gyapay et al. 2023).

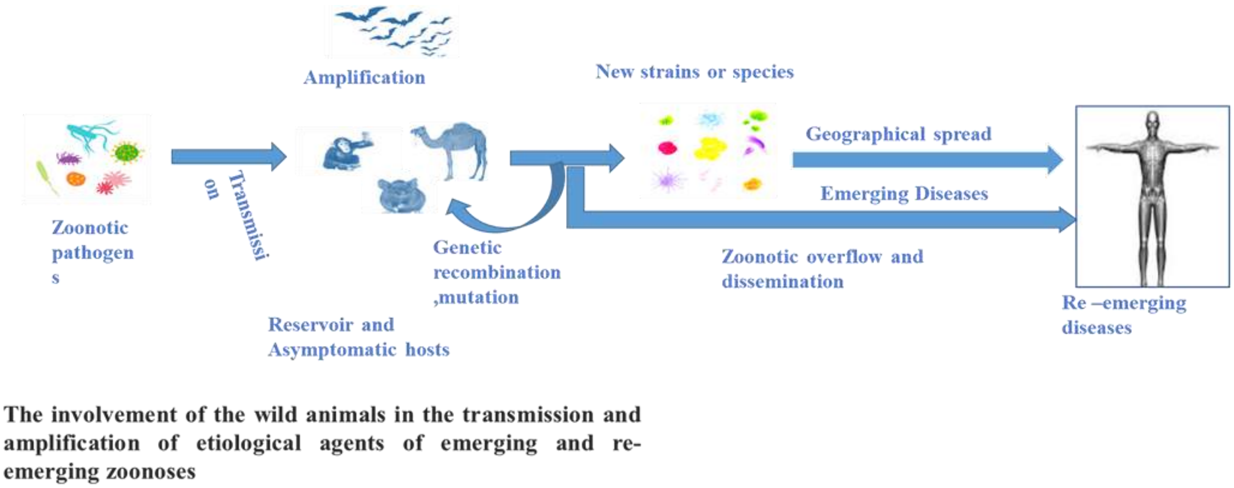

Fig. 2: The Involvement of wild animals in the transmission and amplification of etiological agents of emerging and re-emerging zoonosis.

8. DEFINITION AND SIGNIFICANCE OF COMMUNITY ENGAGEMENT

The active involvement and participation of communities in preventing and managing diseases that can be transferred between animals and humans is referred to as community engagement in zoonosis. Raising public awareness, supporting sustainable behaviors, and developing community-wide solutions are all part of it. It is critical to raise public knowledge of One Health concept, which recognizes the interconnection of human, animal, and environmental health, in order to prevent zoonotic spillover to humans (Wu et al. 2023). Multi-sectoral community participation promotes understanding and appreciation of traditional zoonotic illness mitigation approaches, resulting in effective society-wide One Health efforts (Gwakisa et al. 2023). Community involvement is also important in risk management methods to zoonotic illnesses and promotes a long-term strategy to disease control (Bansal et al. 2023). Furthermore, it bridges the gap between technological knowledge and the practical social environment, guaranteeing that One Health network and collaborations are successfully operationalized (Mwatondo et al. 2023). Active 1: By integrating communities, taking into account social vulnerability, and adjusting approaches to varied social situations, we can improve interventions for neglected zoonotic diseases (Asaaga et al. 2023). Furthermore, community involvement is critical for improving knowledge, attitudes, and preventive practices regarding rodent-borne diseases, as well as raising awareness about potential health concerns related to illegal bushmeat activities (Foya et al. 2023).

9. STRATEGIES FOR COMMUNITY ENGAGEMENT

9.1. BUILDING TRUST AND PARTNERSHIPS WITH LOCAL COMMUNITIES

Various ways for building trust and collaborations with local populations for community engagement in zoonotic disease management are supported by the following sources: creating robust One Health networks and collaborations, while acknowledging the lack of community engagement (Mwatondo et al. 2023). One Health should be implemented as an ecosystem strategy, with a focus on community engagement and learning from local disease control mechanisms (Gwakisa et al. 2023). Highlighting the importance of community involvement and long-term entrepreneurial collaborations in zoonotic disease outbreak management (Jiménez et al. 2023).

9.2. ENGAGING KEY STAKEHOLDERS (GOVERNMENT AGENCIES, NGOS, HEALTHCARE ORGANIZATIONS)

Involving key players such as government agencies, non-governmental organizations, and medical groups is essential for effective zoonotic disease control (Naserrudin et al. 2023). Cooperation with government and non-governmental organisations (NGOs) promotes cooperation, resource allocation, and policy implementation (Mbereko et al. 2023). The active participation of stakeholders in One Health concept promotes disease control efforts (Niranjan et al. 2023). Collaborations with local Non-Governmental Organizations (NGOs) and key stakeholders aid in the expansion of community-based activities and educational programs (Zikankuba et al. 2023). This type of participation fosters intersectoral collaboration and improves zoonotic prevention and control (Nyokabi et al. 2023).

10. HIGHLIGHTING SUCCESSFUL EXAMPLES OF AWARENESS AND COMMUNITY ENGAGEMENT IN ZOONOTIC DISEASE MANAGEMENT

One example is the study by McLean et al. (2022) in which they examine the influence of social media and outreach efforts to hunters in raising awareness about zoonotic disease risks associated with hunting wild pigs. Naserrudin et al. (2022) emphasize the importance of community engagement and understanding the challenges faced by communities at risk, particularly in the context of zoonotic malaria control. Mwatondo et al. (2023) underscore the significance of partnerships and mutual trust in successful community engagement efforts for zoonotic disease management. These examples, along with other studies, highlight the value of community involvement, social media, and interdisciplinary collaboration in raising awareness, fostering engagement, and effectively managing zoonotic diseases.

11. CASE STUDIES FROM DIFFERENT REGIONS AND COMMUNITIES

One case study related to awareness and community engagement in zoonotic disease management is the "Amazonian Tropical Bites Research Initiative" which focuses on resolving neglected tropical diseases in One Health era. The initiative emphasizes community engagement, behavioral change, and perception of bite-related threats and zoonotic diseases (Taylor et al. 2023). Stephens et al. (2021) conducted a study on the characteristics of the 100 largest modern zoonotic disease outbreaks. Alemayehu et al. (2021) investigated the knowledge, attitudes, and practices of smallholder communities in Ethiopia regarding zoonotic disease risks from livestock birth products. Additionally, Burthe et al. (2021) reviewed the ecological evidence base for managing emerging tropical zoonosis, using Kyasanur Forest Disease in India as a case study. These case studies shed light on the prevalence, risk factors, and management strategies related to zoonotic diseases in different regions and communities. They contribute to our understanding of the complex dynamics involved in zoonotic disease transmission and inform future interventions and preventive measures for safeguarding public health. Moreover, the key components or elements of public health preparedness and response are discussed in Fig. 3.

12. LESSONS LEARNED AND IMPORTANT POINTS FROM THESE INITIATIVES

Here are some key lessons learned and takeaways from these initiatives:-

1. Early detection and response: Timely identification of emerging zoonotic diseases in animal populations can help prevent spillover events and limit the spread to humans. (Alders et al. 2020)
2. One Health approach: These initiatives have highlighted the significance of adopting a One Health approach, which recognizes the interconnectedness of human, animal, and environmental health. Collaboration between human and animal health sectors, along with environmental and wildlife experts, is crucial to effectively manage zoonotic diseases (Nkansah-dwamena 2023).
3. Risk communication: Clear, accurate, and timely communication of risks, preventive measures, and outbreak updates helps in gaining public trust, encouraging behavior change, and promoting community participation. (Echaubard et al. 2020)
4. Community engagement: Engaging communities and involving them as active participants in zoonotic disease management initiatives is vital. This can be achieved through community-based surveillance, participatory research, training programs, and community-led interventions. Building trust, understanding local contexts, and empowering communities to take ownership of their health can lead to sustainable solutions. (Nkansah-dwamena 2023).
5. Capacity building: Strengthening the capacity of healthcare workers, veterinarians, laboratory technicians, and other professionals involved in zoonotic disease management is crucial. Training programs, workshops, and knowledge sharing platforms can enhance their skills in disease surveillance, diagnosis, prevention, and control. (Zhang et al. 2023)
6. Behavioral change: Initiatives have highlighted the importance of promoting behavior change at both individual and community levels. Educating people about the risks associated with zoonotic diseases, promoting hygienic practices, responsible pet ownership, and proper handling of wildlife can reduce the likelihood of disease transmission. (Gwakisa et al. 2023)
7. Interdisciplinary collaboration: Zoonotic disease management requires collaboration and coordination across multiple sectors, including human health, animal health, agriculture, environment, and wildlife. Initiatives have emphasized the need for interdisciplinary collaboration, policy integration, and joint decision-making to address the complex challenges posed by zoonotic diseases (Zulu 2022).

8. Surveillance and data sharing: Robust surveillance systems, early warning mechanisms, and real-time data sharing are essential for effective zoonotic disease management. Initiatives have underscored the importance of establishing comprehensive surveillance networks, sharing data across sectors and regions, and using advanced technologies for early detection and monitoring. (George et al. 2023).
9. Preparedness and resilience: Building preparedness and resilience at individual, community, and national levels is critical to effectively manage zoonotic diseases. Initiatives have emphasized the need for developing and regularly updating response plans, conducting simulation exercises, stockpiling essential medical supplies, and investing in research and development for diagnostics, vaccines, and therapeutics. Sustainable funding: Adequate and sustained funding is crucial to support ongoing initiatives for awareness and community engagement in zoonotic disease management (de Vries et al. 2021)
By applying these lessons learned and implementing these key takeaways, initiatives for awareness and community engagement in zoonotic disease management can contribute to better prevention, detection, and control of future zoonotic disease outbreaks (Fig. 4).

13. POTENTIAL BARRIERS TO EFFECTIVE COMMUNICATION AND COMMUNITY INVOLVEMENT

While awareness and community engagement are crucial for effective zoonotic disease management, several barriers can hinder communication and community involvement. Here are

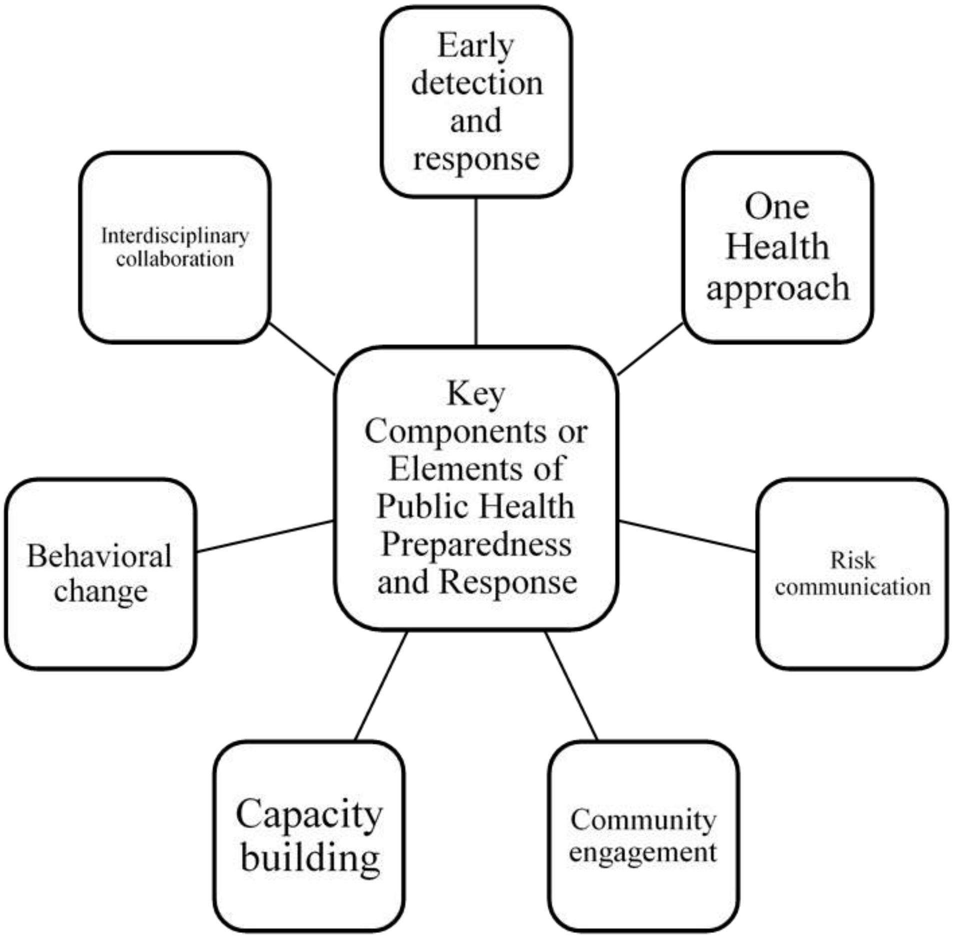

Fig. 3: Key components of public health preparedness and response

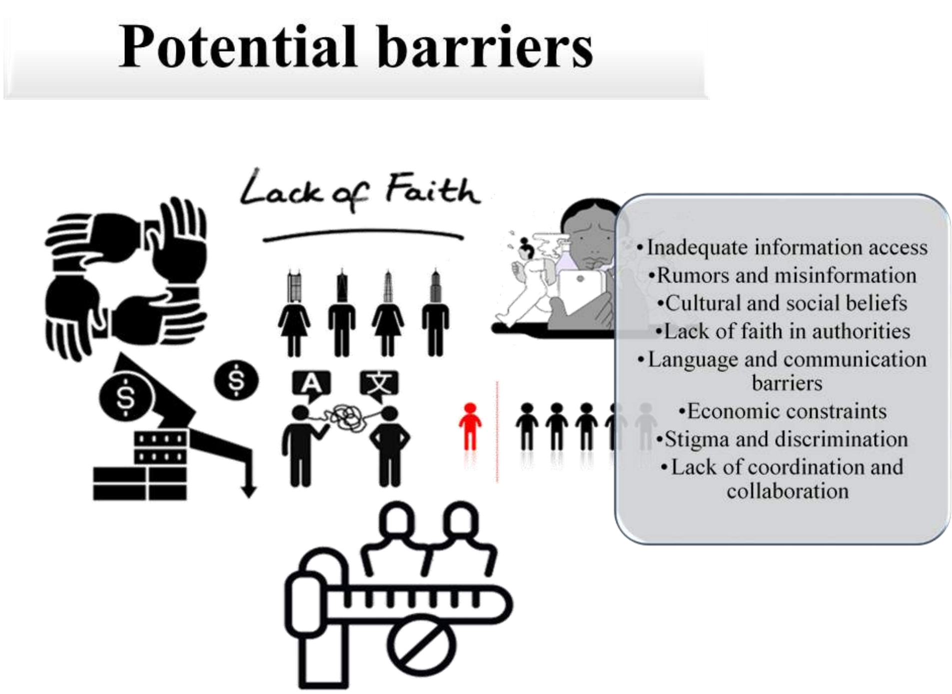

Fig. 4: Potential Barriers to Effective Communication and Community Involvement

1) Inadequate information access: Communities with poor internet connectivity, low literacy rates, or language difficulties may struggle to get timely and reliable information regarding zoonotic illnesses and prevention strategies. (Wen et al. 2021)
2) Rumors and misinformation: False or inaccurate information, particularly through social media and other informal means, can cause uncertainty, anxiety, and mistrust, making accurate messages and preventive steps difficult to transmit. (Zortman et al. 2023)
3) Cultural and social beliefs: Long-held ideas, superstitions, or taboos towards animals, traditional healing practices, or mistrust in modern healthcare systems may stymie acceptance of scientific advice and therapies. (Smith et al. 2023)
4) Lack of faith in authorities: Lack of trust in government agencies, healthcare providers, or scientists might impede effective communication and community participation.
5) Language and communication barriers: If materials or messages are not available in the language of the recipient. (de Vries et al. 2021)
6) Restricted community participation: Due to a lack of representation, restricted chances for interaction, or power imbalances, limited community participation can undermine the effectiveness of awareness and engagement activities. (Taaffe et al. 2023).
7) Economic constraints: Communities facing basic requirements may priorities immediate survival over long-term preventive measures, making participation in zoonotic disease management operations difficult. (Wen et al. 2021)
8) Stigma and discrimination: The stigma and prejudice associated with zoonotic illnesses can obstruct effective communication and community participation. Fear of social isolation or negative consequences may deter people from seeking help, reporting cases, or participating in awareness programs. (Alders et al. 2020).
9) Lack of coordination and collaboration: disjointed activities, inconsistent messaging, or a lack of agreed goals can confuse and hinder community engagement.
Inadequate resources and infrastructure: inadequate resources, including funding and healthcare **(**Zortman et al. 2023). Addressing these potential barriers requires tailored strategies and a comprehensive understanding of the local context. Collaboration between stakeholders, community involvement in program design, culturally sensitive communication, capacity building, and trust-building measures can help overcome these barriers and promote effective awareness and community engagement in zoonotic disease management

14. PROPOSED SOLUTIONS AND STRATEGIES TO OVERCOME THESE CHALLENGES

Here are potential barriers to effective communication and community involvement in zoonotic disease management, along with suggested solution
i) Implement multi-channel communication tactics that reach varied demographics, including radio broadcasts, community meetings, and mobile messaging services. (de Vries et al. 2021)
ii) Provide information in local languages and use visuals and info graphics for enhanced comprehension. (Efua 2023)
iii) Establish a consolidated, reputable source of information on zoonotic diseases that is routinely updated with correct and validated information. Actively monitor social media networks, discover misinformation, and address it immediately. (Wen et al. 2021)
iv) Conduct community conversations, workshops, and educational sessions to dispel misconceptions and provide evidence-based explanations. (Onwineng et al.2023)

v) Involve community representatives in decision-making processes, advisory groups, or task forces relating to zoonotic disease management. Provide regular updates on the development of programs and answer issues or problems honestly. (Wen et al. 2021)
vi) Collaborate with trusted local leaders and organizations to bridge the trust gap.
vii) Translate educational materials and communication messages into local languages. Utilize community health workers or interpreters to facilitate communication with non-native speakers. (Onwineng et al.2023)
viii) Engage cultural mediators who can bridge the language and cultural gaps between healthcare providers and community members. (Smith 2022).
ix) Develop inclusive and participatory approaches by incorporating community people in the conception, execution, and assessment of zoonotic disease management activities. Create venues for community participation, such as community health committees or volunteer programs, to actively include community people. (McLean et al. 2022)
x) Provide incentives for community participation, such as access to healthcare services or income-generating possibilities.
xi) Seek collaborations with NGOs, foreign organizations, or corporate sector firms to gain additional funding for community engagement programs. (Efua 2023)
xii) In order to promote empathy and support for afflicted individuals and their families, emphasize that anyone can be affected. Involve individuals of the community who have personally experienced zoonotic diseases in order for them to share their experiences and minimize stigma. (Zortman et al. 2023).
xiii) Create multi-sectorial coordination systems that include government agencies, healthcare providers, veterinary services, environmental organizations, and community leaders (McLean et al. 2022).
Seek for overseas funders, philanthropic organizations, or public-private partnerships for assistance. Make the most of existing networks and infrastructure to maximize resource utilization and reduce expenses.
To overcome these obstacles, a complete, context-specific approach incorporating teamwork, cultural sensitivity, and community empowerment is required. By implementing these solutions, awareness and community engagement in zoonotic disease management can be increased, leading to more effective zoonotic disease prevention, detection, and control.

15. EMPHASIZING THE SIGNIFICANCE OF AWARENESS AND COMMUNITY ENGAGEMENT IN ZOONOTIC DISEASE MANAGEMENT

Awareness and community involvement are critical components of effective zoonotic disease management. Communities can be better able to prevent and control these infections by boosting their understanding of zoonotic diseases, their mechanisms of transmission, and preventive actions. Promoting the One Health concept, which emphasizes the interdependence of human, animal, and environmental health, is critical to preventing zoonotic spillover. Engaging important players, such as government agencies, non-governmental organizations, and medical organizations, improves coordination and boosts disease control efforts. Message customization and the use of numerous media platforms facilitate efficient communication with various target populations. Community engagement fosters trust and alliances while also empowering communities to take an active role in disease prevention and control, eventually protecting human health. (McLean et al. 2022).

16. CONCLUSION

Understanding the pathways of transmission, identifying risk factors, and recognizing the impact on human and animal health are all necessary components of zoonotic disease management. Raising public awareness and involving the community are critical components of successful zoonotic disease control. We can improve preparedness, early detection, and effective response to zoonotic illnesses by raising public understanding, supporting the One Health idea, and targeting high-risk populations. Using diverse media outlets, adapting messaging for different target audiences, and engaging essential stakeholders such as government agencies, NGOs, and healthcare organizations are among the strategies for efficiently disseminating zoonotic disease information. The cultivation of awareness is the cornerstone of efficient zoonotic disease control. This awareness includes more than just acknowledging the existence of these diseases; it also includes a comprehension of their origins, transmission dynamics, and prevention strategies. Communities can be armed with knowledge that serves as a barrier against the spread of zoonosis through targeted educational programs. This awareness is not a static thing, but rather a dynamic force that changes as new diseases emerge and scientific understanding improves. Community engagement is important for avoiding and responding to zoonotic illnesses because it bridges the gap between technical knowledge and practical social context. The symbiotic relationship between zoonotic disease awareness and community engagement is the foundation of effective zoonotic disease management. It is a dynamic interaction in which knowledge inspires action and action inspires resilience. As we navigate a world where species borders blur and animal and human health are intricately connected, the effectiveness of our efforts to combat zoonotic illnesses is dependent on our capacity to raise awareness and actively engage communities. We see the potential of a healthier, more resilient future in this joint efforta future in which the threads of awareness and community involvement weave a fabric of protection against the ever-present threat of zoonotic diseases. The value of technology in raising awareness and encouraging community involvement cannot be overstated. Information flows at extraordinary speeds in the digital age, providing an opportunity to reach various demographics. Social media platforms, smartphone applications, and other technical tools can be used to spread accurate information, dispel falsehoods, and encourage positive behavior. Using technology to its full potential guarantees that awareness efforts cross geographical boundaries and reach even the most remote locations where zoonotic diseases may pose substantial hazards. Armed with information, communities can become active partners in the prevention and control of zoonotic illnesses. Their participation converts awareness into action, resulting in a formidable line of defence against the possible breakout of diseases with far-reaching implications. Local communities are frequently the first responders in the case of an outbreak, and their ability to detect early warning signs and implement preventive measures is critical. Furthermore, when communities are involved, they act as conduits for sharing knowledge and inspiring behavioral changes that contribute to overall disease transmission decrease.

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Knowledge, Attitude and Practices Toward Zoonotic Diseases

37

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ABSTRACT

The important aspects of Knowledge, Attitude, and Practices (KAP) regarding zoonotic diseases are examined in this chapter, with a focus on how these factors affect public health, the global economy, and overall well-being. Zoonotic diseases that may spread from animals to people have drawn more attention because of their propensity to cause pandemics and epidemics. In tackling zoonotic issues, the chapter explores the notion of One Health, recognizing the interdependence of environmental, animal, and human health. It emphasizes how important it is to evaluate KAP to conduct efficient risk assessments, preventative measures, and behavior modification. The routes of transmission are explained, including vector-borne, foodborne, airborne, waterborne, direct and indirect contact, and fomite transmission. The discourse encompasses the function of public awareness and education initiatives, customized interventions, and the involvement of healthcare practitioners in the dissemination of information. The chapter highlights the significance of evidence-based policies and interventions, outlines obstacles to enhancing KAP, and suggests future study topics. Overall, for efficient prevention, control, and global health security, a thorough understanding of KAP to zoonotic illnesses is crucial.

Key words: Zoonotic Diseases, Knowledge, Attitude, and Practices (KAP), One Health, Transmission Routes, Global Health Security

CITATION

Khanum S, Asad M, Ali K, Baber ZU, Riaz A, Rasheed M, Fatima T, Arif A, Waheed T and Saleem M, 2023. Knowledge, attitude and practices toward zoonotic diseases. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 486-498. https://doi.org/10.47278/book.zoon/2023.037

CHAPTER HISTORY Received: 05-May-2023 Revised: 20-June-2023 Accepted: 14-Aug-2023

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1. INTRODUCTION

Infectious illnesses, known as zoonotic diseases, can spread from animals to people. These illnesses have gotten a lot of attention recently because of their propensity to start outbreaks and pandemics, as well as their impact on the economy and global health. Zoonotic diseases are transmissible through a number of routes, including direct contact with infected animals, consumption of contaminated food or water, and vectors like mosquitoes and ticks. Bacteria, viruses, parasites, and fungi cause zoonotic diseases (Rahman et al. 2020). Zoonotic diseases are conditions that can be transmitted between humans and animals. When such diseases are spread from animals to humans, they are referred to as zoonosis. To establish effective strategies for preventing, controlling, and treating zoonotic diseases, it is important to understand the intricate relationships between humans, animals, and the environment. Zoonotic illnesses, which can be seriously ill and kill both people and animals, have been the root of many epidemics. A number of factors, such as changes in land use, urbanization, climate change, and international trade, influence the development and spread of zoonotic diseases (Peterson and Barnes 2020).

One Health concept has gained significance in tackling zoonotic diseases, by acknowledging the link between human, animal, and environmental health. This approach emphasizes the need for collaboration and coordination among various disciplines, such as human and veterinary medicine, public health, and environmental science. By working together, these fields can address the multifaceted challenges posed by zoonotic diseases (Meurens et al. 2021). Zoonotic illnesses are a significant global problem due to their capacity to start epidemics, impact on human and animal health, and economic implications. Protecting the public's health and the welfare of both humans and animals depends on an understanding of the dynamics of zoonotic diseases and the implementation of suitable prevention and control measures. (Gubler et al. 2002).

2. SIGNIFICANCE OF UNDERSTANDING KNOWLEDGE, ATTITUDES, AND PRACTICES

2.1. ASSESSMENT OF RISK AND PREVENTION

Previous research and data on zoonotic diseases allow researchers to identify knowledge gaps and misconceptions that could increase the risk of transmission. Understanding how individuals think and behave in relation to zoonotic diseases can help create specific interventions and educational initiatives that promote risk-reduction practices and preventive measures (Alemayehu et al. 2021).

3. BEHAVIOR CHANGE AND PUBLIC HEALTH EDUCATION

The way that knowledge and attitudes influence behavior is crucial. People are more likely to adopt preventative measures and engage in behaviors that lower the risk of transmission when they are well-informed about zoonotic illnesses and have accurate knowledge. Misconceptions can be found and dispelled through education, which can encourage behavior change and improve health outcomes. A successful strategy for addressing zoonotic illnesses requires a multidisciplinary approach that involves cooperation between the veterinary, environmental, and human health sectors. To develop policies that effectively tackle the complex interactions between animals, humans, and the environment, it is crucial to gain an understanding of the Knowledge, Attitudes, and Practices of diverse stakeholders, including livestock producers, wildlife dealers, pet owners, and communities. One Health is an approach that acknowledges how linked these areas are and the need for concerted efforts to address them as shown in Fig. 1 (Li et al. 2021).

4. TAILORED INTERVENTIONS

The specific knowledge gaps, attitudes, and practices that must be addressed in various populations or communities are revealed by KAP (knowledge gaps, attitudes, and practices) research in a helpful way. This data enables the creation of customized interventions that are relevant to the target audience's culture and resonate with them. Interventions can be more effective in encouraging behavior change and lowering the risk of zoonotic disease transmission by addressing the unique barriers and difficulties discovered by KAP studies (Bardosh et al. 2014).

5. TRANSMISSION PATHWAYS AND FACTORS INFLUENCING TRANSMISSION

5.1. DIRECT CONTACT

Zoonotic illnesses can be spread by coming into close contact with animals that have the illness. This includes close physical contact, such as handling, stroking, or being bitten or scratched by an infected animal, as well as contact with bodily fluids, including saliva, blood, urine, or feces.

5.2. INDIRECT CONTACT

Indirect contact with contaminated settings or items can potentially spread zoonotic diseases. For instance, disease transmission can occur when people come into contact with surfaces or things that have been exposed to animal excrement or respiratory secretions.

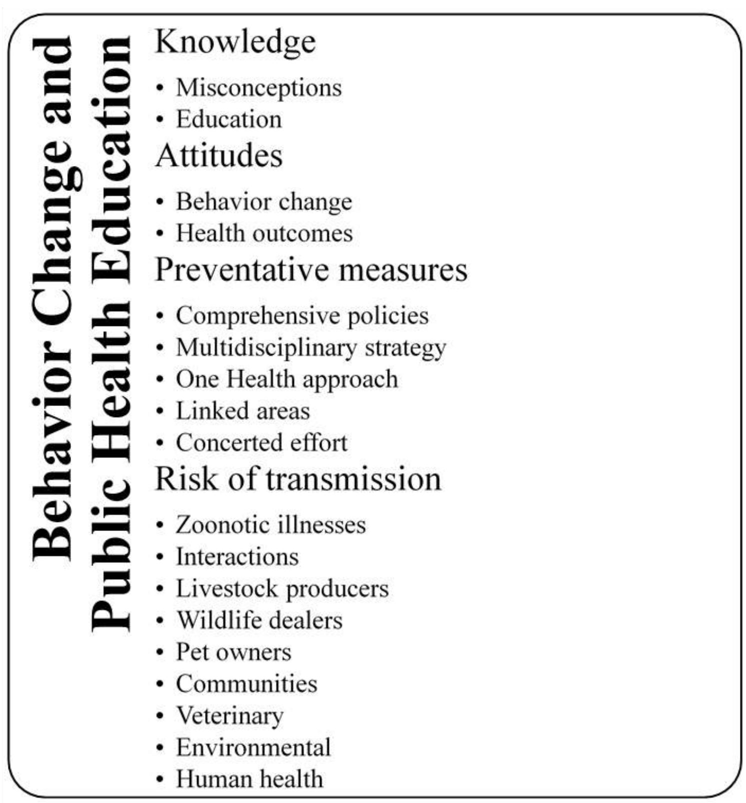


Fig. 1: Behavior Change and Public Health Education

5.3. VECTOR-BORNE TRANSMISSION

The bites of vectors like fleas, ticks, mosquitoes, or flies spread some zoonotic diseases. These vectors can pick up the infections from sick animals and then pass them on to people when they bite them again.

5.4. FOODBORNE TRANSMISSION

Through the intake of tainted food or water, it can spread zoonotic diseases. Consuming pathogen-contaminated, undercooked or raw animal products, such as meat, eggs, or milk, might get you sick.

5.5. AIRBORNE TRANSMISSION

It is possible for some zoonotic diseases to spread through the air, especially through respiratory droplets. Humans can catch an infection from respiratory droplets released by infected animals when they cough, sneeze, or breathe.

5.6. WATERBORNE TRANSMISSION

Water sources that are contaminated can act as a conduit for the spread of zoonotic illnesses. Infection can result from drinking or coming into touch with water that has been polluted with germs or animal waste. There are number of factors responsible for the development of zoonotic diseases and transmission to humans as shown in Fig. 2.

5.7. FOMITE TRANSMISSION

Fomites, which are inanimate items or surfaces that can harbor infections, can also spread zoonotic illnesses. Transmission can happen if someone touches contaminated objects, such as tools, clothing, or utensils, and then touches their face or lips. For effective preventive measures to be put in place, it is essential to comprehend these transmission channels. It is possible to create effective interventions to break the chain of transmission and lower the risk of zoonotic disease outbreaks by identifying the precise routes of transmission (Loh et al. 2015).

6. PUBLIC AWARENESS AND EDUCATION PROGRAMS

Programs for public awareness and education are essential for avoiding and managing zoonotic illnesses. These initiatives seek to inform both the public and specialized groups like butchers, livestock owners, and personnel at animal shelters about the dangers posed by zoonotic illnesses and the best ways to stop their spread. Numerous studies have emphasized the significance of these initiatives and demonstrated how they affect behavior modification and awareness-raising. For instance, a study on butcher's knowledge of zoonotic illnesses was carried out in Proddatur city, Kadapa District, Andhra Pradesh, India. The study placed a strong emphasis on education initiatives' contribution to butchers' increased awareness and understanding. These initiatives can aid in better disease control and prevention. Another study looked at how public education affected rabies, a zoonotic illness that can be prevented (Hasanov et al. 2018). The study emphasized that successful control programs for infectious diseases like rabies depend on widespread public awareness campaigns and educational initiatives.

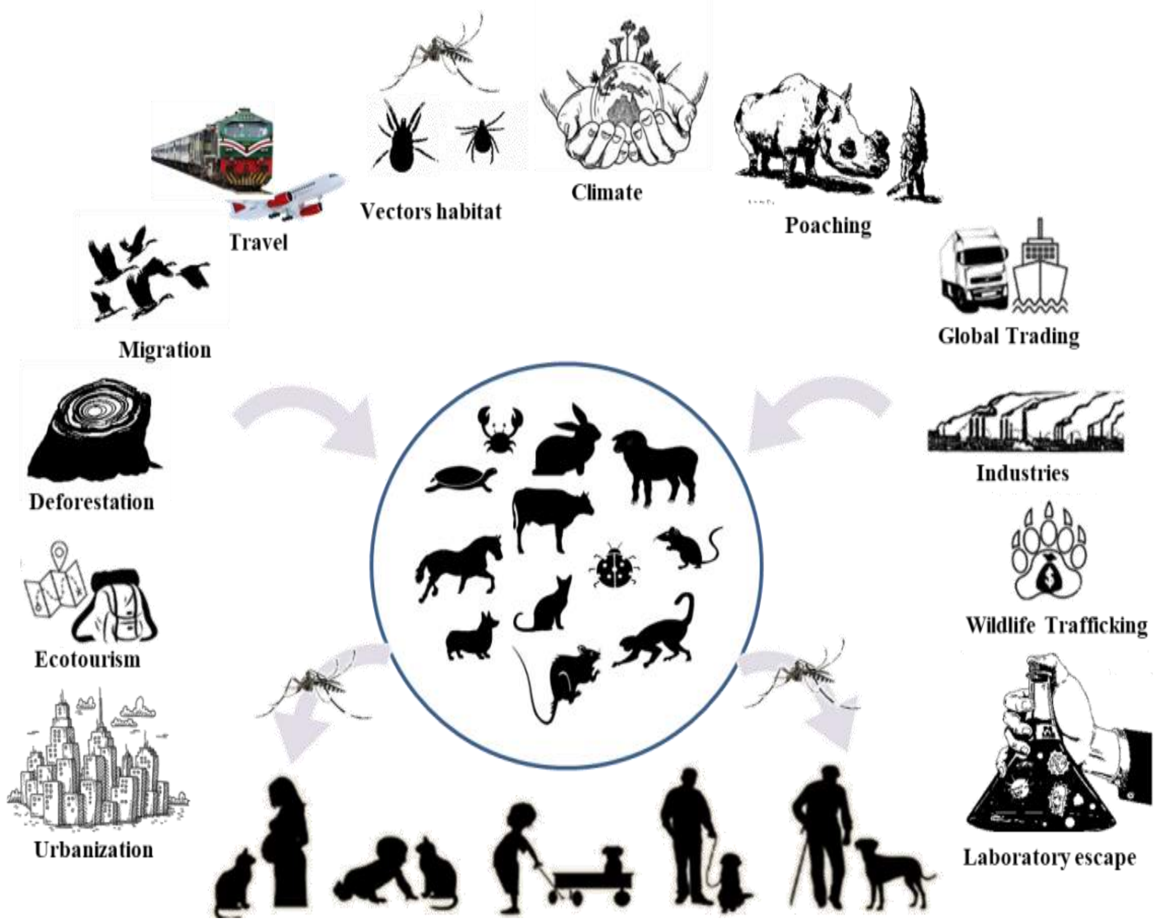


Fig. 2: Factors responsible for the development of zoonotic diseases and transmission to humans (do Vale et al. 2021)

Similar to this, One Health approach was used in Algeria to combat diseases spread by dogs, emphasizing the value of interdisciplinary training and education initiatives to increase public awareness (Kardjadj et al. 2019). These initiatives can increase the effectiveness of control measures and improve both human and animal welfare overall (Hasanov et al. 2018).

It's also vital to remember that programs for education and awareness are not just for the general population. They also target particular populations, like butchers, workers in animal shelters, and owners of livestock. These initiatives seek to educate and train people who interact often with animals and are more likely to spread zoonotic diseases (Steneroden et al. 2011). Public awareness and education campaigns are essential for stopping the spread of zoonotic illnesses. It has been demonstrated that these programs benefit both the general population and particular groups at higher risk by raising awareness, improving attitudes, and promoting behavior change as shown in Fig. 3. These programs provide a healthier and safer environment for both people and animals by spreading knowledge, encouraging ethical behavior, and One Health perspective (Prabhakar et al. 2017).

7. ROLE OF HEALTHCARE PROFESSIONALS IN DISSEMINATING KNOWLEDGE

Healthcare personnel are necessary in spreading information regarding zoonotic illnesses, as well as their attitudes, knowledge, and preventive practices. They are crucial information and direction sources for the public, patients, and other healthcare professionals. Healthcare workers' knowledge, attitudes, and preventive practices surrounding COVID-19 were reviewed in a study carried out in Northern Nigeria, underscoring the significance of healthcare professionals in spreading information about zoonotic illnesses. In addition to highlighting the need for ongoing information distribution on zoonotic disease prevention, the study also found knowledge gaps about the zoonotic origin of diseases. Socio-demographic and occupational factors may influence the knowledge and practices of healthcare workers about zoonotic infections (Tsiga-Ahmed et al. 2021). Healthcare practitioners can disseminate accurate information to help promote preventative actions and raise knowledge of zoonotic illnesses, thereby lowering their negative effects on public health (Stull et al. 2015).

8. ATTITUDES TOWARDS ZOONOTIC DISEASES

8.1. PERCEIVED SUSCEPTIBILITY AND SEVERITY

Perceived susceptibility and severity significantly shaped attitudes toward zoonotic illnesses. Studies have used the Health Belief Model to examine how attitudes and risk perceptions toward zoonotic illnesses are affected by perceived susceptibility and severity (Anderson et al. 2010). A person's perception of their susceptibility to an illness is known as perceived susceptibility, while their perception of the seriousness of the sickness is known as perceived severity (Sukeri et al. 2020). According to research, wildlife biologist's perceptions of protective measure's potential advantages can influence their views towards the risk of zoonotic diseases. (Anderson Bosch et al. 2010). Increasing knowledge and awareness of the zoonotic disease's perceived severity and susceptibility can have an impact on attitudes and encourage preventive behavior (Sukeri et al. 2020).

8.2. ATTITUDES TOWARDS PREVENTIVE MEASURES

Regarding zoonotic diseases, attitudes towards preventive practices such as immunizations, good cleanliness, and animal handling have been studied. Studies have emphasized the significance of people's knowledge, attitudes, and behaviors in avoiding the spread of zoonotic illnesses (Alemayehu et al. 2021). Farmer's adoption of preventive measures was found to be influenced by their knowledge, attitudes, and practices related to zoonotic diseases. Examining cattle producer's knowledge of and attitudes toward zoonotic disease prevention, with a focus on the importance of education and awareness of preventive measures (Tebug et al. 2015). Smallholder communities in Ethiopia demonstrated low levels of understanding and attitudes toward the hazards of zoonotic diseases, highlighting the need for increased education and preventive measures (Delelegn and Girma 2018). Tanzanian animal health professionals and livestock owners were evaluated for their knowledge of and attitudes towards zoonosis, which highlighted the significance of comprehending zoonotic disease indicators and preventative measures (Swai et al. 2010). These studies underline how important it is to spread awareness, a healthy outlook, and preventive behaviors in order to effectively reduce zoonotic infections.

8.3. PRACTICES RELATED TO ZOONOTIC DISEASES

The transmission of zoonotic diseases must be controlled in order to lessen its effects on both human and animal populations. It's crucial to uphold proper standards for sanitation and hygiene, including proper hand washing, waste disposal, and cleanliness in facilities used for housing and handling animals. Another essential practice for reducing zoonotic illnesses is routine veterinary treatment,

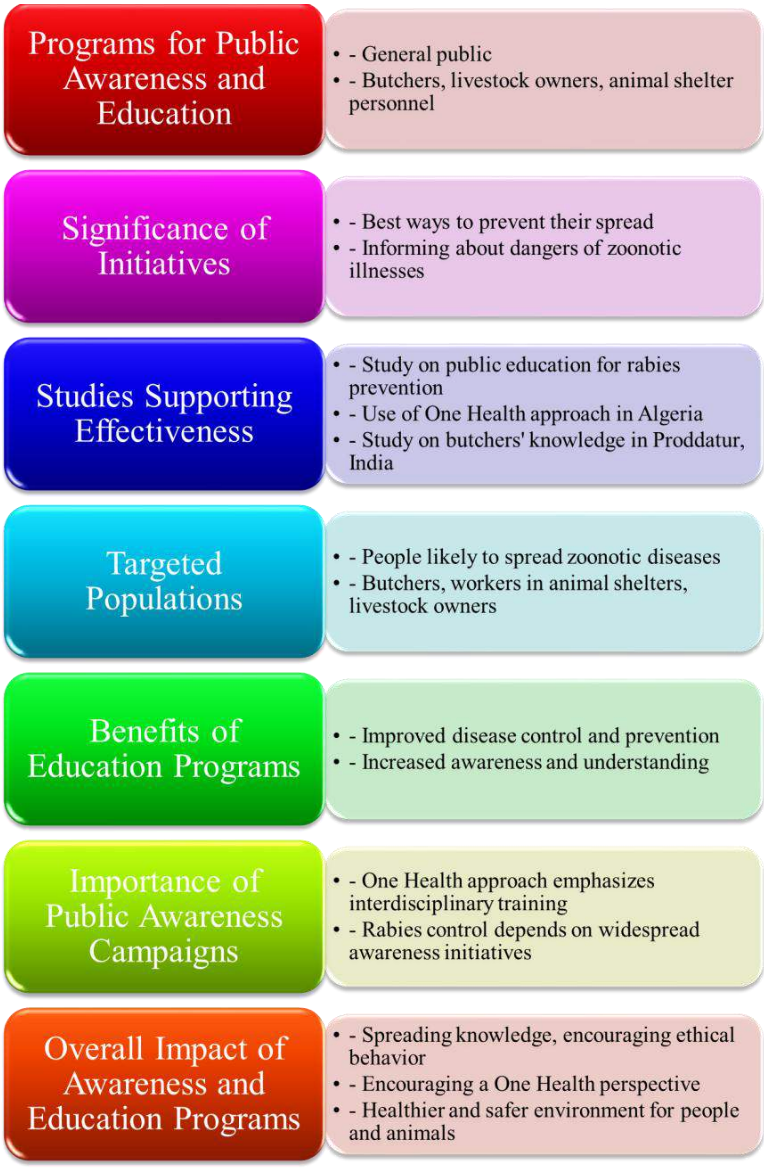


Fig. 3: Benefits of public awareness and education programs

such as vaccination and deworming programs for animals. In order to diagnose zoonosis early, report it quickly, and successfully intervene, it is essential to educate and raise community awareness about it. Understanding the intricate relationships and shared dangers posed by zoonotic diseases requires the application of One Health methodologies that integrate human, animal, and environmental health. Additionally, techniques for early zoonotic disease detection, research, and monitoring are being developed. (Marsh and Babcock 2015).

8.4. FACTORS INFLUENCING KNOWLEDGE, ATTITUDES, AND PRACTICES

8.4.1. CULTURAL, ECONOMIC, AND SOCIETAL FACTORS

Cultural, economic, and sociological variables significantly influenced the occurrence and spread of zoonotic illnesses. Studies have shown how these parameters affect the dynamics of zoonotic disease transmission. Cultural customs and beliefs may have an impact on how people handle, consume, and interact with animals, which may have an impact on the risk of zoonotic disease transmission (Delabouglise et al. 2017). Particularly in situations with limited resources, economic issues, such as poverty and a lack of proper healthcare infrastructure, can contribute to the persistence and spread of zoonotic illnesses (Narrod et al. 2012). Social norms, population density, and globalization are societal elements that can influence how zoonotic disease patterns arise and spread. (Thornhill et al. 2010). To address the underlying socio-cultural and economic causes of disease transmission, these variables interact in complicated ways and must be taken into account in zoonotic disease prevention and control efforts as shown in Table 1 (Holt et al. 2021).

8.4.2. EDUCATIONAL PROGRAMS AND AWARENESS CAMPAIGNS

Educational initiatives and awareness campaigns significantly influenced the control and prevention of zoonotic illnesses. These programs are designed to raise awareness of zoonotic illnesses among a variety of target groups and to change their attitudes and behaviors toward them. Studies have revealed that these initiatives can effectively increase awareness and encourage behavior change (Saegerman et al. 2012). For instance, research examining awareness among hunters and dealers in Sierra Leone discovered that a program of education aimed at the bush meat trade successfully reduced the spread of zoonotic diseases and raised participants' knowledge (Subramanian et al. 2012). These programs give essential information on how diseases spread, how to prevent them, and how crucial early detection and treatment are, enabling people and communities to respond appropriately (Moutos et al. 2022). The burden of zoonotic illnesses is reduced. Educational programs and awareness campaigns that increase awareness and knowledge promote public health.

8.4.3. ACCESSIBILITY TO HEALTHCARE AND VETERINARY SERVICES

By encouraging knowledge, behavior modification, and preventive actions, educational programs and awareness campaigns significantly influence zoonotic illnesses. Studies have demonstrated the value of such programs in boosting zoonotic disease knowledge and awareness among various communities. For instance, a program in Sierra Leone that educated hunters and dealers on the risk of zoonotic diseases brought on by the bushmeat trade was successful in assessing that risk (Subramanian et al. 2012). These initiatives help to strengthen infection control procedures, surveillance systems, and biosecurity measures (Nampanya et al. 2012). Educational programs and awareness campaigns are addressing the variables impacting disease transmission and control by focusing on certain populations or professions, such as veterinarians or cattle farmers, and raising awareness (Moutos et al. 2022). Additionally, they stress the value of early detection, immunization, and good hygiene habits in preventing zoonotic infections (Usuwa et al. 2020). Overall, these programs are extremely important for raising the awareness, information, and behaviors required for zoonotic disease prevention and management.

8.5. IMPACT OF KNOWLEDGE, ATTITUDES, AND PRACTICES ON ZOONOTIC DISEASES

The reduction of disease transmission, the improvement of public health, and the implications for policy-making and interventions are just a few of the many elements that knowledge, attitudes, and practices related to zoonotic diseases have a significant impact on. Studies have emphasized the importance of these elements in dealing with zoonotic illnesses and their effects. For instance, in the case of dengue fever, public knowledge, attitudes, and practices are vital in influencing preventative behaviors and vaccination acceptance, which reduces the spread of disease (Shafie et al. 2023). In order to execute successful interventions, policy-making benefits from comprehensive knowledge regarding zoonotic diseases that take into account both human and animal health. The One Health approach, which combines knowledge from various disciplines, assists in determining how interventions affect the spread of disease and guides policy decisions (Van Herten and Bovenkerk 2021). Furthermore, interventions influenced by knowledge, attitudes, and practices are responsible for the improvement in public health outcomes. For instance, food safety guidelines-based health interventions have been successful in lowering food borne illness and related disorders (Dilley et al. 2012). These interventions take into account social determinants of health and seek equitable results (Richard et al. 2021). Overall, zoonotic illnesses are affected in a variety of ways by knowledge, attitudes, and practices, including disease prevention, enhancing public health, and guiding policy-making and interventions as shown in Graph 1.

9. NEGLECTED ZOONOSIS

Neglected zoonosis usually receives minimal attention and resources for prevention, diagnosis, and treatment, in contrast to well-known zoonotic diseases like rabies or Ebola. These illnesses disproportionately affected low-income groups, particularly those in rural areas with scant access to resources and healthcare. Poverty, poor hygiene, inadequate veterinary care, and a lack of knowledge and resources for preventative and control measures are all factors that contribute to neglected zoonosis as shown in Fig. 4. These illnesses usually receive less attention from the international health community as compared to other severe diseases like malaria, HIV/AIDS, or tuberculosis. (Bangert et al. 2017). On the other side, neglected zoonosis can have disastrous effects on the afflicted community, including sickness, disability, and death. By affecting agriculture, general livelihoods, and livestock production, they can also have an economic impact. Numerous neglected zoonosis is endemic to specific regions and has intricate animal and human transmission cycles. Brucellosis, leptospirosis, cysticercosis, rabies, and zoonotic helminth illnesses like echinococcosis are examples of neglected zoonosis (Cutler et al. 2010).

10. CHALLENGES AND FUTURE DIRECTIONS

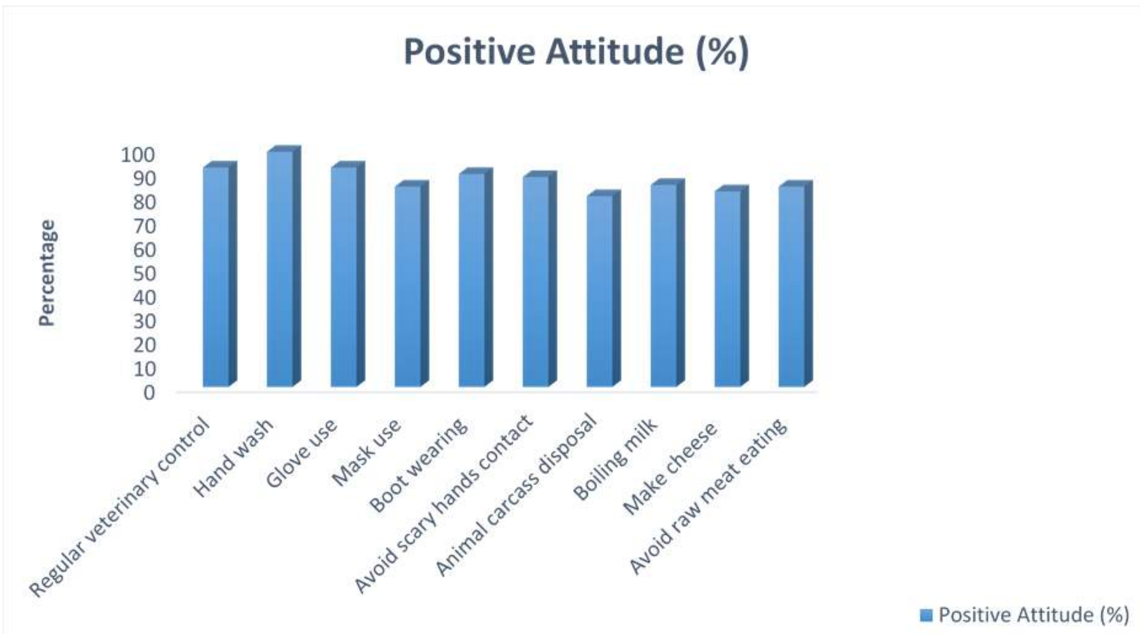
10.1. BARRIERS TO IMPROVING KNOWLEDGE, ATTITUDES, AND PRACTICES

There are a number of obstacles that inhibit advancement in disease prevention and control with regard to improving zoonotic disease knowledge, attitudes, and practices. These obstacles have been noted in various circumstances by studies. For instance, zoonotic disease risks and the practices utilized to reduce such risks were shown to create major obstacles in smallholder communities in Ethiopia (Alemayehu et al. 2021). Lack of disease surveillance and inadequate training of medical personnel are two obstacles to receiving post-exposure care for rabies in Uganda (Bonaparte et al. 2021). Similar obstacles existed in the Yucatan Peninsula of Mexico for better vector control of the Chagas disease, such as knowledge gaps and low community awareness (Rosecrans et al. 2014). Improvements in zoonotic disease knowledge and practices may also be hindered by sociocultural and access to healthcare services issues (Harris and Armién 2020). Effective interventions and the promotion of behavior change in zoonotic disease prevention and control efforts depend on recognizing and addressing these hurdles.

Table 1: The educational level of the farmers who participated in the study dealt with the knowledge, attitude, and practice in regard to zoonotic diseases (Özlü et al. 2020).

Educational status	Positive knowledge level (n)%
Illiterate	30 (19.9)
Literate	32 (21.2)
Elementary School	51 (33.8)
Secondary School	23 (15.2)
High School	8 (5.3)
University	7 (4.6)

n = Number of cattle Farmers



Graph 1: The rates of positive attitudes and practices of the farmers in regard to zoonotic disease and protection against their contamination. Data was presented in tabular form (Özlü et al. 2020)

Fig. 4: Basic features of neglected zoonotic diseases (WHO 2013)

11. FUTURE RESEARCH DIRECTIONS AND RECOMMENDATIONS

To improve disease prevention and control efforts, future research directions and suggestions for boosting understanding, attitudes, and practices relating to zoonotic illnesses are encouraged. Further research is necessary in a number of specialized areas. Studies, for instance, indicate that future interventions should use community-based strategies and concentrate on decreasing barriers to carrying out advised preventative practices. Designing successful interventions requires an understanding of the socio-cultural factors that influence behavior change and the acceptance of preventive measures (Harris and Armién. 2020). In addition, investigating the beliefs, behaviors, and practices of certain target groups, such as medical students and livestock farmers, might offer insightful information for customized interventions (Lincango-Naranjo et al. 2021). Future studies ought to address knowledge and awareness gaps regarding zoonotic illnesses and the usage of antibiotics (Farrell et al. 2021). Policymakers and public health experts may create evidence-based policies and recommendations for successfully avoiding and controlling zoonotic illnesses by filling in these research gaps.

12. CONCLUSION

In conclusion, it is crucial to comprehend zoonotic disease knowledge, attitudes, and practices (KAP) in order to prevent and stop the spread of these diseases. A holistic approach that considers the health of people, animals, and the environment is required for the prevention and control of zoonotic diseases since they have major effects on global health and the economy. Assessing public knowledge of zoonotic diseases may reveal gaps and misunderstandings that can promote the spread of the disease. The creation of individualized interventions and educational campaigns to promote risk-reduction behaviors and preventative measures is made possible by understanding people's attitudes and practices. Programs for educating the public, spreading accurate information, and promoting behavioral change are crucial for raising awareness. Both the general public and specific demographics like farmers, butchers, and livestock owners are targeted by these programs. In order to implement efficient preventative methods, it is essential to identify the transmission pathways and variables impacting transmission. Zoonotic illnesses can be spread through direct contact with infected animals, indirect contact with contaminated environments or objects, vector-borne transmission, foodborne transmission, airborne transmission, waterborne transmission, and fomite transmission. Understanding these pathways makes it easier to come up with efficient solutions to break the transmission chain. Healthcare professionals are crucial in disseminating knowledge about zoonotic diseases and promoting preventive measures. They are essential resources for the general public, patients, and other healthcare professionals in terms of knowledge and direction. Raising awareness and minimizing the impact on public health can be achieved by improving the knowledge and procedures of healthcare professionals about zoonotic diseases. Risk is affected by one's attitude towards zoonotic diseases, including how serious and susceptible they are seen to be. Reducing the spread of zoonotic diseases requires a positive attitude towards preventive measures like immunizations, cleanliness habits, and animal handling. It is possible to effectively control the spread of zoonotic diseases by promoting education, positive attitudes, and preventive measures. Last but not least, controlling and limiting the spread of zoonotic diseases requires knowledge of KAP related to those diseases. By filling in information gaps, promoting positive attitudes, and putting preventive measures into place, we can lessen the negative effects of zoonotic diseases on public health and safeguard the health of both people and animals. There is a need for greater research, public awareness campaigns, and multidisciplinary collaboration in the fight against zoonotic diseases and to safeguard world health.

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Potential Role of Zoonoses in Bioterrorism

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ABSTRACT

The presence of zoonotic pathogens in bioterrorism poses a serious danger to worldwide health and safety. Zoonotic diseases, which can be transmitted from animals to humans, are an attractive choice for individuals looking to cause deliberate harm. This summary explores how zoonotic diseases could be used for bioterrorism, emphasizing the dangers and difficulties involved. Zoonotic organisms like bacteria, viruses, and parasites can be readily acquired from natural sources, presenting a wide range of potential biological weapons. Concealing the source of the pathogen in animals makes it challenging to track, contributing to the covert nature of these acts of bioterrorism. Controlling the spread and identifying deliberate outbreaks of zoonotic diseases, which are transmitted by animal vectors, is challenging due to their complex transmission dynamics. The deliberate use of zoonotic pathogens in bioterrorism is intended to induce sickness, fatalities, or fear in human communities. Malign individuals may attempt to enhance the risk and resistance of zoonotic agents, intensifying their impact on public health and straining healthcare systems. Identifying and dealing with zoonotic bioterrorism poses significant challenges. Recognizing intentional events late can slow down quick reactions. The interconnected nature of human, animal, and environmental health emphasizes the importance of using a One Health approach, which encourages cooperation to address and minimize the effects of purposeful release of disease-causing agents from animals. In order to prevent the deliberate transmission of zoonotic diseases, we require improved monitoring, biosecurity measures, and international collaboration. Global cooperation is essential to tackle the cross-border danger, enhance biosafety measures, exchange crucial data, and reinforce response capacity. It is essential to comprehend and address the possible impact of zoonotic diseases in the event of bioterrorism in order to safeguard public health and global security.

Key words: Zoonoses; Bioterrorism; Biological weapons; One Health approach; Biosecurity

CITATION

Iqbal T, Ahmad A, Naveed MT, Ali A, and Ahmad M, 2023. Potential Role of Zoonoses in Bioterrorism. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 499-512. https://doi.org/10.47278/book.zoon/2023.038

CHAPTER HISTORY Received: 24-Jan-2023 Revised: 12-April-2023 Accepted: 05-July-2023

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1. INTRODUCTION

Zoonotic diseases refer to infectious diseases, which have the potential to be transmitted from animals to humans. The etiologies of these illnesses stem from pathogenic microorganisms consisting of bacteria, viruses, parasites, or fungi, which may exist organically within animals and possess the ability to transmit infections to humans beyond the typical species barrier. Zoonotic diseases possess the potential to spread from infected animals to human beings through various transmission routes, including direct contact with the infected animals, consumption of contaminated food or water, inhalation of infectious particles, or transmission by vectors such as mosquitoes or ticks. Various examples of zoonotic diseases are Rabies, Ebola Virus Disease, Avian Influenza, Lyme disease and Salmonellosis (Allen et al. 2021).

Bioterrorism is the deliberate use of biological agents to harm or create fear among people, animals, or plants. It uses biological weapons to cause illness, death, or disruption in society. Bioterrorism releases biological agents in air, water, or food, or through direct contact with contaminated surfaces or people, to create panic, destabilize economies, and weaken societies. Bioterrorism agents depend on factors like disease-causing ability, ease of transmission, detection and treatment evasion, morbidity and mortality rates. Examples include anthrax, smallpox, botulinum toxin, plague and viral hemorrhagic fever. Preventing/responding to bioterrorism needs coordinated efforts among public health, law enforcement, emergency response, and intelligence agencies. Strategies include early detection, diagnostic tests, improving healthcare, safety measures, and research on treatments (Tumbarski 2020). Table 1 enlist the zoonotic diseases that are used in bioterrorism.

2. ZOONOTIC DISEASES CHARACTERISTICS

Zoonotic diseases exhibit specific attributes that differentiate them from other forms of illnesses (Thornhill et al. 2010).

2.1. CROSS-SPECIES TRANSMISSION

Zoonotic illnesses possess the capability to traverse the interspecies divide, thus allowing for transmission between animals and humans. The etiological agents responsible for the aforementioned diseases have the capability to infect fauna in their natural habitats, though posing a threat to human health through their pathogenicity (Takeda et al. 2020).

2.2. MULTIPLE ROUTES OF TRANSMISSION

Zoonotic diseases have the potential for transmission through diverse means, encompassing direct contact with infected animals or their bodily fluids, consumption of contaminated food or water, inhalation of infectious particles or aerosols, and transmission via vectors such as mosquitoes or ticks. The proliferation and endurance of zoonotic diseases are notably attributed to the multifarious transmission pathways they inhabit (Gao et al. 2021).

2.3. RESERVOIR HOSTS OF ZOONOTIC DISEASE

Zoonotic diseases frequently exhibit animal reservoir hosts that are animal species that can harbor and transmit the pathogen without demonstrating overt clinical manifestations. Reservoir hosts assume a fundamental function in preserving the dissemination of the pathogen within its natural environment and represent plausible foci for human morbidity (Becker et al. 2020).

Table 1: Zoonotic diseases are used in bioterrorism

Sr. No	Disease	Description	References
1	Ebola Virus Disease (EVD)	Deadly virus transmitted via contact with infected animals/humans; high mortality and person-to-person spread	(Jacob et al. 2020)
2	Rabies Virus	The viral infection is spread by infected animal bites or scratches, with intentional release causing outbreaks and health risks	(Gold et al. 2020)
3	Plague Disease	Infection is caused by *Yersinia pestis* and transmitted by fleas infesting rodents. Can be weaponized for the spread	(Bouallegui 2021)
4	Avian Influenza Virus	Bird flu viruses (e.g., H5N1, H7N9) can cause severe respiratory illness in humans	(Shi and Gao 2021)
5	Anthrax Disease	Anthrax caused by *Bacillus anthracis*, is spread via contact with infected animals/products.	(Savransky et al. 2020)

2.4. RE-EMERGING AND EMERGING NATURE

The occurrence or resurgence of zoonotic diseases can be attributed to multiple factors, such as alterations in environmental circumstances, a human incursion into indigenous habitats, agricultural methodologies, global travel and commerce, and genetic variants in the pathogens. The relentless nature of zoonotic diseases renders them a perpetual public health concern (García-Rubio et al. 2023).

2.5. VARIABILITY OF PATHOGENS

A diverse array of pathogens, namely bacteria, viruses, parasites, and fungi, have the propensity to induce illnesses. Each pathogen possesses exclusive attributes, which include techniques of dissemination, duration of incubation, physical indications, and remedial possibilities (Chen et al. 2021).

2.6. EFFECT ON PUBLIC HEALTH

Zoonotic illnesses possess a considerable potential to exert a substantial influence on public health. These agents have the potential to trigger outbreaks or epidemics, leading to elevated rates of morbidity and mortality. Furthermore, zoonotic diseases can present significant difficulties in terms of diagnosis, treatment, and prevention attributable to their intricate characteristics and capacity for prompt dissemination (Naguib et al. 2021).

2.7. ONE HEALTH APPROACH

Zoonotic diseases underscore the significant interconnectedness that exists between the domains of human, animal, and environmental health. The management and prevention of zoonotic diseases necessitate the adoption of a One Health approach that encourages collective partnerships and coordination amongst an interdisciplinary team of medical experts, veterinary specialists, ecologists, epidemiologists, and other stakeholders (Zinsstag et al. 2023).

3. ZOONOTIC DISEASES WITH BIOTERRORISM PROSPECTIVE

3.1. ANTHRAX

Anthrax is a disease caused by *Bacillus anthracis* and can be used as a bioterrorism agent due to its durable spores. Spores can infect humans and animals. Anthrax can infect the skin, respiratory and gastrointestinal systems. Inhalational anthrax is deadly if untreated. Anthrax release in a populated area causes illness, panic and fatalities. It's been used in bioterrorism. Anthrax as a bioterrorism weapon has severe consequences due to its ability to cause illness, ease of dissemination, and potential for creating panic and societal disruption. Detecting, preventing, and responding to anthrax bioterrorism involves surveillance, diagnostics, health preparedness, and medical countermeasures (Hueffer et al. 2020).

3.2. PLAGUE

Plague is a zoonotic disease caused by *Yersinia (Y.) pestis* bacterium and spread by fleas from rodents like rats. Plague has been used as a bioweapon, notably during World War II by Japan's Unit 731. *Y. pestis* causes bubonic, septicemic, and pneumonic plague. Bubonic plague (swollen lymph nodes) is common, while septicemic and pneumonic plague are severe and transmitted directly between humans. Plague is a bioterrorism threat due to its high mortality rate and severity if untreated, especially pneumonic plague. *Y. pestis* can be easily cultured and intentionally released to cause an outbreak. The spread of bacterium could cause illness, panic, and mortality if intentionally released through aerosolization or food/water contamination. Pneumonic plague's person-to-person transmission raises bioterrorism concerns. Preventing bioterrorism involves surveillance, diagnosis, treatment, and public health preparedness to quickly respond to a potential plague outbreak caused by *Y. pestis* (Zizek 2020).

3.3. EBOLA VIRUS DISEASE (EVD)

Ebola is a zoonotic virus that can transfer to humans through contact with infected animals or fluids. The Ebola virus could be used for bioterrorism due to its potency in causing severe hemorrhagic fever. It has a high case fatality rate. Symptoms include fever, headache, weakness, and organ failure. It spreads through contact with infected bodily fluids. The Ebola virus is a concerning bioterrorism agent as intentional spread could result in increased transmission and pose a significant threat to society (Jacob et al. 2020).

3.4. AVIAN INFLUENZA

Bird flu is caused by influenza viruses that infect birds. Some subtypes, like H_5N_1 and H_7N_9, can cause severe illness in humans and may be able to spread easily from person to person. Avian flu viruses have bioterrorism potential due to high disease and mortality rates in humans. It can infect various birds, including domestic poultry which amplify its spread. Genetic modifications could worsen their transmissibility, making them bioterrorism agents. The release of avian influenza could cause respiratory sickness, panic and strain healthcare systems by contaminating supplies, aerosolizing the virus, or introducing infected birds to populated areas. Measures to address avian influenza as a bioterrorism threat include surveillance, quick diagnostics, education, vaccines, and biosecurity (Liu et al. 2020).

3.5. RABIES VIRUS

Rabies is a disease caused by the lyssa virus and transmitted through animal bites but is not a bioterrorism agent. Intentionally releasing rabid animals or infected materials can harm public health. Rabies is a deadly viral disease that affects the nervous system. The virus attacks nerves and spreads to humans through animal contact. Symptoms appear late and lead to death with no cure. Rabies is not linked to bioterrorism, but releasing infected animals or materials in a crowded area could increase transmission and pose health risks. This could cause panic and strain healthcare resources. Efforts to control rabies mainly involve animal vaccinations, wildlife surveillance, and post-exposure treatment of individuals (Gold et al. 2020).

4. THE ROLE OF ZOONOTIC DISEASES IN BIOTERRORISM AND THE CONTRIBUTING FACTORS

4.1. EASE OF ACHIEVEMENT

Surveying the ease of securing for bioterrorism includes numerous variables, such as the openness and accessibility of the operator or substance. Zoonotic diseases occur in animals worldwide and can spread easily to humans. These diseases utilize animal reservoirs as a source of pathogen transmission. The availability of infected animals affects the risk of zoonotic disease. These diseases can spread from animals to humans through bites, scratches, fluids, or tainted products. Simple transmission routes impact pathogen acquisition. Many can be grown in labs. Access to appropriate facilities and expertise enables culturing and multiplying pathogens for potential misuse. Some zoonotic pathogens have legitimate scientific and medical purposes. Research on zoonotic diseases can also be used for bioterrorism, which is raising concerns about malicious individuals acquiring pathogens or information (Etukudoh et al. 2020).

4.2. MORTALITY RATES AND PATHOGENICITY

Pathogenicity is the pathogen's capability of causing disease, usually gauged by the severity of the illness or the harm inflicted. The mortality rate is the proportion of infected individuals who die. Zoonotic disease severity varies based on the pathogen, transmission route, and immune response. Examples of zoonotic diseases with pathogenicity and mortality rates include rabies caused by the lyssa virus, which is always fatal after symptoms appear (Ahmad et al. 2020).

4.3. TRANSMISSION MECHANISMS OF ZOONOTIC DISEASES

Preventing zoonotic disease spread requires understanding transmission routes. Contact with infected animals or their fluids can spread zoonotic diseases. This includes handling, bites, or contact with blood, saliva, urine, feces, or secretions. Rabies and leptospirosis are transmitted through animal bites and contaminated urine, respectively, while indirect contact transmission occurs via contaminated objects or surfaces. Humans can contract infectious agents from contaminated objects, equipment, or environmental surfaces that have been touched or handled. This includes feces from infected animals such as those carrying *E. coli* and *Salmonella* and zoonotic diseases can be transmitted through vectors like mosquitoes, ticks, fleas, and lice. Vectors acquire pathogens and transmit them to humans during blood-feeding. Some zoonotic diseases can be transmitted via contaminated poultry products or meat/soil causing salmonellosis and toxoplasmosis, respectively. Others spread through respiratory droplets or aerosols. Infected animals can spread diseases like avian influenza and tuberculosis through coughing, sneezing, or shedding infectious particles into the air, which can be inhaled by humans. Vertical transmission is the passing of zoonotic diseases from mother to offspring during pregnancy, childbirth, or breastfeeding. Examples include HIV from mothers to babies and animal-to-offspring bacterial infections (Ihekweazu et al. 2021).

5. EFFECT ON PUBLIC HEALTH AND SOCIETY

5.1. PUBLIC HEALTH INFLUENCE

Zoonotic illnesses have the potential to induce a spectrum of health ailments in humans, varying from simple maladies to critical and lethal disorders. The aforementioned diseases have the potential to prompt noteworthy morbidity and mortality rates, thereby leading to escalated healthcare expenses, an imposition on healthcare infrastructure, and decreased efficiency within the workforce. Zoonotic diseases may potentially result in persistent health implications for individuals who survive the preliminary infection, including chronic ailments or disabilities (He et al. 2021).

5.2. EPIDEMICS AND OUTBREAK OF ZOONOTIC DISEASE

Zoonotic diseases possess the capability to instigate outbreaks and epidemics, especially in circumstances where proficient human-to-human transmission exists. The swift dissemination of these epidemics throughout communities, regions, or even on a global scale is capable of stimulating widespread, debilitating sickness, causing alarm and instability, and ultimately disrupting essential societal operations. Illustrative instances comprise the Ebola virus eruption in the western region of Africa alongside the SARS-CoV-2 virus-driven pandemic known as COVID-19 (Judson and Rabinowitz, 2021).

5.3. ECONOMIC EFFECT

Zoonotic diseases are capable of exerting a substantial economic influence on individuals, societies and nations. The occurrence of epidemic outbreaks may lead to reduced productivity owing to the prevalence of illnesses amongst individuals, loss of income, escalated costs incurred towards healthcare, and interruptions in trade and tourism operations. The repercussions pertaining to the economy can be particularly grave in settings that are constrained by resources, where healthcare systems might be inadequately equipped to tackle the implications of widespread outbreaks (Winck et al. 2022).

5.4. PSYCHOLOGICAL AND SOCIAL CONTROL

Zoonotic diseases have the potential to cause psychological and social ramifications among both individuals and communities that are affected by outbreaks. Perceived risk of infection may elicit fear, anxiety, and stigmatization. The relations and beliefs within a community can undergo significant changes, ultimately causing social unrest or discriminatory behavior. These factors may exacerbate the challenges associated with outbreak response and impede the implementation of effective control strategies (Hui et al. 2020).

5.5. ONE HEALTH APPROACH FOR ZOONOTIC DISEASE

The observation of zoonotic diseases brings in light the interdependence of human, animal, and environmental conditions. The significance of these repercussions reinforces the necessity of implementing a One Health strategy, which acknowledges the interrelatedness of these fields and advocates communal endeavors in monitoring, preempting, and managing zoonotic ailments. The proposed methodology entails the establishment of a symbiotic partnership amongst health practitioners, veterinary experts, and environmental specialists in order to holistically mitigate the incidence of zoonotic ailments (Debnath et al. 2021).

5.6. CHALLENGES IN DISCOVERY AND REACTION

Detecting and responding to zoonotic diseases is challenging due to their complexity and the various factors involved. These diseases transmit pathogens from animals to humans. Detecting and responding to diseases can be difficult due to unknown reservoir hosts and transmission dynamics, especially for diseases with multiple potential hosts or wildlife reservoirs. Zoonotic diseases spread fast and need global surveillance. Coordination is tough due to different capacities, infrastructure, and data-sharing. This highlights the interconnection of human, animal, and environmental health. Collaborating across sectors and disciplines is vital for zoonotic disease control, despite challenges in communication and priorities. A prompt and organized response is crucial in dealing with zoonotic disease outbreaks. This requires the involvement of healthcare providers, public health agencies, and veterinary services. However, creating and maintaining response capacity is difficult, especially in areas with limited resources (Traore et al. 2023).

6. HISTORICAL CASES AND OCCURRENCES INCLUDING ZOONOTIC DISEASES IN BIOTERRORISM

6.1. AUM SHINRIKYO CULT’S AND ANTHRAX PLOT

The Aum Shinrikyo cult, a Japanese religious group, used anthrax as a biological weapon in acts of terrorism. Aum Shinrikyo planned to weaponize anthrax in the mid-1990s for mass acts of violence to accelerate the apocalypse, led by Shoko Asahara. Aum Shinrikyo built a lab in Kamikuishiki, Yamanashi Prefecture for their biological weapons program, researching pathogens like anthrax. Scientists and technicians planned to weaponize anthrax spores and release them in Tokyo. Aum Shinrikyo trained for bioweapons and scouted possible release sites, but failed to create a usable anthrax weapon. They struggled to culture and weaponize anthrax but failed to create a deadly weapon. In 1995, Aum Shinrikyo attacked Tokyo's subway with sarin, killing 13 and injuring thousands. This attack raised global awareness and prompted a crackdown by authorities. Afterward, the Aum Shinrikyo cult's failed anthrax plan and biological weapons program were found. Raids on cult facilities uncovered evidence of anthrax plots and other biological activities, exposing the threat of terrorist groups using such weapons. The occurrence led to global efforts to improve biosecurity, surveillance, and prevent biological weapons (Gupta et al. 2021).

6.2. SOVIET UNION'S WEAPONIZATION OF OUTBREAK

During the period of the Cold War, the Soviet Union was involved in a comprehensive program of research and development aimed at advancing the field of biological weaponry, with a particular focus on the weaponization of *Yersinia pestis*, commonly referred as the plague (Blackburn et al. 2020).

6.3. SOVIET BIOWEAPONS PROGRAM

During the 1970s and 1980s, the Soviet Union embarked on the establishment for a considerable bioweapons program, which was named Biopreparat. The objective of this program was to formulate and generate a diverse range of biological agents that could potentially be utilized as weapons (Rimmington 2021).

6.4. BIOLOGICAL WEAPON AND PLAGUE

Plague, an infectious disease caused by the bacterial pathogen *Yersinia pestis*, appeared on the Soviet Union's list of agents that were subject to study and weaponization. The plague has a prolonged historical background as a catastrophic contagious ailment that possesses the ability to disseminate and result in substantial fatality rates if not managed forthwith (Ansari et al. 2020).

6.5. WEAPONIZATION AND RESEARCH

Extensive research pertaining to the plague, encompassing inquiries related to its pathogenesis, modes of transmission and techniques of weaponization, was undertaken by Soviet scholars. The objective was to devise means for the aerosolization of a certain strain of bacteria, thereby facilitating its widespread distribution across vast expanses with the intent of infecting and debilitating or dispatching adversary communities (Carlson et al. 2022).

6.6. DELIVERY SYSTEMS OF WEAPON

The Soviet Union utilized diverse means of deployment for their biological weaponry, encompassing projectile-based technologies such as missiles, artillery shells and bombs, as well as airborne dispensers integrated into spray tanks mounted onto aircraft. The aforementioned systems were ingeniously devised to distribute the weaponized bacteria of the plague to specific geographic regions, thus ensuring a swift and exhaustive dispersion (Zavattaro and Bearfield, 2022).

6.7. AGGRESSIVE BIOWEAPONS PROGRAM

The weaponization of plague by the Soviet Union was a crucial aspect of its aggressive bioweapons program, primarily designed to gain a definitive edge in the realm of warfare. The epidemic disease known as Plague, owing to its capacity for inflicting significant loss of life and generating widespread apprehension and societal chaos, was viewed as an asset capable of advancing military ambitions (Tong et al. 2020).

6.8. COLLABORATION WITH OTHER NATIONS

In 1972, the Soviet Union, in collaboration with other nations, ratified the Biological Weapons Convention that effectively banned the manufacture, procurement, and storage of biological weapons. Based on available evidence, it appears that the Soviet Union persisted in its pursuit of bioweapons research and production endeavors, thereby violating the terms of the relevant treaty (Helvaci et al. 2022).

6.9. POST-SOVIET ERA

The Russian Federation became the successor of the Soviet bioweapons program following the dissolution of the Soviet Union in 1991. In 1992, the Russian government issued an official declaration to discontinue any further development or production of offensive bioweapons and purportedly eradicated their inventory of such weapons, which included specimens containing the plague pathogen (Kerr et al. 2022).

7. PROSPECTIVE USE OF ZOONOTIC DISEASES

The prospect of zoonotic diseases being exploited by non-state actors, including terrorist groups or individuals, is an issue of significant concern.

7.1. THREAT OF BIOLOGICAL WEAPONS

Zoonotic diseases exhibit features that render them suitable for employment as biological weaponry. It can be postulated that certain diseases possess a significant potential for contagion, leading to grave morbidity or even mortality. Additionally, there exists a distinct possibility for such illnesses to rapidly disseminate within the human population. The aforementioned characteristics render them highly appealing to individuals seeking to instill mass terror, disarray, and loss of life (Farkas et al. 2023).

7.2. BIOTECHNOLOGY AND GENETIC ENGINEERING METHODS

Zoonotic diseases are naturally present in animal populations and are potentially accessible to individuals or groups with unkind intentions. Certain zoonotic pathogens have the capacity to be acquired through exposure to contaminated animals or environmental reservoirs. However, certain pathogens necessitate specialized laboratory facilities for proper isolation and cultivation. The progressions made in biotechnology and genetic engineering methods have amplified apprehensions regarding the calculated alteration or augmentation of zoonotic pathogens with the intention of weaponization (Tumbarski 2020).

7.3. COMPARATIVELY SMALL TECHNOLOGICAL BARRIERS

In contrast to alternative armaments, the creation, and implementation of biological armaments, specifically those that target animals and can be transmitted to humans, may necessitate a less intricate technological setup and infrastructure. The mastery of certain skills and the availability of resources is imperative in handling zoonotic pathogens. However, fundamental understanding and tools for such procedures are accessible through scientific literature and secret channels (Lentzos 2020).

7.4. PROSPECTIVE FOR SECRET ATTACKS

Zoonotic diseases can spread without being noticed because they don't show any symptoms until the person or animal get sick. This makes them difficult to detect early. Their main spread could accidentally happen without being noticed, so it avoids being recognized early. This phenomenon may enable malefactors to evade close examination and raise the probability of broader dissemination prior to efficient intervention by governing bodies (Ferreira et al. 2021).

7.5. GLOBAL CONTROL OF ZOONOTIC DISEASE

Zoonotic illnesses possess a capacity for worldwide ramifications owing to the interrelated character of contemporary society. Given the global phenomenon of international travel and trade, an outbreak triggered by the deliberate dissemination of zoonotic disease within one locality may disseminate to other regions of the world, culminating in a widespread epidemic or pandemic (Erkyihun and Alemayehu 2022).

8. PREPARATION, ACTIONS AND PREVENTION

8.1. SURVEILLANCE AND INITIAL WARNING METHODS

Surveillance detects zoonotic diseases and bioterrorism threats by collecting, analyzing, and interpreting disease data. Surveillance for zoonotic diseases monitors animal and human populations for disease outbreaks, using various techniques such as testing, sentinel, syndromic, and event-based. Animal surveillance detects zoonotic diseases and identifies potential reservoirs by monitoring domestic and wild animal populations. Active and passive surveillance is used to detect zoonotic diseases. Detecting these diseases in humans is crucial. International collaboration is necessary to monitor and warn against zoonotic diseases. Networks like the WHO and OIE enable sharing of information, surveillance alignment, and response coordination. Sharing surveillance data and communicating quickly during outbreaks is crucial. Integrating various data sources like epidemiological lab results, environmental, and animal health data is beneficial for surveillance systems. Integrating data provides a comprehensive view of disease transmission, and risks. Advanced analytics identify trends, patterns, and high-risk areas and improve surveillance. Early warning systems alert against potential disease threats by relying on prompt reporting, rapid communication, and efficient data analysis. Timely alerts facilitate quick response, control measures, and resource deployment (Meckawy et al. 2022).

8.2. AWARENESS OF PUBLIC HEALTH EDUCATION

Public health education is crucial for disease prevention and control, including zoonotic diseases. It promotes awareness and empowers individuals and communities to take preventive measures. This involves promoting good hygiene, vaccination, vector control, and safe behavior around animals to reduce the risk of disease transmission. Public health education is crucial in identifying and treating zoonotic diseases. It teaches people about symptoms, transmission, and behaviors that increase risk. This leads to timely medical care and better outcomes. Public health educates on healthy lifestyles to prevent disease. It includes balanced diets, exercise, sleep, stress management, and avoiding risky behaviors. Teaching public health equips people with knowledge about zoonotic diseases to promote informed and appropriate actions during outbreaks or bioterrorism threats. Clear and accurate communication is essential for building trust, dispelling myths, and promoting precautionary measures. Public health education promotes individual and community involvement in health protection through seeking healthcare, vaccinations, and prevention. Targets education efforts to reach rural communities, agricultural workers, pet owners, travelers, healthcare workers, and those in high-risk areas while considering cultural, social, and economic factors. Incorporating public health in schools and workplaces educates individuals on disease prevention through training, workshops, and practical knowledge for life-long safety (Abd El-Ghany 2020).

8.3. AGRICULTURE, WILDLIFE MANAGEMENT AND BIOSECURITY MEASURES

Biosecurity is crucial in agriculture and wildlife management to prevent disease spread. Regular monitoring is vital to detect and respond to outbreaks promptly. Surveillance, testing, and reporting identify threats and enable control measures. Quarantine stops the disease spread. Enforced measures prevent the entry and exit of potentially infected animals or materials. Hygiene is crucial in disease prevention. Clean and disinfect animal housing, equipment, and vehicles. Follow hygiene protocols during the handling, processing, and storage of products to reduce contamination risks. Animal health programs and surveillance in wildlife management aid in the early detection and intervention of diseases for the benefit of both animals and humans. The process includes monitoring wildlife health, detecting diseases early, and implementing management strategies such as population and habitat management. Educating relevant stakeholders is crucial for promoting biosecurity awareness. Educate on disease prevention, implement biosecurity, and report unusual events. Collaborate for effective biosecurity with farmers, vets, agencies, and researchers. Sharing information improves disease prevention and control while enforcing biosecurity regulations is crucial. Standards, guidelines, and policies are established to ensure compliance with biosecurity requirements in agriculture and wildlife management (Gates et al. 2021).

8.4. ESTABLISHMENT OF LABORATORY CAPABILITY FOR DIAGNOSTICS

The successful disease detection and response is enhancing the diagnostic lab capacity, which requires proper infrastructure including lab space, sample handling equipment, and specialized facilities. Maintaining lab equipment and a skilled workforce is essential for accurate diagnostics. Train lab personnel in modern diagnostics, quality assurance, biosafety and biosecurity. Ongoing education and knowledge sharing keeps them updated on emerging technology and best practices. Implementing quality management systems and gaining accreditation from recognized bodies enhances reliability and credibility. The lab must access pathogen and disease tests including rapid, molecular, serological and culture-based methods. Providing affordable and available diagnostic supplies is crucial for accurate testing. Proper biosafety and biosecurity protect personnel from pathogens. Adhering to global biosafety standards ensures safe pathogen handling. Efficient data management systems enable proper documentation, storage, and sharing of lab results. Lab systems and electronic reporting streamline data, enable timely exchange with public health, and support investigations, and surveillance. Collaborative networks boost capacity via info-sharing, pooling resources, and coordinating efforts. Collaboration is key for knowledge exchange and research, while funding is crucial for lab capacity. Allocate resources for infrastructure, equipment, training, and quality improvement (Gradisteanu et al. 2022).

8.5. INTERNATIONAL COLLABORATION AND INFORMATION DISTRIBUTION

Global health challenges require international cooperation and information sharing, especially regarding zoonotic diseases and bioterrorism. Surveillance networks enable the timely exchange of epidemiological and laboratory data and enhance coordination among countries and regions. International cooperation harmonizes standards for health and enables effective collaboration in addressing common health threats. Partnerships transfer expertise, technology, and resources. Research efforts understand zoonotic diseases and develop prevention strategies. Global research collaborations share data, research together and exchange findings, leading to innovation. During health crises, cooperation allows quick response. Coordinated action and shared resources help to contain outbreaks, minimize public health impact, and prevent cross-border spread. International cooperation addresses zoonotic diseases and bioterrorism. Collaboration affects policy, resources, and regulations for global health security. Sharing occurs through international networks. This involves events such as conferences, workshops, online portals, and knowledge-sharing platforms for experts to exchange experiences and find solutions. Collaborative exercises improve coordination and interoperability among countries. Exercises, sharing, and protocols strengthen readiness and response (Kirsch et al. 2022).

9. CONCLUSION

Zoonotic diseases can be used as bioterrorism agents, posing a serious threat to public health. Preparedness and response strategies are necessary due to their ease of acquisition, pathogenicity, mortality rates, and transmission mechanisms. Efforts ensure early detection, quick response, and effective control to prevent harm, and chaos, and safeguard workers while promoting cooperation. To combat zoonotic diseases, education, biosecurity, lab improvements, global teamwork, and information sharing are crucial. Future challenges include understanding emerging diseases, resistance, the One Health approach, vaccine diagnostics, risk assessment/modeling, exploring behavioral factors, and international cooperation. The One Health approach links human, animal, and environmental health to tackle zoonotic diseases and bioterrorism. Collaboration, data integration, and holistic strategies are key priorities. Make safe vaccines for potential bioterrorism zoonotic diseases. Our goal is to improve vaccines and diagnostics for zoonotic diseases, create cost-effective diagnostic tools, prioritize potential bioterrorism diseases, and evaluate their impact with risk assessment models. Understand disease attitudes for effective prevention. Research disease transmission and public health response, study social factors and collaborate globally to address zoonotic diseases and bioterrorism threats. Efforts should be made to safeguard against zoonotic disease and protect public health.

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Role of Cats in Ecology and Modeling of Zoonotic Diseases

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ABSTRACT

This study examines the intricate function that domestic cats play in ecology and their significance in simulating zoonotic diseases. Because they are both buddies and predators, cats have a variety of consequences on local ecosystems. By feeding on small animals and birds, they manage rodent populations, promoting biodiversity, but they can also have negative ecological effects. To completely accomplish their twin purpose, it is imperative to comprehend their ecological footprint. Cats may also have the ability to spread zoonotic diseases, which are illnesses that can spread from domestic animals to humans and other animals. To make sense of the intricate dynamics of zoonotic disease transmission from cat to cat, modeling techniques are used in this work. We want to improve our capacity to forecast and control disease outbreaks by integrating ecological and epidemiological data. The study's conclusions have an impact on laws on public health and wildlife conservation initiatives. It is critical to comprehend the complex interactions that exist between cats, ecosystems, and zoonotic illnesses to design mitigation strategies that balance ecological preservation with public health concerns. This research adds to our understanding of the holistic management of coexisting cats and other species in shared settings.

Key words: Cats, ecology, Zoonotic diseases, pet animals, humans

CITATION

Rasheed M, Riaz A, Naz G, Majeed A, Akhter N, Ashraf K, Khalid A, Nadeem H, Farooq W, Uroos A, Noreen R and Hameed T, 2023. Role of cats in ecology and modeling of zoonotic diseases. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 513-529. https://doi.org/10.47278/book.zoon/2023.039

CHAPTER HISTORY Received: 12-March-2023 Revised: 23-April-2023 Accepted: 21-Aug-2023

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1. INTRODUCTION

Humans are associated with animals in one way or another. The word zoonosis is derived from the Greek word "zoon" which means animals and "noses" implies illness. Zoonosis is referred to be an illness or sickness that spreads from vertebrate animals to people. About 60% of pathogens including viruses, bacteria, fungi, protozoa, and parasites are zoonotic. The re-emergence, dispersion, and trends of zoonosis have been profoundly influenced by a variety of anthropogenic and natural causes, including climate change, urbanization, animal movement and commerce, tourism, traveling vector biology, and travel and tourism. More zoonotic illnesses are re-emerging and emerging as time goes on (Rahman et al. 2020).

1.1. EPIDEMIOLOGY

Routes of Transmission: Zoonotic pathogens can spread through close contact with diseased cats, contact with contaminated litter or feces, and occasionally through fleas and ticks.
Prevalence: The incidence of these diseases varies geographically and is influenced by elements such as cat population density, hygiene standards, and public health awareness.
High-Risk Groups: Some people are more likely to suffer serious problems from zoonotic infections, including those with weakened immune systems, expectant mothers, and young children.
One Health strategy: A One Health strategy that takes into account the health of all these constituent parts is essential for efficient illness management and prevention because many diseases include interactions between people, animals, and the environment.
Preventive actions: The risk of zoonotic disease transmission can be considerably decreased by educating cat owners about proper hygiene, litter box management, regular veterinary care, and responsible pet ownership.
To reduce threats to human and animal health and foster peaceful cohabitation, it is crucial to comprehend the intricate relationships that exist between cats, zoonotic illnesses, and the larger environment.

1.2. CHAPTER'S OBJECTIVES

This chapter's goals are to give readers a thorough grasp of how cats contribute to the spread of zoonotic diseases and to stress the significance of responsible pet ownership and good hygiene habits.
To Instruct the Readers: Make sure that people are aware of the zoonotic diseases that cats can spread to people, including their causes, symptoms, and treatment options. Increase Public Awareness of Hygiene Stress the value of maintaining good hygiene when dealing with cats, emptying litter boxes, and engaging with their surroundings.
Specify Realistic Advice: Provide helpful advice for reducing the danger of zoonotic disease transmission, especially for those who are more susceptible, like expectant mothers, small children, and people with impaired immune systems.
Promote Pet Ownership That Is Responsible: Emphasize the need for routine veterinary care, parasite control, and healthy feeding to preserve cats' health and lower the danger.
Encourage More Research: Identify areas that require more investigation in order to comprehend cat-related zoonotic diseases, their dynamics of transmission, and potential treatments.

1.3. IMPORTANCE OF UNDERSTANDING ZOONOTIC DISEASE TRANSMISSION

People can contract zoonotic diseases from feral cats directly through direct contact, such as when a pathogen is introduced into an animal's bite or scratched wound, or indirectly through ingesting a pathogen that was released into the environment through cat excrement (Fig. 1). Children are more susceptible than adults to diseases brought on by coming into contact with wild cats, whether directly or indirectly (Roebling et al. 2014). Environmental pollutants like infectious parasite ova are more likely to be consumed by children than by adults. This is due to the actions taken by kids, including greater ground contact, hand-to-mouth movement, pica, and generally poor hygiene. (Rabinowitz and Conti 2010; Ferguson and Solo-Gabriele 2016).

Several zoonotic illnesses, such as rabies, dermal larval migraines caused by different nematode parasites, plague, tularemia, and murine typhus, are spread by free-roaming cat populations, which have been highlighted as a serious hazard to public health. In addition to causing death in people, a number of these illnesses have also been linked to other serious health problems like abortion, blindness, itchy skin rashes, and other symptoms (Gerhold and Jessup 2013).

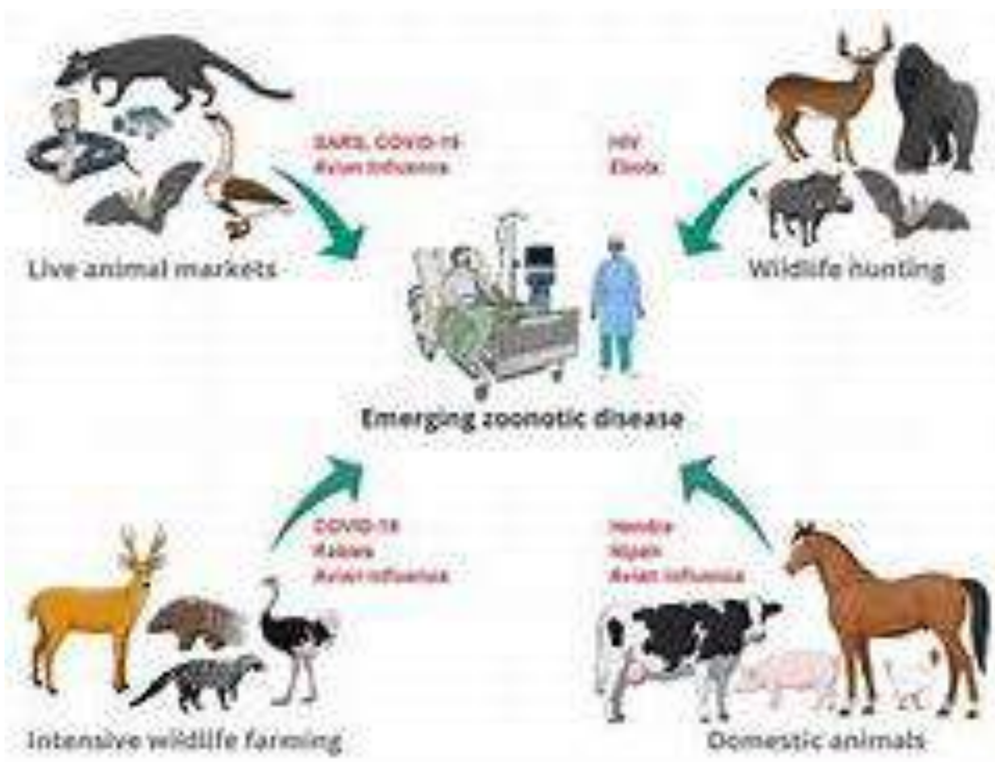

Fig. 1: Example of zoonotic diseases that have (-ve) emerged at the animal-human interface. Transmission pathways include direct contact through the handling of living animals (wildlife trade, domestic animals) and preparation of slaughtered animals for consumption of meat or for traditional medicine uses.

Understanding the spread of zoonotic diseases is essential for safeguarding public health, advancing a holistic approach to health, predicting and preventing outbreaks, advancing research and vaccine development, addressing agricultural and economic issues, protecting biodiversity, and increasing public awareness of how to prevent and control these potentially dangerous diseases.

1.4. SIGNIFICANCE OF CATS IN ZOONOTIC DISEASE DYNAMICS

Although pets offer significant benefits to our society, there are well-documented health hazards associated with owning a pet. Bites, scratches, and allergies are the commonest health hazards;

however, a diverse range of infections, including parasitic, bacterial, fungal, and viral diseases can be transmitted to humans. Although numerous enteric parasites have been recognized in dogs and cats, not all have the potential for transmission to humans. (Bugg et al. 1999). Infection with *Toxoplasma gondii* is common in humans and other animals. (Cook et al. 2000). Cats are the only definitive host for this parasite, i.e., oocysts can only develop in cats. Cats excrete these oocysts 3–4 d after eating the meat of an animal containing the bradyzoites or tachyzoites of *T. gondii*. (Tenter et al. 2000). Even though cats have been linked to zoonosis transmission to their owners, the risk of spreading from exposure to cats is low and might be further diminished by taking a few easy precautions (Sabry et al. 2013).

2. THE ECOLOGICAL ROLE OF CATS

2.1. DOMESTICATION AND HISTORY OF CATS

1. Around 9,000 years ago, cats were tamed in the East, where they probably assisted in reducing rodent populations around habitations.
2. Cats became cherished companions and pest controllers as they expanded across various cultures through commerce and travel over time.
3. Domestic cats are among the most beloved pets in the world right now due to friendship, playfulness, and independent spirits.
According to MacCallum Research and Mackay (1992), having a pet can help people relax, find company, and maintain stability in their lives. Some studies even suggest that having a pet can enhance a person's wellness (Kurushima et al. 2013).

2.2. IMPACT ON LOCAL WILDLIFE POPULATIONS

Feral cats can also influence another ecological process through their predation upon nectivorous and frugivorous vertebrates especially disruption of native seed dispersal systems (Nogales et al. 1996) or secondary long-distance dispersal of invasive plants (Bourgeois et al. 2004). Since then, domestic cats (Felis silvestris catus) have traveled with humans to most corners of the globe including many remote islands where they have become feral. (Fitzgerald 1988). As many native island species have reduced behavioral, morphological, and life-history defenses against mammalian predators, and because islands have a disproportionate share of global terrestrial biodiversity (Kier et al. 2009), In addition to direct impact of predation, indirect impacts, such as apparent competition, food competition, or transmission of disease have also been reported or suggested (Nishimura et al. 1999; Phillips et al. 2007; Rayner et al. 2007). The worldwide introduction of feral domestic cats has led to the extinction of numerous species of wildlife on islands. Large-scale estimations of the number of fatalities they generate in mainland areas are still hypothetical, with little consideration given to scientific evidence and assessments that are not systematic (Loss et al. 2013).

2.3. ECOLOGICAL BALANCE AND BIODIVERSITY

Domestic and feral cats can have a variety of complicated consequences on biodiversity and ecological equilibrium. This might cause local wildlife populations to decrease or perhaps become extinct, which would upset the ecosystem's natural equilibrium. Maintaining the fragile ecological balance and protecting biodiversity requires the implementation of methods that give native species conservation priority while also assuring the well-being of cats (Loss et al. 2013).

2.4. CATS AS VECTORS FOR ZOONOTIC DISEASE TRANSMISSION

Cats can act as vectors for various zoonotic diseases, meaning they can carry and transmit infectious pathogens to humans. The degree of exposure among different cat species to many relevant zoonotic agents is still not fully understood, despite the fact that cats and the arthropod parasites they harbor can occasionally be significant sources of zoonotic infections in humans (Case et al. 2006).

2.5. GUT-ASSOCIATED ZOONOTIC PATHOGENS

Cats' guts can harbor various zoonotic pathogens, which are infectious agents that can be transmitted from animals to humans.

2.5.1. CAMPYLOBACTER

Cats' digestive tracts often have the Campylobacter bacteria. Humans can contract infections by coming into contact with cat feces or polluted areas. Cats' digestive tracts often have the Campylobacter bacteria. Humans can contract infections by coming into contact with cat feces or polluted areas. Campylobacter species have become prominent clinical pathogens over the past three decades, especially as they relate to human public health because they are mostly responsible for acute microbial enteritis in Western nations. The species *C. jejuni* and *C. coli*, which cause the majority of these gastrointestinal-related diseases, are of special concern (Moore et al. 2005).

2.5.2. *ESCHERICHIA COLI* (*E. COLI*)

A few types of E. coli can get people sick with digestive problems. 3. *Yersinia enterocolitica*: Cats' intestines are capable of harboring this pathogen. Contact with contaminated surfaces or cat feces can spread this bacterium, which can cause gastrointestinal diseases in humans. Cats may excrete these germs in their feces as well as carry them around in their intestines.
4. Cats can carry Cryptosporidium, a parasite protozoan that can make people sick if they swallow it after coming into touch with polluted cat feces or water sources.

2.6. RESPIRATORY ZOONOTIC PATHOGENS

Cats can carry various zoonotic pathogens that can be transmitted through their respiratory secretions. Some of the respiratory zoonotic pathogens associated with cats include:
Cats can occasionally infect people with certain types of influenza viruses because they are vulnerable to them. This zoonotic transmission is more likely to occur in environments where sick cats and people are nearby. Cats that are exposed to these bacteria develop feline chlamydiosis, a respiratory condition. Humans can contract the virus from infected cats, which occasionally results in minor respiratory symptoms.

2.6.1. BORDETELLA BRONCHISEPTICA

Cats are capable of carrying the bacteria *Bordetella bronchiseptica*, which results in respiratory conditions in animals (Fig. 2).

2.6.2. MYCOBACTERIUM TUBERCULOSIS

Although it's rare, cats can contract the disease from ill people and, in some cases, transmit it back to people through respiratory secretions.

3. ZOONOTIC DISEASES AND CATS

3.1. COMMON ZOONOTIC DISEASES TRANSMITTED BY CATS

Cats are a source of multiple zoonotic diseases like rabies, toxoplasmosis, cat scratch disease, ringworm, toxocariasis, and salmonella due to several nematode parasites. Several of these illnesses have been linked to death in people and can result in a number of serious health problems, such as abortion, blindness, itchy skin rashes, and other different symptoms (Gerhold and Jessup 2013).

3.2. TOXOPLASMOSIS

One of the most well-known zoonotic diseases linked to cats is toxoplasmosis, which is caused by the Toxoplasma gondii parasite. Although cats are the primary carriers, humans can contract the disease through contact with infected cat feces, contaminated soil, or raw/undercooked meat (Dubey et al. 2020).

3.3. CAT SCRATCH DISEASE

Although rare, cat scratch disease (CSD) can occur when Bartonella henselae bacteria enter the body through a bite or scratch from an infected cat. Less than 15% of CSD cases including visceral lesions, encephalitis, and endocarditis have been reported in complicated form (Klotz et al. 2011).

3.4. RINGWORM

Contrary to its name, ringworm is not caused by a worm but by various dermatophyte fungi. Cats can carry ringworm on their skin, fur, or claws, which can be transmitted to humans through direct contact (de Mendoza et al. 2010).

3.5. TOXOCARIASIS

Toxocariasis is caused by parasites called Toxocara, commonly found in the intestines of cats. Humans can be infected by ingesting contaminated soil or through contact with cat feces (Rostami et al. 2020).

3.6. SALMONELLOSIS

Salmonellosis, caused by the Salmonella bacteria, can be contracted by handling or consuming food contaminated with infected cat feces or reptiles (Carter and Quinn 2000).

3.7. PATHWAYS OF TRANSMISSION

1. Cat-to-Human Transmission
2. Environmental Transmission

3.8. FACTORS INFLUENCING ZOONOTIC DISEASE SPREAD

3.8.1. CAT BEHAVIOR AND ECOLOGY

The environment and behaviour of cats in various ways contribute to the spread of zoonotic illnesses. Additionally, cats may pass zoonotic germs in their waste, which is significant for diseases like toxoplasmosis. Close cat-human contact, especially in families, increases the risk of zoonotic disease transmission. Outdoor activities and interaction with wild animals are two ways that zoonotic illnesses are disseminated. Due to their role as zoonotic illness vectors, cats with flea and tick infestations raise the risk of transmission (Lepczyk et al. 2015).

3.8.2. HUMAN-CAT INTERACTIONS

Zoonotic disease transmission can occur frequently as a result of contact between people and cats. The tight bond between people and cats can facilitate the spread of zoonotic illnesses in a number of ways, including:

3.8.3. DIRECT CONTACT

Direct physical contact between humans and cats includes touching, snuggling, and grooming. When people come into touch with an infected cat, they may get a zoonotic illness. Zoonotic diseases can be found on a cat's hair or skin.

3.8.4. CAT BITES AND SCRATCHES

Cats can bite or scratch people on occasion, especially while playing or when they feel threatened. These wounds have the potential to transmit zoonotic diseases to people (Taetzsch et al. 2018).

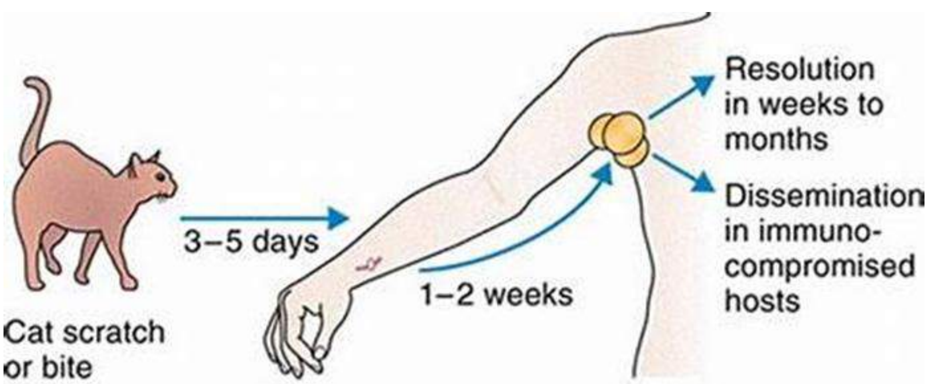

Fig. 2: Transmission of Bartonella. Mammalian intra-erythrocytic bacteremia leads to bacterial presence in the flea digestive tract following a blood meal. The contaminated flea feces then lead to infection in humans and animals, which can be facilitated by animal scratches or licking.

3.9. ENVIRONMENTAL FACTORS

Environmental factors have a critical role in the emergence and transmission of zoonotic diseases. To create zoonotic diseases, humans, animals, and the environment interact with one another and with each other's habitats. Deforestation, urbanization, and changes in land use may cause human populations to encroach into wildlife areas, raising the possibility of coming into contact with disease reservoirs up close (Estrada-Peña et al. 2014).

4. EPIDEMIOLOGY OF ZOONOTIC DISEASES LINKED TO CATS

4.1. CASE STUDIES AND OUTBREAKS

4.1.1. TOXOPLASMOSIS OUTBREAKS IN PREGNANT WOMEN

Throughout the study period, 75 confirmed instances of toxoplasmosis in pregnant women were found. 60% of instances were found during the second trimester of pregnancy. Among the risk factors for toxoplasmosis infections were gardening (15%), eating undercooked meat (20%), and coming into contact with cat feces (30%). According to maternal outcomes, 25% of infected women had moderate symptoms, whereas 15% had serious problems that required hospitalization. 10% of babies had congenital toxoplasmosis, with 5% having serious birth abnormalities.

A public health concern is the continued occurrence of toxoplasmosis epidemics in pregnant women. The study emphasizes the importance of taking preventative measures, such as supporting healthy hygiene practices and urging expecting mothers to refrain from dangerous behaviors (Demar et al. 2007).

4.2. CAT SCRATCH DISEASE CLUSTERS

During the study period, seven CSD clusters in all were found in various states. The size of the clusters varied from two to six cases. The majority of instances affected children and young people, with females being more frequently affected. Fever, localized skin rashes, and regional lymphadenopathy were frequent clinical manifestations. According to exposure histories, 80% of individuals reported recent encounters with cats, either by bites (30%) or scratches (50%) on their skin. Only 20% of people reported that they have come into contact with feral or stray cats. Three clusters were linked to cat contacts at public gatherings, according to cluster investigations, while two clusters were linked to diseased kittens from nearby animal shelters (Chomel 2000).

4.3. GLOBAL AND REGIONAL PATTERNS

4.3.1. ZOONOTIC DISEASE PREVALENCE IN DIFFERENT REGIONS

Because of factors including cat population density, cultural norms, and medical infrastructure, the occurrence of cat zoonotic diseases varies by place. In locations with a large cat population and frequent interactions between cats and people, zoonotic diseases including toxoplasmosis and cat scratch disease may be more prevalent. Toxoplasmosis may be more prevalent in some locations due to cultural practices such as consuming raw or undercooked meat. The prevalence of cat scratch disease may be affected by populations of stray or feral cats. With the help of ethical pet ownership and successful public health programs, the load of cat zoonotic diseases can be reduced in many locations (Kilpatrick and Randolph 2012).

4.3.2. IMPACT OF CAT POPULATION DENSITY ON DISEASE TRANSMISSION

A higher cat population density may increase the danger of disease transmission because cats and people come into contact more frequently. In areas with a large cat population, zoonotic diseases like toxoplasmosis and cat scratch disease may spread more swiftly. Increased environmental contamination from cat waste brought on by more cats may contribute to the spread of some diseases. Responsible pet ownership and population management strategies are essential to reducing the impact of cat population density on disease transmission. (Ostfeld and Holt 2004)

4.3.3. HUMAN AND ANIMAL HEALTH IMPLICATIONS

1. Zoonotic diseases pose risks to both human and animal health as they can be transmitted between species, impacting individuals and populations.
2. Zoonotic diseases can lead to severe illnesses in humans and animals, affecting morbidity and mortality rates.
3. Effective surveillance and control of zoonotic diseases are essential to safeguard public health and prevent outbreaks in animal populations.
4. Understanding zoonotic disease dynamics can help implement preventive measures, promote responsible pet ownership, and foster collaboration between human and veterinary health sectors for comprehensive disease management (Han et al. 2016).

5. MODELING ZOONOTIC DISEASE TRANSMISSION INVOLVING CATS

5.1. IMPORTANCE OF MODELING IN UNDERSTANDING ZOONOTIC DISEASES

Modeling plays a crucial role in understanding zoonotic diseases and their dynamics. Here are some key reasons why modeling is essential in this context:

5.1.1. PREDICTING THE SPREAD OF ILLNESSES

Mathematical and computer models can mimic the transmission and spread of zoonotic diseases, giving us an understanding of how they could spread across the community. (Han et al. 2016)

5.1.2. IDENTIFYING RISK FACTORS

Models can assist in identifying risk variables such as animal reservoirs, environmental circumstances, and human behaviors that contribute to the spread of zoonotic diseases. (Leach and Scoones 2013)

5.1.3. CONTROL MEASURE EVALUATION

Before putting them into practice in the real world, various control measures and intervention procedures may be assessed using modeling. (Liverani et al. 2013)

5.1.4. ANALYZING EPIDEMIC SCENARIOS

Models make it possible to investigate numerous epidemic scenarios, including varied degrees of disease severity and potential responses. (Chakraborty et al. 2022)

5.1.5. STUDYING LONG-TERM PATTERNS

By predicting the long-term patterns of zoonotic illnesses, models can help us better comprehend their potential effects on both human and animal populations (Rees et al. 2021).

5.2. MATHEMATICAL AND COMPUTATIONAL MODELS

5.2.1. AGENT-BASED MODELS

Agent-based models (ABMs) are a useful tool for studying cat-borne zoonotic disease transmission and comprehending the intricate relationships that exist between cats, people, and the environment. ABMs are a particular kind of computational modeling that concentrates on mimicking the activities and interactions of lone agents, like cats and people, inside a predetermined environment. (Braae et al. 2016)
ABM can be used to:
1. Simulate Cat Population Dynamics 2. Assess Contact Patterns
3. Analyze Disease Spread
4. Investigate Intervention Strategies
5. Explore Spatial and Temporal Dynamics
6. Account for individual heterogeneity by employing ABMs, researchers can gain insights into the complex and dynamic nature of zoonotic disease transmission involving cats, aiding in the development of targeted and effective strategies for disease prevention, control, and management.

5.3. NETWORK MODELS

Network models are another powerful approach used to study zoonotic disease transmission involving cats. Network models focus on understanding the connections and interactions between individuals or groups, represented as nodes, within a network.
Here's how network models are applied in this context:

5.3.1. CONTACT NETWORKS

Network models may depict the relationships and contacts that exist between cats and people, including close proximity and shared living quarters. These networks assist in locating potential pathways for the spread of zoonotic diseases. (Craft 2015)

5.3.2. TRANSMISSION DYNAMICS

Network models replicate the dynamics of zoonotic disease transmission both within the cat population and between cats and humans. The models account for elements including the disease's contagiousness, its duration, and that it would spread through contact. (Abakar et al. 2017)
Network models offer valuable insights into the complex transmission patterns of zoonotic diseases involving cats, providing a framework for devising effective strategies to prevent and control these infections (Grant et al. 2016).

5.4. CAT-RELATED PARAMETERS IN ZOONOTIC DISEASE MODELS

5.4.1. CAT POPULATION DYNAMICS

Models of zoonotic diseases must include cat population dynamics because they offer information on the size, growth, and interactions of the cat population. The susceptible pool of cats at risk of zoonotic disease transmission is estimated using models that take into account birth and death rates, reproduction, and travel (Fig. 3). Evaluation of the potential for disease spread is aided by population mixing and interactions with other species. The accuracy of zoonotic disease models is improved by understanding cat population dynamics, which also helps to determine efficient disease prevention and control method (Roebling et al. 2014).

5.5. CAT CONTACT RATES

In zoonotic disease models, cat contact rates describe how frequently and intensely cats interact with other possible hosts. Calculating the possibility of disease transmission between cats and people or other animals depends heavily on these rates. Models take into account both direct contact—such as biting or grooming—and indirect contact—such as touch that occurs in shared settings. Assessing zoonotic disease risk, identifying high-risk populations, and developing focused actions to avoid transmission are all made possible by understanding cat interaction rates. (Roebling et al. 2014).

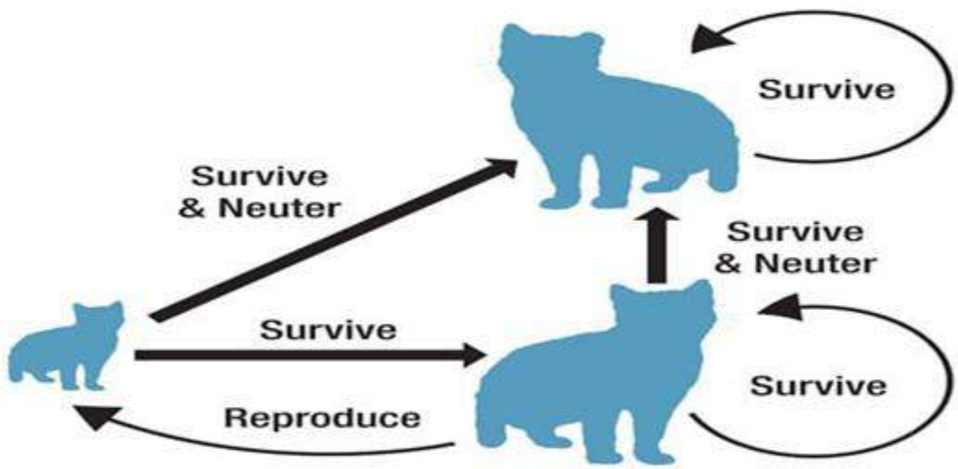

Fig. 3: Dynamic models showing networks that influence variation in density dependence and carrying capacity across a network.

5.6. ZOONOTIC PATHOGEN SHEDDING RATES

In zoonotic disease models, the frequency and number of infectious agents discharged by affected animals, including cats, are represented by zoonotic pathogen shedding rates. These rates change depending on the disease and the species. The potential for virus transmission to other animals, including humans, through direct contact or environmental contamination, is estimated using shedding rates in models. For zoonotic disease models to accurately anticipate disease transmission and evaluate the effects of control measures, accurate shedding rate data is essential. Furthermore, shedding rates assist in identifying important variables affecting the dynamics of disease transmission and guide public health initiatives (Araújo et al. 2023).

6. ONE HEALTH APPROACH: INTEGRATING HUMAN, ANIMAL, AND ENVIRONMENTAL PERSPECTIVES

6.1. COLLABORATIVE EFFORTS IN ZOONOTIC DISEASE RESEARCH

Research on zoonotic ailments must be conducted collaboratively if it is to successfully address the complex problems that these diseases, which harm both people and animals, present. To exchange knowledge, data, and expertise, researchers, medical experts, veterinary professionals, and policymakers collaborate across disciplines and countries. This cooperative method encourages a thorough comprehension of the dynamics of zoonotic diseases, the early identification of outbreaks, and the creation of successful preventative and control methods (Murphy et al. 2019).

6.2. INTERCONNECTEDNESS OF HUMAN, ANIMAL, AND ECOSYSTEM HEALTH

The interconnectedness of human, animal, and ecosystem health is a critical aspect of understanding zoonotic diseases. Zoonotic diseases are infections that can transmit between animals and humans, and their occurrence is influenced by the interactions between these three components.

6.3. DISEASE TRANSMISSION

The strong ties between human and animal health are highlighted by the fact that zoonotic illnesses may spread from animals to people through direct contact, ingestion of tainted food, or exposure to polluted settings. (Goldstein and Abrahamian 2016).

6.3.1. ONE HEALTH STRATEGY

In order to effectively combat zoonotic illnesses, the One Health strategy promotes collaboration among human health, veterinary medicine, and environmental research (Murphy et al. 2019)

6.4. STRATEGIES FOR ZOONOTIC DISEASE PREVENTION AND CONTROL

6.4.1. EDUCATION AND AWARENESS PROGRAMS

Education and awareness programs play a pivotal role in zoonotic disease prevention and control by empowering individuals, communities, and professionals with knowledge and skills to mitigate disease risks.

6.4.2. PUBLIC AWARENESS

Targeted programs inform people about zoonotic illnesses, their transmission vectors, and the best ways to avoid contracting them.

6.4.3. VETERINARY AND HEALTHCARE TRAINING

programs for veterinarians, healthcare workers, and anyone who manages animals increase knowledge of zoonotic illnesses and improve early identification, diagnosis, and reporting.

6.4.4. COMMUNITY ENGAGEMENT

To encourage active engagement in zoonotic disease control, programs involve local communities, stakeholders, and animal owners.

6.4.5. SCHOOL PROGRAMS

Children's understanding of illness risks is increased when zoonotic disease subjects are incorporated into school curricula. This empowers them to adopt healthy habits and become change agents in their families and communities (Butera et al. 2000).

6.4.6. VETERINARY INTERVENTIONS

Following are examples of veterinary interventions for zoonotic disease prevention and control:

1. Monitoring and early zoonotic illness identification in animals to stop human transmission.
2. Animal vaccination and treatment initiatives to lower disease prevalence and spread.
3. Stringent biosecurity measures are put in place in veterinary institutions and farms to stop the transmission of disease (Lloret et al. 2013).

6.4.7. ENVIRONMENTAL MANAGEMENT

1. Environmental management for zoonotic disease prevention and control involves:
2. Monitoring and controlling vectors and reservoirs in the environment to reduce disease transmission.
3. Implementing proper waste disposal and sanitation practices to minimize contamination.
4. Managing wildlife habitats and ecosystems to mitigate potential zoonotic spillover events (Moriello 2003).

7. MANAGING ZOONOTIC DISEASE RISKS ASSOCIATED WITH CATS

7.1. RESPONSIBLE PET OWNERSHIP AND ZOONOTIC DISEASE PREVENTION

7.1.1. CAT HYGIENE AND HEALTH MONITORING

Cat hygiene and health monitoring are crucial for managing zoonotic disease risks:
1. Performing routine grooming and litter box cleaning helps to prevent zoonotic pathogen contamination of the environment.
2. To identify and prevent zoonotic infections in cats, get regular checkups, shots, and parasite management.
3. Zoonotic disease testing ensures prompt detection of diseased cats, lowering the danger of transmission to people.
4. Cat owner education encourages ethical behavior and aids in the prevention and management of zoonotic diseases (Gerhold and Jessup 2013).

7.2. LITTER BOX MANAGEMENT

Litter box management is essential for mitigating zoonotic disease risks associated with cats:
1. Keeping the litter box regularly clean and sanitized helps stop the growth of zoonotic infections such as Toxoplasma gondii.
2. Reducing the risk of disease transmission to people by wearing disposable gloves and properly washing hands after handling the litter box.
3. To minimize the risk of contamination, keep the litter box away from locations where food is prepared.
4. To reduce the danger of catching zoonotic infections from cat feces, pregnant women and immunosuppressed people should refrain from cleaning the litter box (Weese et al. 2002).

7.3. STRAY AND FERAL CAT MANAGEMENT PROGRAMS

7.3.1. TRAP-NEUTER-RETURN (TNR) PROGRAMS

TNR programs are compassionate methods for controlling feral and stray cats:

1. Feral and stray cats are caught.
2. They undergo spaying or neutering.
3. Following this, cats are put back where they came from, limiting population expansion and fostering better relations between neighbors (Foley et al. 2005).

7.4. FERAL CAT COLONY MANAGEMENT

Feral cat colony management involves:
1. Locating and keeping an eye on wild cat colonies in a particular location.
2. Starting TNR (Trap-Neuter-Return) programs to vaccinate and neuter cats.
3. Continuing to give the cats care, food, and shelter while halting further reproduction and fostering a stable and managed colony (Levy 2004).

8. FUTURE DIRECTIONS AND RESEARCH NEEDS:

8.1. EMERGING ZOONOTIC DISEASES AND CATS

Future directions and research need in emerging zoonotic diseases and cats include:
1. Enhanced Surveillance: Strengthening surveillance methods to monitor zoonotic diseases in cat populations and identifying emergent concerns.
2. Risk Factors Identification: Understanding the factors affecting zoonotic spillover incidents involving cats, including environmental and behavioral drivers.
3. Pathogen Evolution: To determine the likelihood of transmission, researchers are examining the genetic diversity and evolution of zoonotic diseases in cat reservoirs.
4. Raising public knowledge of zoonotic disease hazards and encouraging appropriate cat ownership to reduce human exposure.
5. One Health strategy: Stressing the importance of a cooperative One Health strategy to enable quick reaction and efficient management tactics for cats-only zoonotic diseases that are on the rise.

8.2. ADVANCEMENTS IN ZOONOTIC DISEASE MODELING

Advancements in zoonotic disease modeling include:
1. Big Data Integration: Using extensive data from various sources, such as genetics, epidemiology, and environmental factors, to improve the precision and prognostication abilities of models.
2. Agent-Based Models: Making use of agent-based models to mimic individual-level interactions and behaviors, which enables a more accurate depiction of disease transmission patterns.
3. Machine Learning Techniques: Making use of machine learning algorithms to find patterns and trends in data on zoonotic diseases, allowing for more complex and data-driven modeling techniques.

8.3. IDENTIFYING KNOWLEDGE GAPS AND PRIORITIES

Identifying knowledge gaps and priorities in zoonotic disease modeling involves:
1. Evaluating the need for more detailed information on host behaviors, zoonotic diseases, and environmental factors to enhance model accuracy.
2. Setting aside research on the dynamics of specific zoonotic diseases' spillover risks as a top priority to handle new concerns.

3. Determining the areas in which multidisciplinary partnerships involving epidemiologists, veterinary scientists, ecologists, and data scientists can improve model development and application.

9. CONCLUSION

9.1. RECAPITULATION OF KEY POINTS

Emerging conditions
Zoonotic ailments
zoonotic illnesses and cats

9.2. IMPORTANCE OF ADDRESSING CATS' ROLE IN ZOONOTIC DISEASES

Cats can serve as reservoirs, vectors, or carriers of pathogens that can spread to people, making it imperative to address their role in zoonotic diseases. It is possible to reduce the danger of zoonotic disease transmission and protect the health of both people and cats by comprehending and regulating this role.

9.3. CALL FOR FURTHER RESEARCH AND COLLABORATIVE EFFORTS

Further research and collaborative efforts in zoonotic diseases are imperative to:
1. Recognize newly developing diseases and comprehend how they spread between animals and people.
2. Create specialized prevention and control plans to lessen the burden of zoonotic diseases.
3. Encourage a One Health strategy, combining efforts to improve human, animal, and environmental health for more efficient and comprehensive disease management. (Loss and Marra 2017).

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Role of Wild Birds in Spreading Potential Zoonotic Diseases in Poultry

40

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ABSTRACT

There are many pathogens which are of zoonotic concern. Among these major pathogens are directly or indirectly transmitting zoonotic disease. Wild birds are major source of transmission of these diseases including viral as well as bacterial pathogens. Wild birds not only harbor these diseases but also spread these pathogens where it travels to various other species like poultry and ultimately to human. This indicates that there is not incubation risk of those pathogens but also flight risk that result in carrying pathogen load to their migration site or premises where other species are also cultivating or living. These infectious diseases can be worsen when comes in contact with different serotypes of those infectious pathogens resulting in not only severity of disease but also make prevention difficult. There is a need to limit the migration of wild birds to prevent the major loss in poultry as well as human being.

CITATION

Kanwal A, Rashid M, Shakir U, Rizwan M and Akram MS, 2023. Role of wild birds in spreading potential zoonotic diseases in poultry. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 530-540. https://doi.org/10.47278/book.zoon/2023.040

CHAPTER HISTORY Received: 15-Jan-2023 Revised: 12-April-2023 Accepted: 20-June-2023

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1. INTRODUCTION

Avian species in the wild exhibit a wide range of diversity, including several ecological niches. Pakistan has a diverse range of wildlife, including 188 species of mammals, 666 migratory and resident species of birds, 174 species of reptiles, 16 species of amphibians, 525 species of fish, 16 species of amphibians and 20,000 species of insects and vertebrates as mentioned in the workshop of the center of disease control and prevention. Wild birds can transmit pathogens directly and indirectly through vectors and numerous diseases are transmitted from wild birds as they travel long distances. They have a tendency to travel long distances and travel in flocks (Vogt 2023). Birds are less susceptible to zoonotic diseases than mammals as they have developed the immune systems. But they are natural hosts, reservoirs, and amplifying hosts for different zoonotic agents (Contreras et al. 2016).

Direct transmission of zoonotic diseases is possible when other species come in contact with their body excretions. Direct transmission of zoonotic diseases from wild birds is least possible because of taxonomical differences (Bengis et al. 2004). Indirect transmission is possible when other species come in contact with the contaminated surfaces. Examples include pet habitats, aquarium tank water, chicken coops, plants, barns and soil, as well as pet food and water dishes. Tick or insect bites can aid in vector-borne diseases. Foodborne diseases are a major prevalent transmission factor. Wild birds transmit diseases to domestic and commercial poultry, leading to public health concerns. Undercooked meat and eggs will lead to the transmission of zoonotic pathogens. Contaminated water is also a source of pathogen entry (Brown and O'Brien 2011).

Public health concerns about emerging diseases are 60%, and out of these 60%, 70% of these diseases originated from wildlife as reported in "Asia Pacific strategy for emerging diseases: 2010". There are many emerging zoonotic diseases and newly emerged diseases are associated with animal-origin foods (Rahman et al. 2020). Interspecies transmission is an essential factor in the transmission of zoonotic diseases. There are various diseases of public health concerns reported in interspecies transmission. One of them is avian influenza. After interspecies transmission from wild birds to chicken and then human H5 and H7, avian influenza viruses can become highly pathogenic. These viruses have been transmitted directly to humans from birds in Eurasia and Africa (H5N1), the Netherlands (H7N7) and Canada (H7N3) (Uzma et al. 2009). When we talk about viral zoonotic diseases from wild birds to poultry and ultimately to humans, we must consider the Newcastle disease virus (NDV) that transmit from waterfowl. It is also reported that F genes in NDV isolated from wild waterfowl are similar to NDV of poultry (Goraichuk et al. 2023).

Poultry birds getting infected from premises, or direct contact with wild birds can lead to transmission of multi-drug-resistant bacteria that not only transmit pathogens in humans but also create multi-drug resistance. One of the examples is Salmonella and *E. coli* (karim et al. 2020). Wild birds (wild fauna and migratory birds) harbor an emerging pathogen of Enterobacteriaceae, which is closely linked to *E. coli* based on DNA hybridization and is multi-drug resistant (Shah et al. 2022). Wild birds not only transmit Salmonella and *E. Coli* to poultry and humans but are also responsible for transmitting Campylobacter. *C. jejune* is the most prevalent species found in wild birds (Ahmed et al. 2022). It is important to highlight the potential zoonotic diseases from wild birds so that regular surveillance can be done in practice for early detection and control of emerging infectious diseases. These proactive measures help to prevent the spread of diseases and protect human health (Shah et al. 2022). Surveillance over a broad geographical area is possible with hypothesis-driven methods through standardized and local surveys. In surveillance, it is always important to share samples taken and geographical areas from where and when samples are collected (Hoye et al. 2010).

This chapter will cover all emerging and reemerging zoonotic diseases transferring from wild birds to other species of birds like poultry and also infect humans. These pathogens are of serious public health concern because they cannot only affect immune system but also lead to other symptomatic signs.

2. VIRAL DISEASES TRANSMITTED FROM WILD BIRDS

2.1. NEWCASTLE DISEASE

Newcastle disease virus belongs to *Avulavirius* genus. Data was isolated from various wild birds and free-ranging birds and tested for NDV. It is found that almost 17 species of different habitat is found top shed vaccine derived NDV. Lasota and Hitchner B1 are the most commonly found strains. The synanthropic and ubiquitous nature of wild pigeons highlights their potential role in shedding of low virulent NDV in environment (Ayala et al. 2016).

In NDV, there are six genes forming the code of 6 proteins. In this structure of virus fusion protein plays an important role. Fusion protein is basically non-functional, and host protease breaks down this protein into F1 and F2, which is responsible for the induction of pathogenicity (Zanetti et al. 2005). NDV can be transmitted directly from excretion or indirectly by consuming infected poultry products.

3. WILD BIRDS TO OTHER SPECIES

3.1. WILD BIRD-BIRD TRANSMISSION

NDV Pigeon variant virus and virulent enteric NDV transmit from bird to bird or commercial poultry by ingesting feces from infected birds. Birds that take virus from this route usually have respiratory tract involvement.

4. WILD BIRD TO HUMAN TRANSMISSION

Poultry faces numerous economic losses after getting infected by wild birds (Rehan et al., 2019). Humans having direct contact with poultry, i.e., poultry practitioners, may harbor infection. Other route of infection is consuming infected meat and eggs (Abdisa and Tagesu 2017).

5. CLINICAL SIGNS

5.1. POULTRY

Clinical signs in poultry vary according to strains of the virus. It may cause 100% mortality if the strain is virulent, and birds end up with prostration and death. In neurotropic NDV form, neurogenic lesions are followed by respiratory tract involvement. The mesogenic form of ND only causes mortality in young birds and causes respiratory problems associated with a drop in production. The lentogenic form of ND causes few signs only in young birds. These signs include airsacculiutis and colisepticemia. This form of ND is also prevalent after vaccine exposure. In ND, the gross lesions observed are hemorrhages in the proventriculus and ulcers in the intestine as shown in Fig. 1.

6. HUMAN

a) Usually have eye infection including unilateral and bilateral reddening, excessive lachrymation, edema of eyelid, conjunctivitis, and subconjunctival hemorrhages. Transient infection is there, and it doesn't affect the cornea.
b) There may be chill, fever, headache, and can have conjunctivitis or without conjunctivitis.

Fig. 1: Proventricular hemorrhages and ulcers in the intestine of NDV-infected poultry bird

7. AVIAN INFLUENZA

Avian influenza is highly pathogenic and causes major economic loss in poultry. This virus is a pandemic and global threat worldwide as high pathogenic avian influenza (HPAI) not only infects poultry but is also reported as a zoonotic virus and is present in the human population. It is also reported that wild birds and migratory birds, especially waterfowl, is reported as a natural reservoir of this virus. Waterfowl not only carry this pathogen but also transfer it along the path of their migration, leading to antigenic shift and drift in this virus, which results in the emergence of new strains in avian influenza and can be more lethal (Reed et al., 2003)

H5N1, highly pathogenic avian influenza is reported in poultry that is transmitted from wild waterfowl. There are two subtypes of avian influenza depending upon two surface proteins of this virus, one is haemagglutinin (HA) and other is neuraminidase (NA). There are 16 HA and 9 NA proteins identified in birds. These subtypes are also reported in humans and adopt shifting and drifting mechanism to sustain in human population and other species (Abubakar et al. 2023).

Since 2003, HPAI (H5N1) has been reported as enzootic and cause a serious outbreak in poultry and disease in human. Anseriformes, the order of waterfowl in wild birds, are reported as a natural reservoir of low pathogenic avian influenza (LPAI). In a recent study, it is also reported that H5N1 is also present in waterfowl. This led to a conclusion that waterfowl, a natural reservoir of LPAI can get antigen shifting and drifting, which leads to its conversion into HPAI and causes great economic loss and is of serious public health concern (Kim et al. 2012). It is reported that HPAI H5 is only found in the surrounding wild birds where poultry outbreak occurs. Outbreak of H5N1 is also season-dependent. It mostly occurs in winter. Samples collected from juvenile birds are negative for HPAI. H5N1 in mild migratory or adult birds is common due to their migration from one premise to another (Siengsanan et al. 2009).

Influenza A virus causes high mortality (100%) in poultry. HPAI includes H5 and H7 viruses are basically transmitted primarily by direct contact with wild birds and, secondly human involvement either by migration of birds or infected feces. In overall outbreak, this virus caused hundreds of mortalities in poultry and posed a significant public health concern (Alexander 2007). Low pathogenic avian influenza (LPAI) can be converted into high pathogenic avian influenza (HPAI). To report effective surveillance in wild birds, it is important to practice postmortems, lab practice, and improve diagnostic capabilities (Gourlay et al. 2014).

8. CLINICAL SIGNS

8.1. WILD BIRDS

In wild birds, it usually remains asymptomatic. They can only carry the disease virus, harbor it, and transfer it to domestic poultry birds via feces and their secretions in the vicinity of domestic poultry (Abubakar et al. 2023).

8.2. POULTRY

Classical signs involve cyanosis and edema of the head, vesicle and ulceration on combs, edema of feet, petechiation in abdominal fat and various mucosal and serosal surfaces, and necrosis or hemorrhages in the mucosa of proventriculus and gizzard. All AI viruses are categorized as either low or high pathogenic AI. HPAI produces severe signs and symptoms as compared to LPAI. It also produces high mortality and severe systemic infection. This virus is excreted in large amount in the respiratory tract and to a lesser contact in the intestinal tract. Death is always associated with high replicating titers in the host (Swayne and Pantin-Jackwood 2006).

9. HUMAN

Flu-like illness and weak immune response was reported in human infected with HPAI. Reassortment of H1N1 occurred, and this strain is a new emerging zoonotic pathogen. This virus is reported to have a 60% case fatality rate with H5N1 associated and sporadic in nature, and human-to-human transmission is occasionally limited (Van Kerkhove et al. 2011).

10. BACTERIAL DISEASES

10.1. SALMONELLOSIS

Salmonellosis is also an emerging zoonotic disease that is transmitted from wild birds. *Salmonella enterica* subtype typhimurium is commonly associated with wild birds. Viruses can be direct (from contact with their excretions) or indirectly (from an infected environment or surfaces) transmitted from wild birds. Humans get infections by eating contaminated poultry products (Tizard 2004).

In an agriculture farm near affected calves with salmonellosis, samples were collected to check the prevalence of these bacteria in the environment. Samples from municipal waste and in different birds fecal samples were positive for salmonellosis. This result indicates that not only household poultry feeding on infected fecal samples are at risk of infection, but humans can also get infected from the infected environment (Cizek et al. 1994).

In a study, it is reported that salmonella infection is transmitted from wild birds to Humans. Migratory birds are not natural carriers of salmonella bacteria. Therefore, the incidence of the occurrence of salmonella in wild birds is relatively low (Hernandez et al. 2003). There are different pathways in which wildlife can transmit salmonella to humans.

a) Direct contact with humans.
b) Via contact with transmitting vectors or domestic animals.
c) Via consumption of contaminated food products like eggs and meat (Hilbert et al. 2012).

The leading cause of food-borne zoonosis is nontyphoidal salmonella. Antimicrobial resistance of salmonella in food and wildlife is checked by taking samples from both of them and find that none of wildlife samples showed resistance against any antimicrobial. Still, in food samples, there was a resistance of one antimicrobial. Hence, antimicrobial resistance is an issue faced in foodborne pathogens (Aung et al. 2019).

As salmonella is prevalent in feed sources, different strategies must be adopted to control salmonella in feed and cease its replication. Salmonella killing may involve thermal processing and chemical treatment. Contamination of feed is prevented by dust, contaminated vehicles, rodent infestation, and management of the flow of equipments and humans. Thermal treatment prevents the replication of bacteria but does not completely remove it. Chemical treatment, like the addition of organic acids or formaldehyde, may reduce the pathogen load (Jones 2011).

In a recent study, it is investigated that samples of salmonella isolated from wild birds (waterfowl and raptors are found 1.87% multi drug resistance. But their number is quite low that's why it is not major concern but continuous survillence is necessary to prevent antimicrobial resistant *S. typhimurium* in human (Fu et al. 2022).

11. WILD BIRDS

Salmonella typhimurium causes huge mortality in wild birds, as reported in 2000. *S. typhimurium* causes a huge loss in the winter and spring season in wild birds. Birds usually have acute septicemia with multifocal necrosis of the liver and spleen. It is an emerging disease and also reported in wild sparrows as this bird has a close association with humans, which may lead to serious public health concerns (Alley et al. 2002).

12. POULTRY

In poultry, there are two host-adapted serovars: *Salmonella pullorum* (Fowl Typhoid) and *Salmonella gallinarum* (Tariq et al. 2022). White pasted vent due to white diarrhea is a common problem in fowl typhoid. Further gross lesion involves hepatomegaly and bronzed color discoloration of the liver, as shown in Fig. 2.

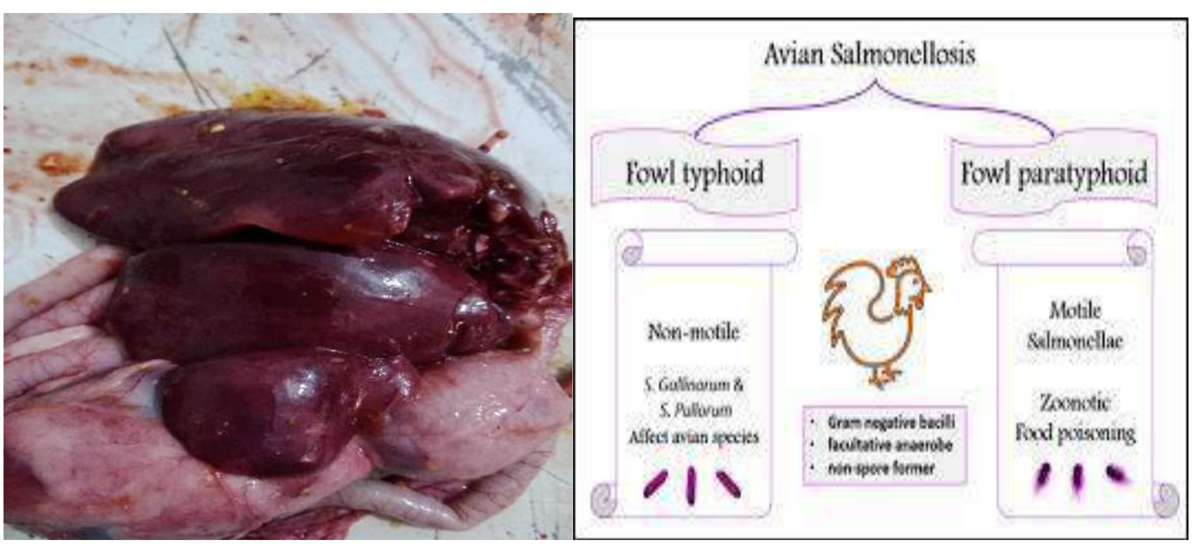

Fig. 2: Fowl typhoid infected poultry bird having bronzed color discoloration.

13. HUMAN

Salmonella in human cause lethargy and anorexia. 57% of infected animals suffered from vomiting, and 31% had diarrhea, as reported in a recent study on transmission of *Salmonella typhimurium* from wild birds (Tauni and Osterlund 2000).

14. *E. coli*

E. coli is a common bacterium found in the gut of animals. It can cause pathogenicity and is now an emerging zoonotic disease. Antimicrobial resistance against these bacteria is a serious public health concern. Samples from wildlife are collected and confirmed for *E. coli*. After this, antimicrobial resistance was checked and samples were found resistant to each class of antimicrobial from 3.8 to 73.1%. These resistant bacteria were further detected for antimicrobial resistant (AMR) genes and found that $bla_{TEM\text{-}1B}$ and qnrS1 could be the resistant genes found commonly in the environment (Ong et al. 2020).
Wild birds and cattle harbor antimicrobial-resistant *E. coli* and have the potential for interspecies transmission. Samples were collected from wild birds pooled and cattle. These samples were tested against *E. coli* and the prevalent serotype was O9H4, O9H9, and O9H30. Many enterobacteriaceae produce third-generation cephalosporins (3GC) hydrolyzing enzymes (Extended spectrum *b* lactamases-ES*B*L), which makes them resistant to 3GC (Fashae et al. 2021).
The emergence of AMR in wild birds is due to the dissemination of contaminated environment and exposure to resistant bacteria because wildlife is rarely exposed to direct antimicrobial agents. There were 5.8% AMR strains, and 26.3% were multi-drug resistant found in isolates of wildlife isolates. These isolates harbor three genes $bla_{CTX\text{-}M\text{-}15}$, $bla_{CTX\text{-}M\text{-}55}$ and $bla_{CTX\text{-}M\text{-}65}$ originating from grey herons, carrion crows and common blackbirds. Among these genes, $bla_{CTX\text{-}M\text{-}55}$ was responsible for recent antimicrobial resistance against fluroquinolone (Zurfluh et al. 2019).
A total of 115 *E. coli* and 138 Enterobacteriaceae were observed antimicrobial resistant. In all enterococcal isolates, *Enterococcus fetalis* is the most prevalent species among this. In the enterococcus strain, high resistance was reported against tetracycline to ciprofloxacin and erythromycin. Low antimicrobial resistance to ampicillin, teicoplanin, and chloramphenicol. These resistance genes were reported to transfer from wild birds to poultry and humans (Santos et al. 2013).
Shiga toxin-producing *E. coli* (STEC) is usually zoonotic and includes O157:H7 strain. STEC with O157 strains is easily detectable. Although non O157 strains are also present these are difficult to detect. The main source of infection is the environment, drinking water, and food contaminated with direct contact or infected feces or contaminated environment. Different strategies are adopted to control the zoonotic STEC, including treatment with probiotics (direct-fed microbial or competitive exclusion), modification of diet, and administration of bacteriophages (Fairbrother and Nadeau 2006).
Wild birds are reservoirs and potential sources of dissemination of antimicrobial-resistant pathogens. These resistant bacteria can be transferred from birds to humans and vice versa (Bonnedahl and Jarhult 2014).

15. WILD BIRDS

None of STEC is reported to cause signs and disease in wild birds (Morabito et al. 2000).

16. POULTRY

In poultry, signs of *E. coli* include fibrinous pericarditis and perihepatitis, as shown in Fig. 3. Acute septicemia and lymphocytic depletion of the thymus and bursa is also observed. *E. coli* results in colibacillosis. Higher prevalence of avian pathogenic *E. coli* causes huge economic loss in poultry (Van der Westhuizen and Bragg 2012).

Fig. 3: Bird suffering from *E. coli* having pericarditis and perihepatitis.

17. HUMAN

Enterotoxigenic *E. coli* can cause complex illness syndrome and basically involve enteric signs due to enteritis (Porter et al. 2016).

18. CAMPYLOBACTER

Campylobacter has been isolated from various species of wild birds and *C. jejuni* is the most prevalent among all. The prevalence of these bacteria in wild birds is variable depending upon bird species, season, geographical location, ecological factor, bird's health status, samples used, and method type. All bacteria reported in poultry or humans can't be of wild bird origin (Ahmed and Gulhan 2022).

Wildlife may be the zoonotic carrier of campylobacter. *C. jejuni* and *C. coli* are not only responsible for enteric syndrome but can also cause extra intestinal disease in human. These two strains were isolated from the long-eared owl and is reported as antimicrobial resistant after testing with different methodologies. These resistant antibiotics are enrofloxacin, ciprofloxacin, sulfamethoxazole and trimethoprim (Casalino et al. 2022).

Campylobacters isolated from wildlife such as waterfowl is isolated and these bacteria are tested to identify the pathogenic genes. There is high variability in testing the pathogenic gene and environmental pathogen. *C. coli* is mostly isolated from environmental samples.

Virulence genes were detected in isolated of wild birds are cadF, flaA and cytolethal distending toxins. It was also reported that in samples of daurian jackdaw, crow, and silver pheasant the virulent gene was cdt gene. Silver pheasant harboring *C. jejuni* has truncated cdt gene clusters. It is also reported that urban and suburban areas having wild birds harbor campylobacteriosis and of serious public health concern not only for poultry but also important for public health concern (Du et al. 2019).

Campylobacter not only involve in gastroenteritis but also trigger Guillain-Barre syndrome which is a poly neuropathic disorder. *C. jejuni* causing this syndrome is reported to have wlaN or cgtB genes. These genes code for an enzyme β-1,3-galactosyltransferase that is required for sialylated lipooligosaccharide. These gene sequencing highlight various new variants that are predominant in wild birds and similar genes were isolated from broiler chicken and human infected with *C. jejuni* (Guirado et al. 2020).

19. WILD BIRDS

Wild birds may serve as a reservoir of campylobacter, but they show no signs. These bacteria reside in the intestinal tract of wild birds (Kwon et al. 2017).

20. POULTRY

Poultry birds may serve as a carrier of this pathogen and show intestinal signs, including gastroenteritis, but are the primary source of pathogen transfer via contaminated carcass or meat (Umar et al. 2016).

21. HUMAN

Poultry birds are the leading cause of campylobacteriosis and gastroenteritis in humans worldwide. Contaminated premises and poultry products are the main routes of transmission by this pathogen (Sahin et al. 2015).

CONCLUSION

Wild birds are natural reservoirs of many zoonotic pathogens. These birds may not directly lead to the potential zoonotic diseases but, transfer these zoonotic pathogens to poultry that comes in contact with human and leads to major public health concern.

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Efficacy of Natural Products against Zoonotic Disorders

41

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ABSTRACT

A zoonosis, as described by many medical and health departments, is an infectious disease that is usually transmitted from animals to humans. The major cause of zoonoses are the microbial species, approximately 61% of which are known to be zoonotic in nature. However, the transmission of zoonotic diseases is also related with factors like climate change, environmental unstabilities, animal health and other activities of human such as urbanization, globalization and travelling. Few of the commonly known zoonoses include leptospirosis, echinococcosis, cysticercosis, rabies, anthrax, brucellosis, Chagas disease, Q fever, severe acute respiratory syndrome (SARS), Rift Valley fever, type A influenza, Ebola, haemorrhagic fever and HIV. Dealing with such deadly infections demands a great deal of advancement in the zone of therapeutics. Over the course of years, a large number of natural products are known to be a chief source of novel drug discoveries. Natural products derived from various medicinal plants have the efficacy to treat zoonotic diseases, given to their bioactive compounds and efficient classes of phytochemicals present in such medicinal plants including flavonoids, polyphenols and many others. Countless plant based classifications of vaccines (such as subunit, conjugate, recombinant, and polysaccharide vaccines) have also been derived to cure zoonotic infections like African swine fever virus (ASFV), SARS-CoV-2, HSV-1, HSV-2, DENV, hepatitis A and B, as well as several categories of notorious infections. Moreover, the recent trends in the medical field have also acknowledged the use of natural products as effective anti-zoonotic agents. One of these current trends is the practice of nanotechnology based applications of natural products. In consideration of the risk posed by threatening and wild zoonotic diseases, there is a tremendous need for such revolutionized plant based drugs and vaccines for the sake of a safer and sustainable environment for humans.

Key words: Zoonosis, transmitted diseases, microbial infections, natural products, plant based vaccines, rabies

CITATION

Rasheed M, Riaz A, Asad M, Mumtaz R, Ehsan S, Batool A, Akhter M, Khalid A, Batool S andShabeer I, 2023. Efficacy of natural products against zoonotic disorders. In: Khan A, Rasheed M and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 541-564. https://doi.org/10.47278/book.zoon/2023.041

CHAPTER HISTORY Received: 25-April-2023 Revised: 21-May-2023 Accepted: 27-June-2023

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INTRODUCTION

A zoonosis (also called zoonoses -plural) is defined by WHO and multiple other medical and health departments as an infectious disease that is usually transmitted naturally amongst species, from animals to humans (Haider et al. 2020). About 61% of microbial species that have possibility to infect human beings are known to be zoonotic. Since 75% of the emerging pathogens have been originated from other animals and 33% of zoonotic diseases can extend from human to human after they have been introduced into human population (Yamada 2004;Jones et al. 2008). Activities like domestication of animals, hunting of wildlife in areas with new habitats as well as clearing of land for grazing farming have remarkably resulted in zoonotic infection in humans by means of microorganisms which are responsible to cause infections and diseases like echinococcosis, rabies, measles and smallpox (Wolfe et al. 2007;Karesh et al. 2012). Several other factors also contribute to the spread of zoonotic diseases which include landscape management, climatic changes, massive human, animal as well as commodity transportation (Jánová 2019). Climate change is reported to have a very complex impact over human health in addition to health of many animals as it alters the circumstances for pathogens in addition to vectors of numerous zoonotic diseases (Leal Filho et al. 2022).
Some of the major zoonotic diseases include leptospirosis, echinococcosis as well as cysticercosis, anthrax, toxoplasmosis, rabies, brucellosis, Chagas disease, severe acute respiratory syndrome (SARS), Q fever, Rift Valley fever, type A influenza,Ebola, haemorrhagic fever as well as the original emergence of HIV (Grace et al. 2012;Karesh et al. 2012). Bovine vaccinia (abbreviared as BV), which is caused by a virus known as Vaccinia virus(VACV), is also a zoonotic disease that is characterized by formation of exanthematous lesions which are present in the mammilla of dairy cows as well as on the hands of milkers and is considered as significant public health problem in recent studies (Matos et al. 2018). The recent Coronavirus disease pandemic occurred in 2019 (COVID-19), which was caused as a result of SARS-CoV-2 has also been designated as a novel zoonosis (Gollakner and Capua 2020).In order to prioritize immediate attention on zoonosis, it is proposed that an ongoing investigation should be launched into the food systems that are animal-based (such as wildlife) for the purpose to identify: (a) Zoonosis risks; (b) Investigation of potential amplifying hosts from acknowledged viral reservoirs; (c) Implementation of IUCN and also OIE methodologies for risk analysis for the sake of emergence of pathogen, plus zoonosis arising due to wildlife trade industries which include much broader investigation of anthropogenic drivers in order to identify crucial factors that can be eventually addressed practically; (d) Encouragement of social distancing among humans and wildlife; (e) Application of international domesticated animal food as well as zoosanitary canons on almost all species that are used for food purposes worldwide (Haider et al. 2020).

2. EFFICACY OF NATURAL PRODUCTS

For many novel drug discoveries, numerous natural products have remarkably been a chief source (Beutler 2009). Though, in the past two decades their use has been reduced as result of technical barriers in order to screen natural products in high-throughput assays against multiple molecular targets (Harvey et al. 2015). Recently, the biological effects of natural products are of great interest for pharmaceutical industries, cosmetics industries, health and food industries and number of scientific studies (Ekiert and Szopa 2020). Several phytochemicals from natural plants have showed anti-cancer

(Khan and Uddin 2021), anti-inflammatory (Azab et al. 2016), anti-microbial (Zida et al. 2017), anti-viral (Shahzad et al. 2020), and anti-parasitic activities (Shabnam et al. 2013). As zoonosis are defined as infectious diseases which spread due to natural cause from animals to humans and or humans to animals, all types of pathogenic agents like bacteria, viruses, parasites, fungi, and prions cause them (Wang et al. 2014).

Transmission of zoonotic disease is related with climate change, environmental factor, animal health and other activities of human like urbanization, globalization as well as travel (Shaheen 2022). Around 75% of incipient infections occurring in humans have been stated to initiate from different zoonotic pathogens (Shahid and Daniell 2016a).Since the mid-20th century, the golden age of natural products and antibiotics have served as influential therapeutics against several pathogenic bacteria (Rossiter et al. 2017). The natural products, mainly the ones that have been derived from microbes, have widely been observed as a copious source of many lead compounds crucial for the drug discovery. Fungal, bacterial, parasitic as well as many viral infections have been treated by these compounds (Frediansyah et al. 2022). Recently the most threatening zoonotic disease is covid-19. Many vaccines derived from plant source have been developed recently against viral diseases (Hager et al. 2022). Natural products have been used widely for their therapeutic effect to many illnesses, several chemical drugs have been isolated from natural products. Though, natural products are byproduct they don’t have scientific validation that’s why numerous scientific trials are being conducted in order to evaluate the efficacy of a broad range of natural products (Kim et al. 2016).

3. NATURAL PRODUCTS AGAINST ZOONOTIC DISEASE

Natural products have the efficacy to work against many zoonotic diseases. Some of the natural products are discussed here that have beneficial effects against the diseases. These are as follow;

3.1. MEDICINAL PLANTS

Traditional Chinese and Ayurvedic medical systems have both utilized plants as a form of treatment (Jaiswal et al. 2016). Because secondary metabolites are produce by medicinal plants, they have served as a source for medications to treat cancer as well as viral, bacterial, and protozoal infections (Harvey 2007). By bonding with viral proteins and enzymes, secondary metabolites found in the medicinal herbs can stop viral penetration and reproduction (Li and Peng 2013).

3.1.1.*GLYCYRRHIZA GLABRA*

The plant *Glycyrrhizaglabra*, is known as licorice, a member of Fabaceae family. The plant's dried roots have a distinctive smell and flavor that is pleasant. The primary element that can be separated from roots is glycyrrhizin. The hepatitis C virus (HCV) was 50% suppressed by glycyrrhizin. Additionally, offering defense against the influenza A virus, glycyrrhizin reduced the number of lung cells that infected by influenza. It has demonstrated its impact on the SARS Co virus in addition to being power full against the viruses ofhepatitis and influenza (Ali et al. 2021). Early on, glycyrrhizin successfully slowed the replication of the SARS-Co virus. Additionally, glycyrrhizin altered transcription factors like protein 1 and nuclear factor B as well as cellular signaling pathways including protein kinase C, casein kinase II, and others. Additionally, it has been concluded that the virus is inhibited by the overexpression of nitrous oxide (Cinatl et al. 2003).

Further research revealed that the two licorice constituents (glyasperin A and glycyrrhizic acid) had an effect on the SARS-Co virus replication process. It has been concluded that glycyrrhizic acid interfered with the virus's ACE-2 receptor and that glyasperin A prevented the virus from replicating (Sinha et al. 2021).

3.1.2. *ALNUS JAPONICA*

The East Asian alder tree, also known as *Alnus japonica*, may reach heights of up to 22 meters. It has a rapid growth rate and is deciduous. It is a member of the *Betulaceae* family, usually referred to as birch family, which has six genera of woody trees and shrubs that grow nuts. *A. japonica* leaves and bark extract are used as a meal to increase immunity to influenza. According to studies, the *A. japonica* bark's methanolic extract has potent antiviral properties against the H9N2 subtype of the avian influenza virus (Tung et al. 2010).
Diarylheptanoids from *A. japonica* were extracted and demonstrated inhibitory action against papain-like protease, which is necessary for SARS-CoV replication. Platyphllenone, hirsutanonol, hirsutenone, rubranol, oregonin, rubranoside A and rubranoside B were the nine diarylheptanoids that were isolated. Additionally, the papain-like protease was inhibited by these compounds. They also demonstrated that the most powerful inhibitor of the papain-like protease was hirsutenone. Additionally, investigation revealed that the compound included catechol and an, -unsaturated carbonyl group, which are essential for inhibiting the cysteine protease of the SARS-Co virus (Park et al. 2012).
To avoid viral infections like influenza in humans and other mammalian and avian species, *A. japonica* extract is helpful. The extract had significant antiviral activity but very little harm in normal cell conditions. The *A. japonica* extract can also be utilized to combat the influenza virus in the food and pharmaceutical industries (Tung et al. 2010).

3.1.3. *ALLIUM SATIVUM*

A. sativum is a member of *Amaryllidaceae* family. It is an annual flowering plant with a tall flowering stem that may grow up to 1 m in height. It originates from a bulb. Garlic, also known as *Allium sativum*, is acomponent of Indian meals. The garlic bulb has an odd odor, which is caused by the presence of sulphur compounds. *A. sativum* exhibits antiviral qualities in addition to antibacterial action. The coronavirus, avian infectious and bronchitis virus, is the single-stranded RNA, is inhibited by an extract of *A. sativum*. Herpes simplex virus 1 and virus 2, cytomegalovirus, influenza A and B, and other viruses have all demonstrated their effectiveness (Ali et al. 2021).
Garlic has been shown through molecular docking experiments to be able to suppress SARS-Co virus 2. The major protease (PDB6LU7) of the SARS-Co virus has been found to combine with the amino acid of the ACE-2 and organosulfur compounds from garlic essential oil using molecular docking. Allyl disulfide and allyl trisulfide showed the most effectiveness. Additionally, it was projected that SARS-CoV-2 might be treated with garlic essential oil or extract (Thuy et al. 2020).

3.1.4. *HOUTTUYNIA CORDATA*

Houttuyniacordata is primarily restricted to damp habitat and is belong to *Saururaceae* family. It is fragrant medicinal herb with a rootstock that creeps. The dengue virus (DENV) can be effectively inhibited by using an ethyl acetate extract of the *H. cordata* plant. Some researchers have demonstrated that ethyl acetate extract of the *H. cordata* plant inhibits DENV-2 (Chiow et al. 2016).

The avian infectious bronchitis virus was likewise suppressed by the extract of *H. cordata*. In the early phases of infection, *H. cordata's* quercetin 3-rhamnoside demonstrated anti-influenza action and prevented viral proliferation (Choi et al. 2009).

H. cordata extract's effects on SARS might be biphasic. The extract of *H. cordata* may trigger the immunity mediated by cell to stop infection from virus prior to the invasion of SARS-Co virus. When a person is infected, HC extract may disrupt crucial viral replication enzymes and start the immune system's negative feedback loop. On SARS-CoV, *H. cordata* significantly inhibited it. The 3CLpro and RdRp were effectively suppressed by the extract of *H. cordata* (Lau et al. 2008).

3.2. *SALVADORA PERSICA* (ARAK)

The *Salvadoraceae* family includes *Salvadoraperscia* (Arak). It is widely recognized as a medicinal herb. As a sunnah of the Prophet, arak has been used for generations as the natural toothbrush (as Mesiwak or Siwak), notably in the Muslim nations. The World Health Organization has promotes the use of its fibrous branches for oral hygiene (Almas and Almas 2014).

Echinococcosis, also known as hydatidosis, is a dangerous zoonotic infection that is spread around the world by the larval phases of cestodes from the genus *Echinococcus*. All continents have *Echinococcusgranulosus* infections, which are the cause of cystic echinococcosis (McManus et al. 2003). Humans and other intermediate hosts' internal organs, particularly the liver and lungs, generate hydatid cysts of *E. granulosus* as unilocular fluid-filled bladders (Thompson and McManus 2002).

Numerous significant phytoconstituents, including indole alkaloids, flavonoids, the sulfur-containing substance tropaedoin, triterpenes, phytosterols, and isothiocyanates are said to be present in the*S. persica*ethanol extract (Sofrataet al. 2008). Results indicated that *S. persica* root extracts had a strong scolicidal impact against the protoscolices of *E. granulosus*, which may be caused by the presence of the anthelmintic isothiocyanates. The results of this investigation demonstrated that HepG2 cells are not cytotoxic when exposed to the *S. persica* ethanol extract. In conclusion, the ethanol extract of roots of *S. persica* is a safe and effective protoscolicide that may be used to treat hydatid cysts and prevent secondary cyst recurrence before surgery (Abdel-Baki et al. 2016).

3.3. *FOENICULUM VULGARE*

The plant *Foeniculumvulgare* is indigenous to the Mediterranean region and is a member of the Umbelliferae (Apiaceae) family. Fennel is grown in several parts of Europe and Asia, with the majority coming from Egypt, India, and China (Ostad et al. 2001). The parasite that causes Leishmaniasis, a zoonotic illness, is treated with by *F. vulgare*. *F. vulgare* is well recognized for having immunomodulatory effects and for having antimicrobial, anti-inflammatory, anti-diabetic, and antitumor properties. As the study demonstrate the therapeutic benefits of *F. vulgare* aqueous and alcoholic extracts as herbal medicines without significantly harming the host cells. The study shows that the alcoholic extract of *F. vulgare* is highly effective against *L*. major promastigotes and amastigotes while having no negative effects on host macrophages. Trans-anethole and bis (2-ethylhexyl) phthalate are primarily responsible for the majority of the anti-leishmanial effects (Maryam et al. 2019).

Both aqueous and alcoholic extracts include active substances with anti-microbial action, such as oleic acid and coumarin. According to this score, macrophages are less toxic to the *L*. major parasite than the alcohol extract of *F. vulgare*. In fact, the alcohol extract shows exceptional anti-leishmanial activity and possesses the ability to reduce the survival rate of amastigotes at host cell-safe doses. Leishmania parasites can be killed using methanolic extract rather than aqueous extract. As a result, further research into *F. vulgare* alcoholic extract might lead to the development of innovative herbal medications against leishmaniasis and other neglected tropical illnesses (Badgujar et al. 2014).

3.4. *PICRORHIZA KURROA*

Picrorhizakurroa is a member of the Scrophulariaceae family, and its ethanol and methanol extracts include essential bioactive substances that may have antibacterial effects. Several harmful microbes, including *E. coli*, *S. aureus*, *S. pyrogens*, and *Salmonella typhi*, have been shown to be inhibited by the ethanol extract of *P. kurroa*. *Yersinia enterocolitica* is a source of the zoonotic illness yersiniosis. The *P. kurroa* extract has antibacterial action against the pathogen *Y. enterocolitica* (Thapaet al. 2022).
The primary chemical component of *P. kurroa* is picroside-1, which is also a component utilized in the manufacture of herbal medicines. *P. kurroa* is particularly important in medicine since it contains a lot of picroside-1 and picroside-11 (Rathee et al. 2016). Comparing the *P. kurroa* ethanolic extract to the control antibiotic (ciprofloxacin), the number of bacterial cells was dramatically decreased. Compared to antibiotics, *P. kurroa* rhizome had high antibacterial activity. This highlights its significant antibacterial properties (Thapa et al. 2022). Table 1 highlights the list of some medicinal plants that have potential against different zoonotic diseases.

4. PLANTS AS SOURCE OF NEW ANTIMICROBIAL AND RESISTANCE MODIFYING AGENTS

The term "natural products" refers to chemical substances derived from living things like plants, fungus, molds, bacteria, marine life, terrestrial animals, and invertebrates. Natural goods have been used by people as their main source of medicine throughout the history of civilization (Rasul et al. 2013).

Table 1: List of some medicinal plants that have potential against different zoonotic diseases

Plant	Compound	Disease	Activity	Reference
Glycyrrhizaglabra	Glyasperin A and glycyrrhizic acid	SARS-CoV-2, influenza and hepatitis	Protects against influenza A virus, inhibit replication of virus, effect on SARS-Co virus.	(Sinha et al. 2021)
Alnus japonica	Diarylheptanoid,platyphyllenone, hirsutenone, hirsutanonol and oregonin	SARS-CoV-2	Antiviral activity against SARS-Co virus, inhibitory effects against papine like protease	(Park et al. 2012)
Allium sativum	Organosulphur compounds, allyl disulfide and allyl trisulfide	SARS-CoV-2, Influenza virus	Anti-bacterial activity, antiviral effects on SARS-CoV and influenza A and B virus.	(Thuy et al. 2020)
Houttuyniacordata	Quercetin 3-rhamnoside	SARS-CoV-2, Influenza virus	Anti-viral, Anti-influenza effects	(Choi et al. 2009)
Salvadorapersica	tropaedoin, triterpenes, phytosterols, alkaloids and flavonoids	Hydatidosis	High Scolicidal effect against protoscolices of *E. granulosus*	(Abdel-Baki et al. 2016)
Foeniculumvulgare	Olic acid, trans-anethole	Leishmaniasis	Antileishmanial effect, anti-microbial	(Badgujar et al. 2014)
Picrorhizakurroa	Picroside-1, Picroside-11	Yersiniosis	Anti-bacterial Activity	(Thapa et al. 2022)

Drug development has a lot of potential for natural products that are enhanced with various antibacterial, anticancer, antioxidant, and neuroprotective chemicals. Antimicrobial resistance (AMR) is a severe global public health concern that impacts people, animals, and the environment. It occurs when pathogens such as bacteria, viruses, fungi, and parasites can survive antimicrobial treatments, leaving them ineffective for treating infections. Numerous infectious diseases, especially those brought on by germs resistant to antibiotics, can be transferred from animals to people (Sarfraz et al. 2017).
An international search for novel therapeutic approaches has been sparked by the rising occurrence of diseases that are multidrug resistant. The growing ineffectiveness of antimicrobial medications

highlights the urgent need for novel therapeutic strategies. The Apocynaceae family, also referred to as the dogbane family and recognized for the wide variety of plants it contains, has recently drawn a lot of attention due to its potential as a source of antibacterial medications. The ability of natural resistance-modifying compounds, phytochemicals, and antimicrobial botanicals derived from various Apocynaceae species to counteract multidrug resistance in pathogenic bacteria (Anand et al. 2020). Recently, there has been a lot of focus on plants as potential sources of novel antibiotics and compounds that can change resistance. the many compounds obtained from plants and how they may be used to combat germs with antibiotic resistance. Alkaloids, terpenoids, flavonoids, phenolics, and essential oils are just a few examples of the many different antimicrobial substances that have been studied. In order to solve the problem of worldwide antimicrobial resistance, it is interesting to investigate plants as sources of antimicrobials and chemicals that change resistance (Abreu et al. 2012). The demand for cutting-edge treatment approaches has increased as multidrug-resistant pathogens like Bacillus anthracis and superbugs have become more prevalent. The potential of phytoextracts as inhibitors of antibiotic resistance has been demonstrated. Development of effective and long-lasting treatments against these deadly infections is possible due to phytoextracts' capacity to alter antibiotic resistance (Dassanayake et al. 2021).

5. NATURAL PRODUCTS DERIVED ANTIMICROBIAL COMPOUNDS

Following are some antimicrobial compounds derived from natural products.

- Coumarin-6-ol, 3,4 dihydro-4, 5, 7, tetramethyl-, a Streptomyces VITAK1 antibacterial agent, inhibits drug-resistant MRSA (ATCC 33591) as well as other Gram-positive and Gram-negative bacterial pathogens (IC50, 40 g/mL) (Brylev et al. 2021). Streptomyces spp. SCSIO 11594 produces two further new compounds. Only dehydroxyaquayamycin (3) suppressed MRSE-shhs-E1 (16.0 g/mL) in addition to other biological activities, but it has no effect on other organisms resistant to other medicines (Song et al. 2015).
- The S. zhaozhouensis CA-185989 (Equatorial Guinea) strain produces ikarugamycin (1-3) derivatives as well as four other recognised compounds that are efficacious against pathogens such as MRSA MB5393 (1–64 g/mL) (Lacret et al. 2014).
- Micromonospora spp. CA-214671 (Gran Canaria, Spain) has been known to develop the chemical phocoenamicin (3), which displayed antimicrobial efficacy against specific diseases such as MRSA MB5393 but was ineffective against *E. faecium* (VRE) MB5570 (Pérez-Bonilla et al. 2018). Diakylresorcins from Zobelliagalactanivorans OII3 are known to be isolated from a Kappeln, Germany, isolate. These compounds had a MIC value of 4.0 g/mL against MRSA LT-1334 and MRSA COL strains (Harms et al. 2018).

6. CLASSIFICATION OF BIOACTIVE NATURAL COMPOUNDS AGAINST ZOONOTIC DISORDERS

Scientists employ the varied pharmacological properties of secondary metabolites, which are phytochemicals produced by plants, to create new medications utilizing their active moieties in the preparation of synthetic pharmaceuticals. Plants utilize their secondary metabolites like polyphenols, alkaloids, saponins, tannins, terpenes,flavonoids, sterols, limonoids, glucosinolates along with several other bioactive substances that are used to ward off herbivores and insects (Şenkal 2020). Because of their numerous pharmacological properties, natural chemicals originating from plants are well-known. Different vegetables, fruits, and herbs contain these chemicals. The majority of these substances are efficient in treating a range of zoonotic diseases (Ashrafizadeh et al. 2021). Fruits, vegetables, spices,

and herbs are the potential sources of polyphenols including phenolic acids. Secondary metabolites are ingested on a regular basis and offer numerous health benefits to humans, including ROS scavenging, cytotoxic affects, anti-inflammatory, anti-allergic, antihypertensive, and antiviral capabilities.Numerous studies have shown how effective polyphenols are at fending off many viruses that are known to cause serious health issues. Antiviral drugs, like polyphenols, have a wide range of action mechanisms that can be used as a therapy or prophylactic method for viral infections (Montenegro-Landívar et al. 2021). Invading human body cells and using their constituent parts for their replication, viruses are comprised of DNA or RNA encased in protein capsules. Frequently, this procedure kills or injures infected cells, which results in a viral illness (Rouse and Sehrawat 2010). Due to their potential health advantages, bioactive substances like polyphenols have recently been suggested as an alternative therapy. These compounds can be obtained through secondary sources, such as agri-food residues (Tapia-Quiróset al. 2020). More than 400 food components include more than 500 different types of polyphenols, according to scientific research (Galanakis and Galanakis 2018).
Here we reviewed a few polyphenolic compounds and their antiviral activity against zoonotic illnesses. The basic chemical structure of polyphenols comprises of one or more hydroxyl groups bound to a benzene ring. Polyphenols can be divided into various classes that range from simple to highly polymerized substances (Ignat et al. 2011).

6.1. POLYPHENOLS

A class of phytochemicals known as polyphenols may have positive health effects. They make up the largest and most diverse collection of bioactive chemicals. The collection of physiologically active substances found in plant-based diets is called polyphenols. These substances, which come from plants including fruits, vegetables, grains, and coffee, are ingested by humans every day. Polyphenols may be further classified into two broader categories namely; phenolic acids and flavonoids. Degenerative disorders are known to be prevented by polyphenols. Phenolic acids are found abundantly in vegetables and fruits (kale, onions, and broccoli). Moreover, polyphenols may also be found in the extracts of various fruits like pomegranate, tea, and grapes(Abbas et al. 2017).
Phenolic acids are typically categorized into hydroxycinnamic andhydroxybenzoic acids while flavonoids among them are further broken down into flavones, isoflavones, flavononse, flavonols(Di Lorenzo et al. 2021). Fruit peel is one of the rich sources of flavonoids, and the amount found in it varies depending on the species and how much light the fruit peel has been exposed to (Abbas et al. 2017).

6.2. *PHENOLIC ACIDS*

The two broad categories of phenolic acids include Hydroxybenzoic acid (Galic acid and Protochatechuic acid), Hydroycinnamic acid (Coumeric acid and Caffeic acid). These subclasses comprise of C1-C6 and C3-C6 backbones. As hydroxybenzoic acids are uncommon in the human diet, it is not thought that these substances have any impact on health. Phenolic acids can also be found in the seeds, hull and bran in addition to fruits and vegetables. Alkaline, acidic as well as enzymatic hydrolysis of aforementioned food items yield phenolic acids in considerable quantities (O'Leary et al. 2004).

6.3. *ANTIVIRAL ACTIVITY OF POLYPHENOLS*

Tannic acid TA ($C_{76}H_{52}O_{46}$), shares characteristics with the two phenolic ligands, TCG (1,3,6-tri-O-galloyl-D-glucose) ($C_{27}H_{24}O_{18}$) and corilagin ($C_{27}H_{22}O_{18}$), as well as other phenolic compounds. It is a naturally occurring polyphenol which is found in a variety of plant species (Gaudreault and Mousseau, 2019).

These three phenolic compounds act on the SARS-CoV-2 target receptor on the cell membrane of host organism and block the chemical bond between SARS-CoV-2 spike RBD (protein receptor binding domain) and ACE2 (angiotensin converting enzyme 2). The entry and replication of SARS-CoV-2 is reported to have been inhibited by phenolic ligands, TMPRSS2 (Transmembrane protease serine 2) and 3CLpro (3-chymotrypsin like protease), respectively (Haddad et al. 2022).

7. *FLAVONOIDS*

Plants produce flavonoids as 2-phenyl-benzo-pyrone derivatives as secondary metabolites. In flavonoids, there are two benzene rings (often referred to as A and B) that are joined by a pyrene ring (C) that contains oxygen, forming a C6-C3-C6 system (Panche et al. 2016).

7.1. *FLAVONOLS*

Flavonoids with a ketone group are called flavonols. The 3-position of the C-ring on flavonols has a -OH group; the hydroxyl group may be glycosylated. Two significant members of the flavonol sub-class of flavonoids include quercetin and kaempferol. Vitexicarpin, fisetin, Galangin and myricetin are other prominent members (Panche et al. 2016).

8. *MYRICETIN*

Flavonols, a subclass of flavonoids that includes myricetin as bioactive natural compound.

9. *ANTIVIRAL ACTIVITIES OF MYRICETIN*

According to reports, it has an IC50 value of 8.4 M for inhibiting the protease of the African swine fever virus (ASFV). Another substance that suppressed ASFV was myricitrin, a myricetin derivative with a rhamnoside moiety (Jo et al. 2020).

Herpes simplex virus 2 (HSV-2)'s highly immunogenic glycoprotein D (gD) is crucial for viral entrance into host cells.Myricetin blocks viral adsorption and membrane fusion to host cells by interacting directly with the viral gD protein. Myricetin also suppresses viral infection and replication by down-regulating the host EGFR/PI3K/Akt (epidermal growth factor receptor/phosphoinositide 3-kinase/Akt or protein kinase B) signaling pathway (Li et al. 2020).

Elderberry extract contains dihydromyricetin, which has antiviral properties against the influenza H1N1 virus in MDCK cells (Roschek et al. 2009).

The synthesis of viral RNA was almost entirely suppressed by myricetin, which also prevented Zika virus multiplication (Zou et al. 2020).

Myricetin from the Dioscoreaceae plants *Marcetiataxifolia* and *Dioscoreabulbifera* L. has been found to have potent inhibitory effects on HIV-1 (RT) and HIV-1 integrase. Myricetin's glycosylated moiety may favourinternalisation within cells and increase anti-HIV-1 efficacy (Ortega et al. 2017).

9.1. *PHLORETIN*

The Puerto Rican strain PRVABC59 and the African strain MR766 are the two ZIKV strains that phloretin is effective against; their respective EC50 concentrations are 22.85 and 9.31 M.Phloretin's inhibitory effects are thought to be due to its ability to prevent cells from absorbing glucose, which prevents the spread of viruses (Lin et al. 2019).

9.2. ANTHOCYANIN

A subclass of flavonoids called anthocyanins gives flowers, vegetables, and fruits different colours like red, blue, pink, or purple. They possess the flavylium ion (2-phenylchromenylium), which bears a positive charge at the oxygen atom of the flavonoid basic structure's C-ring(Khoo et al. 2017). Anthocyanins, from a structural perspective, are anthocyanidins that have been altered by acyl acids (acylated) or sugars (glycosylated).The degree of blue colour of anthocyanins is determined by the quantity of hydroxyl groups on the B ring; methylation results in a red colour (Alappat and Alappat 2020).
The anthocyanidinscyanidin, delphinidin, pelargonidin, peonidin, malvidin and petunidin are widespread in plants and have varying concentrations in fruits and vegetables (Hernández and Elena 2009).

9.3. *DELPHINIDIN*

According to studies, delphinidin (3,5,7-trihydroxy-2-(3,4,5-trihydroxyphenyl)-1--4-chromen-1-ylium) inhibits flaviviruses such the West Nile virus, Zika virus, and dengue virus (DENV). There is evidence that the substance interferes with viral entrance and adhesion to host cells. Delphinidin also lowered ZIKV and DENV infectivity by having a virucidal impact, which was also noted (Vázquez-Calvo et al. 2017).

9.4. *MECHANISM OF ACTION OF DELPHINIDIN*

This unique mechanism of action for preventing viral entrance directly binds to viral particles and hinders viral (HCV) adhesion to the host cell surface. The virus is also susceptible to it in primary human hepatocytes (Calland et al. 2015).
The influenza virus that is hostile to human numerous phytochemical components, notably delphinidin-3-O-sambubioside, have been linked to the action of Hibiscus sabdariffa L. (sorrel) (Lowe et al. 2021).
Delphinidin-3,5-diglucoside interacts with the main protease Mpro of SARS-CoV-2 via hydrogen bonds with Gly143, His163, His164, Glu166, Gln189, Thr190, and Gln192 as well as via -interaction with His41, according to in silico studies. This suggests that the compound may be helpful in preventing viral replication by inhibiting Mpro (Gahlawatet al. 2020).The substance is also said to be able to bind to ACE-2, which is the human receptor for the SARS-CoV-2 spike protein.Delphinidin 3-O-D-glucoside 5-O-(6-coumaroyl-D-glucoside), one of the flavonoids examined, was found to be a powerful inhibitor of all three protein targets of SARS-CoV-2 (Marimuthu Ragavan et al. 2020).

9.5.*FLAVANONES*

With roughly 350 flavanone aglycones and 100 flavanone glycosides found in naturally occurring sources, flavanones—previously thought to be a minor group of flavonoids—are now thought to be a large group (Iwashina 2000).

9.6. *NARINGENIN*

Naringenin ((S)-5, 7-dihydroxy-2-(4-hydroxyphenyl) chroman-4-one), a flavourless and colorless flavanone, is one of the primary flavanones.In grapefruit, it is the predominant flavanone. It's noteworthy to note that naringenin may be able to treat bronchial pneumonia in children, even though COVID-19 pneumonia is distinct from bronchopneumonia because the latter is caused by a bacterial infection (Chrzan et al. 2021).

Naringenin has been evaluated against a replicon of the Chikungunya virus (CHIKV) that was transfected into BHK cells. The replicon contains markers for Rluc, EGFP and viral replicase proteins with puromycin acetyl transferase. It was discovered that naringenin inhibits the expression of the CHIKV replicon-expressed marker genes Rluc and EGFP. Naringenin's anti-alphaviral activity against the Semliki forest virus (SFV) was also verified. Naringenin prevented the generation of SFV virion and further decreased the cytopathic effect caused by SFV and Sindbis viruses.By displaying strong binding affinity to nonstructural protein 2 (nsP3), a protein thought to be crucial for the virus's intracellular replication, naringenin demonstrated potential as a CHIKV inhibitor in silico tests (Pohjala et al. 2011).
Table 2 shows the list of some natural compounds, with the class of the compound, their natural sources from which compound obtained and their antiviral activity.

10. PLANT BASED VACCINE

Vaccination establishes a major advance in the prevention of zoonotic diseases. This process is based on the principle to induce defense against a pathogen through imitating its natural interaction with the immune system of human (Canouï and Launay 2019). Since 1940, several vaccines are being industrialized by the use of attenuated, inactivated as well as live viruses. Among these vaccines, live attenuated or recombinant proteins or killed live attenuated pathogens are the ones that are licensed and the most commonly used vaccines against several infectious animal diseases. Porcilis-PCV2 and also, Suvaxyn PCV2 for pigs, AquaVacFuruvac, AquaVac Vibrio for fish, Periovac for dogs AquaVac ERM, are marketed and also approved vaccines against numerous veterinarian diseases (Meeusen et al. 2007).
There are four main types of vaccines including subunit vaccines, conjugate, recombinant as well as polysaccharide vaccines.

- Subunit vaccines are the ones that separate specific antigens from a virus or germ so that it can be used in the vaccine. However, these specific antigens are accurately chosen in accordance to immune response strength they generate. These vaccines are not known do not cause many drastic effects as they are so precisely targeted (Khalaj-Hedayati et al. 2020).
- Conjugate vaccines are the ones that use specific parts from the superficial antigen coat of the virus or bacteria and these are the ones that are not strong enough to be the basis of illness or even to generate any immune response in body (Bremer and Janda 2017).
- Recombinant vaccines are the one that are made through process of genetic engineering. The protein creating gene is precisely isolated and then placed inside genes of another cell. When this new cell reproduces, it yields vaccine proteins, which means that the immune system will identify this protein and then look after the body against it.These vaccines mostly use two varied components (Yadav et al. 2020).
- Polysaccharide vaccines are the ones that use complex sugar molecules (such as polysaccharides) from external layer of a virus or bacteria. These polysaccharides are chemically linked to that of carrier proteins and also work in the same way as conjugate vaccines (Sun et al. 2018).

An innovative trend of plant-based vaccine has attracted a lot of attraction. A number of these plant derived vaccines against animals' and human infections and diseases have recently been recognized which undergo regulatory and clinical approval. These vaccines have potential to serve as ideal boosters (Shahid and Daniell 2016a). Approximately 200 different proteins have been formed in plants, and according to their expected results, they are known to be new competitors in t recombinant protein field. Plant based vaccine has variety of benefits over different eukaryotic production arrangements. They are largely cost effective as well as safe and thus can be produced productively in bulky amounts. By using systems of plant based production, the expensive usage of fermenters can easily be replaced by a plot of land or a glasshouse (Daniell et al. 2016). The preference of technology as well as the plant

Table 2: Some natural compounds, with the class of the compound, their natural sources and their antiviral activity

NaturalCompounds	Class of the compound	Plant source	Type ofvirus	References
Tannic acid	Phenol	Tarapods (Caesalpiniaspinosa), gallnutsfrom Rhussemialataor Quercusinfectoriaor Sicilian sumac leaves (Rhuscoriaria).	SARS-CoV-2	(Haddad et al. 2022)
Kaempferol	Flavonol (type of flavonoid)	Berries, tea, almonds,beans, tomato,Ficuscarica, cloves, cumin	Corona virus, rotavirus, HSV-1, -2, coxsackie B virus	(Russo et al. 2020)
Catechin	Flavonol	E. cooperi, M. alba, R. succedanea	HIV, HSV-1	(El-Toumy et al. 2018)
Quercetin	Flavonol	Citrus spp., fish mint (H. chordata), Spondiasmombin, S. tuberosa	Rabies virus, poliovirus, HSV-2, SARS-CoV-2, DENV	(Zandi et al. 2011); (Chiow et al. 2016)
Rutin	Flavonol	Spondias spp., Pavettaowariensis (bark)	Rabies virus, influenza virus	(Cushnie and Lamb 2005)
Curcumin	Flavonoid	Turmeric	HIV	(Praditya et al. 2019)
Hesperidin	Flavonone	Citrus spp., grapefruit	Influenza virus, SARS-CoV-2, poliovirus, HSV, syncytial virus,	(Mhatre et al. 2021)
Caffeic acid	Phenolic acids	Pappaya, peach, avocado	HIV, HSV	(Sytar et al. 2021)
Luteolin	Flavone	Broccoli, lentils, pistachio, artichoke, olive, lemon	HSV-1, HSV-2	(López-Lázaro 2009)
Ellagic acid	Phenolic acid	Berries, pomegranate, walnuts, pecans	DENV, hepatitis A and B	(Kang et al. 2006)
Resveratrol	Stilbenoid	Grapes, berries, peanuts	Influenza A, hepatitis C virus, respiratory syncytial virus, HSV, HIV	(Docherty et al. 2006)
Myricetin	Flavonol	Guierasenegalensis leaves, MarcetiataxifoliaandDioscoreabulbiferaL.	African swinefevervirus (ASFV), Herpes simplex virus 2 (HSV-2), Influenza H1N1 virus, Zika virus, Hepatitis B virus (HBV), HIV-1	(Sun et al. 2022);(Mammen 2022)
Phloretin	Chalcone	Apple andStrawberries	Two strains of Zika virus (ZIKV)	(Lin et al. 2019)

species regulate the administration route of vaccine as few plants can only be consumed when they are processed, despite the fact that pressure or heat treatments may abolish the antigen. There are mainly two choices for administration of vaccine including mucosal (nasal or oral) and injection (subcutaneous or intramuscular) administration. However, injection type vaccines can prompt robust protective immunity by favorably inducing production of IgG. Such vaccines are considered the most appropriate against several pathogens that are reported to infect through a respiratory and or systemic route, but antigens need to be highlypurified before they are administered (Takeyama et al. 2015). Various bacterial and viral subunit vaccines production have been practiced in several transgenic plants. Many recombinant subunit vaccines are usually safer as compared to traditional vaccines as they comprise pathogen that are not alive. Vaccines that are produced inside the seeds are usually stable for extended period of storage, due to this reason cereal crops are considered appropriate for production of subunit vaccine (Hefferon 2013). However, the prime plant-made vaccine made commercially wasan accomplishment against NDV by Dow Agro Sciences, which lighted the path for the commercialization of these plant-made vaccines (Yusibov et al. 2011).

11. ZOONOTIC DISEASES AND PLANT-BASED VACCINES

Plant based vaccine offer great results for zoonosis.

Rabies is one of the many zoonotic infections and is most common and circulates amongst wild bats and dogs. Virus belonging to family *Rhatbdoviridae*is the cause of rabies. Vaccines that are currently available give reasonable results but are thoughtful limitations in developing countries due to a number of restrictiohns including high cost and requirement for refrigeration at temperature of 4 °C. Whereas, vaccines that are developed through plant sources can offer effective explanations to such issues (Loza-Rubio et al. 2012).The nucleoprotein of this rabies virus is transiently expressed and can produce remarkable expression and is reported to be immunogenic in case of mice and also confers protection against challenge of rabies viral (Perea Arango et al. 2008). The researchers have fused glycoprotein with ricin toxin -B chain (rgp–rtxB) in roots of tomato, which after intramucosal immunization produced high immune response. The great efficacy of CTB to GM1 receptors assured its anti-rabies antibodies and anticholera toxin (Rosales-Mendoza et al. 2010;Singh et al. 2015). Rabies vaccines which are also plant-based, expressed transitorily in spinach plant, and occurs in phase I of its clinical trials; about five out of nine volunteers expressed neutralizing antibodies against that virus causing rabies (Takeyama et al. 2015).

- Swine flu is a contagious disease that is common in pigs and the virus responsible for this disease belongs to the family *Flaviviridae*. This disease is a major load in the industry of livestock. Plant based oral vaccine proposes key to this disease.E2 protein articulated in chloroplasts of tobacco plant deliberated immune response in animals like mice after oral delivery (Shao et al. 2008). Researchers have also created transgenic rice calli which expressed E2 structural protein, in addition to noticing protective immune response in mice that is immunized orally; pigs also generated cellular, systemic as well asmucosal immune responses that is E2-specific (Jung et al. 2014).
- Pasteurellosis is also one of the commonly occurring infections found in humans as well as animals, and is caused as a result of bacterium called *Pasteurella*. This disease is accountable for loss in pig as well as cattle industry on a large scale, and this infection can be transmitted to humans through an animal's bite in addition to contaminated food. In order to make low-cost and edible vaccines against this Pasteurellosis infection, a remarkable immune response has been the result in plant-based GS60 fed rabbits (Lee et al. 2008).
- Anthrax is reported to be the most commonly emerging zoonosis that is caused by the bacterium called *Bacillus anthracis*. In 2001, anthrax was considered as a biological weapon as it killed 5 people in the US. Recent vaccines obtained from *Bacillus anthracis* by culture filtrate are injectable protective antigen against human anthrax as well as animal anthrax. There are numerous restrictions to this vaccine which include necessity of numerous boosters (approximately eight) as well as withdrawal of specific batches because of occurrence toxin contamination in that culture filtrate. The transplastomic tobacco has been designed by articulating the antigen (PA) which is anthrax protective and detected

immune response by producing high-titre IgG antibodies against anthrax disease (1 : 320 000) in immunized mice and give out to 100% defense after treated a dose of *Bacillus anthracis* which is lethal (Gorantala et al. 2011).

- Listeriosis is also infectious zoonosis in animals and humans. *Listeria monocytogenes* is the causative agent of this disease. Uncooked food is the common reason of this disease transmission to human. Newborn, individuals with weak immune system as well as pregnant women are highly susceptible to severe infection. Extreme complications lead to encephalitis. The causative bacterium of listeriosis is reported as a neglected zoonotic pathogen and several plant derived vaccines might propose the finest solution for this disease. An effort was made to make plant based vaccine against this disease in which transgenic potato is used to orally immunize mice and it showed very auspicious results by notably dropping the bacterial load in liver and spleen after treated with *Listeria monocytogenes*(Ohyaet al. 2005).
- Plague in humans is an infectious disease caused by a bacterial as well as zoonotic pathogen *Yersinia pestis*. Plague can occur in blood vessels (septicaemic infection), in lymph node (bubonic infection) or in lungs (pneumonic infection). In humans, plague causes dreadful infection with approximately 90% mortality rate if continued untreated (Sinclair et al. 2008). The high levels of F1-V have been articulated in chloroplasts of tobacco plant and mice that were fed orally were reported to be extremely immunogenic, and when treated with deadly dose of *Y-pestis* showed 88% protection. When F1-V expressed in chloroplast in lettuce plant, it produced considerably decreased level of antigens but it also revealed immunogenicity (Arlen et al. 2008). Table 3 shows the vaccines antigens expressed in plants against zoonotic diseases.

12. RECENT TRENDS IN THE USE OF NATURAL PRODUCTS AS ANTI-ZOONOTIC AGENTS

12.1. NANOTECHNOLOGY-BASED APPLICATIONS OF NATURAL PRODUCTS AGAINST ZOONOTIC DISEASES

Many zoonotic illnesses have been successfully treated using products produced from plants (Ali et al. 2021). According to sources, the source is zoonotic pathogens 75% of new infectious illnesses in humans(Shahid and Daniell 2016b).Zoonosis, often known as illnesses of animal origin, is the term used to describe diseases that spread from animal to human by direct touch, indirect environmental contact, or ingested food(Chlebicz and Śliżewska 2018).

The advancement of nanotechnology, which has made it possible to comprehend the molecular operations of living cells, has made it possible to design practical technologies that allow early diagnosis and treatment of illnesses (Chakravarty and Vora 2021). Innovations powered by nanotechnology give patients and medical professionals hope for solving the issue of medication resistance.

The domains of medicine and veterinary science both hold great promise for nanomaterial. (Khalaj-Hedayati et al. 2020). Nanoparticles are divided into four categories: 1) nanoparticles made of metals (such as Fe, Zn, Ag, Cu, and Au); 2) oxides of metals and nonmetals(such as ZnO, AlO, VO,and FeO); 3) nanoparticles of semiconductors(such as, CdS, CdSe, and ZnS); and 4) nanoparticles of carbon (From theSociety of NeuroInterventional Surgery (SNIS), American Society of Neuroradiology (ASNR), American Association of Neurological Surgeons (AANS), Congress of Neurological Surgeons (CNS), European Society of Neuroradiology (ESNR),European Stroke Organization (ESO), Cardiovascular and Interventional Radiology Society of Europe (CIRSE), Canadian Interventional Radiology Association (CIRA), European Society of Minimally Invasive Neurological Therapy (ESMINT), Society for Cardiovascular Angiography and Interventions (SCAI), Society of Interventional Radiology (SIR), and World Stroke Organization (WSO) et al. 2018).

Table 3: Vaccines antigen expressed in plants against zoonotic diseases.

Disease	Expressed Antigen	Host plant	Immune response	References
Rabies	Rabies virus G protein	Tomato roots	mice immunized with RGP-RTP showed explicit immune response in the form of IgG1, IgG2 as well as TH2 lymphocyte against RGP-RTP	(Takeyama et al. 2015)
Swine flu	E2 glycoprotein	Tobacco	Subcutaneous immunization produces CSFV-specific serum IgG In comparison to subcutaneous immunization, mice didn't show any specific response after oral immunization	(Shao et al. 2008)
Avian flu	H5 of (HPAI) A	Arabidopsis	When mice immunized orally educed elevated level of HA specific systematic IgG as well as mucosal IgA, sturdy Th1 retorts together with IgG2b production was detected, as well as 72% defense was observed in immunized mice after treated with virus	(Lee et al. 2015)
Pasteurellosis	GS60	Alfalfa/Tobacco	Rabbit Immunized through transgenic plant alfalfa formed antibodies against GS60	(Lee et al. 2008)
Anthrax	PA (protective antigen)	Tobacco	Mice immunized with transplastomic tobacco formed broad range of IgG antibodies against anthrax disease (almost 1: 320 000) as well as 100% protection was noted in immunized mice after treated with lethal dose of *Bacillus anthracis*.	(Gorantala et al. 2011)
Listeriosis	IFN-α	potato	Transgenic potato is used to orally immunized mice it showed very auspicious outcomes by noteworthy dropping the bacterial load in liver and spleen after treated with bacterial pathogen	(Ohya et al. 2005)
plague	F1-V	Tobacco	After oral immunization, mice formed high-titre IgG1, IgG2a, IgA as well as showed 88% protection after treated with fatal dose of *Y. pestis*	(Arlen et al. 2008)

The most prevalent metal nanoparticles are those that are nanosized silver and gold. The improved antibacterial action of AgNPs against a variety of harmful microorganisms, including bacteria, fungi, and viruses, is well recognized. Given that AgNPs and composites have shown efficient antiviral effects against well-known viruses, such as influenza and the human immunodeficiency virus (HIV), they have been suggested by several researchers as possible antiviral medicines to treat a variety of viral illnesses (Jeevanandam et al. 2022).

12.2. APPLICATIONS OF NANOPARTICLES

Gene delivery and drug, the use of fluorescent biological labels, the proteins detection, infections, and tumours, the separation and purification of biological molecules and cells, tissue engineering, the raising of MRI contrast, and pharmacokinetic investigations are some of its uses (Chakravarty and Vora 2021).

Due to their inherent antipathogenic qualities and capacity to photothermally or through the generation of reactive oxygen species (ROS) by photocatalysis inactivate viruses, fungi, bacteria, or yeasts, nanoparticles (NPs) can provide alternatives to conventional disinfection protocols used in healthcare settings. SARS-CoV-2 inactivation techniques using nanotechnology may also be investigated (Weiss et al. 2020).

12.3. BIOFILMS

Bacteria can develop into planktonic, free-floating bacteria or into complex communities known as biofilms. It encourages the variety and proliferation of bacteria and provides them with special habitats that include both aerobic and anaerobic layers. Bacteria are given greater resistance to antimicrobial treatments via biofilms (Johnjulio et al. 2012). By creating biofilms, microorganisms are able to survive with high or low temperatures, antibiotic treatments, and a lack of nutrition. Zoonotic and environmental diseases utilize biofilm development as a method of infection in both animals and people (Clutterbuck et al. 2007).

- Propolis is a beneficial natural product, however some beekeepers have reported allergic reactions including contact dermatitis to this substance. Biofilm development is a significant contributor to poor wound healing; propolis, an anti-microbial substance, can decrease biofilm production and speed up healing (Oryan et al. 2018).
- Herbal essential oils, such as rosemary oil, lime oil tea, tree oil, and, have become more important in dermatology. These are the oils aromatic secondary metabolites are plentiful, particularly terpenes and phenolic compounds, which have strong antibacterial effects and prevent the growth of biofilm (Jain et al. 2022).

12.4. MULTIDRUG EFFLUX

Pathogenic infections caused by multidrug-resistant bacteria are becoming more common quickly over the globe and are in danger of becoming incurable. Numerous studies suggest that efflux pumps have a role in the virulence and adaptive responses that result in the rise of antimicrobial resistance during infection, and moreoverin the process of drug extrusion(Du et al. 2018).

The tet (tetracycline) determinants, which were encoded on plasmids or transposons, were responsible for this resistance, which could be transferred across strains (Roberts 2005).

The "smoke tree," Daleaspinosa, was used to make the isoflavone and pterocarpanarylbenzofuran aldehyde (spinosan A), which had a potential effect when berberine was present (Tagaand Okabe 1991).By reducing the MIC 4- to 8-fold, all three substances improved berberine's efficacy against the wild-type strain of *S. aureus*. An isogenic NorA mutant's MIC was reduced by 2- to 15-fold increaseas a result of these compounds, however none were potent against the NorA overexpressing mutant. Agents 15–17 are expected to block a different efflux pump than NorA (Stavriet al. 2007).

12.5. SYNERGISTIC EFFECTS

Synergistic effects are the collective effects of at least two substances making an influence that is more substantial than both of them could have revealed by themselves. Greek “synergos”, meaning “working together” (Anand et al. 2021).

In order to effectively combat infectious diseases, new strategies must be implemented right now due to the growing global problem of medicine resistance. Recent years have seen a rise in interest in the study of natural compounds, particularly phytochemicals derived from plants, because of their potential to increase the effectiveness of antimicrobial drugs. the expanding idea of synergistic interactions between phytochemicals and traditional antibiotics as a possible countermeasure to drug resistance. Discussions of the mechanics behind these beneficial interactions offer important new information for developing combination medicines (Ayaz et al. 2019). Numerous plant-based essential oils have recently come to light as potential candidates to boost the effectiveness of traditional antibiotics due to their strong antibacterial properties. Essential oils work synergistically with conventional antibiotics when combined. Specifically, the capacity of essential oils to revert bacterial resistance pathways, regaining antibiotic sensitivity in species that have developed bacterial resistance. In order to prevent antibiotic resistance and improve the outcomes of therapy for challenging infectious diseases, synergistic interactions provide significant promise (Lahmar et al. 2017). In the era of antimicrobial resistance, the synergistic antibacterial activity of essential oil-nanoparticle combinations creates new opportunities for the creation of effective and long-lasting antimicrobial treatment methods (Rai et al. 2017).

Among the potential agents being looked at to replace synthetic antimicrobials and traditional antibiotics are plant-based solutions. Numerous investigations on the antibacterial activity of herbal extracts and essential oils were conducted in order to create safer medications. *Myrtuscommunis L.*, sometimes known as the common myrtle or true myrtle, is one of the plants whose essential oils have been thoroughly studied. It is an evergreen shrub from the Myrtaceae family and is frequently seen in typical Mediterranean vegetation. One of the significant fragrant and therapeutic species in this family, *M. communis* has a high concentration of essential oils in the glands of its leaves, flowers, and fruits. Although myrtle essential oils have been shown to have both in vitro and in vivo biological activity (Harikrishnan et al. 2003).

A top goal for global health is the discovery of new, powerful antibacterial agents against MDR microorganisms. It has been demonstrated that certain phytochemicals can make bacteria more susceptible to the effects of antibiotics, inactivating or weakening antibiotic resistance systems. Because of this capacity, some phytochemicals and antibiotics, whose efficiency would be very poor in the absence of phytochemicals, work together synergistically. Some phytochemicals are inactive when taken alone; they only exhibit meaningful action when given together with an antibiotic. Other substances exhibit synergistic action through other ways (Álvarez-Martínez et al. 2021).

13. CONCLUSION

The progress of plant-based vaccines against zoonotic diseases holds great promise in revolutionizing disease control. These innovative vaccines offer advantages such as ease of administration, stability, and reduced production costs. With the increasing global threats posed by zoonotic infections, the research and development of plant-based vaccines are becoming more critical than ever. Continued efforts in this field may pave the way for effective, scalable, and environmentally sustainable solutions for zoonosis control, benefitting both human and animal health.

Plant-based vaccines have shown tremendous potential in addressing zoonotic diseases. The recent progress in this field provides hope for more effective and accessible solutions to prevent zoonotic infections. This review emphasizes the importance of continued research and collaboration between scientists, policymakers, and stakeholders to harness the full potential of plant-based vaccines for safeguarding human and animal health.

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Intestinal Illnesses and One Health

42

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ABSTRACT

Zoonotic diseases can be naturally transmitted from vertebrate animals to humans. These diseases are harmful for both animals and humans. Millions of people throughout the world are susceptible to zoonotic diseases caused by bacteria, viruses, fungi and parasites. Different pathogens are responsible for causing gastroenteritis. The pathogens spread from environment, infected persons, animals or from contaminated water/food. Food-borne zoonotic illnesses arise by the consumption of either infected water or contaminated food. Several pathogens are present in foods such as bacteria (e.g. Campylobacter and Salmonella), virus (e.g. norovirus), and parasites (e.g. Cryptosporidium). Ingestion of raw/undercooked meat or raw milk serves as major sources of zoonotic infections. Throughout the world, zoonotic infections are a matter of serious concern and developing countries are at greater risk. The One-Health approach seems to have a major role in the control and prevention of zoonotic illnesses. During the last three decades, new and re-emerging zoonotic diseases have been evolved partly because of our close connection with companion and food animals, along with our growing dependence on animals including their products. The One-Health functions at global, regional, national and local levels and emphasizes on the collaboration and team work of different sectors. This approach focuses on surveillance, management and eradication of diseases by encouraging collaboration between public health experts, veterinarians, and ecologists. This unifying and integrated approach can alleviate and prevent threats to health at the interface of the environment, humans, animals and plants. The international organizations have acknowledged the One Health as an important need for control of many zoonotic diseases especially intestinal diseases.

Key words: Gastroenteritis, Zoonotic diseases, Bacteria, Public Health, Intestinal health, Foodborne

CITATION

Shafique Z, Naqvi FZ, Somal S, Kiran B, Humayun A, Naeem RF and Zafar MA, 2023. Intestinal illness and one health. In: Khan A, Abbas RZ, Hassan MF, Aguilar-Marcelino L, Saeed NM and Mohsin M (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 565-577. https://doi.org/10.47278/book.zoon/2023.042

CHAPTER HISTORY Received: 04-May-2023 Revised: 12-June-2023 Accepted: 23-July-2023

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1. INTRODUCTION

Zoonoses are defined as the diseases which are naturally transmitted from vertebrate animals to humans. Zoonotic diseases are considered dangerous for both animal and human health. The transmission may occur either directly or indirectly through vectors. The seriousness of symptoms of zoonotic diseases ranges from mild to even life-threatening conditions. Generally, the zoonotic diseases can be transferred at the human-animal interface when there is direct exposure to animals (e.g. rabies), products of animal origin (e.g. salmonellosis, brucellosis), or their contaminated environment (e.g. echinococcosis) (Rantsios 2016).

Zoonotic diseases can emerge from either domestic animals or wild animals. The latter are gradually becoming a significant reservoir for human disease, as recognizable in susceptible groups of human, including hunters, and tourists camping in forests. Around the world, there are millions of people, who are at risk to acquire a number of viral, bacterial, fungal as well as parasitic zoonotic infections. Consequently, there are millions of new annual cases, considerate mortality rate, and cause burden in respect of agriculture, veterinary medicine, livestock production and national and local economies (Christou 2011).

The term gastroenteritis can be referred to the acute emergence of symptoms related to intestine. In accordance to the FoodNet definition, the frequency of gastroenteritis was higher in Canada as compared to the United States, Australia, and Ireland. While the occurrence was higher in the United States as compared to Ireland (Majowicz et al. 2008). The evaluation of the percentage of gastroenteritis of foodborne origin is dependent on the information of known pathogens (ingested by oral route) (Hall et al. 2010). Several pathogens are responsible for infectious gastroenteritis. These pathogens acquire particular characteristics and can be identified by different laboratory procedures. The pathogens spread from environment, infected persons, animals or from contaminated water/food (Hall et al. 2005). It has been reported that, annually up to 10% of the population of humans may suffer from foodborne zoonosis in industrialized countries (Shao et al. 2011).

One Health concept seems to be a cooperation between different sectors. These sectors include health of human, animal and environment. One Health strategy is essential for the successful surveillance, detection and control of different zoonotic diseases. Due to increased emerging infections, One Health concept is being considered as more beneficial to improve animal, human and environmental health by the control of emerging and zoonotic diseases (Shaheen 2022).

2. SIGNIFICANCE OF ZOONOSIS

Zoonoses impose multiple effects on the health of both humans and animals. The effects imposed by zoonoses can be assessed through various parameters like disease incidence, prevalence, mortality, morbidity and economic loss. The livestock sector can be greatly affected by the economic losses generated as a result of animal death caused by zoonotic infections. Although if the animal does not die, its health and productivity are still negatively affected. Therefore, it can lead to a considerable loss (can be more than 70%) in animal products like milk, meat, and eggs. Besides this, human nutrition and health are also influenced because of the decreased supply of high protein foods of animal origin. Different zoonotic diseases may affect differently, e.g. toxoplasmosis and brucellosis can result in weak offspring, abortion, and infertility. Zoonotic infections like avian influenza, anthrax, and BSE hinders the international trade of animal and their products (such as milk, meat and eggs) around the world. The economy is also greatly disturbed due to the measures essential for control and eradication of zoonoses (like surveillance, diagnosis, isolation, quarantine, restriction on transportation of animals, treatment, vaccination, biosecurity and inspection of milk and meat). The economic impact of zoonotic outbreaks has globally exceeded 120 billion USD from 1995 to 2008. In addition to this, different countries experienced extreme economic losses as a result of outbreaks of zoonotic foodborne pathogens (Rahman et al. 2020).

3. NON-FOODBORNE ZOONOTIC DISEASES

Zoonotic non-food borne diseases can be transmitted through:

- Direct Contact (e.g. Avian influenza and Q fever)
- Vectors (e.g. Malaria, Lyme disease, West Nile fever, and Leishmaniosis) (Rantsios 2016).

4. FOOD-BORNE ZOONOTIC DISEASES

Food-borne zoonotic illnesses are developed by the utilization of either infected water or contaminated food. Several pathogens are present in foods such as bacteria (e.g. *Campylobacter* and *Salmonella*), virus (e.g. norovirus), and parasites (e.g. *Cryptosporidium*). Food safety challenges have increased due to changes in food production, processing, distribution and the environment (Rantsios 2016).

4.1. GASTROINTESTINAL ZOONOTIC ILLNESSES

Humans and animals are affected by infectious gastrointestinal illnesses around the world. There are a variety of agents which have the potential to be transmitted (such as *Yersinia enterocolitica,* and *Campylobacter jejuni*). Consumption of raw milk or raw/undercooked meat seems to be major source for zoonoses (Tsegaye et al. 2022). Gastrointestinal illnesses can be caused as a result of the following zoonotic pathogens:

4.1.1. CAMPYLOBACTERIOSIS

Campylobacter spp. and *Salmonella* spp. are responsible for causing more than 90% of bacterial food-borne illnesses (Rahman et al. 2020).

4.1.1.1. ETIOLOGY

Campylobacter is a bacterium that causes campylobacteriosis. Since the 1980s, *C.jejuni* has been considered as a common zoonotic pathogen throughout the world (Shao et al. 2011).

4.1.1.2. TRANSMISSION

In the present time, it is the most commonly occurring foodborne zoonotic disease of bacterial origin throughout the world. The most common causes for campylobacteriosis include the ingestion of contaminated beef, pork or poultry. It was discovered that almost 30 percent cases of this infection were the consequence of consumption of contaminated poultry. Different reservoir for this pathogen include ruminants like sheep, goats and cattle (Chlebicz and Śliżewska 2018).

4.1.1.3. EPIDEMIOLOGY

The prevalence of *campylobacter* infection has become increased and serves as the most common reason for diarrhea in both the developed and developing countries. In the United States, in March 2013, the Centers for Disease Control and Prevention (CDC) revealed nearly 14 percent rise in the cases of *Campylobacter jejuni*. *Campylobacter* affects 1 percent of human population of Europe on yearly basis. The prevalence of this disease throughout the world shows the ability of this pathogen to live in different variety of environments (Fischer and Paterek 2022). In China, the detection of *Campylobacter jejuni* is the most frequent in poultry having an average flock contamination rate and isolation rate as 86.67 % and 18.61 %, respectively. In Jiangsu province, the average incidence rate was reported as 8.70 %, 7.77 %, 5.02% and 4.84 % in heifers, cattle, milk cows and diarrheal patients, respectively (Shao et al. 2011).

4.1.1.4. SYMPTOMS

Campylobacteriosis in humans usually develops 1 to 5 days after exposure with the pathogen. The clinical signs include fever, vomiting, abdominal pain, watery and may be bloody diarrhea (Skarp et al. 2016).

4.1.1.5. DIAGNOSIS

Diagnosis can be made by adopting different methods. These methods include, culture test, stool antigen assays, and molecular techniques. These techniques have different specificity and sensitivity. Beside these, non-culture methods are also available for detection but these do not tell about the difference between *C. coli*, *C. jejuni* and other species of *Campylobacter* (Fitzgerald 2015).

4.1.1.6. TREATMENT

The campylobacteriosis infection is usually mild and self-limiting. Macrolide antibiotics serve as the best treatment option for *Campylobacter* infections. It is important to maintain the hydration status and electrolyte depletion of the patients. Depending on the degree of dehydration and the severity of the disease, the hydration can be either through oral or parenteral route (Fischer and Paterek 2022).

4.1.2. SALMONELLOSIS

Another food-borne zoonotic agent is *Salmonella* which causes Salmonellosis and affects humans and some of the warm blooded animals. In different provinces of China, the contamination of *Salmonella* in food of animal origin is common (Shao et al. 2011).

4.1.2.1. ETIOLOGY

For many years, *Salmonella* has been considered a reason for enteric diseases. The three species of *Salmonella* include *S. enterica*, *S. subterranean* and *S. bongori* (Chen et al. 2013).

4.1.2.2. EPIDEMIOLOGY

Salmonellosis is a major health concern globally and is the main reason for foodborne problems in the US and other parts of the world. The intestinal region of both cold and warm blooded animals acts as a reservoir for *Salmonella*. *Salmonella* has wide range of distribution because of its large number of reservoir hosts, shedding of pathogen in feces of carrier animals, and its persistence in the environment (Griffith et al. 2019).

4.1.2.3. TRANSMISSION

Other than the ingestion of contaminated food, the other less common transmission of this pathogen to humans can occur by direct contact with infected animal (either clinical or sub-clinical infection). In the United States, *Salmonella* infection in humans is often attained as a result of the ingestion of poorly cooked contaminated poultry, beef, and eggs as compared to the ingestion of pork or by direct exposure with pigs (Griffith et al. 2019).

4.1.2.4. SYMPTOMS

Salmonellosis is generally followed by a self-limiting gastroenteritis and exhibits clinical signs such as fever, diarrhea and abdominal pain. Mortality in this case is rare and incubation period ranges between 4-72 hours (Antunes et al. 2016).

4.1.2.5. DIAGNOSIS

Different diagnostic procedures for the identification of this pathogen include serological and molecular techniques. However, blood culture method is primarily used for diagnostic purpose, although it is slow and not that much sensitive (MacFadden et al. 2016).

4.1.2.6. TREATMENT

This infection can be treated with different drugs which include cephalosporins and fluoroquinolones (ciprofloxacin) (Antunes et al. 2016).

4.1.3. CRYPTOSPORIDIOSIS

Cryptosporidium species are popular parasites of wild vertebrates, domestic animals and humans. Cryptosporidiosis has been considered as a zoonotic infection for some time as *Cryptosporidium* species have wide range of hosts (Xiao and Feng 2008).

4.1.3.1. ETIOLOGY

Among *Cryptosporidium* spp., *Cryptosporidium parvum* seems to be a major zoonotic agent (Dorny et al. 2009).

4.1.3.2. EPIDEMIOLOGY

In US, the incidence rate of cryptosporidiosis is higher in mid-western states. The case-control studies demonstrated that contact with cattle was a risk factor for cryptosporidiosis in humans in the United Kingdom, United States, Australia and Ireland (Xiao and Feng 2008).

4.1.3.3. TRANSMISSION

The oocysts are transmitted through fecal-oral path. In humans, direct transmission occurs from human to human or from animals to humans. Indirect transmission can occur through consumption of contaminated food or water. The management and prevention is only possible through profound knowledge of the transmission routes (Ryan et al. 2016).

4.1.3.4. CLINICAL SIGNS

In humans, *Cryptosporidium* is a main reason for moderate to severe diarrhea worldwide. Its infection is associated with water and foodborne outbreaks and can be zoonotic. Cryptosporidiosis in humans is usually characterized by fever, vomiting, mal-absorption, abdominal cramps, and diarrhea which may be profuse and prolonged (Ryan et al. 2016).

4.1.3.5. DIAGNOSIS

The traditional method used to detect the presence of oocyst in feces is the examination through microscope. This can be done by wet mount and followed by staining with a specific dye (e.g. acid fast dye, fluorescence or immunofluorescence) to improve the sensitivity of detection. The oocytes stained with acid-fast stain are intermittently red having a size of about 4-6 um as well as containing crescent shaped sporozoites. Fecal culture techniques are carried out by sedimentation. Several immunological techniques have been evolved as an alternative ways for the identification and include direct fluorescent antibody, dipstick-like tests, ELISA and indirect ELISA (Pumipuntu and Piratae 2018).

4.1.3.6. TREATMENT

The most effective drug for the treatment of infected people include Nitazoxanide. Furthermore, it is the only anti-cryptosporidial drug approved by US Food and Drug Administration for the treatment of cryptosporidiosis in human beings (Pumipuntu and Piratae 2018).

4.1.4. AEROMONIASIS

Areomonas is a gram-negative bacterium in fish and its infection remains asymptomatic till weakness and environmental stress. *Aeromonas* specie is frequently present in freshwater fish (Ziarati et al. 2022).

4.1.4.1. ETIOLOGY

Fish are involved in the transmission of *Aeromonas* to humans. The species which are reported to have zoonotic potential involves *A. caviae*, *A. hydrophila*, *A. sorbia*, *A. veronii*, and *A. jandaei*. Among these, the most usual agent is *A. hydrophila* (Ziarati et al. 2022).

4.1.4.2. EPIDEMIOLOGY

Aeromonas hydrophila is commonly present in salt water, fresh water, sewage, fish tank, sludge, and water supplies. A study demonstrated that more than 50 per cent of samples of raw milk were contaminated with *Aeromonas hydrophila*. The amplification of organism may occur at the time of storage in refrigerated bulk tanks. Similarly, *A. hydrophila* has been isolated from meat, milk, poultry, fish and water. A number of workers of different countries have narrated the role of *A. hydrophila* in causing diarrhea especially in children of developing countries. The disease can occur in sporadic form and also in epidemic form. In China, *Aeromonas hydrophila* outbreak occurred during 1993. In this outbreak, 82 persons got affected, and this happened because the drinking water was contaminated with sewage. Similarly, again in China in 2012, a great foodborne outbreak involving *A. hydrophila* occurred which affected more than 200 college students (Pal 2018).

4.1.4.3. TRANSMISSION

Aeromoniasis is considered as a zoonotic disease and is caused by several species of *Aeromonas*. This infection can occur due to ingestion of contaminated water, fish and sea foods (Ahmed et al. 2018). *A.*

hydrophila has been isolated from vegetables, milk and dairy products, meat and meat products (Stratev and Odeyemi 2016).

4.1.4.4. SYMPTOMS

The clinical signs of infection involve edema to swelling at infection site. Moreover, the other symptoms in humans include gastroenteritis, respiratory infection, sepsis, bacteremia, diarrhea and urinary tract infections (Ziarati et al. 2022).

4.1.4.5. DIAGNOSIS

The diagnosis is based on the isolation of the causative agent i.e. *A. hydrophila* from clinical specimens particularly stool on microbial media (such as Pyan's medium, starch ampicillin agar and ampicillin dextrin agar). For the enrichment of the organism, it is suggested to use trypticase soy broth with ampicillin. Presently, molecular tools are available for the diagnosis of infection caused by *A. hydrophila*. For the isolation of this pathogen from the drinking water, membrane filtration technique has been used. Standard microbiological techniques should be employed to differentiate this bacterium from *Vibrio cholera*, *V. vulnificus*, and *Plesiomonas shigelloides* (Pal 2018).

4.1.4.6. TREATMENT

The persistent use of antibiotics to treat *Aeromonas* infection increases the level of antimicrobial drug resistance. Generally, *Aeromonas hydrophila* is resistant to β-lactam antibiotics. The strains of *Aeromonas* are sensitive to quinolones. Even though, rare resistance to these drugs has been reported (Stratev and Odeyemi 2016).

4.1.5. LISTERIOSIS (*LISTERIA MONOCYTOGENES* INFECTION)

L. monocytogenes causes invasive diseases in animals and humans, particularly Central Nervous System infection (Drevets and Bronze 2008).

4.1.5.1. ETIOLOGY

Listeria monocytogenes is considered a Gram positive bacterium and causes severe foodborne infection characterized by gastroenteritis, meningitis, and meningo-encepahlitis (Cossart and Toledo-Arana 2008).

4.1.5.2. EPIDEMIOLOGY

In 1980-1981, first proven foodborne outbreak appeared in Canada due to the consumption of contaminated coleslaw. In 2017 to 2018, 900 cases and 200 deaths were reported due to listeriosis outbreak in South Africa. Latest studies suggested that hospitalized patients are also susceptible of getting invasive listeriosis. Evidence from recent studies exhibited that sporadic cases of listeriosis are also foodborne (Schlech III 2019).

4.1.5.3. TRANSMISSION

Humans can get listeriosis by eating contaminated poultry meat/meat products, contact with infected birds or poultry and by means of fecal-oral route (Dhama et al. 2015).

4.1.5.4. SYMPTOMS

The implications associated with its infection include gastroenteritis, septicemia, and meningitis in immune-compromised people, elderly people and newborns/neonates having case fatality rate of 30 per cent to 40 per cent (Dhama et al. 2015).

4.1.5.5. DIAGNOSIS

Confirmatory diagnosis depends on the isolation and identification of the pathogen. Gram staining, biochemical test (such as catalase test), immunofluorescence test and DNA analysis are helpful in the identification of this bacterium. To make a confirmatory diagnosis of *Listeria* infection, combination of ELISA and PCR has been recommended to be used (Dhama et al. 2015).

4.1.5.6. TREATMENT

L. monocytogenes is susceptible to most β-lactam antibiotics except cephalosporins. The present treatment choice for all forms of *Listeria* infection is a combination of gentamicin and ampicillin. However, some studies also suggest that this therapy is harmful and not beneficial (Schlech III 2019).

4.1.6. *ESCHERICHIA COLI* INFECTION (*E. COLI* O157:H7)

Escherichia coli (*E. coli*) is a gram-negative, facultative anaerobic bacterium having rod like shape (Lim et al. 2010).

4.1.6.1. ETIOLOGY

E. coli O157:H7 is amongst the most threatening foodborne pathogens and causes abdominal pain, inflammation, diarrhea, hemorrhagic colitis, uremic syndrome and even death (Bai et al. 2022).

4.1.6.2. EPIDEMIOLOGY

In Europe, North America and other regions of the world, the infection caused by *E. coli* O157:H7 is considered as a chief public health concern. The total number of cases of this bacterium are less as compared to other enteric pathogens such as *Campylobacter* or *Salmonella* spp. Apart from this, the illness caused by *E. coli* O157:H7 indicated higher hospitalization and the fatality rates. The Centers for Disease Control and Prevention (CDC) has evaluated that, in the United States, the infections developed by this pathogen result in 73000 illnesses, 2200 hospitalizations and 60 deaths annually. The data about outbreak surveillance retrieved from CDC demonstrated that infections associated with this bacterium are declining after the peak in 1999. Despite that, substantial outbreaks and sporadic cases continue to arise (Lim et al. 2010).

4.1.6.3. TRANSMISSION

The zoonotic transmission of *E. coli* O157:H7 takes place after consumption of poorly cooked meat or improperly pasteurized dairy products or by contacting with contaminated fomites loaded with Shiga toxin entero-hemorrhagic *E. coli*. Other ways of transmission of Shiga toxin entero-hemorrhagic *E. coli* involves exposure to contaminated drinking water, lakes, swimming pools, contaminated food (such as undercooked meat, improperly washed fruits and leafy greens), unpasteurized drinks and direct exposure to contaminated animal (Ameer et al. 2023).

4.1.6.4. SYMPTOMS

E. coli O157:H7 is an entero-hemorrhagic bacterial strain and infects alimentary tract inducing the symptoms of abdominal cramp with hemorrhagic diarrhea. *E. coli* O157:H7 infection also results in Hemolytic uremic syndrome and hemorrhagic colitis (Ameer et al. 2023). Patients suffering from hemorrhagic diarrhea are susceptible to develop major complications (Gambushe et al. 2022).

4.1.6.5. DIAGNOSIS

The early laboratory evaluation involves a complete blood count (CBC) to check out leukocytosis, thrombocytopenia, and hemolysis. The evaluation of metabolic profile will be helpful to determine the dehydration status, electrolytes imbalance and uremia. Most of the patients affected with *E. coli* O157:H7 colitis will exhibit the white blood cells count above 10,000 per microL. Initial diagnosis can be performed by making a stool culture of diarrheal sample during the early days after onset. Confirmatory diagnosis involves the testing of stool for the presence of *E. coli* O157:H7 antigens or toxin genes with polymerase chain reaction (PCR). Enzyme-linked immunosorbent assays are available commercially to detect Shiga toxin in hemorrhagic stool sample (Ameer et al. 2023).

4.1.6.6. TREATMENT

The treatment of gastrointestinal infection associated with *E. coli* O157:H7 is based on supportive care and maintaining the hydration status of the patient. Most of the entero-hemorrhagic *E. coli* patients suffering from diarrhea recover without treatment within a period of ten days other than fluid replacement. The antibiotic treatment has not a favorable effect in the prevention of complications of *E. coli* O157:H7 (Ameer et al. 2023).

4.1.7. YERSINIOSIS

Y. enterocolitica is a bacterium having zoonotic potential and causes yersiniosis (Chlebicz and Śliżewska 2018).

4.1.7.1. ETIOLOGY

Y. enterocolitica is a gram negative and non-spore forming bacterium with rod shape (Chlebicz and Śliżewska 2018).

4.1.7.2. EPIDEMIOLOGY

Infections associated with *Yersinia* are generally sporadic. While outbreaks have also been documented. Pigs act as a reservoir for *Yersinia enterocolitica* strains. In the United States, pasteurized milk and contaminated tofu were detected as the vehicle for *Yersinia enterocolitica* in outbreaks. YE comprise strains of varying pathogenicity: YE biotypes 1B and 2-5 are known as pathogenic, while biotype 1A generally thought to be non-virulent (Huovinen et al. 2010).

4.1.7.3. TRANSMISSION

Mainly, the infection is transferred by means of fecal-oral route. Consumption of pork, particularly, poorly cooked or raw pork products are causes for yersiniosis. In New Zealand and Norway, outbreaks have been reported due to the consumption of water contaminated with this bacterium. Cases of this infection have also been reported in which the infection is being transferred from an infected household pet and by means of transfused blood products (Aziz and Yelamanchili 2018).

4.1.7.4. SYMPTOMS

Most commonly, YE infection is manifested in the form gastroenteritis which is self-limiting (Huovinen et al. 2010). Major clinical signs include acute diarrhea, terminal ileitis, mesenteric adenitis, and pseudo-appendicitis. It can rarely cause sepsis (Aziz and Yelamanchili 2018).

4.1.7.5. DIAGNOSIS

Generally, cultural methods are used to isolate and detect this bacterium from food. The introduction of molecular and serological methods has refined the detection of *Y. enterocolitica* in food. These methods include ELISA, colony hybridization, IMS, PCR, microarray and LAMP methods (Gupta et al. 2015).

4.1.7.6. TREATMENT

The treatment of yersiniosis is to provide supportive care with nutritional support and hydration. The drug of choice for its treatment include trimethoprim-sulfamethoxazole or aminoglycosides. Additional effective drugs include quinolones, cephalosporins and tetracycline (not in children) (Aziz and Yelamanchili 2018). Table 1 highlights some zoonotic diseases, their pathogens and symptoms.

5. ONE HEALTH

The One Health which functions at global, regional, national and local levels is an interdisciplinary, collaborative and multi-sectoral approach. Its objective is to ensure optimal health by recognizing the connections among environment, humans, animals, and plants. This unifying and integrated approach can alleviate and prevent threats to health at the interface of the environment, humans, animals and plants. The One Health approach encourages several sectors, disciplines and communities at different levels to work together to fight against ecosystem and health threats. Its aim is to address the collective need for clean water, safe and nutritious food, energy and air, taking action on climatic change and thus contributing to sustainable development. In terms of legislation and policy, the One Health approach can be enforced to implement programs, policies and legislation through communication across several sectors working together to achieve better health (Erkyihun and Alemayehu 2022).

5.1. THE IMPORTANCE OF THE ONE HEALTH APPROACH

The One Health approach is used to carry out joint surveillance of disease, control and prevent outbreaks of zoonotic diseases, improve food safety and security, and lessen antimicrobial resistant infections to make better human and animal health. The One Health promotes strong collaboration among various sectors. The One Health approach provides strength to the disease surveillance system, diagnostic laboratory systems, and the network for early response and detection of zoonotic infections.

Table 1: Some zoonotic diseases, their pathogens, hosts and major symptoms in humans (Rahman et al. 2020)

Zoonotic Diseases	Pathogen	Hosts	Symptoms in Humans
Viral			
Ebola Hemorrhagic Fever	Ebola virus	Monkeys, apes, and gorillas	Fever, weakness, headache, muscle ache, diarrhea, vomiting, sore throat, and hemorrhage
Marburg Viral Hemorrhagic Fever	Marburg virus	Monkeys and Fruit bats	Watery diarrhea, muscle ache, hemorrhage, pain in abdomen, fever and non-itchy rash
Bacterial			
Campylobacter enteritis	*C. jejuni, C. coli*	Chicken, turkeys, cats, dogs, cattle, sheep and pigs	Enteric disorder
Campylobacter fetus infection	*C. fetus* subsp. *fetus*, *C. fetus* subsp. *testudinum*	Sheep, goats and cattle	Enteric disorder
Enterohemorrhagic *Escherichia coli* infections	*E. coli* O157:H7	Sheep, dogs, poultry, cattle, pigs	Hemolytic uremic syndrome (HUS) and enteritis
Salmonellosis	*S. bongor, S. enterica*	Birds, dogs and domestic animals	Enteritis
Vibriosis	*V. parahaemolyticus*	Farm animals	Enteritis
Parasitic			
Trichinellosis	*Trchinella* spp.	Cats, dogs, rats, pigs and other wild species	Gastrointestinal disease, pain in abdomen, nausea, vomiting, and diarrhea
Cryptosporidiosis	*Cryptosporidium parvum*	Sheep, goats, horses, deer, cattle, and pigs	Pain in abdomen, diarrhea, nausea, slight fever and malaise
Visceral larva migrans	*Baylisascaris procyonis*, *Toxocara canis*, *Toxocara cati*, and *Ascaris suum*	Cats, prairie dogs, rabbits, birds, and woodrats etc.	Gastrointestinal, abdominal pain, coughing, fever and shortness of breath

This approach works to improve the zoonotic disease prevention and control and ensures effectual and coordinated public health emergency preparedness, in which all strategies contribute to the effective reduction of zoonotic infections. Generally, the One Health approach strongly supports international health security by its efficacious multi-sectoral collaboration, coordination and information communication at the interface between relevant sectors by addressing common health threats, such as zoonoses, antimicrobial resistance, food safety and security issues (Erkyihun and Alemayehu 2022).

5.2. THE ROLE OF ONE HEALTH IN THE CONTROL OF ZOONOTIC DISEASES

Zoonotic infections are of great concern globally and there are more risks for developing countries. Brucellosis and rabies are common zoonotic illnesses and cause annual human deaths (Kheirallah et al. 2021). The One Health approach has an important role to prevent and control zoonotic diseases. The World Health Organization (WHO) has observed that about 75 % of the new emerging human infectious diseases are considered zoonotic (it means that they may be transmitted from vertebrate animals to human by natural means). During the last three decades, new and re-emerging zoonotic diseases have been evolved partly because of our close connection with companion animals, along with our growing dependence on animals including their products. The One Health approach engaging surveillance of disease, management, and eradication by the collaboration between veterinarians (dealing with livestock and wild animal populations) ecologists (examining ecosystem biodiversity) and public health experts, may have yielded a more rapid resolution to the outbreak. The application of the One Health approach has been acknowledged as an important need by international organizations. It is also a preferred approach for addressing global health issues (Bidaisee and Macpherson 2014).

6. CONCLUSION

Different pathogens can be transmitted from animals to humans. Most of these pathogens are acquired by the consumption of contaminated food and cause severe gastrointestinal illnesses in humans. These pathogens also affect the health of animals and can also cause mortality in some cases. It is the need of the hour to adopt necessary precautions to prevent and manage these zoonotic gastrointestinal diseases. The One Health approach plays an important role in this regard and aids in the prevention and control of zoonotic diseases.

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Strategies of Prophylactic and Metaphylactic Approaches for the Control of Zoonotic Diseases

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ABSTRACT

In this chapter, we explore the far-reaching impacts of zoonotic diseases on human health, shedding light on their historical importance and the profound effects they exert on societies. The section emphasizes the s requirement for decisive interventions to prevent and manage the transmission of these diseases. We navigate the intricate interplay linking zoonotic diseases to the rapid dissemination of diseases, with specific reference to the current global impact of the ongoing COVID-19 pandemic. Within this framework, the chapter underscores the pivotal role of prophylactic and metaphylactic approaches in directly addressing these diseases. These approaches encompass strategies such as One Health surveillance, vaccination, and antimicrobial stewardship. Importantly, the chapter reveals the significance of advancements in rapid diagnostics and genomic surveillance. These breakthroughs are deemed essential for tailoring metaphylactic interventions and implementing comprehensive containment strategies. The integrated One Health approach assumes a central position, urging collaboration among experts from diverse disciplines dedicated to human, animal, and environmental health. The narrative highlights the crucial role of public awareness, risk communication, and international collaboration in the collective endeavor to combat zoonotic diseases.

Shifting the focus to prophylactic and metaphylactic strategies, the chapter provides an extensive overview. Vaccination emerges as a pivotal element in disease prevention, complemented by strategies such as antimicrobial prophylaxis, vector control, sanitation enhancements, biosafety, biosecurity measures, and early detection through surveillance and monitoring. Health education and public awareness initiatives take precedence, alongside targeted antimicrobial utilization and strategies for the management of wildlife and rodent populations, all contributing to the mitigation of the spread of zoonotic diseases. In conclusion, the chapter emphasizes the interconnected significance of zoonotic disease control. It advocates for evidence-based decision-making, risk-based approaches, and a collaborative front across diverse disciplines and sectors. The chapter underscores the imperative for strategic, proactive measures to eliminate these global health threats, providing a compelling directive in response to the ongoing challenges posed by zoonotic diseases.

Key words: One health surveillance, Biosafety and biosecurity measures, Interdisciplinary collaboration, Metaphylactic interventions, Prophylactic approach

CITATION

Saleem MI, Zaka F, Butt AA, Mahfooz A, Ijaz M, Shah SK, Kaleem QM, Saleem MW, Shakir AH, Raza A, and Khan MU, 2023. Strategies of Prophylactic and Metaphylactic Approaches for the Control of Zoonotic Diseases. In: Khan A, Abbas RZ, Hassan MF, Aguilar-Marcelino L, Saeed NM and Mohsin M (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 578-593. https://doi.org/10.47278/book.zoon/2023.043

CHAPTER HISTORY | Received: 26-Feb-2023 | Revised: 12-March-2023 | Accepted: 01-June-2023

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1. INTRODUCTION

Zoonotic diseases, which are contagious diseases that propagate from animals to humans, continue to be an evolving and emerging worldwide health issue (Jones et al. 2008). The most significant example of these zoonotic diseases that have emerged in recent years is COVID-19 (Calderon et al. 2023), which has gained extraordinary attention. As the ongoing epidemic has demonstrated, zoonotic diseases may have disastrous effects on societies, economies, and public health systems (Jones et al. 2008). As a result, there is a pressing need for an increased emphasis on developing measures that can effectively control and prevent the transmission of zoonotic diseases.

It is not a recent phenomenon that zoonotic diseases have such a significant influence on human health. Zoonotic outbreaks had a profound impact on the development of human civilization throughout history and had catastrophic impacts on populations all over the world. The *Yersinia pestis* bacterium, which caused the bubonic plague and was spread by rodent fleas, caused millions of deaths throughout the era of the Middle Ages (Barbieri et al. 2021). Similarly, an H1N1 virus with avian origins that caused the 1918 influenza pandemic is thought to have killed 50 million people globally.

The current COVID-19 pandemic caused by the novel coronavirus SARS-CoV-2 has brought attention to the connection between the human-animal interface and the rapidity with which zoonotic illnesses may spread globally (Gorbalenya et al. 2020). COVID-19, which is thought to have originated from bats and may have spread via an intermediary animal host, has caused social unrest, overloaded healthcare systems, and had substantial socioeconomic consequences (Cascella et al. 2020).

As a result, the scientific community and policy-makers worldwide are more committed than ever to implementing comprehensive and innovative measures to combat zoonotic diseases effectively.

This chapter explores the most recent scientific findings and developments in prophylactic and metaphylactic approaches, which are essential in combating zoonotic diseases. In order to control epidemics, prophylactic methods such as One Health surveillance and vaccination that attempt to prevent the early transfer of zoonotic pathogens from animals to humans. Metaphylactic approaches that involve controlling zoonotic disease outbreaks within animal populations are essential to prevent further transmission and lessen the likelihood of the emergence of novel infectious agents.

Additionally, Antimicrobial stewardship has gained traction among health professionals in recent years (Nassar et al. 2022) since misuse and overuse of antimicrobials are contributing to antimicrobial resistance, thereby complicating disease management (Okocha et al. 2018). Our capacity to swiftly detect and monitor zoonotic diseases has been revolutionized by advances in fast diagnostics and genomic surveillance, enabling tailored metaphylactic interventions and containment approaches.

In order to develop holistic and sustainable disease control strategies, it is essential to embrace an integrated One Health approach, which brings together specialists from diverse disciplines to address the interconnectivity of human, animal, and environmental health (Bonilla-Aldana et al. 2020). Public

awareness and risk communication are also vital components in order to increase awareness among the public, develop cooperation, and mitigate fear during epidemics.
Zoonotic diseases continue to pose a threat to world health. With the aim of effectively combat these threats, it is crucial to stay up-to-date with technological advancements and the most recent scientific knowledge. We can actively combat zoonotic diseases and protect the health and well-being of present and future generations by synthesizing this knowledge and encouraging international collaboration (Shanko et al. 2015). Multifaceted approaches that rely on preventive and metaphylactic approaches to prevent and manage the zoonotic disease in a constantly changing world are covered in the sections that follow.

2. ONE HEALTH APPROACH: THE ANALOGY OF HUMAN, ANIMAL, AND ENVIRONMENTAL HEALTH

The one health approach, which is universal and interdisciplinary, acknowledges the connection between the health of people, animals, and the environment (Bonilla-Aldana et al. 2020). The control of zoonotic diseases requires cooperation across the fields of human and veterinary medicine, public health, environmental science, and wildlife biology.

2.1. COLLABORATIVE NATURE OF ONE HEALTH

One Health recognizes that none of the business or profession can effectively handle complex health concerns like zoonotic diseases by acting alone. As a consequence, it encourages collaboration and coordination among a variety of disciplines, including environmental science, veterinary and human medicine, epidemiology, wildlife biology, and public health (Ghai et al. 2022). To offer comprehensive zoonotic disease management, each profession provides distinctive perspectives, skills, and knowledge.

2.2. UNDERSTANDING ZOONOTIC PATHWAYS

One Health promotes a thorough understanding of zoonotic pathways, including the discovery of reservoir hosts, intermediate hosts, and disease-transmission vectors (Osterhaus et al. 2020). Such information is necessary for creating focused measures for controlling and halting the transmission of zoonotic diseases. For instance, researchers may find high-risk transmission locations and take precautions by researching the connections between animals, livestock, and humans.

2.3. IMPROVED PUBLIC HEALTH OUTCOMES

It is possible to get better public health results through the implementation of the One Health strategy for zoonotic disease management. Public health systems become more robust and better prepared to defend human populations from zoonotic risks by identifying the possible sources of zoonotic transmission, reducing spillover occurrences, and improving early diagnosis and response capabilities (Everard, et al. 2020).

2.4. COLLABORATIVE RESEARCH AND DATA SHARING

The One Health strategy places a strong emphasis on the need for teamwork in research and knowledge sharing in order to effectively combat zoonotic diseases (Hailat et al. 2023). Experts may develop a thorough grasp of the ecological and epidemiological variables influencing the development of zoonotic diseases by collaborating across disciplines and sectors. In order to reduce the danger of zoonotic epidemics, evidence-based measures and regulations are informed by the aforementioned knowledge.

2.5. GLOBAL IMPORTANCE

Zoonotic diseases transcend state boundaries, making the One Health philosophy a worldwide need. International cooperation and coordination are necessary for effective zoonotic disease management in order to jointly address global health concerns (Berthe et al. 2018). International cooperation is crucial to identifying, restricting, and mitigating zoonotic disease outbreaks before they turn into pandemics.

The One Health strategy emphasizes the interconnection of human, animal, and environmental health in the context of zoonotic illnesses as a crucial model for averting the next pandemic. Effective zoonotic disease management requires cooperation across the fields of environmental science, veterinary and human medicine, wildlife biology, and public health. The One Health strategy may result in better public health outcomes and a safer, healthier environment for everyone by comprehending zoonotic pathways, sharing data, and putting evidence-based treatments into practice.

3. PREVENTING THE NEXT PANDEMIC: THE INTERCONNECTED SIGNIFICANCE OF ZOONOTIC DISEASE CONTROL

Recent scientific knowledge supports the critical urgency of halting zoonotic diseases. Zoonotic diseases are widely acknowledged to be a serious public health issue. There is potential for the transmission of infections between species due to the interactions between humans, animals, and the environment. The most devastating example of the devastation that such epidemics may bring is the COVID-19 pandemic, which was brought on by the zoonotic SARS-CoV-2 virus. (Andersen et al. 2020). Epidemics of zoonotic diseases might have catastrophic consequences for the well-being of animals and humans, the productivity of agriculture, and the sustainability of the economy (Asrar et al. 2021). Effective control techniques must be implemented in order to lessen the social burden of these diseases.

Numerous variables, such as globalization, an upsurge in human intrusions on ecosystems that are natural, geographic shifts, and climate change, have had an impact on the emergence and transmission of zoonotic diseases. To avoid such disasters, it is crucial to comprehend the root causes of zoonotic spillovers, such as degradation of the habitat, interactions between humans and animals, and wildlife trade (Hailat et al. 2023). The key to reduce the transmission of zoonotic diseases is to take preventive measures, including strengthening surveillance systems to spot emerging viruses, promoting responsible wildlife management, and advocating One Health initiatives, which integrate human, animal, and environmental health. In addition, to maintain efficient treatments for zoonotic diseases, measures to minimize antibiotic resistance must also be given top priority. We can safeguard public health, protect economies, and conserve biodiversity for a healthier and more resilient future by realizing the gravity of zoonotic diseases and implementing evidence-based preventive measures (Fig. 1).

4. PROPHYLACTIC APPROACHES

Prophylactic approaches, featuring a diverse range of scientifically based interventions, play a crucial role in public health and in mitigating the impact and spread of zoonotic diseases. These proactive measures aim to interrupt the chain of transmission and lessen the likelihood of disease spread (WHO 2003). Prophylactic strategies protect individuals and communities from potential pathogens and reduce the burden of disease. The following are some essential prophylactic measures:

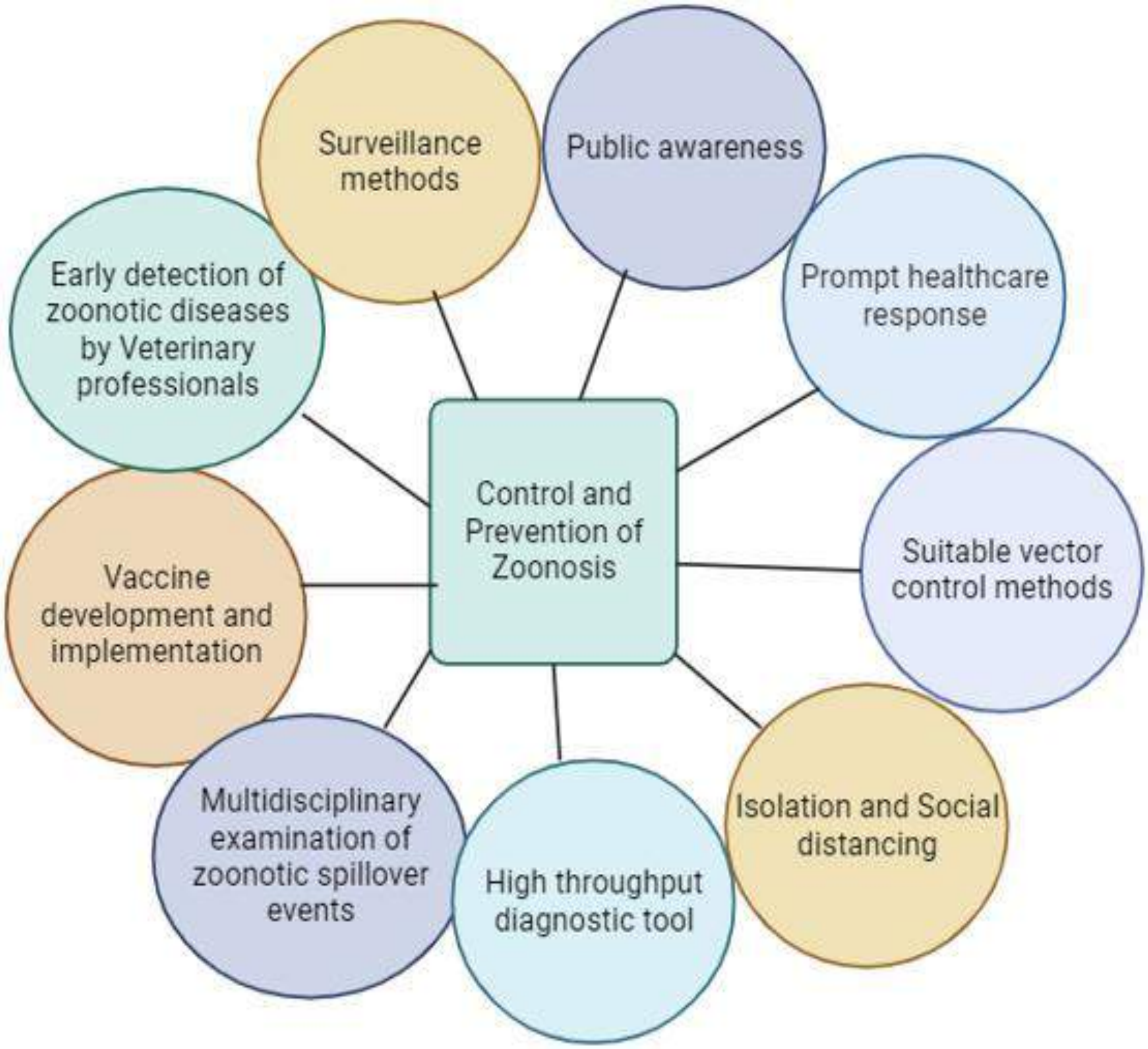

Fig. 1: Control and Prevention measures for zoonotic diseases (Created with BioRender.com).

4.1. VACCINATION

Vaccination is the cornerstone of prophylactic approaches to prevent the transmission of zoonotic diseases (Heaton 2020). Vaccines are one of the best prophylactic approaches at our disposal. Veterinarians prevent the spread of zoonotic diseases by immunizing animals against zoonotic infections, which not only safeguards the health of the animals but also reduces the danger of transmission to humans. Vaccines promote protection without causing sickness by inducing the immune system to produce antibodies against specific infections. Innovative vaccinations, like the mRNA vaccines utilized to combat COVID-19, have been created as a result of recent advancements in vaccine technology (Alshrari et al. 2022). Vaccination campaigns against zoonosis, including avian influenza, brucellosis, and rabies, have been effective in halting disease outbreaks and lowering disease burden (Blanton et al. 2007). For proactive disease prevention, continued research and vaccine development on emerging zoonosis are crucial.

4.1.1. ONE HEALTH APPROACH TO VACCINATION

The One Health paradigm acknowledges the interdependence of health in terms of humans, animals, and the environment (Bonilla-Aldana et al. 2020). Veterinarians work with medical experts to identify zoonotic hazards, develop potent vaccines, and execute immunization programs for humans as well as animals.

4.1.2 EMERGING AND RE-EMERGING ZOONOTIC INFECTIONS

The emergence and re-emergence of zoonotic infection pose ongoing challenges (Rahman et al. 2020). Veterinarians continuously monitor and adapt vaccination strategies to address new zoonotic threats effectively.

4.1.3 NOVEL VACCINES TECHNOLOGIES

Novel vaccine technologies have brought significant advancements to zoonosis prevention, allowing veterinarians to develop more effective and accessible vaccines. These innovative approaches have revolutionized the field of veterinary medicine, contributing to the control and eradication of zoonotic diseases (Francis 2022). Some of the key novel vaccine technologies that veterinarians are exploring include vector-based vaccines, DNA vaccines, and subunit vaccines.

4.1.3.1. VECTOR BASED VACCINES

Vector-based vaccines utilize harmless viruses or bacteria, known as vectors, to deliver specific antigens from the target pathogen into the animal's body. These antigens stimulate the immune system, enabling it to recognize and defend against the actual pathogen when it comes into contact in the future (Ura et al. 2014). The modified adenovirus (Ndwandwe and Wiysonge 2021), which carries the genes encoding the antigens of the zoonotic pathogen, is an often-used vector for veterinary vaccinations. With this method, numerous antigens may be delivered effectively, boosting the vaccine's potency. For instance, in order to produce the viral glycoproteins and stimulate strong immune responses in animals, researchers have employed a chimpanzee adenovirus vector to construct a vaccine against the Rift Valley Fever virus (Warimwe et al. 2016).

4.1.3.2. SUBUNIT VACCINES

Only certain pathogen components (subunits), such as polysaccharides or proteins, which are required to elicit an immune response, are included in subunit vaccines (Bill 2015). These subunits are specifically chosen to reflect the pathogen's most immunogenic and preventive components. Since subunit vaccinations don't include live or attenuated pathogens, they have better safety profiles. They may also be more precisely tuned to trigger certain immunological responses (Zhang et al. 2014). For instance, researchers have employed certain subunit proteins to induce immunity against the pathogen without actually producing disease in order to produce a vaccine against *Brucella melitensis*, the cause of brucellosis in humans as well as animals.

4.1.3.3. DNA VACCINES

Another cutting-edge tool for preventing zoonosis is DNA vaccination. In this method, the vaccine comprises genetic material (DNA) that encodes certain pathogen-specific antigens. The DNA is ingested by the cells of the recipient after administration, and the body then produces the antigens. These antigens subsequently cause an immunological response, leading to the development of protective immunity. DNA vaccines provide a number of benefits, such as easy synthesis and the capacity to stimulate both humoral and cellular immune mechanisms (Shafaati et al. 2023). With encouraging outcomes in animal models, veterinarians have started investigating DNA vaccines for several zoonotic diseases, such as avian influenza and West Nile virus.

Novel vaccine technologies have significantly enhanced zoonosis prevention efforts. Vector-based vaccines, DNA vaccines, and subunit vaccines offer innovative and potent approaches to improving vaccine efficacy and accessibility.

4.2. ANTIMICROBIAL PROPHYLAXIS

Antibiotic prophylaxis entails the proactive administration of antibiotics or other antimicrobial substances to people who have been exposed to certain pathogens in order to reduce their risk of contracting zoonotic diseases. The most recent research highlights the necessity for judicious antimicrobial use:

4.2.1. EVIDENCE-BASED DECISION MAKING

Evidence-based antimicrobial prophylaxis should take into consideration regional epidemiology and antibiotic resistance dynamics.

4.2.2. TARGETED USE

Targeted antimicrobial prophylaxis is given to those individuals who are susceptible to a particular zoonotic pathogen.

4.2.3. DURATION AND DOSAGES

Antimicrobial effectiveness is improved, and the risk of resistance development is reduced by choosing the right doses and treatment durations.

4.2.4. SURVEILLANCE AND MONITORING

Carrying out resistance surveillance and monitoring the effectiveness of antibiotic prophylaxis affects future treatment decisions.

4.3. PRE-EXPOSURE PROPHYLAXIS (PREP)

PrEP entails administration of drugs to people who are at high risk of acquiring a specific infectious disease before they are exposed to the pathogen (Grant et al. 2014). This strategy is especially important for avoiding some viral infections, including HIV, and certain zoonotic diseases in those who have a higher chance of direct exposure (Grant et al. 2014). The most recent research supports the use of PrEP in particular circumstances especially PrEP's preventive effect is maximized when it is targeted at people with a higher likelihood of exposure. It may be advised for several zoonotic diseases when there are effective medications and a high risk of exposure. Moreover, its efficacy depends on adequate adherence to the prescribed PrEP regimens and continuous follow-up care.

4.1. VECTOR CONTROL

Controlling vectors is an important prophylactic approach to lessening the spread of zoonotic diseases transmitted by insects and other vectors. The most recent research supports a multi-faceted, integrative approach to vector control. Important components include:

4.1.1. SURVEILLANCE AND MONITORING

Regular monitoring of vector populations aids in the identification of potential outbreaks and areas with a high risk of transmission. By using cutting-edge technology like geographic information systems (GIS) and remote sensing, surveillance activities can be more accurate and effective.

4.1.2. INSECTICIDE USE

Vector populations can be greatly reduced with targeted pesticide usage in accordance with evidence-based recommendations. Insecticides that are ecologically friendly and selective help reduce the impact on non-target species.

4.1.3. HABITAT MODIFICATION

Changes in the environment, such as removing mosquito breeding grounds, can interrupt the life cycles of vectors and lessen the transmission of disease.

4.1.4. BIOLOGICAL CONTROL

An environmentally benign and sustainable way to manage vector populations is by introducing natural predators or pathogens.

4.2. ENVIRONMENTAL HEALTH MEASURES

Promoting hygiene, improving sanitation, and guaranteeing access to clean water are the main objectives of prophylactic environmental health strategies. Insect breeding sites and proper waste management are important environmental controls that can help prevent the transmission of vector- and water-borne diseases (Batterman et al. 2009). Important components include:

4.2.1. SANITATION IMPROVEMENTS

The risk of contamination is reduced, and the transmission of disease is decreased, with proper waste management and sewage treatment.

4.2.2. SAFE WATER SUPPLY

Water-borne zoonotic infections can be prevented by having access to clean, safe water.

4.2.3. FOOD SAFETY PRACTICES

The risk of foodborne zoonosis is lower when appropriate food handling, preparation, and storage are encouraged.

4.2.4. VECTOR CONTROL

Reduced disease transmission and improved environmental health are two benefits of implementing vector control strategies, such as eliminating mosquito breeding sites.

4.2.5. ZOONOTIC WASTE MANAGEMENT

Environmental contamination is reduced in agricultural areas by properly disposing of excrement from animals.

4.3. BIOSAFETY AND BIOSECURITY

In order to prevent the introduction and spread of infectious agents in different environments, such as labs, animal facilities, and healthcare institutions, it is crucial to implement biosafety and biosecurity measures. Strict pathogen handling standards, PPE usage, and decontamination processes are essential prophylactic measures to safeguard both personnel and the general public (Denis-Robichaud et al. 2020). Important elements of this strategy include:

4.3.1. STANDARD OPERATING PROCEDURES (SOPS)

To protect the health of people and animals, Standard Operating Procedures (SOPs) for zoonotic disease prevention must be implemented. These thorough directions include risk evaluations, hygienic standards, quarantine procedures, animal health surveillance, immunization programs, and safe handling techniques. The establishment and execution of SOPs ensures that personnel follow safe handling practices for infectious materials. SOPs aid in preventing the spread of diseases by putting a strong emphasis on infection control, waste management, and monitoring. It also promotes the One Health cooperation between veterinary, medical, and environmental health specialists. Their efficacy and adaptation to changing zoonotic risks are ensured by regular evaluation and personnel training. We strengthen our defenses against zoonotic diseases by proactively adopting SOPs in farms, wildlife reserves, labs, and healthcare institutions. This reduces the likelihood of outbreaks and improves the security of world health.

4.3.2. PERSONAL PROTECTIVE EQUIPMENT (PPE)

By providing personnel with proper PPE, zoonotic pathogen exposure can be reduced (Macpherson 2005).

4.3.3. RISK ASSESSMENT

By identifying possible vulnerabilities and threats, risk assessments enable the development of focused mitigation approaches.

4.3.4. CONTAINMENT FACILITIES

Zoonotic diseases can be handled safely by employing appropriate containment measures, such as high-containment facilities and biosafety cabinets.

4.4. HEALTH EDUCATION AND PUBLIC AWARENESS

Prophylactic approaches might entail health education and public awareness initiatives that educate communities about infectious diseases, their modes of transmission, and preventive measures. Raising awareness stimulates quick medical attention-seeking, promotes responsible behavior, and enhances disease detection. Campaigns for public awareness and health education are essential in the battle against zoonotic diseases. These initiatives empower individuals and communities to take proactive actions by disseminating accurate and up-to-date knowledge regarding zoonotic hazards, transmission pathways, and preventive measures. According to the most recent research, effective communication is crucial for increasing understanding and adherence to preventive measures. Important elements of this strategy include:

4.4.1. ZOONOTIC DISEASE EDUCATION

It is crucial to educate the public about zoonotic diseases, their causes, and any potential concerns related to interactions between humans and animals. Raising awareness of particular zoonotic diseases like COVID-19, rabies, and avian influenza belongs to this category.

4.4.2. HYGIENE PROMOTION

The risk of disease transmission can be reduced by emphasizing proper handwashing, protocols for food safety, and hygiene precautions when handling animals. This involves educating pet owners, animal handlers, and farmers about the best practices (Denis-Robichaud et al. 2020).

4.4.3. RESPONSIBLE PET OWNERSHIP

Promoting appropriate pet ownership aids in lowering the probability of diseases caused by pets. It is crucial to promote vaccinations, routine veterinary checkups, and proper pet waste disposal (Shanko et al. 2015).

4.4.4. BEHAVIORAL CHANGE

Public awareness initiatives that encourage behavior modification can result in safer interactions with wildlife by encouraging people to avoid direct contact and abstain from feeding wild animals.

4.4.5. ONE HEALTH APPROACH

The interconnections between human, animal, and environmental health are emphasized in order to promote a coordinated strategy for zoonotic disease prevention (Bonilla-Aldana et al. 2020).

5. METAPHYLACTIC APPROACHES

In veterinary medicine, metaphylactic approaches are focused interventions intended to reduce the incidence and severity of zoonotic diseases in animal populations (Lees and Aliabadi 2002). These approaches concentrate on preventing disease progression and subsequent transmission in populations of animals that are susceptible to diseases. Here are a few prominent categories of metaphylactic strategies:

5.1 SURVEILLANCE AND EARLY DETECTION

The metaphylactic strategies of surveillance and early detection are essential to halting the transmission and detrimental effects of zoonotic diseases. This metaphylactic strategy uses ongoing diagnostic tests, rapid response procedures, and continual animal health monitoring (McNabb et al. 2004). The detection of novel zoonotic infections and unique disease patterns is made possible by utilizing real-time data collection and analysis using cutting-edge technologies like syndromic surveillance and genomic sequencing. Surveillance systems that incorporate information from cross-species species such as humans, livestock, and wildlife improve early warning systems for the occurrence of zoonotic spillover. Quick implementation of control measures, like quarantine, mobility restrictions, and targeted antibiotic use, is made possible by timely diagnosis, which reduces disease spread and the risk of zoonotic transmission. Building effective surveillance networks, improving readiness for zoonotic epidemics, and managing possible health concerns all require collaboration between veterinary and public health authorities. The most recent knowledge and improvements in early detection and monitoring have greatly enhanced disease preparedness and response (Lees and Aliabadi 2002).

5.1.1. ONE-HEALTH SURVEILLANCE

One Health Surveillance is a comprehensive strategy that evaluates the interdependence of human, animal, and environmental health. Environmental scientists, wildlife specialists, and veterinary and public health organizations work closely with one another in this collaborative strategy (Binot et al. 2015). Authorities may more effectively study zoonotic disease dynamics and identify and address potential threats by collaborating and sharing data and knowledge across disciplines.

5.1.2 SYNDROMIC SURVEILLANCE

Monitoring particular symptoms or clinical patterns in humans and animals that may be early indicators of disease outbreaks is known as syndromic surveillance (Henning 2004). For instance, keeping an eye out for clusters of flu-like symptoms in both humans and animals might give a heads-up on possible zoonotic transmission.

5.1.3 SENTINEL SURVEILLANCE

A sentinel surveillance program monitors certain animal populations or geographic areas that are known to be at high risk for zoonotic diseases (Colman et al. 2019). Authorities may swiftly identify epidemics and take action before they spread to larger populations by concentrating surveillance efforts at these sentinel sites.

5.1.4 GENOMIC SURVEILLANCE

Genomic surveillance makes use of cutting-edge sequencing technologies to identify and monitor zoonotic diseases genetically (WHO 2023). This makes it possible to implement more focused control measures by better understanding the origin, modes of transmission, and development of zoonotic pathogens.

5.1.5 ENVIRONMENTAL SURVEILLANCE

In environmental surveillance, zoonotic pathogens are monitored in the environment, such as water sources and wildlife habitats. This strategy can promote early intervention by assisting in the identification of possible sources of zoonotic spillover.

5.1.6 DIGITAL SURVEILLANCE AND BIG DATA

Disease monitoring has evolved dramatically as a result of the use of digital tools and big data analytics. Large datasets may be collected, analyzed, and visualized in real-time by automated systems, allowing for the quick identification of anomalous patterns or disease clusters (Andrejevic and Gates 2014).

5.1.7 INTERNATIONAL COLLABORATION

The fact that zoonotic diseases know no boarders draws attention to the importance of global collaboration in surveillance and early identification. The security of global health is increased, and coordinated responses to potential pandemics are made possible through timely information exchange across countries and regions (Rabaa et al. 2015).

5.1.8 PUBLIC HEALTH REPORTING AND COLLABORATION

In order to report atypical disease occurrences and potential zoonotic cases, the active involvement of both the public and healthcare professionals is crucial (Rabaa et al., 2015). Systems for public health reporting that encourage early zoonotic disease diagnosis improve systematic disease monitoring.

Authorities are able to swiftly diagnose and address zoonotic concerns by combining these sophisticated surveillance and early detection techniques. To prevent future transmission and mitigate the impact of zoonotic diseases, proactive measures such as targeted antibiotic use, quarantine, and mobility limitations can be implemented. In addition to saving lives, early detection reduces the financial cost of epidemics and supports the One Health concept, which emphasizes the interdependence of human, animal, and environmental health.

5.2 TARGETED ANTIMICROBIAL USE

The metaphylactic administration of antimicrobial drugs to particular animal populations at risk of zoonotic infections is known as targeted antimicrobial use. Prophylactic antimicrobial treatment may be employed in cases where disease outbreaks have been detected or are suspected in order to prevent further transmission and reduce the burden of the disease. However, to prevent the emergence of antimicrobial resistance, which might make it more difficult to treat zoonotic diseases in humans as well as animals, it is crucial to use antimicrobials judiciously (Lees and Aliabadi 2002).

Targeted antimicrobial use as a metaphylactic approach plays a significant role in reducing the risk of zoonotic disease transmission and preserving the effectiveness of antimicrobials. To guarantee its effectiveness and prevent any adverse consequences, targeted antimicrobial use should adhere to evidence-based recommendations and be carried out under the supervision of veterinary specialists.

5.3 CULLING AND DEPOPULATION

Depopulation and culling are radical metaphylactic measures employed in situations of emergency to manage zoonotic disease outbreaks. When zoonotic diseases have high rates of mortality and morbidity and containment is difficult, afflicted animals may be targeted for depopulation or targeted culling (Thornber et al. 2014). This strategy seeks to get rid of potential infection sources, disrupt disease propagation chains, and prevent more zoonotic spillover. The use of culling and depopulation techniques, however, should adhere to moral standards and be coordinated with animal welfare concerns. When other control measures are ineffective or impractical, they are typically implemented as a last resort.

5.4 QUARANTINE AND MOVEMENT RESTRICTIONS

During disease outbreaks or in high-risk scenarios, quarantine and movement limitations are crucial metaphylactic measures. Strict quarantine measures isolate potentially infected animals and prevent the spread of disease to unaffected populations. Similar to mobility limitations, zoonotic epidemics are prevented from spreading to other locations by limiting the movement of animals from such places (Lei and Qiu 2020). To stop the rapid spread of zoonotic pathogens, quarantine and mobility controls are especially important in intensive farming systems and animal trading. Animal health authorities can swiftly implement these measures in order to prevent disease outbreaks and safeguard both human and animal populations from the transmission of zoonotic diseases.

5.5 RODENT CONTROL

A crucial metaphylactic approach is rodent control, which aims to prevent the spread of zoonotic diseases from rodents like rats and mice to humans as well as other animals. Rodents are important zoonotic disease vectors because they act as reservoirs for a variety of pathogens, including viruses, parasites, and bacteria (Meerburg et al. 2009). In order to decrease the danger of zoonotic spillover, protect public health, and reduce financial losses caused by disease outbreaks, effective rodent control measures are crucial (Terpstra 2003).

Veterinary and public health authorities can effectively reduce the risk of zoonotic disease transmission from rodents to humans and animals by implementing a comprehensive rodent control strategy that integrates rodenticides, integrated pest management, habitat modification, and vigilant surveillance. Successful rodent control programs depend on cooperation between a variety of stakeholders, including governmental organizations, researchers, and communities. Given that zoonotic diseases continue to be a hazard to global health, it is crucial to take preventive and scientifically apprized rodent management strategies in order to safeguard human health and enhance overall disease preparedness.

5.5.1 SURVEILLANCE-BASED RODENT CONTROL

Effective rodent control strategies must include surveillance and monitoring. In order to pinpoint high-risk locations and find zoonotic pathogens, veterinarians regularly examine rodent populations in partnership with public health authorities. This proactive strategy enables the prompt deployment of control measures and early intervention.

5.5.2 INTEGRATED PEST MANAGEMENT (IPM)

IPM is a comprehensive strategy for rodent control that aims to utilize the least quantity of chemical pesticides possible while still achieving long-term outcomes. To lower rodent populations and their effect on the spread of zoonotic diseases, IPM incorporates a number of tactics, including habitat alteration, biological control, trapping, and exclusion (Ehler 2006).

5.5.3 RODENTICIDES-BASED RODENT CONTROL

When traditional rodenticides are used, there is a chance that other animals—including predators and scavengers—will get secondarily poisoned. Rodenticides with lower secondary poisoning hazards have been developed recently, including non-toxic bait substitutes and anticoagulant bait stations.

A crucial metaphylaxis strategy to avert the spread of zoonotic diseases is rodent control. Successful rodent control programs must include surveillance, reduced-risk rodenticides, integrated pest management (IPM), public education, and multidisciplinary cooperation. The veterinary profession may successfully safeguard animal and human populations from the danger of zoonotic diseases transmitted by these pervasive pests by adopting a proactive approach to rodent management (Ehler 2006).

5.6 WILDLIFE MANAGEMENT

A metaphylactic strategy that addresses the risks of zoonotic diseases originating from wildlife reservoirs is wildlife management. In order to prevent the spread of zoonotic diseases, it is essential to manage wildlife populations and habitats. In order to mitigate disease transmission at the animal-human interface, habitat modifications, such as minimizing human-wildlife interaction zones, may be used in wildlife management (Kruse et al. 2004). Additionally, where practical, implementing vaccination programs in wildlife populations can operate as a proactive measure to prevent the spread of particular zoonotic diseases, including rabies. Innovative approaches such as oral vaccination have shown promise in safeguarding wildlife against zoonotic diseases. Wildlife management strategies may effectively reduce the danger of disease spillover and maintain ecological balance by comprehending the ecological dynamics of zoonotic diseases.

5.7 RISK-BASED APPROACH

The risk-based approach to zoonotic disease control entails configuring treatments in accordance with the specific hazards associated with specific pathogens, geographic regions, and animal populations. This strategy makes use of data-driven analysis to pinpoint high-risk areas and prioritize resources effectively (WHO 2020). Authorities may concentrate on preventive measures where zoonotic transmission is highest by investigating the epidemiology of zoonotic diseases and their drivers. Recent advances in disease modeling, pathogen surveillance, and geographical analysis enable more accurate risk assessments. The risk-based strategy helps to execute focused monitoring, allocate scarce resources effectively, and improve vaccination or antibiotic prophylactic techniques. By lowering the possibility of zoonotic spillover events and successfully protecting both humans and animals, such proactive measures improve preparedness as well as response capacity (WHO 2020).

As a result of deploying these metaphylactic approaches, veterinary and public health authorities may proactively reduce the risks of zoonotic disease transmission, control and prevent the spread of infectious agents, and detect outbreaks before they become widespread. These diverse strategies improve disease preparedness, promote global health security, and safeguard both human and animal populations from zoonotic hazards. In order to effectively implement metaphylactic strategies in the face of emerging zoonotic threats, the integration of One Health concepts, collaborative efforts, and evidence-based decision-making remain critical (WHO 2020).

6. CONCLUSION

In conclusion, a strategic and united front is needed to combat zoonotic diseases. Prophylactic and metaphylactic approaches provide us with powerful tools to combat these global health threats. We fortify our defenses on a personal level by vaccinating, implementing targeted antimicrobial use, and empowering communities via health education and public awareness. Moreover, we can safeguard populations by implementing risk-based decision-making, environmental health interventions, and vigilant surveillance. Embracing the One Health perspective, the interdependence of human, animal, and environmental health serves as our defense. With the most recent scientific knowledge at our disposal, we embarked on a proactive quest to eradicate zoonotic diseases, ensuring a better future for everyone.

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Public Health Awareness of Zoonosis through Veterinary Profession

44

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ABSTRACT

In the intricate realm of infectious diseases, zoonotic diseases emerge as a formidable threat, disrupting ecosystem dynamics and affecting human and animal populations alike. This chapter illuminates the vital role of veterinary professionals in maintaining a delicate equilibrium amidst the increasing intermingling of species. It highlights their dedicated efforts and advanced knowledge, outlining the remarkable journey in raising public awareness about zoonosis. Zoonotic diseases, crossing species barriers and creating complex webs of danger, pose a global health risk. Veterinary professionals serve as the first line of defense, combating these dangers to safeguard both human and animal welfare. Historical epidemics leave lasting imprints on public health consciousness, guiding the ongoing fight against these invisible foes. The veterinary field, characterized by a tapestry of knowledge and compassion, employs cutting-edge knowledge to eliminate diseases and control hazards. Veterinarians bridge human-animal health gaps through the One Health approach, forming alliances across sectors to confront zoonotic challenges. Disseminating accurate information becomes crucial in dispelling public misconceptions, especially in the face of accelerated zoonotic spread due to globalization. Veterinary-led One Health campaigns and partnerships empower awareness strategies, turning pet owners and livestock managers into health stewards. Looking to the future, embracing innovation and preparedness against zoonotic threats become priorities. The chapter applauds veterinarians as unsung heroes, acknowledging their tireless dedication and positioning them as defenders against zoonotic risks. Emphasizing education and training, veterinarians play a crucial role in recognizing, alleviating, and communicating health hazards. Their collaboration with healthcare sectors contributes to success stories, monitoring innovations, and international cooperation, creating a safety net for both humans and animals. This collaborative effort paves the way for a safer and healthier world, recognizing veterinarians' unwavering dedication in protecting our interconnected global community from the growing danger posed by zoonotic illnesses.

Key words: Zoonotic diseases, veterinary profession, One Health, public awareness, global health, disease prevention, collaboration, innovation, education, preparedness.

CITATION

Saleem MI, Mahfooz A, Zaka F, Butt FA, Shah SK, Manzoor A, Ahmar M, Raza A, Khan MU and Shakir AH, 2023. Public Health Awareness of Zoonosis through Veterinary Profession. In: Khan A, Abbas RZ, Hassan MF, Aguilar-Marcelino L, Saeed NM and Mohsin M (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 594-611. https://doi.org/10.47278/book.zoon/2023.044

CHAPTER HISTORY Received: 04-May-2023 Revised: 10-June-2023 Accepted: 15-Aug-2023

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1. INTRODUCTION

Within the domain of infectious diseases, a discrete but formidable menace arises, instilling perturbations in the complicated dynamics of ecosystems and impacting both populations of humans and animals. This phenomenon acquaints us with the domain of zoonotic diseases, where the diligent endeavors of veterinary professionals assume a pivotal function in safeguarding a delicate equilibrium, notwithstanding the escalating intermingling of various species (Shanko et al. 2015). This chapter outlines the incredible journey made possible by the unwavering dedication and cutting-edge knowledge of the veterinary community in raising zoonosis awareness among the general public.

Imagine a world where diseases cross species barriers and create complex webs of potential danger. Zoonotic diseases, those sneaky intruders, have the power to wreak havoc on the health of the entire world. The veterinary profession steps up as the first line of defense in this situation, tenaciously combating zoonotic dangers to safeguard the welfare of humans as well as animals (Shanko et al. 2015). We learn more about the distinguishing characteristics of zoonotic diseases as we venture deeper into this captivating narrative, a worldwide enigma that demands our full concentration. Historical epidemics have left lasting impressions on public health consciousness, leading us in the fight against the invisible foe, much like ancient footprints in time.

The veterinary field is characterized by a unique tapestry of knowledge and compassion that is delicately woven with cutting-edge knowledge. We observe the noble efforts of veterinarians, the dedicated keepers, whose efforts have succeeded in eliminating rabies and controlling avian influenza. Their widespread vaccination programs, community involvement, and vigilant monitoring act as beacons of hope in the shadows of zoonotic hazards (Richeson et al. 2019).

Veterinarians bridge the gap between human and animal health by adhering to the One Health approach and understanding the intimate connection between every living being (Bonilla-Aldana et al. 2020). They establish a powerful alliance that stands diligently against zoonotic challenges by working cooperatively with different health sectors. But like in every conflict, we must face the obstacles and misconceptions that cloud our path. In the battle against zoonosis, dispelling misunderstandings among the public becomes a paramount task. The advent of globalization, a double-edged sword, accelerates the spread of zoonotic diseases and necessitates a united stance on a global scale.

Empowering awareness strategies are the crux of the prevention of zoonosis. At the vanguard of this effort, the veterinary profession directs One Health campaigns and public-private partnerships that raise awareness and spark preventative actions against zoonotic diseases. Equipped with knowledge, pet owners and livestock managers become stewards of health, strengthening the barrier of protection between humans and animals.

As we focus on the horizon of the future, we accept the opportunities and challenges that lie ahead. As we arm ourselves with the latest innovations in monitoring and technology, being prepared for zoonotic threats becomes a priority. Together, we establish the foundation for a safer, healthier future in which it is a shared responsibility to maintain sustained awareness (Bodrud-Doza et al. 2023).

In this riveting chapter, we honor the veterinary profession as the unsung heroes of our times and salute their tireless dedication. We enlighten their way with scientific rigor and recent knowledge, pointing the way to a future in which zoonotic risks are confronted with courage, cutting-edge solutions, and compassion. We are invited into a world where science and heroism collide as we delve into the realm of zoonosis from the perspective of the veterinary profession, creating an everlasting mark on the legacy of public health awareness (Bodrud-Doza et al. 2023).

2. DEFINING ZOONOTIC DISEASES: A GLOBAL THREAT

Zoonoses, alternatively classified as zoonotic diseases, indeed foreshadow an impending danger to human and animal wellness ubiquitously (Rahman et al. 2020). This constellation of infectious conditions stems from pathogens that traverse the animal-human divide, with the potential to trigger pandemics and epidemics. The zoonotic disease panorama is a variegated one, offering a challenge to achieve full comprehension, given that the compendium of zoonotic agents encompasses viruses, bacteria, parasites, and fungi (Rahman et al. 2020).

In a phenomenon dubbed "zoonotic spillover", the zoonotic lifecycle initiates when pathogens transit from animal hosts to human ones. This spillover episode can manifest through multiple channels: direct encounters with infected animals, consumption of tainted nourishment, exposure to vectors, or entanglement with environmental factors that accelerate disease transmission. As human settlements advance into natural habitats, the specter of zoonotic spillover heightens, underscoring the necessity for a more profound grasp of zoonotic perils and efficacious containment strategies (Vora et al. 2022).

2.1 HISTORICAL OUTBREAKS THAT SHAPED PUBLIC HEALTH AWARENESS

Zoonotic flare-ups have scratched themselves onto the canvas of public health consciousness over time, enriching our perception of zoonosis and fueling endeavors to prevent subsequent pandemics.

2.1.1. THE BLACK DEATH (14TH CENTURY)

The Black Death, a catastrophic pandemic that seared human history, was incited by the bacterium Yersinia pestis, dispatched to humans via fleas that resided on rats (Duncan and Scott 2005). This cataclysm stimulated initial attempts at disease regulation and quarantine, spotlighting the weightiness of zoonotic maladies.

2.1.2. SPANISH FLU (1918-1919)

The H1N1 influenza virus, the provocateur of the Spanish flu, first emerged in avian species and underwent genetic metamorphosis to acquire high virulence in humans. This terrifying pandemic underscored the capacity of zoonotic influenza strains to destabilize global health, emphasizing the requisiteness of vigilant influenza surveillance and preparedness (Liu et al. 2020).

2.1.3. EBOLA VIRUS OUTBREAKS (ONGOING)

Fruit bats are conjectured to be the conduit of Ebola viruses to humans, triggering recurrent outbreaks with stark fatality rates in Africa. These episodes punctuate the indispensability of prompt detection, brisk response, and synergistic endeavors in the containment of zoonotic diseases.

2.1.4. SEVERE ACUTE RESPIRATORY SYNDROME (SARS, 2002-2003)

The SARS-CoV virus precipitated a worldwide contagion, presumably hailing from bats and relayed to humans via intermediary hosts (civets). The SARS pandemic accentuated the demand for bolstered zoonotic disease observation, international cooperation, and expedited communication amidst outbreaks.

2.1.5. COVID-19 (ONGOING)

The ongoing COVID-19 pandemic, engineered by the novel coronavirus SARS-CoV-2 (Gorbalenya et al. 2020), has culminated in an acute global health crisis. This continuing event underscores the responsibility of veterinarians and public health specialists in identifying and tackling zoonotic infections. It has additionally amplified the importance of integrated "One Health" strategies and worldwide collaboration to preclude future zoonotic epidemics (Erkyihun et al. 2022).
These historical zoonotic contagions have steered public health legislations, kindled research vigor in academia, and highlighted the need for interdisciplinary cooperation in grappling with zoonotic threats. Lessons extracted from these historical vignettes persistently shape our stratagem for zoonosis management and deterrence in the face of newly burgeoning zoonotic diseases. The veterinary domain continues to pioneer the defense against the perpetually shifting landscape of zoonosis through incessant research, vigilant monitoring, and fostering public cognizance (Erkyihun et al. 2022).

3. VETERINARY WARRIORS ON THE FRONTLINES

In the struggle against zoonotic threats, valiant combatants are necessitated. This section showcases the crucial role the veterinary profession occupies as frontline defenders against zoonosis. Veterinarians rise to the challenge, employing advanced techniques for early discovery and prompt notification. They are fortified with scientific precision, unwavering dedication, and a profound understanding of animal physiology, disease mechanisms, and epidemiology (Habib et al. 2019).

3.1 SURVEILLANCE AND RAPID REPORTING FOR EARLY DETECTION

Adopting the role of an ever-watchful guardian, surveying the horizon for markers of emerging zoonotic epidemics, surveillance stands as the silent sentinel (Table 1: for different types of surveillance). Veterinarians harness their expertise to observe animal populations, wildlife, and potential zoonotic infection hotspots via intricate surveillance systems. They detect early warning signs via real-time data collection and analysis, facilitating rapid intervention and containment. Swift reporting embodies the veterinary profession's proclivity for collaboration. Veterinarians liaise with public health authorities to pinpoint abnormal or suspicious disease patterns and promptly alert stakeholders and pertinent agencies. This harmonized approach ensures seamless information flow, enabling prompt action and stalling potential epidemics from spiraling beyond control.

3.1.1. ADVANCEMENTS IN DISEASE SURVEILLANCE SYSTEMS

Disease surveillance systems have made incredible strides in recent years, giving veterinarians access to real-time data monitoring and analytic capabilities. These sophisticated systems, which incorporate big data analytics, geographic information systems (GIS), machine learning, and artificial intelligence models, enable veterinarians to process enormous amounts of data, spot patterns and trends that might escape human eyes, and act as early warning systems for the spread of zoonotic diseases. Veterinarians may assist proactive response measures by spotting developing disease trends in animal populations and promptly alerting public health authorities (Habib et al. 2019).

3.1.2. CUTTING-EDGE SURVEILLANCE TECHNOLOGIES

Recently, veterinarians have improved their ability to make early diagnoses by using modern surveillance technologies. Veterinary professionals may follow the DNA signatures of zoonotic pathogens to learn more about their origins and modes of transmission thanks to genomic surveillance's unparalleled accuracy. Modern molecular technologies like next-generation sequencing facilitate quick responses to subsequent epidemics by enabling rapid zoonotic pathogen detection (Habib et al. 2019).

3.1.3. SENTINEL SURVEILLANCE SYSTEMS AND ENVIRONMENTAL MONITORING: EYES ON THE GROUND

The veterinarian's arsenal continues to be completely dependent on sentinel observation. As long as they exist, sentinel animals are essential sources of zoonotic disease detection systems. Animal populations that serve as reservoirs or vectors for zoonotic diseases, such as migrant birds, bats, and sentinel species in wildlife, are monitored strategically by veterinarians. In order to forecast zoonotic spillover occurrences, surveillance of carrier populations, such as mosquitoes, is essential. These sentinel systems serve as vigilant alarms, offering early warnings that prompt immediate action to halt future transmission and also contribute to understanding the intricate dynamics of zoonotic transmission (Erkyihun et al. 2022).

3.2 EMBRACING THE ONE HEALTH APPROACH WITH PUBLIC HEALTH

In the fight against zoonotic diseases, the One Health strategy acts as a compass. Professional veterinarians comprehend the complex relationship between environmental, human, and animal health and are aware of how linked everyone's well-being is. By adopting an all-encompassing strategy, veterinarians work together with public health professionals, environmental scientists, and epidemiologists to eliminate obstacles and effectively address zoonotic challenges. Veterinarians may see beyond conventional limitations by adopting the One Health perspective. They actively engage in risk assessment, disease monitoring, and preparation planning, which strengthens their position as significant players in the decision-making and policy-making processes (Tripartite 2021).

3.2.1. INTEGRATION OF ONE HEALTH POLICY

Recent years have seen a considerable uptick in the One Health movement, which encourages interdisciplinary cooperation between veterinary professionals, medical professionals, environmental researchers, and public health specialists (Bonilla-Aldana et al. 2020). Since human, animal, and environmental health is interconnected (Fig. 1), this comprehensive strategy acknowledges how zoonotic diseases emerge. Professionals in public health and veterinary medicine collaborate on research endeavors and share expertise and data. By combining their knowledge, they are able to design powerful preventative measures by developing a thorough grasp of the dynamics of zoonotic diseases (Lakan and Yani 2021).

3.2.2. PREPAREDNESS AND RESPONSE TO EMERGING ZOONOTIC OUTBREAKS

Recent events demonstrate the One Health approach's enormous influence. Cooperation among veterinary professionals and public health agencies was crucial in containing zoonotic epidemics like Ebola and COVID-19 and mitigating their impact on health worldwide (Rabaa et al. 2015). Veterinarians and public health specialists working together have sped up the development of methods for diagnosis, vaccine candidates, and therapeutic choices (Asrar et al. 2021). In order to prevent zoonotic epidemics before they turn into major global health emergencies, a well-coordinated response is essential.

Table 1: Comparing Different Types of Surveillance to Identify Zoonotic Diseases.

Type	Main points	Application	Advantages	Challenges
Syndromic surveillance	-Monitors clinical symptoms and indications -Incorporates vague data to spot possible epidemics	-Prompt detection of possible epidemics -Economical with resources -Ideal in areas with minimal resources	-Quick acquisition of data -Monitoring in real-time -Able to recognize odd patterns -Warnings for prompt inquiry	-Generalized signs and symptoms -Might cause erroneous warnings -Insufficiently verified diagnoses
Passive surveillance	-Depend on case reports-Data originates from regular healthcare practices -Minimally engaged effort -Able to recognize new instances	-Finds recognized diseases -Uncovers catastrophic events -Observes patterns -Monitoring of communicable and endemic diseases	-Economical -Simple to use -Makes use of current systems	-Maybe omitting emerging diseases -scant information on cases that are asymptomatic or mild -Lack of control over the quality of the data -Insufficient reporting
Wildlife surveillance	-Tracking diseases in populations of wild animals -Prompt identification of potentially hazardous zoonotic spills	-Identifies reservoirs and the means of transmission in populations of wildlife -Safeguard conservation initiatives.	-Conservation of biodiversity -Rationale for preventive strategies -Recognizing zoonotic threats -Pre-emptive alert for human spillover	-Restricted access to populations of wildlife -Costly in terms of resources and time-consuming collection of information -Sampling techniques affect the quality of the data. -May not be able to identify diseases without the presence of wildlife
Active surveillance	-Focused inspections -Prompt detection of cases -Frequent collection and reporting of data	-Prompt detection of hazards and patterns -Detects epidemics and anomalous occurrences	-Extensive information -Superior quality of data -Prompt reaction to epidemics -Makes sure every case is captured	-Might still overlook uncommon instances -High resource requirements -Bias in reporting because of proactive work -Calls for qualified individuals
One health surveillance	-Combines environmental, animal, and human data -Interdisciplinary strategy -Concentrate on managing health holistically	-Assesses zoonotic hazards and possible outbreaks -Uses a multidisciplinary strategy to manage health and the environment	-Complete comprehension -Lowers the risk of zoonotic diseases -Early identification and intervention -Coordination among disciplines	-Intricate data interfacing -Standardization of data might be difficult Multidisciplinary cooperation is necessary. -Can be time and resource-consuming -Significant cross-sector communication is necessary -Might necessitate substantial legal and policy frameworks

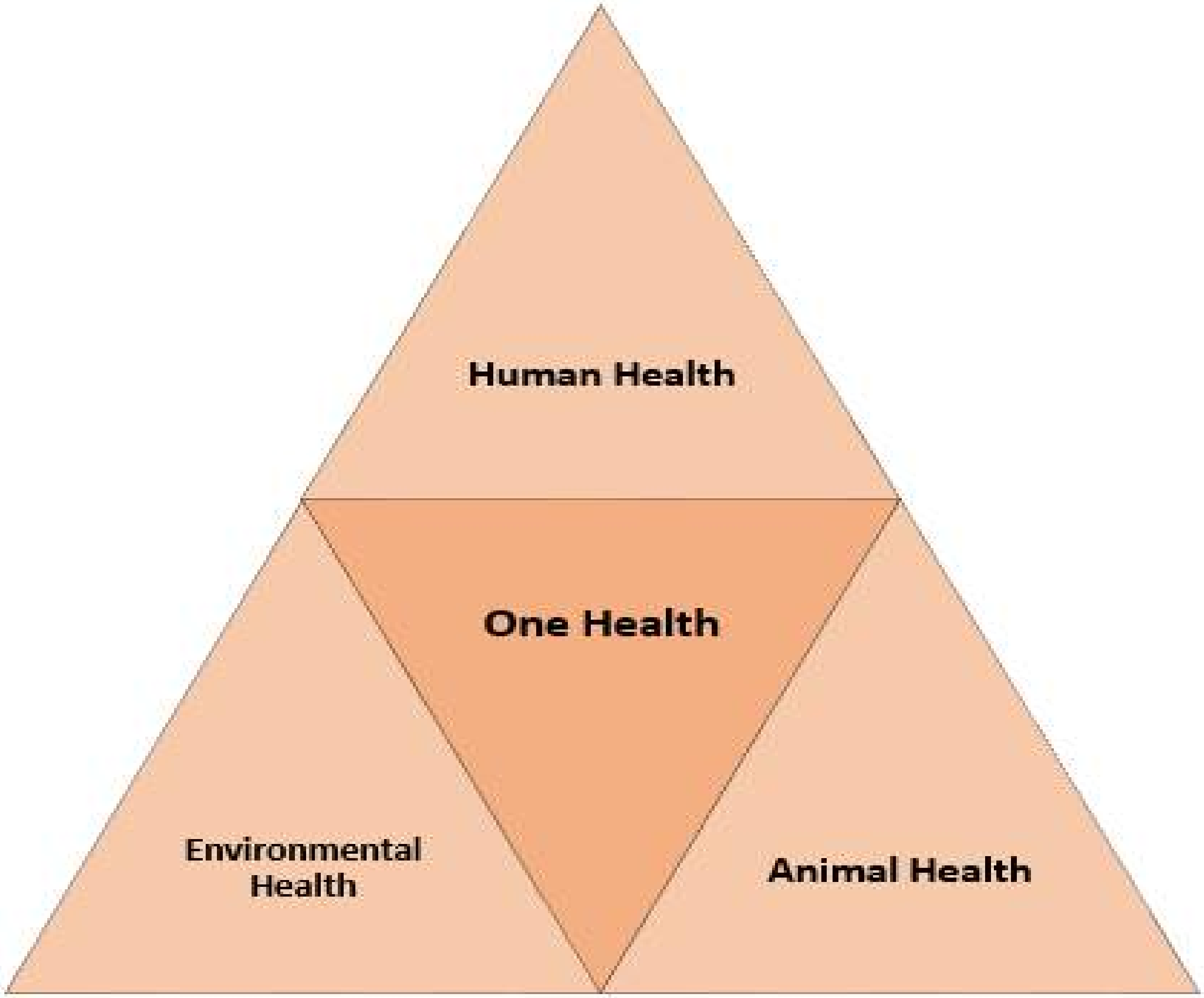

Fig. 1: Illustrating the Interrelationship of components in the One Health strategy.

3.2.3. GLOBAL SURVEILLANCE NETWORKS: STRENGTHENING INTERNATIONAL COLLABORATION

The development of worldwide monitoring systems strengthens the power of global cooperation (Childs & Gordon 2009). Veterinarians throughout the globe keep connected via real-time data exchange and communication, forging a unified front against zoonotic risks. This worldwide coordination allows for rapid response to evolving epidemics and strengthens our collective power to avoid zoonotic cross-border spillover.

3.2.4. CAPACITY BUILDING AND PUBLIC AWARENESS

Veterinarians regularly participate in capacity-building and public awareness campaigns in addition to their scientific work. Veterinarians encourage a sense of shared responsibility by educating community members about zoonotic threats and protection strategies (Denis-Robichaud et al. 2020). To provide community members with the knowledge and abilities they need to safeguard them and their animals, community outreach and education programs have been implemented.

In the constant fight for global wellness, veterinarians play a crucial role as steadfast defenders, safeguarding against the persistent spread of zoonotic diseases. Their expert vigilance operates as a finely tuned early-warning system, swiftly identifying and tackling potential threats of a zoonotic nature with astute immediacy. Embracing the One Health paradigm, these dauntless professionals form a robust phalanx, joining forces with experts spanning diverse disciplines, to staunchly resist zoonotic adversities (Denis-Robichaud et al. 2020).

4. UNMASKING CHALLENGES AND MYTHS

As we delve deeper into the labyrinthine world of zoonosis, we inevitably encounter panoply of barriers and deeply entrenched myths that stubbornly persist. In this section, our aim is to explore how veterinary professionals, equipped with empirical information, effectively address the challenges they encounter. In their tireless crusade, they strive to dispel erroneous beliefs clouding the understanding of zoonotic afflictions (Denis-Robichaud et al. 2020).

4.1. EMERGING ZOONOTIC DISEASES: A CONSTANT BATTLE

Deforestation, modifications to the world's habitats and urbanization have all increased the risk of zoonotic spillover occurrences (Hockings et al. 2020). The continued emergence of novel zoonotic infections presents unexpected hurdles for early diagnosis and control. In order to develop preventive measures to reduce future outbreaks, it is essential to understand the environmental factors that drive zoonotic transmission.

4.2. ANTIMICROBIAL RESISTANCE: A LOOMING CRISIS

Antimicrobial resistance (AMR) has increased as a result of the overuse and improper use of antibiotics in the veterinary and human medical sectors. Zoonotic infections with AMR compromise the efficacy of treatments, which is a worrying concern. To address this impending problem, vigilant antibiotic stewardship and cross-sector coordination are required (Rabaa et al. 2015).

4.3. DIAGNOSTIC DILEMMAS: IDENTIFYING THE CULPRIT

Given that many of these infections resemble the symptoms of common diseases, diagnosing zoonotic diseases may be challenging. The requirement for specialized laboratory tests and cutting-edge technologies highlights the significance of well-equipped diagnostic facilities. Veterinarian laboratories are essential for correctly detecting zoonotic pathogens and accelerating containment procedures (Rabaa et al. 2015).

4.4 RAISING AWARENESS AMONG PUBLIC MISCONCEPTIONS

Zoonotic diseases can skulk in the mists of misunderstanding and erroneous knowledge. As they traverse the huge ocean of public beliefs about zoonosis, veterinarians face a key mission: raising awareness. By combining recent knowledge with effective communication strategies, veterinarians work tirelessly to educate the public about the risks and preventative measures associated with zoonotic diseases (Shanko et al. 2015).

While social media and digital platforms are effective tools for spreading information (Leung et al. 2021), they are also the source of a lot of false or erroneous content. Veterinarians use evidence-based communication to address this, using the power of social media to spread factual information and dispel falsehoods. Furthermore, community involvement is the key to successful initiatives to raise awareness. In order to reach a variety of groups, including pet owners, farmers, and students, veterinarians organize public outreach programs, seminars, and educational activities. They address public concerns and debunk myths by promoting open discussions, which instill a sense of shared responsibility for the prevention of zoonotic diseases (Denis-Robichaud et al. 2020).

The success of focused campaigns to raise awareness has been shown by recent research. Veterinarians may successfully target people who are most susceptible to zoonotic threats by adapting their communications to diverse demographics and cultural contexts.

4.5 GLOBALIZATION: A DOUBLE-EDGED SWORD IN DISEASE TRANSMISSION

In the realm of zoonosis, globalization offers both benefits and challenges due to its interwoven networks of communication, trade, and travel. While it promotes cooperation and knowledge exchange, it also has a negative side since it hastens the spread of zoonotic diseases throughout the globe (Erkyihun and Alemayehu 2022). Communities are exposed to zoonotic infections from remote regions due to the frequent movement of people and products. For instance, avian influenza strains may travel across continents through migratory birds, but emerging viruses like coronaviruses have the potential to cross species boundaries, infect other animals, and cause pandemics on a large scale.

As a result, public health authorities and veterinarians use a risk-based monitoring strategy at animal trade checkpoints and international borders. They keep an eye on animal movements to ensure that biosecurity regulations are being followed, and they act fast to address any risks in order to stop the uncontrolled transmission of zoonotic diseases. Additionally, global cooperation is essential to halting the spread of zoonosis. In order to combat zoonotic risks as a unified global community, veterinarians take part in collaborative research projects, data-sharing efforts, and coordinated epidemic responses.

Veterinarians stand out as defenders of truth in the ocean of misinformation, using focused efforts and promoting international cooperation to dispel zoonotic convictions. They work tirelessly to protect both humans and animals from unknown dangers, paving the way for a future backed by cutting-edge research and coordinated efforts to combat emerging zoonotic threat (Erkyihun and Alemayehu 2022).

5. EMPOWERING AWARENESS STRATEGIES

Empowering awareness campaigns are effective weapons in the fight against zoonotic diseases because they provide people with knowledge and best practices, they need to safeguard both themselves and their animals. Veterinarians can illuminate the path to a safer future as torchbearers of zoonosis prevention through targeted initiatives that empower pet owners and livestock handlers while also strengthening communication between the healthcare and veterinary fields.

5.1 POWERING UP PET OWNERS AND LIVESTOCK HANDLERS

5.1.1. RESPONSIBLE PET OWNERSHIP: A SHIELD AGAINST ZOONOSIS

Animal handlers and pet owners are essential in the prevention and management of zoonotic diseases. Considering this, veterinary professionals take the lead in educating and equipping these crucial stakeholders (Shanko et al. 2015). Veterinarians interact directly with pet owners via specialized teaching programs, establishing best practices in animal care and the prevention of zoonotic diseases.

These initiatives, which range from sanitary handling to responsible pet ownership, advance knowledge of zoonotic dangers and encourage a proactive attitude towards safety and health.

5.1.2. BIOSECURITY MEASURES IN LIVESTOCK MANAGEMENT

In order to protect themselves against zoonotic dangers, livestock workers, who often come into contact with animals, need specialized instruction. It is crucial to arm these people with biosecurity and hygiene practices in order to prevent the transmission of zoonotic diseases (Denis-Robichaud et al. 2020). To preserve the health of both humans and animals, veterinarians undertake training programs and seminars that encourage safe handling procedures, the use of personal protective equipment, and proper waste disposal. Veterinarians enhance the first line of defense against possible epidemics by empowering these individuals.

To reach a broader audience, the power of digital platforms and social media is leveraged (Leung et al. 2021). Veterinarians use these channels to provide educational information, interact with pet owners and livestock managers directly, and provide real-time answers to questions and debunking of common beliefs.

5.2 STRENGTHENING VETERINARY-HEALTHCARE COMMUNICATION

The cornerstone of successful zoonosis prevention is founded upon robust communication echelons. The primacy of efficacious discourse, bridging the veterinary sphere with the broader healthcare milieu, is a well-recognized principle among veterinarians.

5.2.1. INTERDISCIPLINARY WORKSHOPS AND CONFERENCES: THE KEY TO SUCCESS

Solving the complex puzzle of zoonotic issues mandates unimpaired channels of communication between veterinarians and medical practitioners. Armed with the collective aim to thwart zoonotic diseases, these professionals congregate in interdisciplinary conclaves, seminars, and conventions, forging a platform to disseminate knowledge, collate best practices, and sculpt collaborative tactics. These intellectual gatherings serve as catalysts, promoting symbiosis among stakeholders and promulgating the tenets of the One Health model (Lakan and Yani 2021).

5.2.2. ZOONOSIS REPORTING PROTOCOLS

The veterinary community nurtures a dynamic knowledge transfer matrix, constructing robust liaisons with physicians, public health stewards, and epidemiologists. This knowledge pooling augments early detection and reporting of zoonotic diseases, halting potential epidemic developments in their nascent stages. Through this enhanced dialogic construct, the bond between veterinary and human health arenas is fortified, paving the way for synchronized strategies in zoonotic disease prevention (Lakan and Yani 2021).

5.2.3. SYNDROMIC SURVEILLANCE: EARLY WARNING SYSTEMS FOR HUMAN HEALTH

With an eye on issuing early warnings for zoonotic epidemics, syndromic surveillance systems weave together animal health data with human health indicators. Through scrutinizing the tapestry of animal disease trends, healthcare savants can detect looming threats to human health. This interdisciplinary lens amplifies the recognition of zoonotic diseases, enabling swift interventions and containment stratagems (Vora et al. 2023).

5.2.4. SURVEILLANCE DATA SHARING AND ANALYSIS

The exchange of epidemiological data and research findings between the veterinary and healthcare sectors is streamlined via reinforced communication highways. The abilities to detect threats promptly and respond swiftly are amplified when veterinarians and public health guardians mutually disclose surveillance data. Analyzing and interpreting this data enables the identification of zoonotic patterns, high-risk loci, and potential outbreak hubs. This mutualistic endeavor provides a comprehensive understanding of the zoonotic disease milieu, equipping both vocations to execute informed decisions within their respective domains. Moreover, collaborative efforts and training symposia engender a sense of mutual responsibility across veterinary and healthcare sectors. Synchronized engagement in risk appraisal, disease tracking, and outbreak response culminates in formidable preventive armors and a harmonized plan for safeguarding public health (Lakan and Yani 2021).

The robust bulwark against zoonosis is fortified by powerful awareness drives, with veterinarians leading the vanguard of this mission-critical task. By imbuing pet caretakers and livestock handlers with knowledge and reinforcing connective threads with the healthcare collective, veterinarians become an indispensable bastion against the burgeoning threat of zoonotic diseases.

6. SUCCESS STORIES IN ZOONOSIS MANAGEMENT

6.1 ERADICATING RABIES: THE TRIUMPH OF VACCINATION AND AWARENESS

Rabies is a fatal zoonotic disease that frequently spreads through animal bites and has long been a concern for public health around the world (Singh et al. 2017). The eradication of rabies in certain areas has been made possible by veterinarians' stringent vaccination campaigns that target both domestic and wild animals. Additionally, via community engagement programs, they have raised public awareness of this lethal zoonotic disease, encouraging people to take preventative action. A ray of hope is provided by the successful eradication of rabies in some areas, which emphasizes the need for vaccination and public knowledge in the control of zoonosis. The victory over rabies is a prime example of how veterinarian efforts to avoid zoonosis have had a profoundly positive influence (Singh et al. 2017).

6.2 CONTROLLING AVIAN INFLUENZA: HOW VETERINARY SURVEILLANCE SAVES LIVES

One continuing concern for the health of humans as well as animals is avian influenza, a zoonotic disease that mostly affects birds. A global effort by veterinarians was required to control avian influenza, a disease with the potential to spread globally. They have effectively controlled epidemics and safeguarded both animal and human populations by implementing early detection systems, quick reaction measures, and strict biosecurity rules (Denis-Robichaud et al. 2020). Their revolutionary approach to avian influenza containment is proof of the important role that veterinary vigilance plays in ensuring the security of global health.

The eradication of rabies and the management of avian influenza are two zoonosis success stories that highlight the effectiveness of vaccinations, public awareness, and veterinary monitoring. The eradication of rabies in certain areas has been made possible by widespread vaccination efforts and community involvement. Avian influenza epidemics have been successfully controlled simultaneously by careful veterinarian monitoring and quick response measures, protecting the health of animals as well as humans.

These successes highlight the value of continual scientific advancement, preventive measures, and global cooperation in the ongoing struggle against zoonosis. The devotion and knowledge of veterinarians, who are at the forefront of zoonosis control, provide hope for a future when the impacts of these devastating diseases are reduced, opening the way for a safer and healthier society (Singh et al. 2017).

7. UNITING NATIONS FOR HEALTH: GLOBAL COLLABORATION

7.1 CROSS-BORDER COLLABORATION: A SHIELD AGAINST ZOONOSIS

In light of the global threat that zoonotic diseases pose (Salyer et al. 2017), cross-border cooperation among nations has emerged as a crucial defense against the transmission of these pathogens (Erkyihun et al. 2022). Acknowledging that zoonotic diseases transcend state boundaries, veterinarians play a crucial role in fostering global collaboration to successfully address these challenges.

7.1.1. EARLY WARNING SYSTEMS: TIMELY INFORMATION EXCHANGE

Veterinarian specialists develop and maintain reliable early warning systems that enable quick information sharing on zoonotic disease epidemics. Veterinarians swiftly disseminate information about emergent zoonosis via global networks and platforms, ensuring that afflicted countries are alerted and can take precautions immediately. This proactive strategy inhibits the uncontrolled cross-border spread of zoonotic diseases.

7.1.2. JOINT RESEARCH AND SURVEILLANCE: STRENGTHENING GLOBAL PREPAREDNESS

Global zoonotic threat readiness is improved through international research collaboration (Kahn 2006). In order to study the dynamics of zoonotic transmission and locate possible reservoirs and vectors in various ecosystems, veterinarians collaborate. Countries may proactively recognize and combat emerging zoonotic threats before they develop into pandemics by combining their resources and expertise.

7.2 IMPACTFUL GLOBAL INITIATIVES

Veterinary professionals have a longstanding commitment to zoonosis management, spearheading global initiatives that address zoonotic diseases from the perspective of One Health. These programs serve as an example of how veterinarians take the initiative to promote international collaboration.

7.2.1. ONE HEALTH PLATFORMS: SYNERGIZING EXPERTISE

One health platform that brings together experts in veterinary, environmental, medicinal, and public health facilitates multidisciplinary cooperation (Tripartite 2021). Veterinarians actively engage in these forums, sharing their specialized knowledge of the ecological causes, animal reservoirs, and modes of transmission of zoonotic diseases. In order to overcome zoonotic concerns together, veterinarians collaborate with other health sectors via such initiatives.

7.2.2. GLOBAL VACCINATION CAMPAIGNS: ERADICATING PREVENTABLE ZOONOSIS

Veterinary professionals support international immunization initiatives that attempt to eliminate avoidable zoonosis in animal populations that are vulnerable to it (Richeson et al. 2019). They safeguard human populations by immunizing at-risk animals like livestock and dogs in order to prevent the spread of zoonotic diseases. These efforts, which are often carried out in cooperation with global organizations, have proven to be quite successful in diminishing the load of zoonotic diseases in the targeted areas.

7.2.3. ONE HEALTH CAPACITY BUILDING: EMPOWERING NATIONS

In order to empower countries with the information and abilities required to effectively combat zoonotic diseases, veterinarians actively participate in capacity-building initiatives across the globe. The ability to confront zoonotic epidemics autonomously is provided to countries through the provision of training and knowledge in zoonosis monitoring, diagnosis, and prevention. No country is left behind in the battle against zoonotic diseases as a result of these initiatives, which improve global health security.

8. EQUIPPING VETERINARY WARRIORS

To properly confront these constantly changing threats, veterinarians—frontline fighters in the struggle against zoonotic diseases (Habib et al. 2019)—need continual training and empowerment. This section outlines crucial steps to arm veterinarians with the information and abilities they need to maintain the well-being of the public.

8.1 INTEGRATING ZOONOSIS AWARENESS INTO VETERINARY CURRICULA

8.1.1. ZOONOTIC DISEASE SURVEILLANCE AND DIAGNOSIS: CORE COMPETENCIES

Veterinary curricula increasingly contain specific modules on zoonotic diseases in recognition of the crucial role that veterinarians play in the treatment of zoonosis. The subjects covered in these courses include zoonotic agents, routes of transmission, diagnostics, and preventive approaches. Aspiring veterinarians are better equipped to handle zoonotic difficulties when they join the field by fostering zoonosis knowledge early in their education (Fountain et al. 2023).

8.1.2. ONE HEALTH APPROACH: INTERDISCIPLINARY EDUCATION

Veterinary curricula combine multidisciplinary learning, embracing the One Health concept (Tripartite 2021), to develop a thorough grasp of zoonosis. Veterinary experts are exposed to many perspectives on zoonotic diseases via joint meetings with public health and medical students, emphasizing the interconnection of human, animal, and environmental health.

8.1.3. FIELD TRAINING AND REAL-LIFE SIMULATIONS

Students in veterinary courses benefit from exposure to zoonosis management in real-world contexts by participating in hands-on activities such as field placements and simulations of actual life situations. Aspiring veterinarians may improve their capacity for problem-solving and decision-making by taking advantage of these opportunities, which arm them with direct exposure to the intricacies of zoonotic disease management (Tripartite 2021).

8.2 CONTINUOUS LEARNING AND CAPACITY BUILDING

8.2.1. PROFESSIONAL DEVELOPMENT PROGRAMS

The ever-changing characteristics of infectious diseases make it necessary for veterinarians to engage in continuous education. Veterinarians keep themselves abreast of the most recent developments in zoonosis management by participating in regular training, webinars, and conferences. They acquire the knowledge and skills necessary to successfully adapt to emerging zoonotic hazards and execute practices that are evidence-based when they engage in lifelong learning. Veterinarians are able to maintain their position as champions in the fight against zoonotic diseases by ensuring they are abreast of the latest knowledge (Habib et al. 2019).

8.2.2. VETERINARY NETWORKS AND PARTNERSHIPS: KNOWLEDGE SHARING

Networks and collaborations among veterinarians provide beneficial venues for knowledge exchange (Lakan and Yani 2021). Veterinarians participate in sharing knowledge on zoonotic cases, standard procedures, and effective outbreak management techniques. By fostering a strong sense of community among veterinary warriors, this collective endeavor improves the security of global health.

8.2.3. SURVEILLANCE AND REPORTING TRAINING

Veterinarians get ongoing training in monitoring and quick reporting, which enables them to recognize the first indications of zoonotic epidemics. As a result of improved reporting capabilities, zoonotic disease transmission is slowed down, and public health is safeguarded.

8.2.4. GLOBAL COLLABORATIVE LEARNING

Global cooperation helps veterinary professionals share information and enhance their capacities. By exchanging knowledge and best practices, veterinarians from all over the globe get access to a collective body of knowledge that strengthens their capacity to counter zoonotic risks (Lakan and Yani 2021).

8.2.5. CAPACITY BUILDING INITIATIVES: EMPOWERING VETERINARY PROFESSIONALS

Especially in areas with limited resources, participating in capacity development efforts empowers veterinary practitioners. These initiatives, which are frequently under the control of international organizations, offer coaching in zoonosis monitoring, prevention, and diagnosis. Veterinarians are better able to defend their communities against zoonotic diseases by strengthening local capacities, which has a ripple impact on public health (Lakan and Yani 2021).

Zoonosis awareness training for veterinary personnel is essential for protecting both human and animal health. Institutions of higher learning provide aspiring veterinarians with the knowledge and skills necessary for monitoring and diagnosis by including zoonotic disease education in the veterinary curriculum. The importance of the One Health concept encourages multidisciplinary cooperation, which increases the effectiveness of zoonosis control initiatives (Bonilla-Aldana et al. 2020). Additionally, programs for capacity development and continual learning guarantee that veterinary professionals stay at the forefront of the fight against zoonotic diseases. These programs provide veterinary warriors with the tools, knowledge-sharing platforms, and learning opportunities they need to effectively combat the ever-changing threats posed by zoonotic diseases.

9. TOWARDS THE FUTURE: FACING NEW CHALLENGES

The challenges posed by zoonotic diseases get more complex as the globe develops so quickly. This section examines how the veterinary profession is preparing for emerging zoonotic threats and the innovations in surveillance and technology that make those challenges more manageable.

9.1. PREPARING FOR EMERGING ZOONOTIC THREATS

9.1.1. ANTICIPATING SPILLOVER EVENTS: ONE HEALTH VIGILANCE

Veterinarians maintain vigilance in their One Health strategy due to the possibility of outbreaks of novel zoonotic infections. Constant observation of animal populations, especially those found near human proximity, permits the early identification of possible spillover situations (Aliyi et al. 2015). The veterinary profession may minimize the impact of increasing zoonotic concerns by being proactive and implementing quick containment techniques.

9.1.2. RESEARCH AND RISK ASSESSMENT: UNDERSTANDING TRANSMISSION DYNAMICS

To be adequately prepared for emerging threats, research on zoonotic diseases and their transmission patterns is crucial. To better comprehend zoonosis, its reservoir hosts, and possible transmission pathways, veterinarians work in collaboration with scientists and researchers. Models for risk assessment can identify regions vulnerable to zoonotic epidemics, allowing the development of focused prevention strategies (Lakan and Yani 2021).

9.2 INNOVATIONS IN SURVEILLANCE AND TECHNOLOGY

9.2.1. GENOMIC SURVEILLANCE: UNRAVELING ZOONOTIC ORIGINS

Veterinarians may now detect and monitor zoonotic infections with an unparalleled level of accuracy because of developments in genomic surveillance. They can identify the origin and modes of transmission of zoonotic pathogens by whole-genome sequencing, enabling immediate response and control measures (ECDC 2016). The identification of prospective hotspots and the prevention of zoonotic spillover events in the future are made possible through genomic surveillance.

9.2.2. BIG DATA ANALYTICS: REAL-TIME MONITORING

Real-time data monitoring systems have been developed as a result of technological advancements. Big data analytics and complex algorithms have revolutionized the monitoring of zoonotic diseases (Leung et al. 2021). Veterinarians discover current disease patterns by analyzing massive volumes of data from several sources, including social media, animal monitoring, and health records. This pro-active strategy permits early identification and response to evolving zoonotic hazards, preventing possible epidemics from spreading and escalating into pandemics.

9.2.3. TELEMEDICINE AND REMOTE DIAGNOSTICS: EXTENDING VETERINARY REACH

For expanding veterinarian access to isolated and underprivileged areas, telemedicine and remote diagnostics have emerged as effective methods. By overcoming gaps in zoonotic disease identification and response, veterinarians may now provide expert guidance and diagnoses remotely. With the use of this technology, local veterinarians and healthcare professionals are better equipped to control zoonotic epidemics (Lakan and Yani 2021).

10. CELEBRATING VETERINARY HEROES

Indeed, the veterinary profession's consistent dedication to zoonosis prevention merits celebration and sincere acclaim. In an effort to protect the health of humans and animals, these unsung heroes set out on a heroic adventure, bravely negotiating the complexity of zoonotic diseases. Their unwavering commitment ensures a world that is safer and healthier for all living beings, serving as a beacon of hope.

10.1 PIONEERS OF ZOONOSIS PREVENTION

In the never-ending struggle against zoonotic dangers, veterinarians stand as pioneers (Habib et al. 2019). Their knowledge and unrelenting dedication have contributed to tremendous victories in the fight against avian influenza and the eradication of rabies. These veterinary warriors have accomplished ground-breaking achievements via widespread immunization programs, community involvement, and careful observation, saving countless lives and revolutionizing healthcare perspectives.

10.2 SUSTAINED AWARENESS: A SHARED RESPONSIBILITY

While veterinarians play an essential role in the prevention of zoonotic diseases, continuous awareness requires a cooperative effort by governments, global organizations, enterprises, and individuals on a personal level. In order to avoid the reemergence of zoonotic diseases and mitigate their negative effects on public health, shared responsibility is crucial. To encourage cross-sector cooperation, governments, international organizations, and stakeholders must work collaboratively. They strengthen the worldwide defense against zoonotic diseases by pooling their resources, knowledge, and experience. Collaboration reduces obstacles, enables immediate responses to imminent threats, and guarantees an uninterrupted flow of information and operations beyond countries (Erkyihun et al. 2022).

10.2.1. GLOBAL AWARENESS CAMPAIGNS: EMPOWERING COMMUNITIES

Educating communities on zoonotic threats and precautions is necessary for sustained awareness. Veterinary professionals and public health experts are leading global awareness initiatives that are essential for educating the public (Shanko et al. 2015). These initiatives debunk misconceptions, advocate ethical pet ownership, and promote proactive zoonosis avoidance.

10.2.2. INVESTING IN RESEARCH AND SURVEILLANCE: PROACTIVE PREPAREDNESS

To stay ahead of evolving risks, governments and organizations must encourage zoonotic research and monitoring. Proactive preparation is increased by funding initiatives that monitor animal populations, look into the ecological roots of zoonosis, and use predictive modelling. Prompt responses protect the public's health by reducing the spread of emerging zoonotic diseases.

Celebrating the veterinary heroes is not just a testament to their unwavering commitment but also a call to action to prevent zoonosis. They are pioneers in zoonosis management and have successfully eradicated rabies and managed avian influenza. But since this is a shared obligation, it requires cross-sector cooperation, international awareness efforts, and proactive expenditures in research and monitoring. Collectively, as a unified front, we can strengthen our defenses against zoonotic risks, celebrating not just the successes of the past but also a better future where humans and animals can coexist in harmony without the dreaded threat of zoonotic diseases (Shanko et al. 2015).

11. CONCLUSION

Veterinarians play the role of ferocious defenders, bravely defending against zoonotic risks in order to ensure the wellbeing of all living things. By putting emphasis on education and training pertaining to zoonotic diseases, veterinarians enhance their readiness to proficiently recognize, alleviate, and effectively convey health hazards. They serve a crucial role in the prevention of zoonotic disease transmission, the maintenance of food safety standards, and the promotion of community health. The recognition of the crucial role played by veterinarians in the prevention and management of diseases that may impact both human and animal populations has fostered increased collaboration between the veterinary and healthcare sectors. Their enormous effect can be seen in success stories, innovations in monitoring, and international collaboration, all of which have contributed to the establishment of a safety net for both people and animals. Through cooperation and a shared sense of mission, we have laid the groundwork for a world that is both safer and healthier. Let us recognize the unwavering dedication of veterinarians to the fight against zoonotic diseases at a time when unsung heroes are working tirelessly and giving their all to protect our interconnected world from the growing danger posed by zoonotic illnesses.

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Development of Sustainable Curative and Preventive Tools for the Control of Zoonotic Diseases

45

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ABSTRACT

Zoonosis, the transmission of diseases between humans and animals, is categorized into endemic, epidemic, and emerging or re-emerging forms. The latter, exemplified by viruses like West Nile and MERS-CoV, presents a global challenge, causing one billion illnesses and millions of fatalities annually. Sixty percent of reported infectious ailments worldwide are zoonosis-related, with 75% of 30 novel human pathogens originating from animals in the last three decades. The Eastern Mediterranean Region is particularly vulnerable due to high population density, international trade, and frequent outbreaks, necessitating a strategic approach for early detection and management. Factors such as globalization and differing health system capabilities contribute to the genesis and transmission of zoonotic diseases, with disparities in surveillance and response capacities exacerbating outbreaks. The interconnectedness of the world raises concerns about the rapid international spread of these infections. Economic implications, including livestock losses and trade disruptions, further underscore the need for effective control strategies.

This chapter addresses public health challenges posed by emerging zoonotic infections in the Eastern Mediterranean Region, emphasizing rising risks, control challenges, and the importance of strategic approaches. Sustainable development of therapeutic and preventive tools is crucial for effective control. While advancements in diagnostics, treatments, vaccinations, and vector control have improved disease management, challenges like antibiotic resistance persist. Collaborative efforts, research, and innovation are essential for sustainable tools, ensuring effective zoonotic disease control with minimal environmental impact and long-term wellness for human and animal populations.

Key words: Zoonosis, Emerging Infections, Global Health, Eastern Mediterranean Region, Disease Control, Sustainable Development, One Health, Antibiotic Resistance, Collaboration, Public Health Challenges.

CITATION

Saleem MI, Butt AA, Mahfooz A, Rehman MS, Ramzan F, Zaka F, Shah SK, Bhutta ZA, Raza A and Khan MU, 2023. Development of Sustainable curative and preventive tools for the control of Zoonotic Diseases. In: Khan A, Abbas RZ, Hassan MF, Aguilar-Marcelino L, Saeed NM and Mohsin M (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 612-626. https://doi.org/10.47278/book.zoon/2023.045

CHAPTER HISTORY Received: 27-Jan-2023 Revised: 08-July-2023 Accepted: 04-Aug-2023

ZOONOSIS

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1. INTRODUCTION

The natural transmission of diseases and infections between humans and animals is referred to as zoonosis (Nii-Trebi 2017). There are three primary categories of zoonosis: a) endemic, which is widespread and affects both humans and animals; b) epidemic, which has sporadic temporal and spatial distribution; and c) emerging and re-emerging, which is either newly discovered in a population or has already existed but is now rapidly spreading both geographically and in terms of incidence. Examples of the latter include the West Nile virus, the Middle East respiratory syndrome coronavirus (MERS-CoV), SARS, the 2009 H1N1 pandemic, Yellow fever, Rift Valley fever, and SARS (Nii-Trebi 2017) AA.

Globally, zoonosis has been reported to be responsible for one billion diseases and millions of fatalities each year. About 60% of infectious ailments reported worldwide are zoonosis-related (Klous et al. 2016). 30 novel pathogens have been discovered in humans during the past three decades, 75% of which have animal origins (Gebreyes et al. 2014).

Due to a number of factors, the WHO has determined that the Eastern Mediterranean Region is extremely vulnerable to zoonotic diseases (WHO 2022). These involve the massive population density in the region, which causes close contact between humans and animals. Moreover, the region experiences a significant volume of international trade, including the cross-border movement of human beings and animals. Due to variables like foreign travel for tourism, business, or religious purposes, the area remains vulnerable to the danger of the rapid worldwide spread of illnesses with zoonotic origins due to its history of frequent outbreaks of emerging infectious diseases (Buliva et al. 2017). Significant risk factors in the genesis and transmission of such infectious diseases have been identified as globalization and differing health systems' abilities to identify epidemics early on.

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At the animal-human interface, disparities in surveillance and response capacities between countries have typically made these outbreaks more severe (WHO 2022). The potential for rapid international spread of these zoonotic infections poses a significant concern to global health security, given the interconnectedness of the world and the proliferation of trade, including the movement of animals across borders (Buliva et al. 2017). Additionally, evolving zoonotic diseases have implications for the economy as they may result in a decline in opportunities for individuals to earn a livelihood owing to livestock losses, the loss of the animal trade, and disruptions to travel (Seimenis and Battelli 2018).
This chapter strives to address the serious public health issues brought on by the region's rising incidence of emerging zoonotic infections. It will particularly shed light on (a) the rising risks to public health posed by emerging zoonotic infections, (b) the challenges that need to be encountered in effectively controlling these infections, and (c) the importance of adopting a strategic approach focused on anticipating, detecting, and effectively managing these infections. As part of the overall control strategy, the chapter also emphasizes the necessity for the sustainable development of therapeutic and preventative tools (Seimenis and Battelli 2018).

2. INSIGHTS INTO THE REGION: A COMPREHENSIVE OVERVIEW

The WHO's East Mediterranean Region is still unsure of the full scope of the burden zoonotic diseases pose there. The region continues to encounter periodic and epidemic outbreaks of emerging zoonosis despite the prevalence of endemic zoonosis like brucellosis, anthrax, and rabies within the countries (Buliva et al. 2017). Numerous variables may be responsible for the widespread and repeated appearance of zoonotic diseases. These include the lack of efficient zoonosis management initiatives, the limited interaction between the human and animal health sectors, the lack of agreement on the roles and responsibilities of each sector, and the inadequate prioritization of zoonosis. These variables lead to both explosive outbreaks and continued difficulties in managing zoonotic diseases in the region. There are several disease amplifiers that may be directly responsible for the recent increase of emerging zoonosis in the region. In particular, in crisis-affected countries, they include factors like population shifts, fragmented health systems, insufficient response capabilities, inadequate laboratory diagnostic capabilities, and interruptions in standard public health services (Bloom et al. 2017). The growth and spread of developing zoonosis in the region have been significantly aided by these disease amplifiers.

3. CONNECTING THE DOTS: WHY ZOONOTIC DISEASES CANNOT BE IGNORED

The haphazard emergence and global transmission of novel pathogens, particularly viruses of animal origin, is a noteworthy finding about the trend of zoonotic diseases (Marano et al. 2007). Due to their propensity for epidemics, high case fatality rates, lack of particular treatments, and readily accessible vaccinations for the majority of these zoonotic diseases (apart from the yellow fever vaccine), these diseases constitute a serious threat to world health (Samad 2011). Emerging zoonosis in a single country has the potential to endanger the security of global health due to the world's growing interconnection.
However, zoonosis has an influence that goes beyond just being common. These diseases are significant owing to their prevalence as well as the morbidity, death, and heavy financial load they inflict on healthcare systems (Samad 2011). Furthermore, zoonosis have significant financial consequences for countries, leading to losses in the trade of animals, interruptions in travel, and reduced employment prospects for people owing to the loss of livestock (Buliva et al. 2017).
The waves of zoonotic ailments, diseases transmitted from animals to humans, reverberate far and wide, generating profound implications that can destabilize a nation's fiscal infrastructure (Hassan et al. 2011). These medical maladies, persistent and devastating, often precipitate not only a significant commercial

contraction but also the erosion of trust amongst consumers and tourists. To underscore the fiscal fallout of such diseases, one only needs to cast their gaze back to the SARS outbreak of 2003. This medical catastrophe thrust the global economy into financial turmoil, with the total expenditures in response to the disease skyrocketing past USD 50 billion, attributable to mounting medical expenses and the unforeseen hibernation of the tourist industry.

Additionally, it behooves us to revisit the Rift Valley Fever (RVF) epidemic in Kenya. The tendrils of this disease infiltrated every household, compelling each one to grapple with an average financial setback of US$500 (WHO 2022 A). This unforeseen burden was principally linked to plunging productivity and the allocation of resources towards the containment of the disease. These instances, among others, underscore the profound and sizable monetary burden that zoonotic diseases can impose on nations. They elucidate the undeniable fact that the economics of disease are not confined merely to health care budgets but, rather, entwine themselves inextricably with the larger tapestry of a country's economy.

4. NAVIGATING COMPLEXITY: KEY CHALLENGES IN EFFECTIVE MANAGEMENT

Globalization has made it possible for the unparalleled movement of people, animals, and items to travel across international borders, which has helped zoonotic diseases spread throughout the world (Marano et al., 2007). Zoonosis affects a variety of industries, including trade, commerce, tourism, and consumer confidence. A substantial portion of zoonosis is trans-boundary diseases that may transcend borders from their place of origin. These diseases can, therefore, have devastating consequences for the economy (Hassan et al., 2011).

The Eastern Mediterranean Region of WHO’s past instances have shown that the majority of zoonotic epidemics have happened in remote regions, making it difficult to reach these communities with public health services. Multiple factors have severely impeded the early identification and diagnosis of numerous diseases (WHO 2022). A few of these include the lack of suitable and secure mechanisms for sample shipment, the inadequate availability of on-site or in-country laboratory diagnostic facilities, the difficulty of deploying field investigation teams to remote areas, and the countries’ inadequate ability to effectively plan, mobilize, and implement appropriate control measures in such configurations. It has also proven challenging to monitor the progress of control measures in geographically dispersed areas (WHO 2022 B).

It is essential to set up operational sub-national surveillance capabilities in order to identify and successfully combat these disease pitfalls (Van der Giessen et al. 2010). As a result, it is crucial to make investments in strengthening subnational outbreak surveillance and response capacities in countries that are consistently afflicted by these diseases. A significant proportion of the viral pathogens that cause emerging zoonotic diseases in humans have their origins in animals, especially wildlife or goods obtained from animals (Gebreyes et al. 2014). Understanding the epidemiology of these zoonotic diseases and creating viable strategies for control require knowledge of the existence of reservoirs of these diseases beyond human hosts.

It is frequently insufficient and results in a lack of transparency to promptly report new zoonotic diseases to WHO or other international organizations responsible for investigating and addressing potential hazards to global health security (OIE 2008). As a result, it might be difficult for these organizations to comprehend the epidemiology of the diseases, demonstrate the progression of diseases, and discover successful strategies for control in different settings. In some instances, medical authorities in certain countries deny the existence of human cases. This emphasizes the need for more global innovation and collaboration to overcome these issues (Berthe et al. 2018; World Bank 2010). In the section below, we go through a few of the key challenges in controlling zoonotic diseases (Fig 1).

4.1. LIMITED SURVEILLANCE SYSTEMS

The intricate battle against zoonotic diseases hinges significantly on the establishment and sustenance of steadfast monitoring apparatuses (Van der Giessen et al. 2010). The challenge, however, arises in many sectors, predominantly those grappling with a paucity of resources, as the initiation and consistent implementation of wide-ranging surveillance schemes prove taxing (Van der Giessen et al. 2010). The impediments, such as the constraints on resources, subpar infrastructure, and scarcity of skilled workforce, pose substantial hurdles to timely diagnosis and efficient reporting of zoonotic diseases. Augmentation of investment directed towards the reinforcement of surveillance frameworks, initiation of capacity amplification programs, and the generation of platforms for data interchange are all imperative elements in forging a robust response to the stipulations of this problem.

4.2. INTRICACIES OF TRANSMISSION DYNAMICS

The interplay in the transmission of zoonotic infections is inherently multifaceted, with a plethora of hosts, vectors, and environmentally dependent variables in play. The architecture of proficient control mechanisms hinges on the deciphering and comprehension of these intertwined pathways. However, conducting a meticulous dissection of the dynamics governing zoonotic disease transmission presents a formidable challenge, necessitating a confluence of expertise from epidemiology, ecology, and molecular biology. Confronting such formidable obstacles necessitates the synthesis of wisdom across various domains and fostering synergy among the stakeholders in the environmental, animal, and human health sectors (Coker et al. 2011). This collaborative momentum is vital for enhancing our understanding of the transmission mechanisms underlying zoonotic diseases and for fine-tuning the strategies aimed at their control.

4.3. GAPS IN VETERINARY AND PUBLIC HEALTH SYNERGIES

Effective coordination between the veterinary and public health sectors is crucial for the control of zoonotic diseases. However, poor communication and cooperation across these fields of study can prevent quick and well-planned responses to zoonotic disease outbreaks. The establishment of multidisciplinary training programs, the promotion of the One Health approach, and bridging the gap between veterinary and medical experts are vital when trying to solve this obstacle (Lee and Brumme 2013). These measures are critical for enhancing coordination between the veterinary and public health sectors in order to control zoonotic disease outbreaks successfully.

4.4. IMPACT OF ANTIMICROBIAL RESISTANCE ON GLOBAL HEALTH

Globally, antimicrobial resistance (AMR) has a significant impact on the management of zoonotic diseases. The improper use and overconsumption of antimicrobial drugs in both human and animal healthcare systems lead to the emergence and spread of resistant pathogens (Okocha et al. 2018). The limited supply of new antimicrobial drugs makes this problem severe. Antimicrobial stewardship programs must be put in place in order to combat AMR and maintain zoonotic diseases treatment options. Investing in research and development for new antimicrobial drugs and promoting the safe use of antibiotics are two additional important strategies for effectively combating AMR (FAO 2019 A).

4.5. THREAT OF EMERGING AND RE-EMERGING ZOONOTIC DISEASES

Public health systems remain confronted with challenges as a result of the emergence and reemergence of zoonotic diseases (Nii-Trebi 2017). The probability of zoonotic disease outbreaks is enhanced by factors including urbanization, deforestation, trade of wildlife, and climate change (Lindahl and Grace 2015). In order to manage these dynamic and evolving threats, prompt detection, early alert systems, and adaptive techniques are crucial. It is also possible to lessen the hazards brought on by developing zoonotic diseases by investing in research to comprehend the drivers of emergence and by putting preventive strategies in place, such as restrictions on the trade in wild animals and habitat preservation.

Significant obstacles must be overcome in order to effectively manage infectious diseases on a local, national, and international scale. An integrated strategy for controlling zoonotic diseases must address antibiotic resistance, improve coordination between the veterinary and public health sectors, strengthen surveillance systems, and effectively handle emerging challenges (Bidaisee and Macpherson 2014). We can overcome these obstacles and improve our capacity to prevent, detect, and control zoonotic diseases, thereby protecting public health and advancing the welfare of both humans and animals. We can do this by investing in research, innovation, capacity building, and promoting interdisciplinary collaboration (Zinsstag et al. 2011).

5. EVOLVING PARADIGMS IN ZOONOTIC DISEASE CONTROL

The sectors of animal and human health are not yet coherent in their approaches to the prevention and control of zoonotic diseases. For the prevention and management of newly developing zoonotic diseases, there are no initiatives either globally. The region hasn't undertaken any systematic attempts to design any strategy for the management and control of zoonotic diseases and related public health hazards because of a shortage of resources and satisfactory responses from policy makers.

6. PROMISING DEVELOPMENTS IN SUSTAINABLE CURATIVE AND PREVENTIVE TOOLS FOR THE MANAGEMENT OF ZOONOTIC DISEASES

For these diseases to be properly managed and controlled, the development of sustainable preventative and curative strategies seems crucial. This chapter examines how developments in medical science and technology have produced sustainable tools for the management of zoonotic diseases. It also covers the value of diagnostics, treatments, vaccinations, vector control methods, and the One Health strategy in preventing zoonotic diseases and maintaining long-term sustainability.

6.1. DIAGNOSTIC TOOLS

In order to effectively manage a medical issue, an accurate and prompt diagnosis is essential. Sustainable diagnostic methods provide quick and precise diagnosis of zoonotic diseases. By providing great sensitivity and specificity, molecular techniques like polymerase chain reaction (PCR) and next-generation sequencing have revolutionized diagnostics (Barzon, et al. 2011).

Due to their great sensitivity and specificity, molecular diagnostic methods are widely used to identify zoonotic diseases. Pathogen nucleic acids may be quickly and precisely identified using Polymerase Chain Reaction (PCR) and its variants, such as Reverse Transcription PCR (RT-qPCR) and Real-Time PCR (RT-PCR). These techniques are very useful for identifying infectious diseases in both human and animal specimens, including coronaviruses and avian influenza (Cruz et al. 2022).

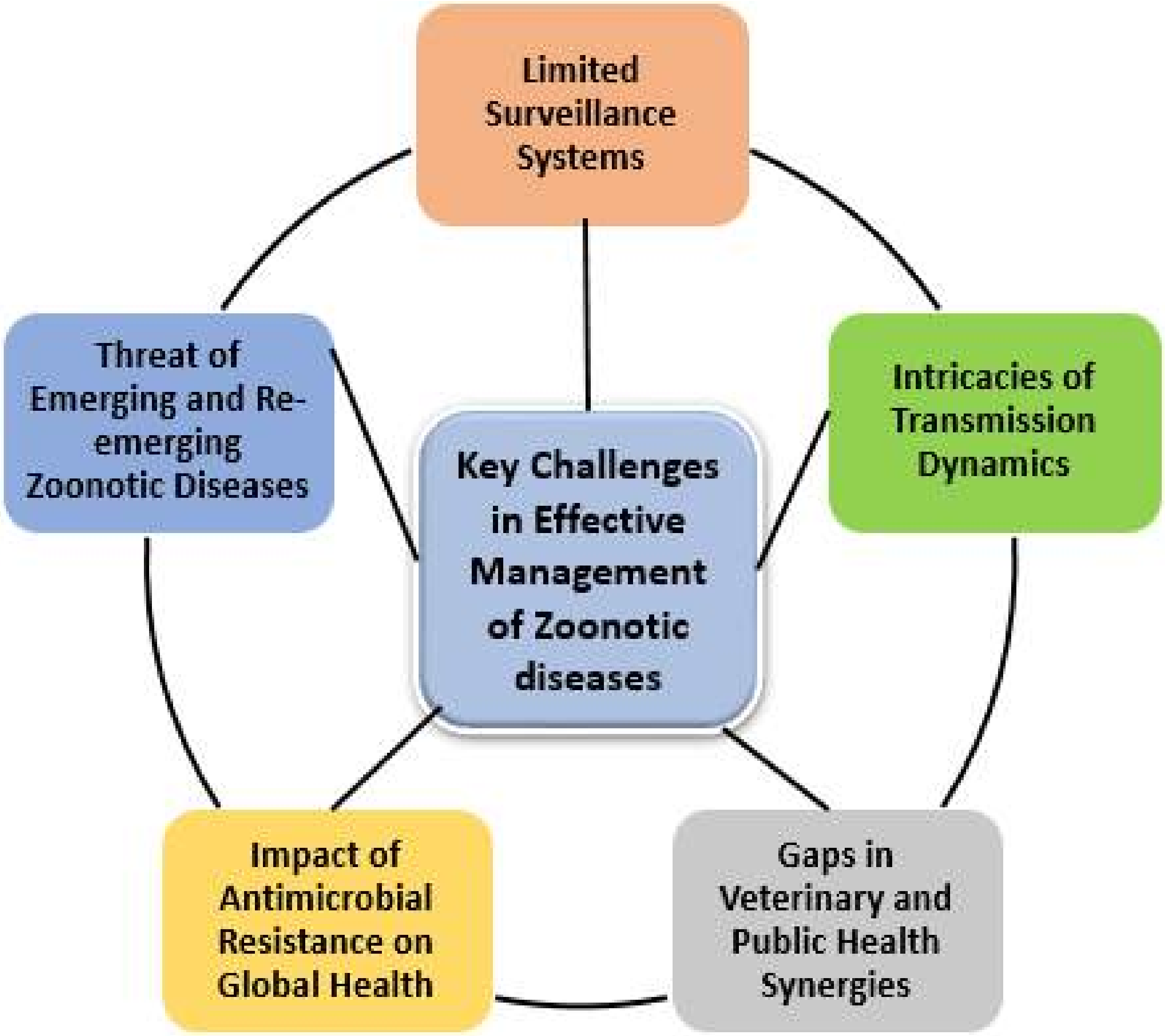

Fig 1: Key Challenges in Effective Management of Zoonotic Diseases.

Serological investigations and point-of-care testing tools have also been crucial in providing rapid and precise diagnosis, especially in contexts with limited resources. Furthermore, novel zoonotic agents may now be found using strong metagenomic sequencing methods, facilitating early diagnosis and prevention. These sustainable diagnostic technologies provide effective disease surveillance, early diagnosis, and targeted therapy approaches (Cruz et al. 2022).

6.1.1. POINT OF CARE TESTING

Improvements in point-of-care testing have transformed zoonotic disease diagnostics, particularly in areas with limited resources. Rapid on-site testing is made possible by portable and user-friendly diagnostic tools, including handheld PCR instruments and lateral flow assays, which do not need a large laboratory setup (Velayudhan T and Hemant K 2022). These tools are crucial during epidemics because they allow for quick action and control efforts.

6.1.2. NEXT GENERATION SEQUENCING

Research and diagnosis of zoonotic diseases now have new directions thanks to next-generation sequencing technology. NGS makes it possible to thoroughly analyze pathogen genomes, making it easier to find genetic variants, virulence factors, and possible resistance to drugs. Furthermore, meta-genomic NGS has streamlined diagnostic procedures and improved our comprehension of complicated zoonotic diseases by enabling the identification of several pathogens in just one specimen (Lu X et al., 2022).

6.1.3. BIOSENSORS AND NANOTECHNOLOGY

The identification of zoonotic diseases has improved because of the incorporation of biosensors and nanotechnology in diagnostic tools. Biosensors have a high sensitivity and speed of detection for certain biomolecules, such as antigens or nucleic acids. Assays using nanoparticles provide better target selectivity and better detection capabilities (Ramakrishnan SG et al. 2021). The development of portable, quick, and affordable diagnostic tools for zoonotic diseases has a lot of promise using these technologies.

6.1.4. SEROLOGICAL ASSAYS

The diagnosis of zoonotic diseases, particularly those brought on by bacteria and certain parasites, still relies heavily on serological testing. Rapid Diagnostic Tests (RDTs) and enzyme-linked immunosorbent assays (ELISAs) are often used to identify particular antibodies in the blood that signify recent or ongoing diseases (Kumar et al. 2018). Serological testing is essential for tracking the incidence of diseases in animal populations, locating possible reservoirs, and determining the threat of human transmission.

The veterinary industry has recently experienced notable improvements in diagnostic methods for the control of zoonotic infections. Molecular approaches, serological tests, point-of-care testing, next-generation sequencing, and the use of biosensors and nanotechnology have all made it possible to better diagnose, treat, and prevent diseases (Velayudhan T and Hemant K, 2022). For successful zoonotic disease management, prompt interventions, and the reduction of public health hazards, sustainable diagnostic technologies must be developed and immediately implemented. Veterinary field stays at the forefront of using cutting-edge methods to fight zoonotic diseases and guarantee a better and healthier future for humans as well as animals as technology advances.

6.2. CUTTING-EDGE THERAPEUTIC INTERVENTIONS FOR IMPROVED OUTCOMES

For the treatment of zoonotic diseases in both humans and animals, the development of sustainable therapeutic interventions is essential. Drugs that are antiviral, antibiotic, anti-parasitic, and antifungal have proven crucial in the fight against zoonotic diseases. The emergence of antibiotic resistance, however, poses a severe danger to the long-term sustainability of these drugs (Okocha et al. 2018).

Responsible use of antibiotics, the creation of alternative therapy decisions, and the implementation of antimicrobial stewardship programs are all examples of sustainable therapeutic techniques. These strategies also reduce the emergence of resistance. The combination of conventional drugs and natural remedies can also support sustainable treatment strategies. This section examines contemporary advancements in veterinary medicine, focusing on novel treatment methods that have fundamentally changed the practice of veterinary medicine.

6.2.1. IMMUNOTHERAPY

In animals, immunotherapy has shown significant potential for treating a variety of malignancies as well as immune-mediated diseases. It is possible to boost the immune system so that it targets and destroys aberrant cells through the use of therapeutic vaccinations and immune modulators. This may lead to better results for cancer patients (Grosenbaugh et al. 2011).

6.2.2. REGENERATIVE MEDICINES

The discipline of veterinary medicine known as regenerative medicine has recently emerged as a potentially fruitful area of study. This subspecialty of veterinary medicine focuses on leveraging the body's natural healing mechanisms in order to repair and regenerate damaged tissues and organs. For instance, therapy with stem cells has shown substantial promise in treating orthopedic problems and boosting tissue regeneration in animal models (Black et al 2007).

6.2.3. PERSONALIZED MEDICINES

The use of personalized medicine in veterinary practice has been made possible by recent developments in molecular diagnostics and genetic testing. It is possible to achieve greater precision and efficacy in therapeutic interventions by customizing therapies according to the genetic make-up of particular individuals (Mellersh 2015).

6.2.4. TARGETED DRUG THERAPIES

Animal disease treatments that use targeted drug therapies, which explicitly target certain biochemical pathways, have had a tremendous amount of success. In comparison to conventional treatments, these therapies are more beneficial and less harmful (London et al. 2009).

With the development of cutting-edge therapeutic interventions, veterinary medicine has significantly advanced, providing hope and improved outcomes for animals suffering from various diseases. These advancements, which range from immunotherapy and regenerative medicine to personalized medicine and less invasive treatments, are a reflection of the veterinary profession's commitment to provide the best possible treatment for animals (Grosenbaugh et al. 2011).

6.3. VACCINES

The prevention of zoonotic diseases continues to be accomplished with great success through vaccination. The development of sustainable vaccines is essential for preventing the spread of zoonotic diseases. These sustainable vaccines are distinguished notably for their great effectiveness, safety, and accessibility. To fight zoonotic diseases, several vaccination platforms have been used over the years. Live attenuated vaccines, inactivated vaccines, subunit vaccines, and vector-based vaccines are only a few examples of the wide variety that these platforms cover. Additionally, techniques for manufacturing vaccines sustainably have emerged, taking into account important factors including thermo stability, cold chain logistics, and cost-effective production. These factors are essential for ensuring that vaccines are widely accessible and distributed fairly, reaching people in need throughout the globe (Bird and Nichol 2012).

6.3.1. INACTIVATED VACCINES

The pathogens in inactivated vaccinations commonly referred to as killed vaccines, have been rendered non-viable by chemical or physical processes. As a result of the viruses' inability to reproduce and spread diseases, these vaccinations are regarded as safe. However, adjuvants may be necessary to boost the immune response in order for them to be effective. The use of inactivated vaccinations against zoonotic diseases, including rabies and certain strains of avian influenza, has proved beneficial (Hemachudha et al. 2018).

6.3.2. SUBUNIT VACCINES

In contrast to entire microorganisms, subunit vaccines use particular antigenic parts of the pathogen. These vaccinations are simple to make using recombinant DNA technology and are safe. They reduce the possibility of negative effects by inducing focused immune responses. Subunit vaccines have shown potential in the fight against zoonotic diseases, including hepatitis B and other diseases transmitted by ticks (Sureau 2019).

6.3.3. LIVE ATTENUATED VACCINES

Live attenuated vaccines include microorganisms that are less virulent than wild-type strains but nonetheless capable of replication. These vaccinations often cause strong immune reactions that endure for a long time and provide durable protection. A rigorous selection of strains and safety testing are necessary due to the possibility of reversion to virulence. Measles, mumps, and certain influenza strains are examples of zoonotic diseases that have been effectively prevented by live attenuated vaccinations (WHO 2022).

6.3.4. VECTOR VACCINES

In order to deliver particular pathogen antigens to the immune system, vector vaccines employ non-pathogenic viruses or bacteria as carriers. These transporters, sometimes referred to as vectors, strongly incite immunological reactions against the transmitted antigens. When combating zoonotic diseases with intricate life cycles, vector vaccines are very helpful. They have shown potential in the fight against diseases, including West Nile virus infections and Lyme disease (van Eijk et al. 2019).
The veterinary field has made incredible strides in creating a variety of vaccinations for zoonotic disease prevention. In terms of security, effectiveness, and focused immune responses, inactivated vaccines, subunit vaccines, live attenuated vaccines, and vector vaccines each have specific benefits (Kaba et al., 2009). The strategic use of various vaccine types becomes essential in protecting both human and animal populations from the devastating effects of zoonotic diseases as zoonotic risks continue to develop (Haas and Petrovsky 2017). The veterinary field continues to play a crucial role in mitigating zoonosis and advancing the security of global health by leveraging the strength of contemporary vaccination technology and upholding a One Health approach.

6.4. VECTOR CONTROL STRATEGIES

Public health is severely compromised by vector-borne diseases that are transmitted through the bites of infected arthropods, such as mosquitoes, ticks, and fleas (WHO 2019). Zoonotic diseases often depend on vectors like mosquitoes, ticks, and fleas for transmission. In order to stop the cycle of disease transmission, it is essential to implement sustainable vector control techniques. It has been proven successful to adopt integrated vector management strategies, which combine the use of insecticides, biological control agents, and genetic modification strategies (Welburn S et al. 2009). In order to reduce vector populations and minimize ecological impact, sustainable vector control measures prioritize environmental management, habitat modification, and community involvement. Long-term sustainability in vector control efforts can be attained through the adoption of integrated strategies that take ecological and social concerns into consideration.

6.4.1. INTEGRATED VECTOR MANAGEMENT

As we delve into the complex realm of vector control, it becomes clear that a multifaceted, interdisciplinary framework, known as Integrated Vector Management (IVM), is the key to success. Uniting a myriad of strategic mechanisms, IVM forms a harmonious orchestra of interventions designed to bring about the reduction of vector populations and thereby, the containment of zoonotic infections.

Consider IVM as a vibrant mosaic. Each piece – or intervention – plays a vital role, and together they form a coherent whole. The centrality of community engagement cannot be overstressed; it is in the social fabric of our societies that we discover the allies needed to halt the growth of vector populations.

Likewise, education serves as an empowering tool, fostering understanding and fueling a proactive stance against vectors. A well-informed society becomes the most potent defense, able to recognize and react to the threats posed by vectors.

Then, there are the carefully calculated applications of pesticides - a tactical component requiring precision. These chemicals, deployed judiciously, act as powerful adversaries to vectors. Not to be overshadowed is the employment of biological control strategies, where the canvas of Mother Nature herself is used to counteract vector proliferation. This approach harnesses the inherent balance of nature to keep vector populations in check.

Lastly, let's draw attention to environmental management. This aspect points to the optimization of our surrounding environment to inhibit vector growth and spread. It is a fascinating piece of the puzzle, bridging the gap between humans, their behavior, and their habitat (WHO 2019).

Hence, Integrated Vector Management embodies a synergistic approach, a chorus of interventions singing the same tune: Decrease vector populations, curtail the spread of zoonotic infections. It is a song of unity, resilience, and ultimately, survival.

6.4.2. BIOLOGICAL CONTROL

Utilizing natural predators, parasites, or pathogens to manage vector populations is known as biological control. For instance, adding fish that feed on mosquito larvae to bodies of water helps prevent mosquito reproduction. Similar to this, controlling tick and flea populations may be accomplished by using parasitoids or entomo-pathogenic fungi (Lacey et al. 2015).

6.4.3. ENVIRONMENTAL MODIFICATION

Controlling vectors requires significant modifications to the environment. Simple actions like eliminating standing water, reducing possible breeding grounds, and enhancing cleanliness may drastically reduce vector populations. Additionally, reducing human-vector interaction and disease transmission may be assisted through habitat alteration and land-use planning (Qualls et al. 2018).

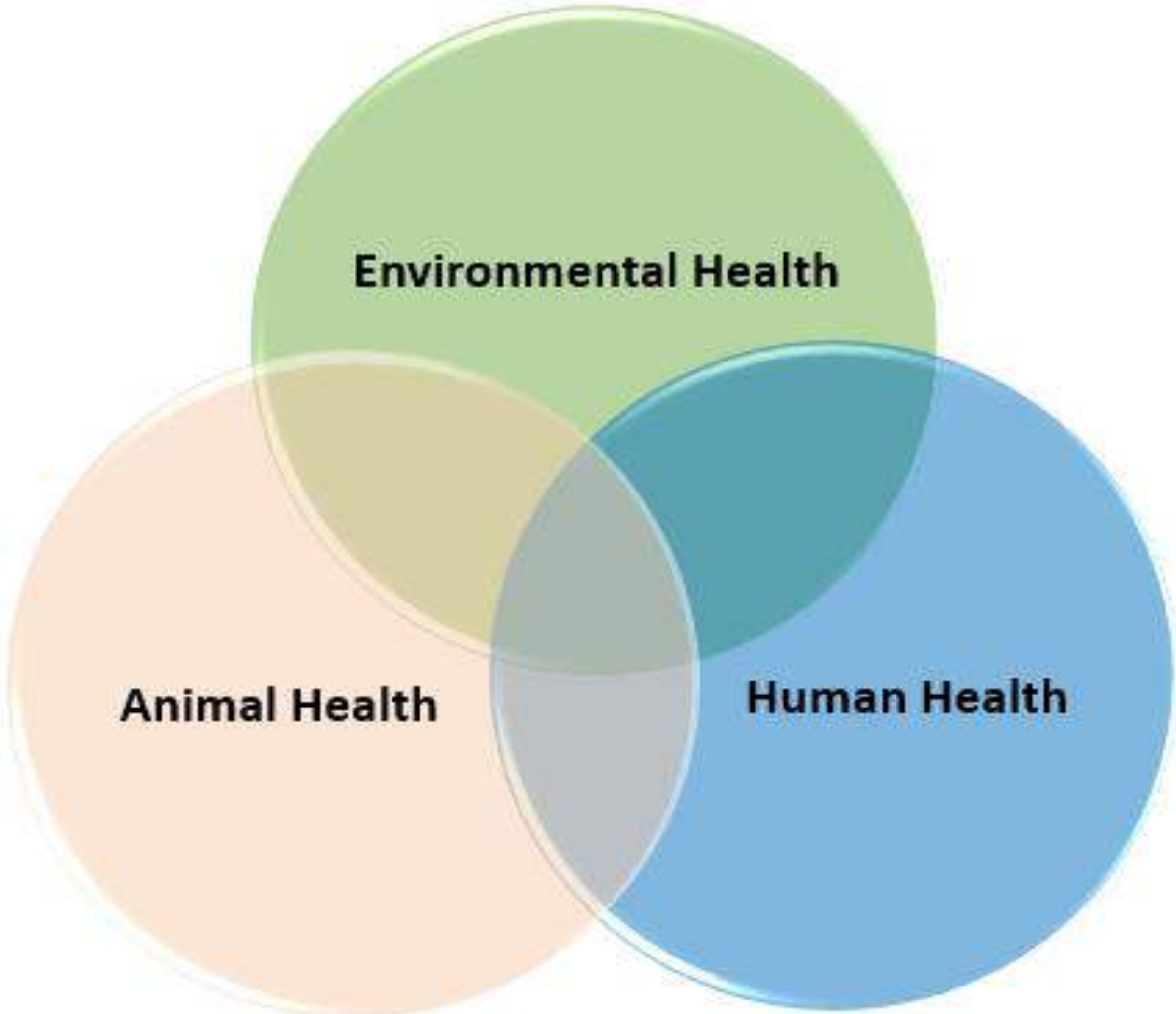

Fig. 2: Components of the one health approach: interdependencies between human, animal, and environmental health.

6.4.4. INSECTICIDE-BASED CONTROL

As a method for managing vectors, insecticide-based control is still crucial. Insecticide-treated bed nets and residual spraying may both help reduce vector populations and halt the spread of diseases. The rise of pesticide resistance, however, emphasizes the necessity for responsible and sustainable use of these agents (Pennetier et al. 2013).

6.4.5. GENETIC CONTROL

With the swift evolution in the sphere of genetic tech wizardry, we are witnessing the dawn of imaginative, avant-garde strategies for the absolute eradication of disease carriers, or as they are scientifically known, vectors. Consider this illustrative scenario: vectors that have undergone a genetic transformation, effectively reducing their capability to transmit diseases - a phenomenon coined as

"vector competence". Or, an equally captivating case - the infusion of sterile vectors, essentially creating a population of vectors that cannot reproduce. What fundamental principle underlies these incredible feats of genetic engineering? It's relatively straightforward - the overall reduction of vector populations (Deredec et al. 2008).
Strategies aimed at controlling vectors are an essential component of programs designed to avoid zoonosis. The competence of the veterinary profession in understanding the biology of vectors and the transmission of diseases is essential for the implementation of comprehensive and sustainable ways to decrease the number of vector populations and restrict the transmission of zoonotic diseases (Qualls et al. 2018). Integrated Vector Management (IVM), which offers a complete framework for coordinating many control techniques, is one example of a new strategy. Other creative approaches, including biological control and genetic control, provide potential avenues for the future of vector management.

6.5. THE ONE HEALTH APPROACH

The One Health strategy recognizes the complex interdependencies between human, animal, and environmental health (Fig 2) in the struggle against zoonotic diseases (Brückner 2009; FAO 2019). Effective cooperation between experts in human health, veterinary medicine, ecology, and policymakers is necessary to ensure the sustainable management of zoonotic diseases. In order to effectively combat zoonotic threats, the One Health strategy promotes multidisciplinary research, makes data exchange easy, and provides policy frameworks. It emphasizes the necessity of responsible animal husbandry, wildlife protection, and sustainable land use practices to prevent and control zoonotic diseases at their source (Zinsstag et al. 2011).

7. CONCLUSION

For effective zoonotic disease control and management, it is crucial to develop sustainable curative and preventive methods. Significant improvements in disease prevention and control have resulted from developments in diagnostics, treatments, vaccinations, vector control strategies, and the adoption of the One Health strategy. Nevertheless, problems including antibiotic resistance, evolving zoonotic challenges, and a lack of resources persist. Strengthening the development and use of sustainable tools requires continued research, innovation, and collaboration across borders. We can successfully manage zoonotic diseases while minimizing adverse environmental impacts, sustaining treatment options, and ensuring the long-term wellness and health of both human and animal populations by investing in sustainable measures.

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Role of Veterinary Students in Propagation of Awareness Regarding the Public Health Education of Zoonotic Diseases

46

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ABSTRACT

The escalating frequency of zoonotic diseases, from SARS to COVID-19, underscores the urgent need for effective measures to diagnose, hinder, and control these biotic catastrophes. Public health education plays a pivotal role in enlightening individuals about the threats posed by zoonotic diseases, making it imperative to empower communities with the intellectual tools to combat these maladies. Within this landscape, veterinary scholars emerge as crucial torchbearers, equipped with profound knowledge of animal well-being, diseases, and the intricate interdependence between humans and the animal kingdom. Veterinary students, operating beyond the conventional boundaries of veterinary medicine, bridge the gap between human and animal health. Their interdisciplinary training in the principles of One Health provides them with a unique perspective on zoonotic diseases, considering factors like wildlife reservoirs, ecological change, and socioeconomic drivers of disease transmission. Leveraging this perspective, they engage in a variety of strategies and initiatives to disseminate knowledge about zoonotic diseases, including community workshops, seminars, and digital platforms. Despite their crucial role, veterinary students face challenges in implementing comprehensive awareness campaigns, such as limited funding and resources, public misconceptions, resistance to behavioral change, and cultural and socioeconomic concerns. However, their passion and dedication, coupled with collaborative efforts, can overcome these challenges and make substantial contributions to mitigating the risks associated with zoonotic diseases.

This chapter sheds light on the indispensable role of veterinary students in propagating awareness about zoonotic diseases, examining effective initiatives and considering suggestions to enhance their involvement in public health education. Veterinary students contribute significantly to disease prevention and control by utilizing their unique knowledge, abilities, and enthusiasm, ensuring a safer and healthier future for both humans and animals.

Key words: Zoonotic diseases, Veterinary students, Public health education, One Health, Community engagement, Digital platforms, Disease prevention and control, Interdisciplinary training.

CITATION

Saleem MI, Mahfooz A, Khan MS, Ramzan F, Zaka F, Nazar M, S Ali, Saleem MW, Sultan T and Ahmad A, 2023. Role of Veterinary Students in Propagation of awareness regarding the Public Health education of Zoonotic diseases. In: Khan A, Abbas RZ, Hassan MF, Aguilar-Marcelino L, Saeed NM and Mohsin M (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 627-642. https://doi.org/10.47278/book.zoon/2023.046

CHAPTER HISTORY Received: 26-Jan-2023 Revised: 19-March-2023 Accepted: 21-May-2023

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1. INTRODUCTION

In the present chronicle of our planet, we have witnessed the emergence of several zoonotic maladies with an escalating frequency, from the devastation wrought by severe acute respiratory syndrome (SARS) to H1N1 Influenza (Liu et al. 2020), and then the onslaught of Middle East Respiratory Syndrome (MERS) (dos S Ribeiro et al. 2022), Ebola (Shang et al. 2023), culminating in the contemporary plague of COVID-19. This series of biotic catastrophes underscores the compelling urgency for actionable steps to diagnose, hinder, and control zoonotic diseases. The provision of enlightenment, thereby endowing individuals with the necessary intellectual artillery to counteract the threats of these maladies, stands as a crucial ambition of public health education (Pellegrini et al. 2022).

In this landscape of necessary enlightenment, scholars of veterinary science emerge as pivotal torchbearers in dispersing the understanding of zoonotic ailments as an integral facet of public health education. Their intellectual reservoir concerning animal wellbeing, diseases, and the complicated interdependence between Homo sapiens and the animal kingdom is of profound breadth and depth. Their rigorous training capacitates them with the requisite acumen and prowess to decipher, avert, and control zoonotic diseases, thereby situating them as potent emissaries of public campaigns engineered to elevate societal consciousness about zoonotic illnesses (Wu et al. 2023).

Operating within an expansive scope that transcends the conventional boundaries of veterinary medicine, these budding veterinarians are uniquely positioned to erect a bridge spanning the health of humanity and the animal kingdom, serving as potent agents for societal metamorphosis. Their potential to educate varied demographic groups, ranging from their academic counterparts and animal caregivers to healthcare mavens and the broader citizenry, stems from their profound comprehension of zoonotic maladies and the communicative proficiency to relay this understanding (Becker 2003). By interfacing with these diverse stakeholders, veterinary scholars can inculcate a more nuanced comprehension of zoonotic disease hazards and the salience of preventive stratagems.

The potential veterinarians also stand advantaged as they weave through the complex tapestry of zoonotic diseases. They have a unique perspective on zoonotic diseases because of their training in the principles of One Health, an interdisciplinary philosophy that acknowledges the symbiotic relationship between human, animal, and environmental health. This perspective allows them to view zoonotic diseases holistically, taking into account factors like wildlife reservoirs, ecological change, and socioeconomic drivers of disease transmission (Nyatanyi et al. 2017).

To effectually disseminate knowledge about zoonotic diseases, veterinary scholars engage a plethora of strategies and initiatives. By forging alliances with community assemblies, educational establishments, and universities, they catalyze community engagement via the conduits of workshops, seminars, and awareness crusades (Becker 2003). Embracing the digital zeitgeist, they generate educational content on blogs, websites, and social media to disseminate critical insights and engage a broader demographic. Concurrently, they contribute to the compilation and scrutiny of data for research and surveillance programs, thereby enriching our understanding of zoonotic disease dynamics and shaping data-driven public health initiatives.

While veterinary students are essential in propagating awareness, in their endeavors they often encounter obstacles. The implementation of the Comprehensive awareness campaigns may be hampered due to a lack of funding and resources (Becker 2003). Additional challenges include factors like overcoming public misconceptions, overcoming resistance to behavioral change, and addressing cultural and socioeconomic concerns. The passion and devotion of veterinary students, together with cooperative efforts among stakeholders, may overcome these challenges and make a substantial contribution to mitigating the risks associated with zoonotic diseases (Becker 2003).

This chapter aims to shed light on the crucial role veterinary students' play in propagating awareness regarding zoonotic diseases and their implications for public health education by examining effective initiatives undertaken by them and comprehending the advantages they provide. In addition, it considers suggestions on how veterinary schools and students might improve their involvement in public health education, fortify their collaborations, and ultimately assist in preventing and managing zoonotic diseases.

2. UNVEILING THE INVISIBLE THREAT: DECODING THE COMPLEXITY OF ZOONOTIC DISEASES AND THEIR PUBLIC HEALTH IMPACT

2.1. UNDERSTANDING THE DEFINITION AND NATURE OF ZOONOTIC DISEASES

Zoonosis (also known as zoonotic diseases) is an infectious disease spread from animal to human by pathogens such as bacteria, viruses, parasites, or fungi (Rahman et al. 2020). These diseases have the capacity to cross species barriers, allowing the viruses to spread from animals to people or vice versa (Fig. 1). Zoonotic diseases can appear in several different ways, such as through close contact with sick animals (Woolhouse and Gowtage-Sequeria 2005), consuming contaminated food or water (Newell et al. 2010), being exposed to contaminated environments, or by vector-borne transmission.

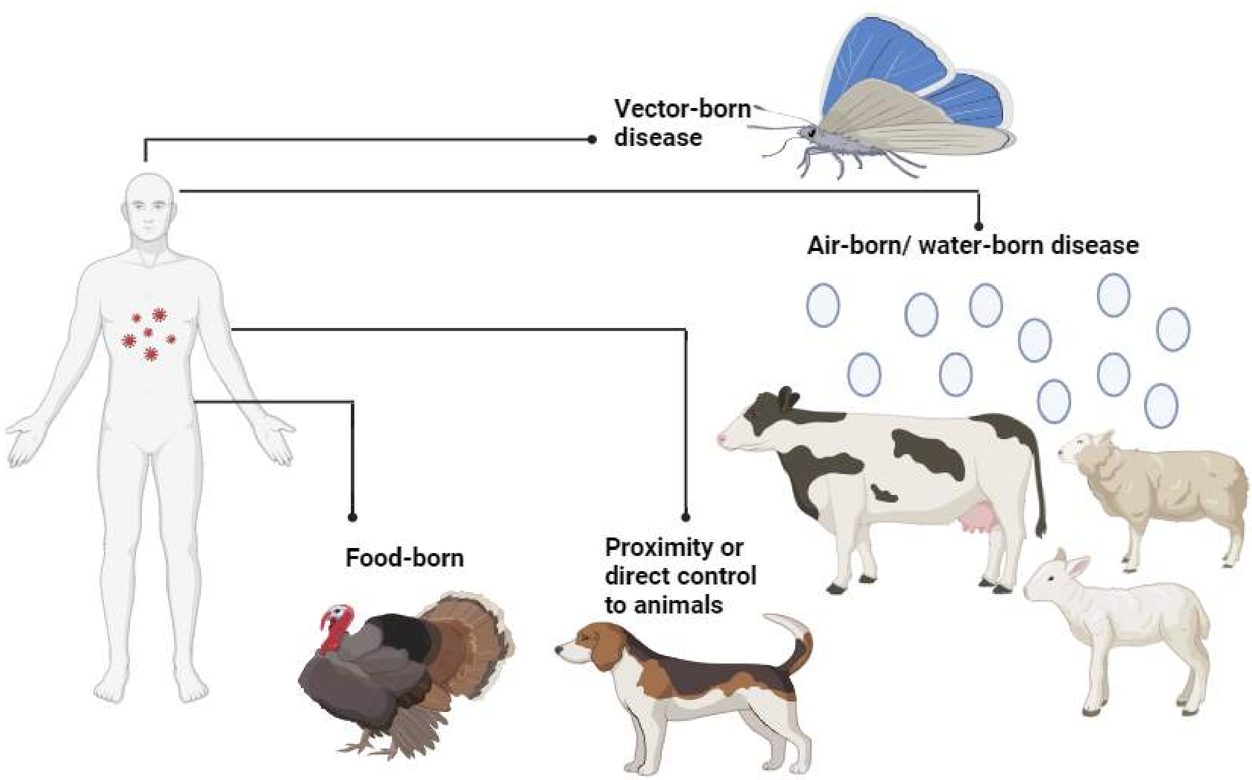

Fig. 1: Transmission of Zoonotic diseases (Created with BioRender.com).

3. ZOONOTIC THREATS UNCOVERED THROUGH KEY EXAMPLES OF PATHOGENS AND THEIR LIKELY IMPACT ON PUBLIC HEALTH

3.1. RABIES

As a viral zoonotic disease, rabies is usually transmitted through the bite or scratch of an infected animal, such as a dog, bat, or other wildlife (Fooks et al. 2017). It has an impact on the central nervous system and is virtually always lethal if left untreated. Particularly in areas lacking dog vaccination programs, rabies is a serious public health concern.

3.2. BIRD FLU

Influenza, colloquially dubbed "Bird Flu", is a malady anchored in the realm of influenza viruses, predominantly exerting their pathogenic prowess over avian species. Nevertheless, intriguing inter-species permeability exists in this biosphere, permitting a selection of these avian influenza viral strains to leap over their customary domain, breaching into Homo sapiens, the human species (Liu et al. 2020). The result potentially grave afflictions of the respiratory system. The primary highways for this viral journey into human hosts pivot around two fundamental routes. The first encompasses the ingestion of poultry-based products, tainted by the stealthy presence of this virus (Alexander 2007). Secondly, a proximate association with avian species under the influence of this illness, particularly poultry, stands as another key bridge that facilitates this viral incursion (Alexander 2007). Despite its moniker, the bird flu isn't confined to the aviary world but rather can clandestinely traverse to humans, igniting severe respiratory disorders. Thus, maintaining a keen eye on our dietary choices and the birds we interact with, particularly of the poultry variety, remains pivotal.

3.3. LYME DISEASE

Borrelia burgdorferi is the bacterium responsible for Lyme disease, a zoonotic disease transmitted by ticks (Magnavita et al. 2022). Primarily Ixodes scapularis and Ixodes pacificus, two types of black-legged ticks that have been infected, bite humans, and transmit disease, if left untreated, Lyme disease can cause a variety of symptoms, such as a skin rash, tiredness, joint discomfort, and neurological issues (Magnavita et al. 2022).

These examples emphasize the variety of zoonotic diseases and the potential implications they may have on the general public's health. For efficient prevention, early diagnosis, and control strategies, it is essential to understand the mechanisms of transmission, reservoir hosts, and clinical symptoms of zoonotic diseases. Public health authorities and veterinary professionals can develop tailored treatments that mitigate the risks and effects associated with zoonotic diseases by recognizing the specific characteristics of these diseases.

Table 1: Zoonotic diseases, their characteristics and considerations.

Zoonotic Disease	Causative Agent	Morbidity/Mortality	Economic loss	Vaccination
Influenza	Influenza A, B, C Viruses	Moderate Morbidity	Moderate	Available
Lyme disease	Borrelia burgdorferi	Moderate Morbidity	Moderate	Available
Rabies	Rabies virus	High Mortality	High	Available
Ebola Virus disease	Ebola virus	High Mortality	High	Experimental
Covid-19	SARS-CoV-2	Variable	High	Available

3.4. PUBLIC HEALTH IMPLICATIONS

Zoonotic diseases pose major implications for public health since they affect both healthcare systems and human populations (Rahman et al. 2020). Implementing efficient preventative strategies and assigning appropriate resources to prevent and control zoonotic diseases require an understanding of these consequences.

3.5. IMPACT ON HUMAN HEALTH

Zoonotic diseases, which can result in varying degrees of morbidity and mortality, can have a considerable influence on human health. The pathogen involved, the mode of transmission, the susceptibility of the host, and the accessibility of medical interventions are only a few examples of the factors that affect how severe the impact is. While some zoonotic diseases might result in mild illness, others can have severe or even life-threatening consequences (Liu et al. 2020).

If timely medical attention is not sought, certain zoonosis, like rabies, can have a high case fatality rate. Others, such as human-virulent strains of avian influenza, have the ability to spread quickly and widely and cause severe morbidity and mortality. As an illustration, the H5N1 avian influenza virus has caused numerous human cases and has a high fatality rate in the afflicted areas (Liu et al. 2020).

Besides having an immediate impact on human health, infectious diseases can also have consequences that persist. If an infection, such as Lyme disease, is not properly diagnosed and treated, it might result in persistent symptoms and consequences. A further complicating public health initiative is the emergence of antibiotic resistance among zoonotic infections, which poses an imminent threat to effective treatment (Jordan 2019).

4. COUNTING THE COSTS: ANALYZING THE ECONOMIC BURDEN OF ZOONOTIC DISEASES ON HEALTHCARE SYSTEMS

Zoonotic diseases impose an immense burden on the world's healthcare systems (MacLachlan and Dubovi 2011). The expenditures associated with control, diagnosis, treatment, and preventive measures might be high. The monetary magnitude of this burden includes spending on monitoring, research, public health initiatives, the infrastructure of the healthcare system, and the development of treatments and vaccinations.

Direct medical expenses are just one aspect of the economic impact. Zoonotic disease epidemics can cause economic disruptions by reducing agricultural output, causing lost workdays, and lowering productivity (Pénzes et al. 2022). For instance, zoonotic disease epidemics in livestock can cause enormous financial losses for farmers, compromising their livelihoods and food security. Costs related to public health response measures, such as quarantine, monitoring systems, and communication campaigns to promote preventive measures, are also included in the economic burden.

A comprehensive strategy that includes preventive measures, early detection, effective treatment, and cooperative efforts between the human and animal health sectors must be implemented to address the financial burden of zoonotic diseases. For prompt identification and response to zoonotic disease outbreaks, it is essential to invest in research, surveillance, and public health infrastructure (MacLachlan and Dubovi 2011). This will ultimately mitigate the financial burden on healthcare systems and societies across the globe.

Governments, public health organizations, and healthcare systems may allocate resources and create policies to prevent, detect, and effectively respond to these diseases by acknowledging the major public health consequences and financial burden of zoonotic diseases. In order to protect human health and lessen the economic effects of these diseases, comprehensive zoonotic disease management programs must include efficient surveillance systems, multidisciplinary collaboration, and public health education campaigns (Becker 2003).

5. FROM ASPIRING TO INSPIRING: THE DISTINCTIVE IMPACT OF VETERINARY STUDENTS

Veterinary students are uniquely equipped to contribute significantly to the propagation of knowledge about zoonotic diseases since they have a thorough understanding of animal health and diseases. As a result of their specialized education and training, they have a thorough understanding of many facets of animal health, including anatomy, physiology, pathology, epidemiology, and infectious diseases.

As part of their education, veterinary students receive thorough training in zoonotic disease prevention, surveillance, and control. They study the tenets of One Health, which emphasizes the importance of collaboration between veterinary and human healthcare practitioners and the interconnection of human, animal, and environmental health (Gebreyes et al. 2014).

To fend off the menace of diseases jumping species, or zoonotic ailments, a robust pedagogical framework is introduced which underlines the comprehension of catalysts for disease outbreak and dispersion, coupled with strategies to curtail the associated risks. Aspiring veterinarians investigate into the multifaceted transmission avenues of these zoonotic diseases, spanning direct animal-human interaction, ingestion of tainted food or water resources, propagation through carrier organisms, or the indirect influence of the broader environment (MacLachlan and Dubovi 2011). It's instilled in them the salience of rigorous hygiene rituals, the use of personal defensive gear, and the adherence to strict biosecurity measures, all converging to form a bulwark against the proliferation of zoonotic maladies.

Within this intricate mosaic of veterinary instruction, students cultivate the proficiency to identify, explain, and disseminate information regarding zoonotic diseases within surveillance frameworks (MacLachlan and Dubovi 2011). The curriculum equips them to discern clinical manifestations, undertake diagnostic examinations, and interpret lab findings indicative of zoonotic infections. These competencies serve to fortify rapid response systems and promote proactive detection mechanisms, thereby helping stifle the inception and onward march of these outbreaks.

Furthermore, the curricular endeavors aimed at buffering against the onslaught of zoonotic diseases involve training veterinary students in the application of control strategies. These range from composed vaccination drives, to the formulation of treatment blueprints, and the implementation of optimal management methodologies. An integral part of this instruction involves honing the communication and counselling abilities of the students, enabling them to relay information about zoonotic diseases to a varied audience, which includes pet owners, public health custodians, and the wider community (Wu et al. 2023).

Beyond this, they are indoctrinated in the nuances of outbreak investigation and response mechanisms, with interdisciplinary collaboration being a cornerstone of this learning process. The students acquire an understanding of how to operate in cross-functional teams composed of epidemiologists, public health mavens, and environmental scientists to undertake epidemiological research, roll out control initiatives, and gather and analyze data for the management of these diseases.

Veterinary students are effective advocates for the prevention and management of zoonotic diseases due to their extensive knowledge and skills. Their knowledge enables them to bridge the gap between scientific understanding and common comprehension by making difficult subjects transparent and understandable. Veterinary students can play a critical role in raising awareness, encouraging proactive measures, and working with other healthcare professionals to mitigate the dangers connected with zoonotic diseases by utilizing their specialized expertise (Wu et al. 2023).

5.1. CHAMPIONING HEALTH: PROMOTING ADVOCACY FOR ZOONOTIC DISEASE PREVENTION

Veterinary students play a significant role as advocates for public health education, particularly in promoting awareness regarding zoonotic diseases (Kahn 2006). They are in a unique position to advocate for zoonotic disease prevention and control strategies both within the veterinary community and among the general public due to their future careers as veterinary practitioners.

As advocates, veterinarians, due to the knowledge and expertise they possess, are well-equipped to inform and involve a variety of stakeholders in conversations about zoonotic diseases. They are able to articulate the significance of preventing zoonotic diseases while highlighting the shared accountability of the veterinary and human healthcare sectors. By advocating for a One Health strategy, veterinary students encourage collaboration among veterinary experts, public health authorities, legislators, and the community in order to fully address the difficulties posed by zoonotic diseases (Nyatanyi et al. 2017).

The scientific underpinnings of infectious diseases and their impact on human and animal health are well understood by veterinarians. They can bridge the gap between scientific research and common comprehension by clearly and simply expressing complicated scientific facts. For raising awareness and encouraging behavioral changes that can prevent the spread of zoonotic diseases, this ability to convert scientific information into messages that people can actually take action on is critical.

Veterinary students use a range of communication tools in their advocacy campaigns to involve both the veterinary profession and the general public. Through professional networks, veterinary organizations, and academic platforms, they may share knowledge with other students, practicing veterinarians, and other veterinary stakeholders. Additionally, veterinary students have opportunities to participate in conferences, workshops, and seminars where they may share their expertise and experiences, furthering the communication of knowledge about zoonotic diseases.

In addition, veterinary students have the ability to interact well with the general public. To spread the word about zoonotic diseases and preventive measures, they can collaborate with local agencies, public health organizations, educators, and pet owners. Veterinary students can educate people about zoonotic disease risks, transmission motifs, and doable preventive measures through community outreach programs, including public speeches, workshops, and awareness campaigns. Veterinarians may significantly increase the effectiveness of their advocacy efforts by tailoring their communication strategies to the unique requirements and contexts of varying audiences (Shanko et al. 2015).

In addition, veterinary students frequently interact directly with pet owners, giving them the chance to talk about zoonotic disease prevention on an individual basis. They can impart knowledge on zoonotic disease prevention practices, excellent animal hygiene, vaccination protocols, and responsible animal care practices to pet owners, livestock producers, and others (Shanko et al. 2015). Veterinary students help foster a better and safer environment for humans as well as animals by arming pet owners with resources and knowledge (Shanko et al. 2015).

In conclusion, veterinary students act as advocates for the prevention of zoonotic diseases, leveraging their knowledge and communication abilities to engage and educate both veterinarians and the general public. They are crucial for raising awareness, encouraging behavioral changes, and fostering collaborative efforts to stop the propagation of zoonotic diseases because of their capacity to effectively communicate scientific facts and tailored messages to various audiences. Through their advocacy, veterinary students significantly contribute to the development of a society that is knowledgeable, pro-active, and resistant to zoonotic diseases.

6. SPREADING THE MESSAGE: EFFECTIVE STRATEGIES FOR RAISING AWARENESS

6.1. ENGAGING WITH THE LOCAL COMMUNITY

Veterinary students use community involvement as a potent strategy to raise awareness of zoonotic diseases and promote preventative measures. By building collaborations with local community organizations, schools, and colleges, veterinarians can effectively reach a broader audience and disseminate information (Suu-Ire et al. 2021).

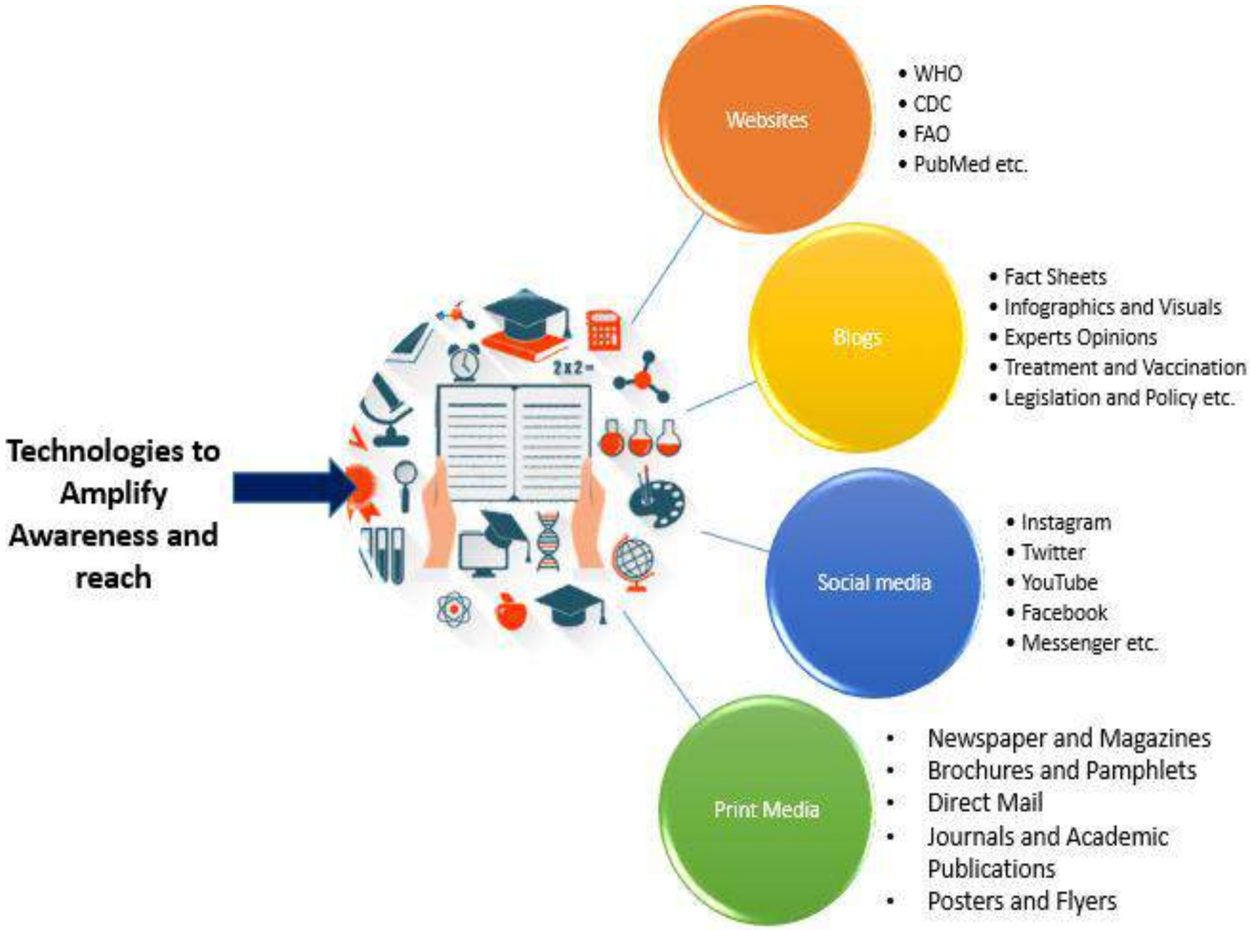

Fig. 2: Information Technologies for awareness and outreach of Zoonotic diseases.

Conducting interactive workshops, seminars, and awareness campaigns on zoonotic disease prevention is one successful strategy. To plan teaching sessions, veterinary students can work with nearby educational institutions, community centers, and public health organizations. These gatherings may feature hands-on activities, live performances, and panel discussions that actively involve attendees and deepen their knowledge of zoonotic diseases. Veterinary students can emphasize critical topics such as zoonotic disease transmission pathways, typical risk factors, and viable preventative techniques in these workshops and seminars. They may offer details on safe animal handling, responsible pet ownership, vector control, and proper hygiene practices. Veterinary students may dispel myths, respond to inquiries, and foster a supportive atmosphere for information exchange by facilitating open discussions. Veterinary students may develop and disseminate educational materials, including pamphlets, information sheets, and infographics, to further enhance awareness. These materials ought to be simple, clear, and suited to the intended audience. They can draw attention to crucial details concerning zoonotic diseases, such as typical signs and symptoms, preventive measures, and the need for early diagnosis and treatment. These resources may be made more accessible and widely available by being distributed in public places like schools, veterinary clinics, and community centers (Suu-Ire et al. 2021).

Additionally, to spread awareness of zoonotic diseases, veterinary students might work with regional media sources, including newspapers, radio stations, and community newsletters. To communicate proper information and address any misconceptions, they might offer articles, interviews, or conversations. Leveraging online resources like social media, websites, and blogs helps expand the audience for their message. Veterinary students may successfully engage with a broader audience and promote knowledge sharing and conversations by producing relevant and interesting material. Furthermore, veterinary students can actively take part in community fairs and events by setting up booths or informational stations to raise awareness of zoonotic diseases. They may provide community members with free animal health examinations, provide educational information, and have one-on-one discussions to address any concerns or inquiries that individuals might possess. Through these collaborative opportunities, veterinary students may directly influence the knowledge and behaviors of community members while also fostering personal relationships. Veterinary students successfully propagate awareness about zoonotic diseases by interacting with the local community through partnerships, interactive workshops, lectures, and the distribution of educational materials. These strategies not only offer useful information but also give community members the capacity to take preventive measures. Through coaching and cooperation, veterinary students can establish a chain reaction that raises public awareness and encourages good behavioral changes that make the world a safer and healthier place for humans as well as animals (Suu-Ire et al. 2021).

6.2. DIGITAL FRONTIERS: LEVERAGING TECHNOLOGY TO AMPLIFY AWARENESS AND REACH

Veterinary students have realized the enormous potential of digital platforms to raise awareness of zoonotic diseases in the connected world of today (Fig 2). Veterinary students can successfully spread knowledge about zoonotic diseases, increase awareness, and interact with a variety of audiences through the utilization of websites, blogs, social media campaigns, and other digital resources (Leung et al. 2021). Veterinary students can impart thorough knowledge to the public by developing informative websites and blogs about zoonotic diseases. With materials like fact sheets, frequently asked questions, and updates regarding emerging zoonotic disease risks, these platforms may operate as centralized knowledge centers. Veterinary students may leverage their scientific knowledge to deliver factual information in a way that is both clear and intelligible, empowering visitors with the information they need to safeguard themselves and their animals. The transmission of current and pertinent information is ensured through routine content updates.

Campaigns on social media are extremely important for reaching new audiences and raising awareness of zoonotic diseases (Leung 2021). In order to interact with a variety of demographics, veterinary students may create social media profiles on platforms like Facebook, Twitter, Instagram, and YouTube. Veterinarians may deliver important lessons in an interesting and simple-to-understand way by sharing educational videos, infographics, and articles. These multimedia sources can provide information on a variety of topics, such as case studies, personal testimonies, and updates on new occurrences of zoonotic diseases. The use of aesthetically appealing material aids in grabbing the audience's attention and promotes social sharing, boosting the campaign's reach to a greater extent.

Social media platforms also provide chances for engagement and tailored messages (Lakan and Yani 2021). Veterinary students might modify their coursework to appeal to particular groups or communities in order to address their particular issues and cultural contexts. For instance, they might target certain cultural practices that affect the transmission of zoonotic diseases or create content in multiple languages to reach members of other language groups. Veterinary students foster a sense of community while establishing themselves as trustworthy sources of information by actively responding to the comments, inquiries, and concerns of their followers. This interactive method promotes debate, boosts participation, and magnifies the effect of their digital campaigns for advocacy.

In order to expand their reach, veterinary students may collaborate with influential individuals, groups, and stakeholders digitally. They can tap into current networks and leverage their collective influence to promote zoonotic disease awareness by collaborating with animal welfare organizations, public health organizations, or well-known social media personalities with an interest in veterinary medicine (Leung et al. 2021). Through joint initiatives, veterinary students may interact with people who might not typically seek information about zoonotic diseases and reach out to new audiences. It's essential for veterinary students to keep updated on the most recent advancements in digital communication technologies. Emerging technologies like virtual reality, live streaming, and interactive webinars may be used to enhance participation and create immersive learning environments. Veterinary students can have the biggest influence on the propagation of awareness about zoonotic diseases by embracing innovation and adapting to evolving media platforms.

In conclusion, veterinary students may effectively disseminate knowledge about zoonotic diseases, increase awareness among various groups, and interact with them by using digital platforms, including websites, blogs, social media campaigns, and multimedia resources (Leung et al. 2021). These platforms make it possible to deliver targeted messages, foster discussions, and effectively share educational information. Veterinary students can significantly contribute to the empowerment of individuals throughout the world and the prevention and management of zoonotic diseases by harnessing the possibilities of digital communication.

6.3. ACTIVE PARTICIPATION IN RESEARCH AND SURVEILLANCE

In order to aid in the understanding, prevention, and management of zoonotic diseases, veterinary students actively participate in research and surveillance. Veterinary students make a substantial contribution to knowledge advancement and the improvement of monitoring and reporting systems by assisting with data collection and analysis, writing for research publications, and working with public health organizations.

6.3.1. ASSISTING IN DATA COLLECTION AND ANALYSIS

The role veterinary students’ play in the meticulously crafted tableau of research on zoonotic diseases is not merely tangential but considerably substantial. They delve into this scientific endeavor by aligning their efforts with those of seasoned researchers, astute epidemiologists, and public health connoisseurs in the intricate process of garnering and decrypting data pertaining to zoonotic maladies (Leung et al. 2021). This could encompass a spectrum of tasks - executing empirical investigations in the field, procuring samples from the animal kingdom and their habitats, and collaborating in the laboratory for assaying and data dissection.

These bright, young minds act as a pivot in deciphering the mysteries of zoonotic infections - not only illuminating the characteristics and precise identification of these diseases but also revealing the prevalence and transmission risk factors in their full scope. Further elevating their contribution, veterinary students are integral to the generation of indispensable evidence, a critical element for erudite decision-making and efficacious public health stratagems, achieved through their active participation in data procurement endeavors.

6.3.2. CONTRIBUTING TO RESEARCH PUBLICATIONS

Veterinarians have the chance to participate in research publications related to zoonotic diseases. To analyze data, understand findings, and reach meaningful conclusions, they collaborate with professors, researchers, and fellow students. By adding to the corpus of scientific knowledge on zoonotic diseases, veterinary students can influence public health policies and practices. Their participation in research publications enables them to share insightful knowledge, support evidence-based interventions, and foster worldwide awareness of zoonotic diseases (Bonilla-Aldana et al. 2020).

6.3.3. COLLABORATING WITH PUBLIC HEALTH AGENCIES

In order to improve zoonotic disease surveillance and reporting systems, veterinary students collaborate with public health agencies. They collaborate with regional, international, and local public health organizations to share information, contribute data, and aid in surveillance initiatives. By cooperating with one another, veterinary students improve the early identification and quick response to zoonotic disease epidemics. They collaborate with experts in public health to develop protocols for surveillance, improve reporting mechanisms, and improve data exchange and analysis. Veterinary students strengthen the entire surveillance infrastructure and improve their ability to successfully monitor and manage zoonotic diseases by actively participating in these collaborative efforts.

Concomitantly, animal health custodians, in their role as veterinarians, can integrate their expertise into 'One Health' programs. These initiatives underscore a crucial transdisciplinary collaboration that weaves together the strands of human and animal health domains (Bonilla-Aldana et al. 2020). An interesting facet of this fusion is the potential role of veterinary scholars who, through their intellectual input, can cultivate a synergistic methodology towards the study, surveillance, and understanding of diseases that transcend species barriers, known as zoonotic diseases.

Engaging in a dynamic consortium with epidemiologists, human health maestros, environmental science specialists, and a potpourri of relevant stakeholders allows them to discern the intricate web of relationships that underpin human, animal, and environmental health. It is through this discernment that the expansive panorama of zoonotic disease dynamics unravels itself, empowering us with the insight to devise robust strategies for efficient disease prevention and their astute management. This integrated approach underscores the entwined fate of all living entities and the ecosystems they inhabit, facilitating a deep-rooted comprehension that can only arise from such symbiotic collaborations (Suu-Ire et al. 2021).

Veterinary students contribute to the collective understanding of zoonotic diseases by actively participating in research and surveillance operations. Their participation in data collection, analysis, and research publication contributes to the improvement of public health practices and policies. Additionally, their partnerships with public health organizations strengthen monitoring systems, enhancing the ability to monitor and efficiently handle zoonotic disease epidemics. The advancement of knowledge and the use of evidence-based strategies for zoonotic disease prevention and control are greatly aided by the contributions made by veterinary students.

7. THE MULTIFACETED JOURNEY OF VETERINARY STUDENTS: BENEFITS AND CHALLENGES

7.1. PERSONAL AND PROFESSIONAL BENEFITS

Veterinary students can gain a variety of personal and professional advantages through the propagation of knowledge about zoonotic diseases. It is advantageous for veterinary students to be actively involved in raising awareness for the following reasons:

7.1.1. ENHANCING VETERINARY KNOWLEDGE AND SKILLS

Veterinary students can put their theoretical learning into practice by participating in zoonotic disease awareness campaigns. Veterinary students gain practical experience in zoonotic disease prevention, monitoring, and control by working closely with animals, participating in field surveys, and cooperating with public health specialists. Their veterinary knowledge and abilities are improved by this practical application, which also helps them better comprehend zoonotic diseases and prepare for challenges they might encounter in the future (Shanko et al. 2015).

7.1.2. BUILDING STRONG RELATIONSHIPS WITH THE COMMUNITY AND PUBLIC HEALTH PROFESSIONALS

Veterinary students can forge enduring relationships with fellow citizens, animal owners, and public health specialists by participating in community outreach initiatives for zoonotic disease awareness. Veterinary students establish themselves as trustworthy resources by actively listening to community problems, responding to their inquiries, and offering helpful guidance. These connections promote mutual respect and cooperation among veterinary students and the community, encouraging future involvement and fostering a spirit of shared accountability in the fight against zoonotic diseases (Shanko et al. 2015).

7.1.3. CONTRIBUTING TO THE OVERALL PREVENTION AND CONTROL OF ZOONOTIC DISEASES

Veterinary students contribute to the overarching objective of preventing and controlling these diseases by actively contributing to the propagation of knowledge about zoonotic diseases. Their efforts are essential for disseminating accurate knowledge, encouraging behavioral modifications, and enabling people and communities to take preventive measures. Veterinary students promote responsible pet ownership, proactive zoonotic disease prevention, and public awareness through their advocacy and educational initiatives (Shanko et al. 2015). Their efforts directly affect mitigating zoonotic disease transmission and enhancing public health outcomes.

8. EMBRACING THE JOURNEY: NAVIGATING CHALLENGES AND OVERCOMING OBSTACLES WITH TENACITY

While participating in zoonotic disease awareness campaigns has many advantages for veterinary students, there are some drawbacks as well:

8.1. TIME CONSTRAINTS

Due to the rigorous nature of their studies and clinical rotations, veterinary students frequently struggle with time management issues. It might be difficult for students to juggle their engagement in zoonotic disease awareness campaigns with their academic obligations. To overcome these obstacles and set aside enough time for their advocacy work, veterinary students might benefit from developing excellent time management and prioritization skills.

8.2. LIMITED RESOURCES AND FUNDING

Resources and funds are needed for the execution of comprehensive zoonotic disease awareness programs. Veterinary students may face difficulties obtaining educational materials, venues for workshops, and access to digital platforms. These obstacles may be addressed, and their awareness campaigns can have the greatest impact, by working with community organizations, pursuing partnerships with public health agencies, and utilizing existing resources.

8.3. OVERCOMING PUBLIC MISCONCEPTIONS AND RESISTANCE TO CHANGE

It might be difficult to alter people's attitudes and actions towards zoonotic diseases. Individuals who are unfamiliar with the hazards posed by zoonotic diseases or who are hesitant to take preventive measures may show resistance, skepticism, or misconceptions about them, which veterinary students may confront. These challenges may be addressed and positive behavioral changes can be influenced with the use of effective communication techniques, targeted messaging, and the provision of scientific evidence.

It takes persistence, adaptation, and strong communication skills to overcome these obstacles. Veterinary students may overcome these obstacles by working together with other professionals, participating in multidisciplinary teamwork, and leveraging their knowledge of science to address misconceptions and promote a greater awareness of zoonotic diseases within the community.

In conclusion, veterinary students who participate in zoonotic disease awareness campaigns gain personal and professional advantages, such as improved veterinary knowledge and skills, strong relationships in the community, and opportunities to assist in preventing and controlling zoonotic diseases. Veterinary students may overcome difficulties including time restraints, a lack of resources, and dispelling public preconceptions by using efficient time management, resource utilization, and targeted communication techniques. Improved public health outcomes and fostering a culture of proactive zoonotic disease prevention within communities are directly impacted by their active engagement in increasing awareness.

9. CULTIVATING SUCCESS: KEY RECOMMENDATIONS FOR VETERINARY SCHOOLS AND ASPIRING STUDENTS

9.1. INTEGRATION OF PUBLIC HEALTH EDUCATION

To prepare veterinary students for their role in raising awareness about zoonotic diseases and public health education, it is crucial for veterinary schools to integrate public health education into their curricula. This integration can be achieved by:

9.1.1. FROM AWARENESS TO ACTION: ADVOCATING FOR THE INCLUSION OF PUBLIC HEALTH EDUCATION

Public health education should be promoted by veterinary schools as a core component of the veterinary curriculum. This involves coursework that emphasizes zoonotic disease surveillance, communication, and prevention. Institutions may better equip students to deal with zoonotic disease challenges by emphasizing the significance of public health in veterinary practice.

9.1.2. PROVIDING COMPREHENSIVE TRAINING

A comprehensive zoonotic disease prevention, surveillance, and communication program should be offered at veterinary educational institutions. Epidemiology, risk assessment, epidemic investigation, and techniques for efficient public outreach and collaboration with other healthcare professionals should all be included in the program of study. Veterinary schools may enable students to become advocates for the prevention and control of zoonotic diseases by providing them with a strong foundation in public health principles and practices.

9.2. TRAINING AND MENTORSHIP OPPORTUNITIES

It is essential for veterinary schools to incorporate public health education into their curricula in order to prepare veterinary students for their role in raising awareness of zoonotic diseases and public health education. This integration may be accomplished by:

9.2.1. ENCOURAGING TRAINING AND MENTORSHIP PROGRAMS

Veterinary institutions should support the development of mentorship and training programs that are specifically focused on public health advocacy. These initiatives can give future veterinarians hands-on training in zoonotic disease control, community involvement, and public health policy. They may include involvement in fieldwork for zoonotic disease surveillance and control, rotations in public health organizations, and partnerships with health professionals.

9.2.2. ESTABLISHING PARTNERSHIPS

Partnerships between veterinary institutions and public health organizations, businesses, and experts in the sector are essential (Suu-Ire et al. 2021). These collaborations may give veterinary students access to mentorship, guidance, and hands-on learning opportunities. Veterinary institutions may offer experiential learning opportunities that improve students' comprehension of zoonotic diseases and their role in advocating for public health by working with public health organizations.

9.3. POWER OF SYNERGY: EMBRACING COLLABORATION AND NETWORKING FOR COLLECTIVE IMPACT

The importance of collaboration and networking is essential for veterinary students in raising awareness about zoonotic diseases (Shanko et al. 2015). The following are some ways veterinary schools and students might promote networking and cooperation opportunities:

9.3.1. PROMOTE COLLABORATION

Collaboration between professors, students, and public health organizations should be encouraged at veterinary institutions (Shanko et al. 2015). This may be accomplished through joint initiatives on zoonotic disease prevention and control programs, collaborative research projects, and multidisciplinary courses. Veterinary schools may establish an environment where students are encouraged to collaborate with public health experts and other stakeholders to successfully address zoonotic disease concerns by developing a culture of collaboration.

9.3.2. FACILITATE NETWORKING OPPORTUNITIES

Veterinary institutions should encourage networking between veterinary students and experts in the field of public health (Shanko et al. 2015). Veterinary students and public health professionals might interact in this way through guest lectures, workshops, seminars, and conferences. Veterinary institutions offer avenues for mentoring, information exchange, and potential careers in public health advocacy by bringing students in touch with professionals in the field.

By putting these suggestions into practice, veterinary institutions and students may improve their ability to propagate knowledge about zoonotic diseases while promoting public health education. To ensure that veterinary students possess the knowledge, abilities, and associations necessary to have a significant impact on zoonotic disease prevention and control efforts, public health education is integrated into training and mentorship opportunities, as well as collaboration with public health agencies and professionals (Suu-Ire et al. 2021).

10. CONCLUSION

In conclusion, veterinary students play an essential role in propagating awareness about the prevention and control of zoonotic diseases. Veterinary students greatly contribute to the prevention and management of zoonotic diseases by utilizing their special knowledge, abilities, and enthusiasm. In addition to engaging community members, utilizing digital platforms, and actively participating in research and surveillance, they play an essential role in disease prevention and control. Promoting the inclusion of public health education in the veterinary curriculum guarantees that future veterinarians will be equipped with the necessary skills and knowledge. Veterinary students contribute to a safer and healthier future for both people and animals by embracing these opportunities. The dedication and commitment of veterinary students make a lasting impact. They are dedicated to mitigating the risks of zoonotic diseases and fostering a culture that values the interconnectedness of health between species.

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Development and Decision Support Programs for Wildlife Trading to Mitigate the Risk of Zoonosis

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ABSTRACT

Recent zoonotic outbreaks, notably the COVID-19 pandemic, highlight the urgent need for enhanced knowledge and effective measures to address the risks associated with wildlife trading. The role of wildlife trafficking in the transmission of infectious diseases from animals to humans is increasingly evident, necessitating the development and implementation of decision support programs to manage wildlife trade activities and mitigate the risk of zoonotic disease transmission. These programs, grounded in a multidisciplinary approach, aim to provide scientific guidance, evidence-based strategies, and legislative frameworks to promote ethical behavior and minimize the emergence of zoonotic diseases. Decision-assistive programs emphasize the importance of hazard evaluation to identify high-risk animal species and trade pathways. By efficiently allocating resources, concentrating surveillance efforts, and implementing precision-guided measures, stakeholders can curb the potential for zoonotic disease transmission. Collaboration across sectors is deemed essential, with state actors, international bodies, academic entities, and communities collectively addressing challenges posed by wildlife commerce and zoonotic afflictions. Cooperative structures facilitate the exchange of insights and best practices, paving the way for effective strategies and innovative solutions. Recognizing that our understanding of zoonotic diseases and wildlife trade is continually evolving, decision-support programs must stay abreast of the latest scientific revelations and recalibrate strategies accordingly. The chapter emphasizes the creation and operationalization of wildlife trade-centric decision-support systems to minimize the threat of zoonotic diseases. Through evidence-based practices and cross-disciplinary perspectives, the aim is to establish a sustainable and safe wildlife trade that safeguards both human and animal well-being.
To mitigate the risk of zoonosis, the chapter advocates for holistic, multidisciplinary strategies that encompass risk assessment, improved regulatory frameworks, sustainable trade practices, public awareness, and collaboration. Stakeholders, by integrating scientific research, field observations, and evidence-based decision-making, can work together to mitigate risks, protect public health, preserve biodiversity, and build a safer and better future for all.

Key words: Zoonotic diseases, Wildlife trade, Decision support programs, Multidisciplinary approach, Risk assessment, Collaboration, Sustainable trade, Public awareness, Ethical behavior, Zoonotic risk mitigation.

CITATION

Saleem MI, Ramzan F, Nazar M, Khan MS, Mahfooz A, Zaka F, Sultan T, Raza A, Ahmad A and Shakir AH, 2023. Mitigate the Risk of Zoonosis. In: Khan A, Abbas RZ, Hassan MF, Aguilar-Marcelino L, Saeed NM and Mohsin M (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 643-658. https://doi.org/10.47278/book.zoon/2023.047

CHAPTER HISTORY Received: 11-Jan-2023 Revised: 23-June-2023 Accepted: 20-July-2023

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1. INTRODUCTION

The world has witnessed the devastating impact of zoonotic diseases in recent years, such as the COVID-19 pandemic, underscoring the urgent need for increased knowledge and effective measures to address the hazards linked to animal trading. These risks have been brought to the forefront of global consciousness with the emergence of the COVID-19 pandemic, which is believed to have been initiated by wildlife sold in wet markets (Rahman et al. 2020). As zoonotic diseases continue to be better understood, it is becoming increasingly obvious that wildlife trafficking plays a key role in the spread of infectious diseases from animals to humans (Asrar et al. 2021). As a result of increased knowledge, it is becoming increasingly clear that decision support programs must be developed and immediately put into implementation in order to effectively manage wildlife trade activities and mitigate the risk of zoonotic disease transmission that goes along with them (Walzer 2020). Such programs seek to offer scientific direction, evidence-based strategies, and legislative frameworks that encourage ethical behavior and minimize the potential for the emergence of zoonotic diseases. We can develop comprehensive decision support programs that address the complex dynamics of the wildlife trade and its potential consequences for human health by adopting a multidisciplinary approach that combines ideas from ecology, epidemiology, conservation biology, and public health (Ghanbari et al. 2020).

Decision-assistive programs underscore the imperative of hazard evaluation in pinpointing those animal species and commerce pathways inherently oppressed with risk.

Such a system enables stakeholders to allocate resources efficiently, concentrate surveillance undertakings, and take specific, precision-guided measures to curtail the potential for zoonotic malady transmission. The procedure hinges on methodical examination and deduction. These guiding programs catalyze forward-looking, informed judgment. They do so by bringing into focus species under high-risk radar, fathoming their biological intricacies, tracing their trade dynamics, and deploying relevant statutory governance already in force.

In the same vein, these initiatives unreservedly admit the indispensability of collaboration that transcends sectors, fostering a culture of knowledge reciprocity (Dessie 2017). State actors, international bodies, academic entities, and popular communities collectively shoulder the task of tackling challenges proffered by wildlife commerce and the relay of zoonotic afflictions. Through the construction of cooperative structures and platforms, stakeholders gain the opportunity to swap insights, sterling practices, and lived experiences, thereby paving the way for the rise of efficacious stratagems and the uncovering of novel solutions (RIVM 2019).

It is vital to acknowledge that our comprehension of zoonotic ailments and the labyrinthine wildlife trade is a living, breathing body of knowledge, incessantly growing and evolving. Our understanding can expand and decision-assistive schemes can become more potent, all thanks to the tireless pursuit of scientific enquiry, vigilant oversight mechanisms, and strides in technology. To dampen the threat of zoonotic diseases, it is incumbent on decision-support programs to stay in lockstep with the freshest scientific revelations and recalibrate their strategies to keep pace (Shiferaw et al. 2017).

In the quest to lessen the menace of zoonotic ailments, the crafting and rollout of wildlife trade-centric decision-support systems take center stage. This chapter zooms in on the creation and operationalizing of such schemes aimed at the wildlife trade to minimize the specter of zoonotic diseases. Through the adoption of practices rooted in empirical evidence and the infusion of cross-disciplinary viewpoints, we can blaze a trail for a wildlife trade that is sustainable and safe, one that offers protection to both human beings and the animal kingdom (Plowright et al. 2021).

2. UNDERSTANDING THE LINK BETWEEN WILDLIFE TRADING AND ZOONOSIS

The relationship between the trade in wildlife and the development of zoonotic diseases is an important area of study that necessitates an understanding of science and evidence-based analysis that examines the numerous factors involved in disease transmission as well as the information from relevant case studies. Understanding the fundamental mechanisms that promote disease transmission is essential before diving into solutions to mitigate the zoonotic risks associated with the animal trade. The capture, transportation, and sale of live animals, animal products, and plants encompass the category of wildlife trade and have significant implications for the emergence of zoonotic diseases (Walzer 2020).

Numerous species are handled in close proximity during poorly regulated and unlawful trading operations, which creates an ideal environment for zoonotic infections to spread from wildlife to humans. Globalization, habitat loss, and increased human-wildlife interactions all increase the probability of the emergence of zoonotic diseases. The goal of this section of the chapter is to give a thorough review of the wildlife trade and how it affects the emergence of zoonotic diseases. Subsequently, it explores the zoonotic disease transmission factors in the context of wildlife trade and provides case studies that highlight the link between zoonotic disease outbreaks and wildlife trade (Walzer 2020).

2.1. OVERVIEW OF WILDLIFE TRADE AND ITS IMPACT ON ZOONOTIC DISEASE EMERGENCE

Globally, the wildlife trade involves a variety of species and ecosystems, both legally and illegally. Due to the close interaction between humans, domestic animals, and wildlife, this multibillion-dollar trade offers a substantial risk for the transmission of zoonotic diseases (Smith et al. 2017). Infectious diseases emerge when pathogens cross species barriers and invade human populations as a result of these interactions. The wildlife trade has significant implications for the establishment of zoonotic diseases.

Due to habitat loss and fragmentation brought on by trade-related activities, people, domestic animals, and wildlife have been brought into closer proximity, which makes it easier for zoonotic diseases to spread (Bloomfield, McIntosh and Lambin 2020). Furthermore, high-density trading strategies, which are frequently associated with unregulated and illegal wildlife trade, can result in congested and unhygienic conditions, offering the perfect conditions for the spread of infectious diseases among various species and humans.

The trading of wildlife requires special consideration in certain domains. The trade of exotic pets, bush meat, wild animal meat consumption, and wet markets, where live animals are bought and slaughtered right there, all contribute significantly to the spread of zoonotic diseases (Rahman et al. 2020). The likelihood of zoonotic spillover incidents is increased by the fact that these traditional activities frequently include subpar hygiene standards and the mixing of several species.

Numerous case studies demonstrate the impact of wildlife trading on the emergence of zoonotic diseases. For instance, we might look at well-known instances of zoonotic diseases that have been transmitted through the trade in wild animals. The severe acute respiratory syndrome (SARS) outbreak, which took place between 2002 and 2003, brought attention to the link between the trade in wildlife and zoonotic diseases. Similarly, bush meat intake has been connected to Ebola virus epidemics in Central and West Africa, highlighting the threats of this kind of trade in wildlife. The ongoing COVID-19 pandemic, which is being caused by the SARS-CoV-2 virus, has also raised awareness of the possible effects of wildlife trade on an international level (Rahman et al. 2020). The importance of understanding and addressing the risks posed by the trade of wild animals to protect public health is evident from these examples.

2.2. FACTORS CONTRIBUTING TO ZOONOTIC DISEASE TRANSMISSION IN WILDLIFE TRADING

2.2.1. BIODIVERSITY LOSS AND HABITAT DISRUPTION

Wildlife trade frequently causes habitat loss and fragmentation, which increases human-wildlife interaction and promotes the spread of zoonotic diseases.

2.2. 2. HIGH-DENSITY TRADING PRACTICES

Poorly regulated and unlawful wildlife trading can entail congested and unhygienic conditions that allow the spread of infections among humans and various species.

2.2.3. EXOTIC PET TRADE

Due to their frequent interaction with people and the potential for disease transmission, the trade in exotic pets, such as reptiles, birds, and monkeys, is particularly risky.

2.2.4. WET MARKETS AND BUSH MEAT TRADE

Due to inadequate hygiene standards and species mixing, traditional marketplaces that sell live animals and bush meat offer an ideal environment for the introduction and spread of zoonotic infections.

2.2.5. ILLEGAL WILDLIFE TRADE

The urge for rare animals and their goods fuels the illegal wildlife trade, which compromises legal restrictions and conservation efforts. This uncontrolled trade frequently employs unhygienic practices, careless handling, and smuggling techniques, raising the possibility of zoonotic disease transmission.

2.2.6. CROSS-SPECIES INTERACTIONS

Species that would not typically interact with one another in the wild may come together through wildlife trade. Because of the close proximity and interbreeding of many species, it is more likely that zoonotic infections may spread from one species to another, including humans.

2.2.7. STRESS AND IMMUNE SUPPRESSION

The wildlife trade's methods for capturing, moving, and confining wild animals can cause stress, which affects the immune systems. Animals with weakened immune systems are more vulnerable to infections, which raises the risk of zoonotic disease transmission to humans.

2.2.8. GLOBALIZATION AND TRAVEL

The interdependence of global trade and travel may accelerate the quick spread of zoonotic diseases. Transporting sick animals or their products across borders can spread new infections to areas where they had not previously existed.

2.2.9. LACK OF DISEASE SCREENING AND MONITORING

Insufficient zoonotic infection screening and monitoring procedures in the wildlife trade increase the likelihood of undiscovered disease transmission. It is difficult to recognize and respond to possible disease risks in a timely way in the absence of adequate surveillance.

2.2.10. LACK OF PUBLIC AWARENESS AND EDUCATION

Lack of knowledge about the dangers of zoonotic infections linked to the trade in wildlife may contribute to continued demand for wildlife goods. Education campaigns that stress possible health concerns and conservation implications can help to reduce the demand and associated trade.

Stricter laws, better enforcement, more surveillance and monitoring, public awareness campaigns, and community involvement are all necessary components of a multifaceted strategy to address these concerns (Aenishaenslin et al. 2013). We can reduce the chance of zoonotic disease transmission in the context of wildlife trade and advance the health and well-being of humans as well as animals by addressing these contributing variables. Fig. 1 shows the factors contributing to the transmission rate of zoonotic diseases.

2.3. CASE STUDIES ILLUSTRATING ZOONOTIC DISEASE OUTBREAKS LINKED TO WILDLIFE TRADE

2.3.1. SARS-COV AND THE WILDLIFE TRADE

An important case study illustrating the connection between the wildlife trade and the spread of zoonotic diseases is the severe acute respiratory syndrome (SARS) epidemic that took place between 2002 and 2003. The sale of live wild animals, such as palm civets, at a wet market in Guangdong, China, played a crucial role in the spread of the virus to humans and is thought to have been the beginning of the SARS pandemic (Lam et al. 2020). Southeast Asian native palm civets were traded in these marketplaces as a delicacy and for their alleged therapeutic benefits. The SARS-CoV (SARS-associated coronavirus) that caused the pandemic likely originated in bats and was transmitted to humans through an additional host, particularly palm civets, according to an investigation and later study.

Wet markets provided an ideal environment for the virus to spread from bats to palm civets, and then it was discovered that the virus was present in the gastrointestinal and respiratory tracts of the affected animals, making it simpler for it to be spread by consumption of contaminated meat or respiratory droplets (Lam et al. 2020). More than 8,000 cases were documented, and there were about 800 fatalities as a result of the SARS-CoV outbreak, which affected more than thirty different countries. Travelling internationally helped the disease spread quickly, underscoring the interdependence of global trade and the potential for zoonotic diseases to pose a danger to global health.

The necessity for better regulation and monitoring as well as the need to recognize the hazards connected to the wildlife trade are both highlighted by this case study. It serves as a reminder of the value of maintaining stringent rules, promoting public awareness, and enforcing good hygiene procedures to mitigate the hazards associated with wildlife trade and, therefore, prevents future zoonotic disease outbreaks. China banned the hunting, trade, and consumption of wild animals after the SARS pandemic, including palm civets.

Fig. 1: Factors contributing to the transmission rate of zoonotic diseases.

2.3.2. EBOLA VIRUS AND BUSH MEAT TRADE

The 2013–2016 Ebola virus outbreaks in West Africa serve as a notable case study for demonstrating the connection between the bush meat trade and the spread of zoonotic diseases. This outbreak, which predominantly affected Guinea, Liberia, and Sierra Leone, brought attention to the serious dangers associated with the trading and eating of bush meat (Shang et al. 2023). The Ebola virus, which is thought to have originated in bats, may be transmitted directly from infected animals to humans through contact or by eating their flesh. In the case of the West African outbreak, it is thought that the virus was transferred to humans by handling and eating bush meat, such as non-human primates, bats, and other wild animals.

Deeply rooted in the heart of West African traditions, the bush meat commerce contributes significantly to the sustenance and food security of numerous communities; however, it is not without its pitfalls. The close encounter and handling of bush meat, potentially contaminated, opens up the doors to zoonotic crossover events, possibly ushering in the Ebola virus to human populations. The blend of substandard sanitation practices with direct exposure during hunting, slaughtering, and cooking escalates the transmission risk (Han et al. 2016). Furthermore, manipulation and preparation of bush meat coming into contact with body fluids from infected animals, including blood and secretions, expand the potential for infection.

The blow dealt by the Ebola outbreak was catastrophic, causing a massive loss of lives, straining healthcare infrastructures to their breaking point, triggering social upheavals, and resulting in adverse economic impacts. The epidemic underscored the pressing necessity for comprehensive measures to confront the peril associated with the bush meat trade and zoonotic disease transmission. An assortment of multifarious strategies is under application in an attempt to curb the threat posed by zoonotic disease spread linked to the bush meat market. These include the drive to improve public awareness about the risks tied to consuming tainted bush meat, advocating for safe and ecologically balanced hunting methods, bolstering surveillance and monitoring mechanisms, and laying down regulations to ensure food safety and restrict the sale of infected bush meat.

To tackle the challenges posed by the bush meat trade and the looming threats of zoonotic diseases, it has been found crucial to foster community involvement and form alliances with local stakeholders. A close-knit collaboration with communities, honoring cultural norms and integrating local wisdom in strategizing, can pave the way for trust-building, bolster adherence to rules and promote practices that are both sustainable and capable of reducing zoonotic disease transmission risk, all while taking into account the communities' socioeconomic necessities (Morse et al. 2012).

The exploration of the West African bushmeat trade and the Ebola virus outbreak exemplifies the complex interconnections between social conduct, cultural norms, and the spread of zoonotic diseases. By grasping these dynamics, we can make strides towards lowering the occurrence of zoonotic infections, all through the implementation of comprehensive policies addressing both the health hazards and the socioeconomic factors at play.

2.3.3. COVID-19 PANDEMIC AND WILDLIFE TRADE

Unveiling the intricate relationship between wildlife commerce and the dissemination of zoonotic maladies, the ongoing saga of COVID-19, triggered by the notorious SARS-CoV-2 microbe, provides a fascinating exposé. The genesis of several early instances of this virus intertwine with a seafood bazaar located in Wuhan, China, a place where wildlife, too, was traded live, a possible nexus hinting at the wildlife commerce involvement (Zhang et al. 2020). While the exact cradle of the virus remains a subject of meticulous scrutiny, this pandemic has unfurled the terrifying potential of zoonotic diseases, casting a stark light on their far-reaching impacts on societal health, economic stability, and the very fabric of social structures (Andersen et al. 2020).

With its crippling repercussions manifested through millions of verified infections and an overwhelming global fatality rate, the COVID-19 epidemic has shaken the societal and economic scaffolding to its very core (Cantlay et al. 2017). Its tendrils have reached into the recesses of healthcare infrastructures, instigating profound disruptions in the rhythms of everyday existence for individuals, communities, and nations globally. In response, steps of varying intensities have been orchestrated to stave off the hazards associated with zoonotic disease transference via wildlife commerce. Nations have either outlawed or imposed rigid controls on wildlife trade, specifically targeting those species perceived as high-risk vectors for zoonotic maladies. Vigilance and monitoring measures have been amplified to detect potential diseases early and barricade their advancement.

By taking the ongoing COVID-19 pandemic as a revealing case study, we are compelled to confront the potential risks entwined within the complex web of wildlife commerce. By forging comprehensive strategies that put public health first, advocate for sustainable practices, and rally for wildlife conservation, we can aspire to dampen the risk of zoonotic disease transmission. This, in turn, would safeguard our societies from the ravages of such pandemics, establishing a more secure and sustainable path forward.

Implementing effective measures to mitigate these hazards requires a thorough understanding of how trade in wildlife affects the emergence of zoonotic diseases. Policymakers, conservationists, and communities can collaborate to develop and enforce regulations, increase public awareness, and promote sustainable alternatives by recognizing the factors causing disease transmission, such as habitat destruction, high-density trading practices, and specific trade sectors (Utermohlen 2020). These initiatives are essential for sustaining both animal and human health as well as halting future zoonotic disease outbreaks associated with the wild animal trade.

3. RISK ASSESSMENT AND MONITORING

Strong risk evaluation and surveillance systems are the first steps towards developing effective decision-support programs (Nuñez et al. 2020). In order to pinpoint high-risk wildlife species, areas, and trade networks, these programs should integrate scientific study, field observations, and data-driven analysis. We can gain valuable insights into the dynamics of zoonotic risks associated with wildlife trade by mapping the disease transmission pathways. The prioritization of initiatives and resource distribution will be based on these risk assessments.

3.1. IMPORTANCE OF RISK ASSESSMENT IN IDENTIFYING HIGH-RISK WILDLIFE SPECIES AND TRADE NETWORKS

The identification of high-risk animal species and trade networks that may aid in the spread of zoonotic diseases depends critically on risk assessment (Van der Giessen et al. 2010). It is a scientific and systematic technique that assesses many aspects of the threats from zoonotic diseases and the illegal trade of animals. We can make informed decisions and focus interventions by conducting risk assessments to get useful insights into the possibility and effects of the emergence of zoonotic disease (Ogden et al. 2019). The significance of risk assessment in identifying high-risk animal species and trade networks is further explained here:

3.1.1. EARLY DETECTION AND PREVENTION

The advent of prophylactic strides lies in the realm of identifying species of the wild brimming with high stakes and intricate trade networks, acting as foreshadowing harbingers of potential zoonotic afflictions. A distilled blend of influences - the distinct idiosyncrasies of the species, the omnipresence of pathogens, the scale of trading flux, and the matrix of human interplay - shapes our analytical approach in delineating which creatures and channels are prime transmitters of such diseases. This advanced discernment, akin to the first golden thread in the complex tapestry of disease mitigation, unlocks the potential for the swift orchestration of countermeasures (Van der Giessen et al. 2010). Among these safeguards, bolstered surveillance systems stand tall, complemented by heightened regulatory efforts, all converging on targeted intercessions. The intent, in this layered defense strategy, is to minimize the odds of disease dissemination, thus establishing a robust shield in the face of these biological threats.

3.1.2. RESOURCE ALLOCATION

By concentrating on high-risk wildlife species and trade networks, risk assessment aids in the prioritization of resources and efforts (Ogden et al. 2019). Effective resource allocation is crucial given the limited resources available for surveillance, monitoring, and control measures. Authorities can more accurately focus their resources, maximize the impact of interventions, and improve public health by identifying the targets that pose the highest risk (Rahman 2017).

3.1.3. INFORMED DECISION-MAKING

Risk assessment has benefited scientifically in the prevention and management of zoonotic disease threats related to the wildlife trade (Rahman 2017). It aids stakeholders, policymakers, and regulators in comprehending the possible implications and consequences of various trade practices and species decisions. This knowledge is essential for the development and implementation of rules, laws, and policies that effectively mitigate risks while taking ecological, economic, and social factors into account.

3.1.4. TARGETED INTERVENTIONS

Zoonotic diseases are reduced through the implementation of precise measures that are based on risk assessment (Ogden et al. 2019). Authorities can implement particular measures, such as increased biosecurity, potent laws, and focused surveillance, to lessen the likelihood of disease spillover by identifying high-risk wildlife species and trade networks (Utermohlen, 2020). The efficacy of interventions is increased by this targeted approach since resources are directed to the areas that require them the most.

3.1.5. PUBLIC AWARENESS AND EDUCATION

Risk assessments unfold as instrumental levers for illuminating the masses and nurturing educational endeavors. A grand, cohesive awareness canvas could be painted for the general populace, wildlife commerce facilitators, and end-users, showcasing the lurking health perils intertwined with high-risk wildlife species and their associated trade pathways. Being furnished with such crucial insights endows individuals with the power to navigate the decision-making labyrinth effectively, shape ethical behavioral patterns, and endorse wildlife trade policies that align with sustainability's ethos. By amplifying the circumference of public cognizance, the echo of conservation motives reverberates more robustly, simultaneously shrinking the demand sphere for wildlife commodities fraught with high risk.

3.1.6. INTERNATIONAL COLLABORATION

Navigating the intricate labyrinth of zoonotic disease risk management linked to wildlife trade, the compass points towards a paradigm of global unity and cooperative risk evaluation (Morse et al. 2012). This collaborative avenue, stretching beyond national borders, fosters a spirit of reciprocal learning through the dissemination of risk assessment paradigms, data repositories, and research revelations. In the grand global chessboard where wildlife trade and zoonotic diseases cast their far-reaching shadows, this multilateral handshake takes on an indispensable hue. As countries pool their intellectual resources under this shared umbrella, it paves the way for a collective problem-solving odyssey to counter the challenges imposed by high-risk wildlife species and their commercial networks.

In conclusion, to mitigate the risks of zoonotic disease transmission, risk assessment is crucial in identifying high-risk animal species and trading networks. It enables early diagnosis, resource allocation, informed decision-making, focused interventions, public awareness, and global collaboration (Morse et al. 2012). We can manage and reduce the risks associated with wildlife trading effectively, safeguarding both human health and biodiversity conservation, by undertaking thorough, evidence-based risk assessments (Nuñez, Pauchard and Ricciard 2020).

3.2. DATA COLLECTION METHODS AND ANALYSIS TECHNIQUES FOR RISK ASSESSMENT

Robust data-collection methods and analysis methodologies are essential in the field of risk assessment for acquiring accurate and trustworthy information to guide decision-making and successfully manage risks (Nuñez, Pauchard and Ricciard 2020). Data collection and analysis contribute to the accuracy and scientific rigor of risk assessment through the implementation of systematic, scientific procedures (EFSA, 2009). Here, we investigate numerous methodologies and procedures for collecting and analyzing data for risk assessment:

In the grand scheme of risk assessment, the key lies in adopting a meticulous stance in the acquisition and evaluation of data. Monitoring systems, field explorations, trade ledgers, market assessments, geographical information system (GIS) technology, statistical modeling, and cooperative enterprises compose the symphony that fine-tunes the precision and reliability of risk assessments. These scientific melodies enhance our comprehension of the hazards that zoonotic diseases pose in the realm of wildlife commerce, empowering us to architect effective risk minimization strategies and make informed decisions.

3.3. INTEGRATION OF SCIENTIFIC RESEARCH AND FIELD OBSERVATIONS IN MONITORING ZOONOTIC RISKS

Observations collected in the field and scientific studies must be combined to monitor zoonotic threats. The dynamics of zoonotic diseases can be better understood by studying wildlife ecology, behavior, and pathogens, among other things (Ghanbari et al. 2020). It assists in locating possible reservoir hosts, modes of transmission, and variables affecting the disease's emergence. Monitoring animal populations and their interactions with humans requires field observations such as surveillance programs and ecological studies. This entails monitoring disease prevalence, spotting possible spillover events, and comprehending the factors that contribute to the spread of zoonotic diseases. It is possible to identify emerging risks, develop early warning systems, and apply targeted actions to stop or mitigate zoonotic disease epidemics by integrating scientific research with field observations (Verloo et al. 2016). We can better identify zoonotic risks and develop decision-support programs to address them by combining scientific knowledge with pragmatic observations.

3.4. STRENGTHENING REGULATORY FRAMEWORKS

Asserting a more fortified, rigorous legal framework is a sine qua non for the control of wildlife commerce to efficaciously curtail the peril of zoonotic diseases transmission. In the limelight of this exigency, the panoptic incorporation of stringent strategies to curb unauthorized wildlife trade forms an indubitable element of the approach. Emphasis must be laid on the augmentation of monitoring and enforcement measures at entry points like harbors and airports - the veritable frontiers of such illicit trade. This strategic maneuver requires an expeditious global effort to orchestrate legislative policies with an aim to foster harmonious legal apparatus across nations. Concomitantly, adopting a proactive stance in the form of preventative action, including implementation of commerce restrictions or outright interdictions on species deemed to carry a high zoonotic risk, becomes instrumental in impeding both the ingress and dissemination of such diseases. This two-pronged approach is a truism for achieving the ultimate goal of safeguarding our global ecosystem from the potential devastation of zoonosis.

3.4.1. OVERVIEW OF EXISTING REGULATORY FRAMEWORKS FOR WILDLIFE TRADING

Wildlife trading regulations seek to control and govern the trade of wildlife and the products they produce. These frameworks differ between countries and regions but often consist of a combination of national regulations, conventions, and agreements. Insuring sustainable trade, protecting biodiversity, and preventing the spread of zoonotic diseases are the key objectives of these frameworks. To govern legal trade and associated hazards, they frequently entail the establishment of permits, limits, and monitoring systems. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and regional agreements like the European Union Wildlife Trade Regulations are examples of international accords. These frameworks serve as a base for managing the wildlife trade, although problems and loopholes still exist.

3.4.2. CHALLENGES AND GAPS IN CURRENT REGULATIONS

Despite the existence of legal frameworks, a number of obstacles and shortcomings prevent the effective control of the wildlife trade and the corresponding decrease in zoonotic threats. These obstacles include:

3.4.3. INADEQUATE REGULATION AND ENFORCEMENT

Regulatory frameworks failed to be adequately strong, leaving openings for unlawful trading and poor enforcement. Lax punishments, corruption, and a lack of resources make it difficult to implement regulations and govern effectively.

3.4.4. FRAGMENTED AND INCONSISTENT LEGISLATION

Legislation governing the wildlife trade may be disorganized, differing across countries and resulting in inequitable methodologies. This discrepancy can make it easier for trade laws to be broken while hampering productive global collaboration.

3.4.5. LACK OF FOCUS ON ZOONOTIC RISKS

Conservation of biodiversity is frequently prioritized by current regulations; however, concerns about zoonotic diseases may not be sufficiently addressed. In order to better mitigate health risks associated with the wildlife trade, zoonotic disease considerations should be strengthened in regulatory frameworks.

3.4.6. LIMITED CAPACITY AND EXPERTISE

Building the necessary ability and knowledge to execute and enforce laws governing the wildlife trade poses challenges for many countries. This covers obstacles with surveillance, identifying species, and comprehending the intricate dynamics of zoonotic disease transmission.

3.4.7. FORTIFYING SAFEGUARDS: STRATEGIES FOR STRENGTHENING AND ENFORCING REGULATIONS TO MITIGATE ZOONOTIC RISKS

Following strategies can be employed to strengthen and implement rules to mitigate zoonotic risks in the wildlife trade:

3.4.8. STRENGTHENING LEGISLATION

To provide a full spectrum of zoonotic disease threats, governments should evaluate and update existing legislation, including measures to control trade networks and high-risk wildlife species. This entails filling up regulatory loopholes, harmonizing laws across countries, and enacting increased penalties for illegal trade.

3.4.9. ENHANCING SURVEILLANCE AND MONITORING

At the wildlife-human interface, robust surveillance mechanisms should be implemented to identify and track zoonotic diseases. This entails developing early detection capabilities, upgrading reporting workflows, and funding technological advancements for disease surveillance and monitoring in wildlife trading environments.

3.4.10. PROMOTING SUSTAINABLE TRADE PRACTICES

By instigating responsible commerce techniques, we can create a precipitous decline in the demand for wildlife products that pose a significant risk. This can be achieved through the application of certification initiatives, explicit consumer labeling, and comprehensive education of consumers. Our societies can benefit from strategic public awareness campaigns that elucidate the health implications tethered to wildlife trade. This critical information empowers individuals to make discerning and responsible choices when purchasing such items.

3.4.11. CAPACITY BUILDING AND COLLABORATION

The impetus to cultivate expertise and expand capabilities in navigating zoonotic diseases and judicious regulation of wildlife trade is undeniably paramount. This endeavor encompasses the comprehensive training of critical actors such as law enforcement officers, customs agents, and other relevant stakeholders, in essential areas such as species recognition, risk computation, and surveillance methodologies. The establishment of a cooperative interface among governments, non-governmental organizations (NGOs), scholars in the field, and community members can substantially augment our collective efforts to share knowledge, enhance capacities, and rigorously enforce legal frameworks (Dessie 2017).

3.5. INTERNATIONAL COLLABORATION FOR HARMONIZING REGULATIONS AND COMBATING ILLEGAL WILDLIFE TRADE

In order to combat the hazards of zoonotic diseases and maintain biodiversity, global collaboration is essential for harmonizing rules and preventing the illegal wildlife trade. Due to the complexity of the wildlife trade, effective regulation and enforcement of laws require coordinated efforts by governments, international organizations, and stakeholders (Bordier et al. 2018). Global collaboration is crucial to combating the transnational nature of the illegal wildlife trade and the hazards of zoonotic diseases associated with it.

Countries can collectively combat illegal wildlife trade, safeguard biodiversity, and reduce the dangers of zoonotic disease transmission by promoting collaboration, exchanging information and intelligence, harmonizing policies, and offering support for capacity-building (Bordier et al. 2018). In order to ensure the efficiency of regulatory measures and protect the wellbeing of ecosystems and human populations globally, strong international coordination is essential.

4. SHAPING A SUSTAINABLE FUTURE: ADVANCING SUSTAINABLE WILDLIFE TRADE FOR A BETTER FUTURE

It's crucial to recognize the potential advantages of sustainable wildlife trade for conservation and livelihoods, even though the focus is on mitigating zoonotic risks. Programs for decision support should strive to strike a balance between reducing zoonotic threats and encouraging ethical and legal trade. This may be accomplished through the development of certification programs that ensure that trade is carried out in accordance with best practices, including disease screening, adequate animal welfare, and traceability.

5. PUBLIC AWARENESS AND EDUCATION

Campaigns for consumer responsibility and public awareness are essential for lowering the market for illegal wildlife products. These efforts ought to place a strong emphasis on the risks of zoonotic transmission associated with the trade in wildlife, the significance of conservation of biodiversity, along with various sources of livelihood for the people that participate in the trade. We can mobilize public support for successful policy measures and behavioral change by generating an expanded understanding of the potential consequences of wildlife trade.

6. FROM COMPETITION TO COLLABORATION: MAXIMIZING POTENTIAL THROUGH EFFECTIVE COLLABORATION AND KNOWLEDGE SHARING

Collaboration among stakeholders, such as governments, conservation groups, researchers, and local communities, is required to address the complex issues of wildlife trade and zoonotic risks (Bordier et al. 2018). Furthermore, assisting developing countries financially and technically will help them improve their ability to successfully deploy decision-support programs. It can be beneficial to establish knowledge-sharing platforms, such as international databases and networks, to facilitate the exchange of scientific research, best practices, and lessons learned.

6.1. UNVEILING THE ROLE OF STAKEHOLDERS IN WILDLIFE TRADE FOR SUSTAINABLE ZOONOTIC RISK MITIGATION

A variety of stakeholders play an important role in the mitigation of zoonotic risks and the wildlife trade. Developing effective measures to address zoonotic risks associated with the wildlife trade requires their cooperation. Our discussion here focuses on the key stakeholders:

6.1.1. GOVERNMENT AGENCIES

The primary stakeholders in wildlife trade and zoonotic risk mitigation are governmental organizations such as wildlife departments, health ministries, and customs and border control authorities. They are in charge of making rules and enforcing them, performing seizures and inspections, as well as organizing surveillance and response operations (Bordier et al. 2018). These organizations are essential for implementing legal frameworks, supporting programs that build capacity, and guaranteeing adherence to international agreements and national regulations.

6.1.2. INTERNATIONAL ORGANIZATIONS

Important stakeholders in the trade of wildlife and in mitigating the danger of zoonotic diseases are international organizations like the World Health Organisation (WHO), INTERPOL, and United Nations Environment Programme (UNEP). To combat zoonotic diseases and the illegal wildlife trade, these organizations provide technical assistance, promote knowledge exchange, and coordinate international efforts (FAO 2019). They assist countries in coordinating rules, improving monitoring systems, and fortifying enforcement mechanisms.

6.1.3. SCIENTIFIC AND RESEARCH INSTITUTIONS

Institutions engaged in science and research provides crucial knowledge for the wildlife trade and the mitigation of zoonotic risks. They carry out research on zoonotic diseases, the ecology of wildlife, and trade dynamics, offering insightful information for risk evaluation, the formulation of policies, and the establishment of surveillance plans (Trippl et al. 2015). The collaboration of scientists and researchers helps inform evidence-based decision-making and foster innovation in detecting, preventing, and controlling diseases.

6.1.4. NON-GOVERNMENTAL ORGANIZATIONS (NGOS)

NGOs are essential for mitigating the risk of zoonotic disease and wildlife trade, concentrating on conservation, community involvement, and lobbying for legislation. They actively collaborate with neighborhood communities, increase public awareness, and support ethical business practices. In order to combat the illegal wildlife trade and safeguard biodiversity, NGOs also promote capacity building, aid in the development of sustainable livelihood alternatives, and work in conjunction with governments and other international organizations (Hassan 2007).

6.1.5. LOCAL COMMUNITIES AND INDIGENOUS PEOPLES

Indigenous peoples and communities that reside in or are close to areas where wildlife is traded are significant stakeholders in the mitigation of zoonotic risk. They have important traditional knowledge about ecosystems, wildlife, and sustainable resource management. These communities' participation in decision-making processes, respect for their rights and traditions, and the availability of alternative livelihood alternatives can all help to regulate the wildlife trade sustainably and mitigate the risk of zoonotic diseases (Salihu et al. 2015).

6.1.6. BRIDGING THE GAP: BUILDING KNOWLEDGE-SHARING PLATFORMS AND NETWORKS

Building networks and platforms for information exchange is essential for successful wildlife trade and the mitigation of zoonotic risk. These platforms encourage collaboration, improve understanding, and advance evidence-based decision-making by facilitating the sharing of knowledge, best practices, and experiences among stakeholders (Van Metre et al. 2009). They offer stakeholders an umbrella forum to exchange surveillance information, research findings, policy papers, and case studies pertaining to zoonotic diseases, the dynamics of the wildlife trade, rules, and enforcement procedures. Knowledge-sharing platforms improve stakeholder competencies and guarantee a more coordinated response to zoonotic threats by encouraging information exchange, collaborative projects, and capacity building (Van Metre et al. 2009). They also aid in defining shared objectives, organizing activities, and allocating resources, which promote collaboration and partnerships among stakeholders involved in the trade of wildlife and the mitigation of zoonotic risk.

6.1.7. ENABLING SUCCESS: EMPOWERING DEVELOPING COUNTRIES WITH FINANCIAL AND TECHNICAL SUPPORT FOR ENHANCED CAPACITY

For developing countries to improve their capabilities in wildlife trade regulation and zoonotic mitigation, financial and technical help is crucial. Countries with developing economies frequently struggle with issues related to a lack of resources, knowledge, and infrastructure. The development of surveillance systems, equipment acquisition, training efforts, and laboratory facilities may all be adequately supported financially. Both technical support and knowledge transfer are crucial because they contribute to the development of local stakeholders' skills. This may entail offering specialists, consultants, and mentors in order to help facilitate the development and execution of rules, surveillance systems, and enforcement strategies.

For effective disease detection, surveillance, and response, technology transfer, including the use of diagnostic equipment, laboratory tools, and data management systems, is essential. The international community may enable developing nations to build their capacity, apply sustainable practices, and successfully safeguard public health and biodiversity by offering financial and technical assistance (Salihu et al. 2015).

7. CONCLUSION

To mitigate the risk of zoonosis, development and decision-support programs for the wildlife trade are critical. We can achieve a more resilient and responsible wildlife trade system by implementing a holistic, multidisciplinary strategy that includes risk assessment, improving regulatory frameworks, promoting sustainable trade, increasing public awareness, and encouraging collaboration. Stakeholders may collaborate to mitigate risks, safeguard public health, maintain biodiversity, and build a safer and better future for all by integrating scientific research, field observations, and evidence-based decision-making. This chapter has emphasized crucial measures and considerations in order to guarantee a sustainable and responsible approach to wildlife trade that prioritizes zoonotic risk mitigation and the well-being of ecosystems and human populations.

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Echinococcosis: Recent Advancements in OMIC Technologies

48

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1. INTRODUCTION

Cystic echinococcosis (CE) and alveolar echinococcosis (AE), two severe zoonotic tapeworm infections caused by *Echinococcus granulosus sensu lato* and *Echinococcus multilocularis*, respectively, are referred to as echinococcosis (McManus et al. 2012). The yearly occurrence of CE varies from 1 to 200 / 100,000 people in endemic regions, whereas the incidence of AE varies between 0.03 to 1.2 / 100,000 people (Schweiger et al. 2007). Ninety percent of AE patients who receive no treatment or insufficient treatment die within 10 to 15 years after their diagnosis (Budke et al. 2013). Although the CE fatality rate (2% to 4%) is less it might rise significantly in cases of insufficient care management. Echinococcosis is one of the 17 neglected illnesses that the World Health Organization (WHO) hopes to manage or eradicate by 2050. While CE is more prevalent and has a cosmopolitan distribution, several countries have claimed it to be eliminated (Craig and Larrieu 2006; Craig et al. 2007). Still, the disease is distributed all over the world with high prevalence in Asian, American, and African countries as given in Fig. 1 (Wen et al. 2019; Larrieu and Zanini 2012; Cucher et al. 2016; Alvi et al. 2021; Alvi et al. 2022; Alvi et al. 2023a; Alvi et al. 2023b; Alvi et al. 2023c). In fact, significant recent advancements are expected to bring revolution in control and management of CE and AE. However, due to less sensitivity and specificity of current diagnosis tools, side effects and less potency of available medications, the frequently inappropriate surgery, and the difficulties in preventive measures, the discovery of novel therapy and vaccine potential sites is highly needed.

CITATION

Ali RMA, Ali RMM, Ahsan S, Hussain G, Mateen L, Kabir A, Bilal H, Younas J and Arooj, 2023. Echinococcosis: recent advancements in OMIC technologies. In: Khan A, Abbas RZ, Hassan MF, Aguilar-Marcelino L, Saeed NM and Mohsin M (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol. I: 659-669. https://doi.org/10.47278/book.zoon/2023.192

CHAPTER HISTORY Received: 26-March-2023 Revised: 14-April-2023 Accepted: 19-May-2023

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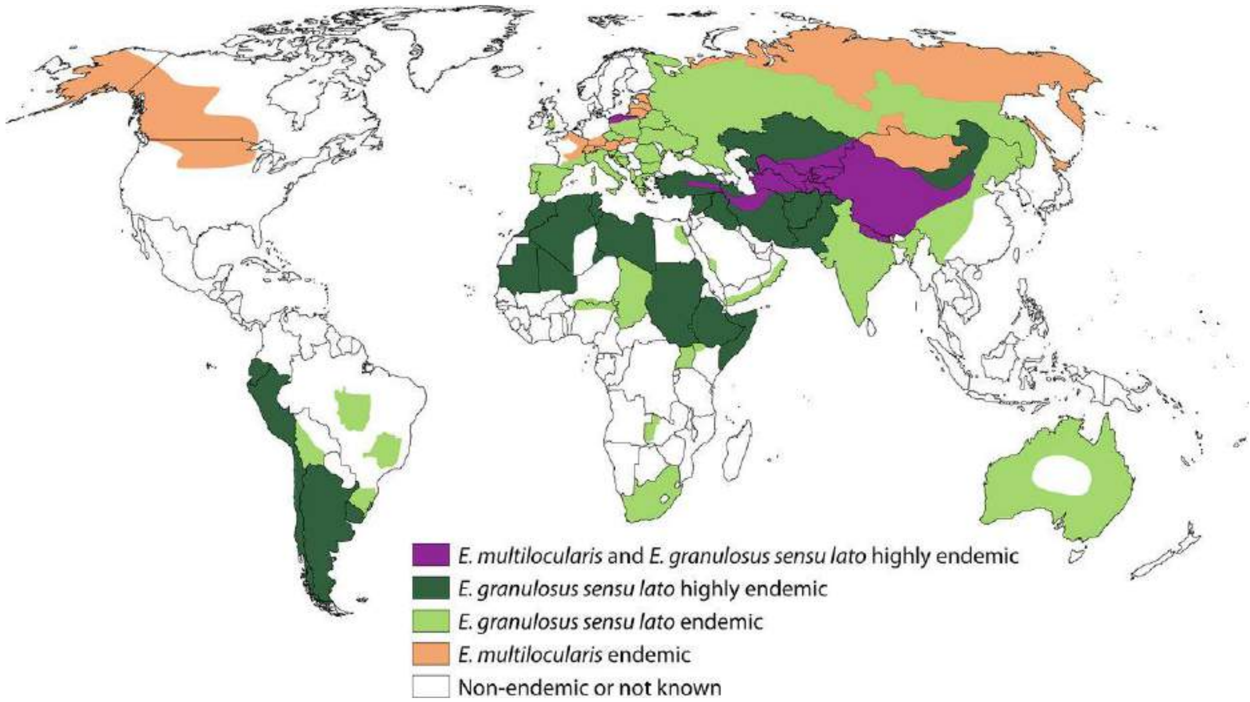

Fig. 1: Worldwide distribution of CE and AE with colors representing their endemicity (Wen et al. 2019)

Our methods for examining biological systems have been significantly transformed by "OMICS," which is defined as exploring and analyzing a significant amount of information that represents the structure and function of the entire composition of a specific biological system at a particular level (Wen et al. 2019; Dai and Shen 2022).

In this chapter, we have discussed how current advancements in genome and transcriptome analysis, are exploring the interaction between a parasite and its host, giving access to the data that can help to prepare new drug interactions and treatments against CE and AE.

2. ENHANCING INFORMATION ON THE DIVERSE LIFECYCLE OF CE AND AE AS WELL AS REVEALING PHENOTYPIC VARIATIONS IN PARASITES

Transcriptomic analysis of various forms of CE has revealed different aspects of biological and parasitological processes (Zheng et al. 2013). Moreover, the current reports on the complete genome of *E. granulosus* as well as *E. multilocularis* (Tsai et al. 2013) have disclosed other important things, linked with parasitism, comprising of details of family domains, obtained during the evolution. Other genes discovered relate to signaling pathway, the neurological and endocrine systems, development and reproduction, as well as other processes that played their part in evasion mechanisms. For a deeper comprehension of cestode biological processes, differentiation, growth and development, evolution, disease, and other host-parasite relationships, genetic and transcriptomic data thus serve as a crucial foundation.

CE and AE life cycles give information about the significance of the parasite's secretory/ excretory products being translated from new genes. The phenotypic changes connected to the various phases of parasite life and the corresponding modifications of the immunity in each host are probably driven by up or down-regulation of gene expression. For the purpose of identifying the specific roles of these genes and searching for important genes linked to these alterations, comprehensive transcriptome analysis is essential. The protoscoleces have unbelievable potential to convert into a cyst or adult which is a distinguishing characteristic of *E. granulosus* and *E. multilocularis*. A particular host stimulus, controls how a development will proceed (Constantine et al. 1998). 3,900 of the 11,325 genes anticipated to be in the genome of *E. granulosus* (s.s.) could not be assigned a function; of these, 361 genes did not transcribe in adult worms, and among these, 21 showed significant expression and might be related to adult worm growth (Zheng et al. 2013). The eggs from the gravid proglottid excreted into the surroundings to infect intermediate hosts including humans. 55 genes were preferentially expressed in adult *E. granulosus* compared to immature stages, and were among the 361 genes that mRNA transcriptome analysis revealed to be well-expressed in these species. The unlimited asexual development related to the metacestode stage contrasts with the limited sexual development associated with adult worms. Of the 8,361 genes expressed in the two phases, 498 genes were strongly expressed in the adult worm whereas 502 genes were involved in the metacestode (Zheng et al. 2013). Future research using gene deletion methods may reveal their functional properties.

The knowledge of morphology, anatomy, and clinical features between two cestodes will therefore depend heavily on a thorough relevance of genetic structure and transcribed proteins of CE and AE. The form and shape of the metacestode are one of the main differences between the two. The cysts of *E. granulosus* have a distinctive shell-like adventitia that distinguishes them from the hepatic and pulmonary and brain. In contrast, the *E. multilocularis* metacestodes are infiltrating lesion that continuously advances irregularly and harms the liver or other target organs. It is made up of compiled cells as a result of immunological reactions in the form of necrosed or fibrosed tissue.

Using RNA sequencing (RNA-Seq) or microarray technological advances, comparative investigation into differing or conjoining gene pairs and their course of expression can be utilized for recognizing patterns that are exhibited by multiple or specific species. Such gene pair study has shown that both species contain 5418/10,018 genes with strong sequence analogy, despite the fact that research on *Echinococcus* spp. is yet in its beginning. The identification and characterization of nonsimilar/unique genes will be the next step in elucidating the fundamental differences in biology or pathogenesis in two species.

3. ADVANCING ECHINOCOCCOSIS DIAGNOSIS AND TREATMENT

The comprehensive genomic and transcriptome data currently accessible might be helpful for creating new public health treatments against *E. granulosus sensu stricto*, such as enhanced diagnostic procedures and the discovery of fresh therapeutic targets. One-third (n3,903) of the genes in the *E. granulosus* genome have no gene similar in other taxonomic group, according to BLAST sequence analysis. This finding suggests the distinctive nature and biological features of *E. granulosus* genes. The byproducts of these genes might likewise be useful as fresh suspects in echinococcosis diagnostics and as novel medication targets. Certain proteins may be effective as chemotherapeutic targets along with enhanced immunodiagnosis or immunotherapy because they function as chemical mediators for networking between CE and its mammal host (Zheng et al. 2013; Tsai et al. 2013). For example, genes of a germinal layer of the parasite prepare polypeptides and proteins that can be used in the development of vaccines such as GPCRs, MAPK, neuro-peptides, and ion channel (Lu et al. 2016; Lin et al. 2011; Gelmedin et al. 2010; Gelmedin et al. 2008).

Both *E. multilocularis* and *E. granulosus* protoscoleces contain hormone- and cytokine-activated pathways, therefore, it is of the utmost importance that host components activate or deactivate them (Yang et al. 2017; Koziol et al. 2016a; Hemer et al. 2014; Lu et al. 2016; Gelmedin et al. 2008; Gelmedin et al. 2010; Hemer et al. 2014; Zhang et al. 2014; Brehm and Spiliotis 2008; Konrad et al. 2003; Brehm 2010;

Spiliotis et al. 2006; Spiliotis et al. 2005; Zavala-Gongora et al. 2003; Spiliotis et al. 2003). If we compare the genetic structure of both parasites, it will become obvious that parasites have a high level of similarity, revealing that many compounds are produced by both parasites and can be aimed at creating new therapies. A lot of research is being done right now to see whether MAPK inhibitors can kill metacestodes or protoscoleces. ML3403 interacts with the P38-like MAPK in CE and inhibits Egp58 function and causes considerable protoscolex mortality within five days in vitro (Lu et al. 2016). Similar outcomes were bought with *E. multilocularis* specifically SB202190, and ML3403, a different pyridinyl imidazole, investigated on protoscoleces vesicles propagated in vitro resulting in the removal of phosphate group of the parasite's EmMPK2 and ultimately destroy the vesicles at the levels that did not influence grown cells of mammals (Gelmedin et al. 2008).

Various metabolic processes have been investigated as an outcome of the publication of the full genetic structure of CE and AE, along with different inhibitors are now being researched (Siles-Lucas et al. 2018; Joekel et al. 2018; Flo et al. 2017; Koziol et al. 2016b; Schubert et al. 2014; Hemer and Brehm 2012). Nilotinib altered protoscoleces structure of *E. multilocularis* in vitro; but, neither of these drugs prevented the development of the parasite in *E. multilocularis*-infected rats (Joekel et al. 2018). It was discovered that the Polo-like kinase inhibitor, BI2536, inhibited EmPlk1 activity and prevented the development of protoscoleces from cultured *E. multilocularis* inner germinal cells as shown in Fig. 2A and 2B. Additionally, it removed the inner cell growth in laboratory, producing worm tissue that was not able to undergo development (Schubert et al. 2014). Imatinib is an a different ABL inhibitor considered for treatment of cancer. It has been demonstrated to interact with kinases in AE and to be very efficient in eliminating stem cells of *Echinococcus*, vesicles of metacestode, and protoscoleces in vitro (Hemer and Brehm 2012). However, it is yet uncertain if such kinase inhibitors have the ability to cure AE in vivo.

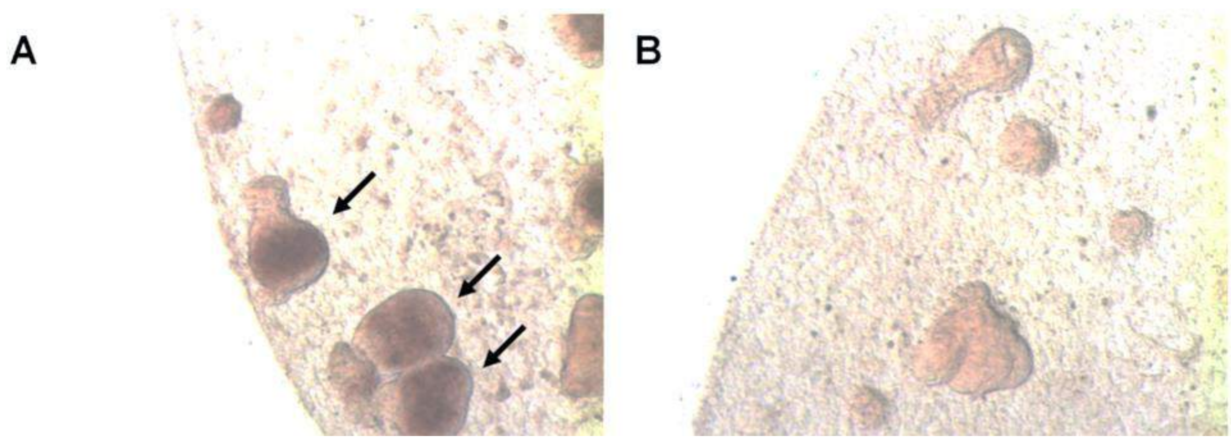

Fig. 2: Protoscoleces are enriched with EmPlk1 as indicated by arrows (A). Cells are stained with EmPlk1 antisense probe (A and B).

4. ENHANCING KNOWLEDGE OF IMMUNOLOGICAL PATHWAYS AT THE PARASITE-HOST INTERFACE TO PREPARE NOVEL THERAPY

Despite of high vulnerability of CE parasite, and particularly of AE cestode, to the defense system cells of the host was known from the last three decades (Vuitton 2003), the majority of a thorough understanding of immunological processes underlying the delicate equilibrium between protection of hosts and growth of parasites has been attained in the twenty-first century (Vuitton and Gottstein 2010; Gottstein et al. 2017). The advancement of genomics in this area has been beneficial by pointing to novel molecular pathways and potential therapeutic targets. Investigations of the transcriptional patterns seen in the hepatic tissue of rats inoculated with AE parasite and the rat models used with specific gene losses have been essential in this regard (Wang and Gottstein 2016; Wang et al. 2014; Gottstein et al. 2010; Siracusano et al. 2012a). According to recently discovered evidence, immunotherapy may be able to cure echinococcosis in combination with anti-infective medication therapy. On the other hand, deeper comprehension of the defense system of hosts diseased with AE and CE parasites may result in the development of new therapeutic strategies for the treatment of ongoing inflammatory illnesses.

At the later phase of infection in people, there is the majority of helper T cells, comprising of immunoglobulin-E mediated responses and elevated amounts of the cytokine IL-10 (Vuitton 2004). After adventitial fibrous barrier formation, a strong T helper-2 profile is quickly developed in CE (Siracusano et al. 2012a; Tuxun et al. 2018). In AE, the immune system's response advances in three stages, with the initial phases being characterized by a mixed Th1/Th2 profile, the middle stage being distinguished by a dominant Th2/Treg profile, including IL-10 and transforming growth factor (TGF) regulatory cytokines, and the final phase of infection being marked by a T-cell exhaustion status (Gottstein et al. 2017; Zhang et al. 2017). According to clinical investigations on CE, therapeutic sensitivity is linked to a Th1 profile, whereas therapy resistance is linked to a T helper 2 profile (Gottstein et al. 2017; Siracusano et al. 2012b). Certain proteins may be beneficial as targets for enhanced immuno-diagnosis or follow-up of patients because they function as code of communication between the parasites and their hosts as shown in Fig. 3 (Tsai et al. 2013; Zheng et al. 2013).

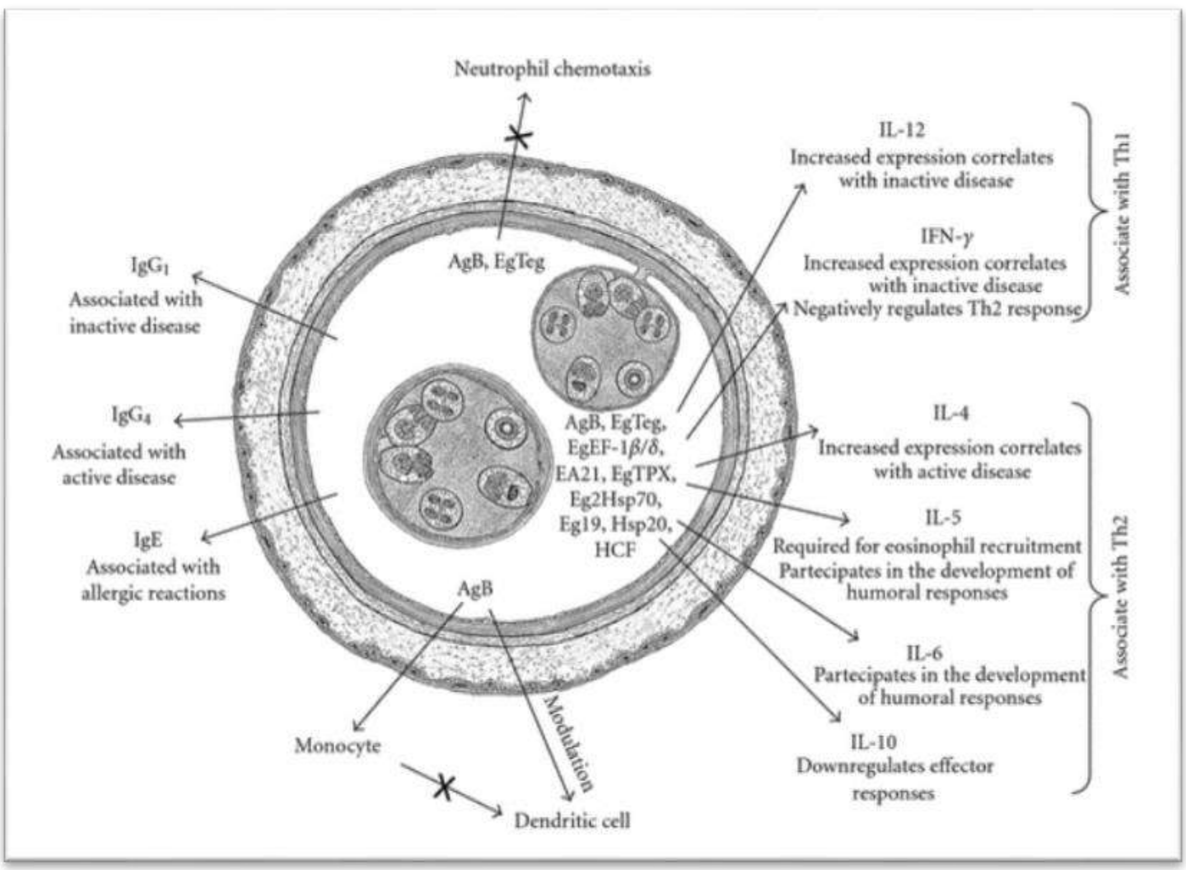

Fig. 3: Major products produced as a response to hydatid cyst components which can be used as drug targets

With effects varying from resistance (self-cure) to quickly increasing host mortality (high vulnerability), the content and kind of feedback produced by CE parasites causally affect the results and course of disease (Wang et al. 2014). In *E. multilocularis*, this feedback as well as the body cells, are strongly influenced by the parasite burden, which may be statistically measured in a laboratory setting including infection by intraportal inoculation of protoscoleces (Zhang et al. 2017). A major element in resistance, according to current investigations, is Th1/Th17 polarization, whereas FoxP3 Tregs are essential to immune regulatory mechanisms that support *E. multilocularis* metacestode survival (Wang et al. 2017). After being infected with *E. granulosus sensu stricto*, mice were treated in vivo with a single IV administration of 200 l recombinant IL-17A at the ideal dose of 125pg/ml. This dropped the infection rate by 2/3 and suppressed metacestode production by over 90 percent (Labsi et al. 2018).

FoxpP3 has the potential to be a useful target in immunotherapy in humans (Wang et al. 2018a). Another strong contender is the PD-1/PD-L1 signaling process, which is important for the onset of Foxp3 CD25 CD4 Tregs, influences IL-10 secretion favorably, prevents growth of effector T cell, and blocks the generation of Th1 cytokines (Liu et al. 2013). In contrast to healthy counterparts, those with CE had higher levels of soluble PD-L1 (Li et al. 2016) and more helper T cells that expressed PD-1 (Zhang et al. 2015; La et al. 2015). A PD-1/PD-L1 engagement blocker has shown promise in early trials (Wang et al. 2018c). Clinicians have access to various PD-1/PD-L1 inhibitors that have already been employed to address cancer (Swaika et al. 2015) for pilot immunotherapeutic studies in AE. Clinicians may also benefit from antiinfective and immunological therapy when treating CE cases that are severe and involve many organs. Attention has been drawn to the unique profile of the chronic phase of CE and AE parasite infections because it is a known tolerance phase that may be employed to lessen the harmful consequences of inflammatory processes in a range of clinical circumstances. While concurrent CE infection decreases inflammation in rodents (Wang et al. 2014), concurrent AE inoculation in the mice postpones refusal of a hepatic tissue allograft (Li et al.2011). In both cases, the outcomes were linked to elevated IL-10 levels in the animals being studied. Though it was also suggested that *Echinococcus* sp. substances would be effective in treating rheumatoid arthritis, this has not yet been proven (Apaer et al. 2016). The observations in the experimental colitis study provide the best support for regulating the immune function of developed *Echinococcus* spp. infection in its intermediate host. Infections with E. *granulosus sensu stricto* (Khelifi et al. 2017) and *E. multilocularis* (Wang et al. 2018b) can both prevent mice from developing dextran sulfate sodium (DSS)-induced colitis (Wang et al. 2018c).

The potential use of non-infectious *Echinococcus* spp. extracts is confirmed by findings provided after treating rodents regularly with extracts from *E. granulosus sensu stricto* laminated layer beginning three days prior to colitis induction. The medication significantly lowered clinical signs and intestinal histological parameters while maintaining mucus production by goblet cells and inducing a sufficient drop in IFN. The change that the immune system of the host may experience as a consequence of the immune system regulation has been extensively researched (Gottstein and Hemphill 2008; Vuitton and Gottstein 2010). This shift may boost metacestode proliferation and subsequently impair host defense. Recent studies identified some immunoregulating products of *Echinococcus* species such as AgB, Eg2, Em2, EmAP, and EgTeg (Siracusano et al. 2012a; Wang and Gottstein 2016).

5. ENHANCING THE DEVELOPMENT OF VACCINE

5.1. INTERMEDIATE HOST VACCINATION

In pilot and field studies, the EG95 antigen vaccination of *E. granulosus* intermediate hosts illustrated a significant protective efficiency, and it is presently being employed in endemic regions of China and South America (Lightowlers and Heath 2004; Heath et al. 2012; Larrieu et al. 2013; Craig et al. 2017; Larrieu et al. 2015). The infection phase for people, as well as intermediate hosts, is the oncosphere of *Echinococcus*. Antibodies produced by the eg95 (oncosphere-specific) gene provides an elevated defense against egg infection in small and large ruminants (Chow et al. 2004; Heath et al. 2012) and the end results of other genes that are differently produced at this phase likely represent possible additional vaccine candidates. According to gene transcription analysis, Eg95 has significant expression in oncospheres (Zheng et al. 2013), and recent research has found that Eg95 is really a family of 7 different genes. Other products are also encoded by oncosphere genes that are potential targets for vaccination as given in Table 1.

Table 1: Potential targets for vaccines against CE and AE in intermediate hosts expressed in different life forms (oncosphere, mature and protoscoleces).

Gene (ID)	Number in Sequence reading				Gene information
	Oncosphere	Mature	Cyst	Protoscoleces	
Eg_05614	806	2	0	0	Eg95
Eg_08805	481	2	0	0	Eg95
Eg_10541	266	4	5	1	Eg95
Eg_06928	185	1	0	0	Eg95
Eg_11122	30	0	0	0	Eg95
Eg_06751	27	2	0	0	Eg95
Eg_10281	24	79	12	12	Eg95
Eg_08721	108	6	0	0	Serine protease inhibitor
Eg_06806	209	1733	83	21	Antigen B3
Eg_05439	329	2	0	1	Hypothetical protein
Eg_09040	133	16	0	0	Hypothetical protein
Eg_07993	554	3	0	0	Diagnostic antigen gp50
Eg_00010	533	1	0	0	Host-protective antigen
Eg_04657	98	18	50	30	Reticulon-4
Eg_08098	222	1	0	0	Gli pathogenesis-related 1
Eg_05449	66	0	23	12	Hypothetical protein
Eg_04921	65	1	0	0	Hypothetical protein
Eg_04940	125	2	1	13	Novel hemicentin protein
Eg_05345	55	48	42	11	Proteasome (macropain) beta 1
Eg_00715	33	146	154	69	Tetraspanin 1-TSP6
Eg_07633	2700	2	8	1	Hypothetical protein
Eg_03592	61	64	36	24	Low-density lipoprotein receptor
Eg_00394	72	0	0	0	e74-like factor 2

Additionally, gene transcription analysis revealed that in contrast to the mature and cystic phases of *E. granulosus*, 340 (out of 3,811) genes had been significantly increased in oncospheres (Zheng et al. 2013) and 2% (74/3,811) of the genes transcribed in the oncosphere are secreted proteins that probably play a crucial role in the hatching oncosphere's passing through the mammalian intestine and in the growth of the oncosphere itself.

5.2. DEFINITIVE HOST VACCINATION

A step in integrated echinococcosis control that protects dogs from mature *Echinococcus* spp. infection would be extremely desired. There isn't presently a vaccination for this condition. In the canine gut, the protoscolex stage gives rise to a mature worm. In the protoscoleces or in the mature, proteins of genes that are significantly transcribed may offer promising vaccination candidates against adult parasites in the target host. When dogs were vaccinated with egM gene and a necropsy was performed forty-five days after inoculation, they were found to have good immunity against parasites (Zhang et al. 2006; Zhang et al. 2018). These substances might be linked to adult worm growth and/or egg development. Mature *Echinococcus* parasites are found in the center of their definitive hosts' small intestines, which contain high concentrations of trypsin and trypsin-related enzymes as well as an extensive amount of nutrients, including amino acids. It is probable that the worms serve a crucial protective function in avoiding proteolytic enzyme assault and preserving the survival of *E. granulosus* inside its definitive hosts by secreting specific inhibitors that neutralize the potentially harmful outcomes of host GIT enzymes. These presumably indicate additional vaccination options that require further investigation, along with molecular receptors for neurotransmitters and transporters, as well as other inhibitions of protease that are specifically translated in adult worms (Zheng et al. 2013; Ranasinghe et al. 2015; Behrendt et al.2016; Cuesta-Astroz et al. 2017; Morais et al. 2018).

6. CONCLUSION

Due to novel proteomics data, the entire sequencing of the CE ad AE genomes, and improved knowledge of interactions between hosts and parasites for AE and CE, novel pharmacological or immunological treatment sites have been discovered. While a precise understanding of the pathogenic species/genotypes can assist healthcare organizations better concentrate and maximize the efficacy of control initiatives, limiting the spread of *Echinococcus* spp. remains a significant challenge. However, significant advancements in molecular assays to identify *Echinococcus* spp. in specific hosts and the environment has made CE ad AE control program easier to understand.

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