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

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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.

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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).

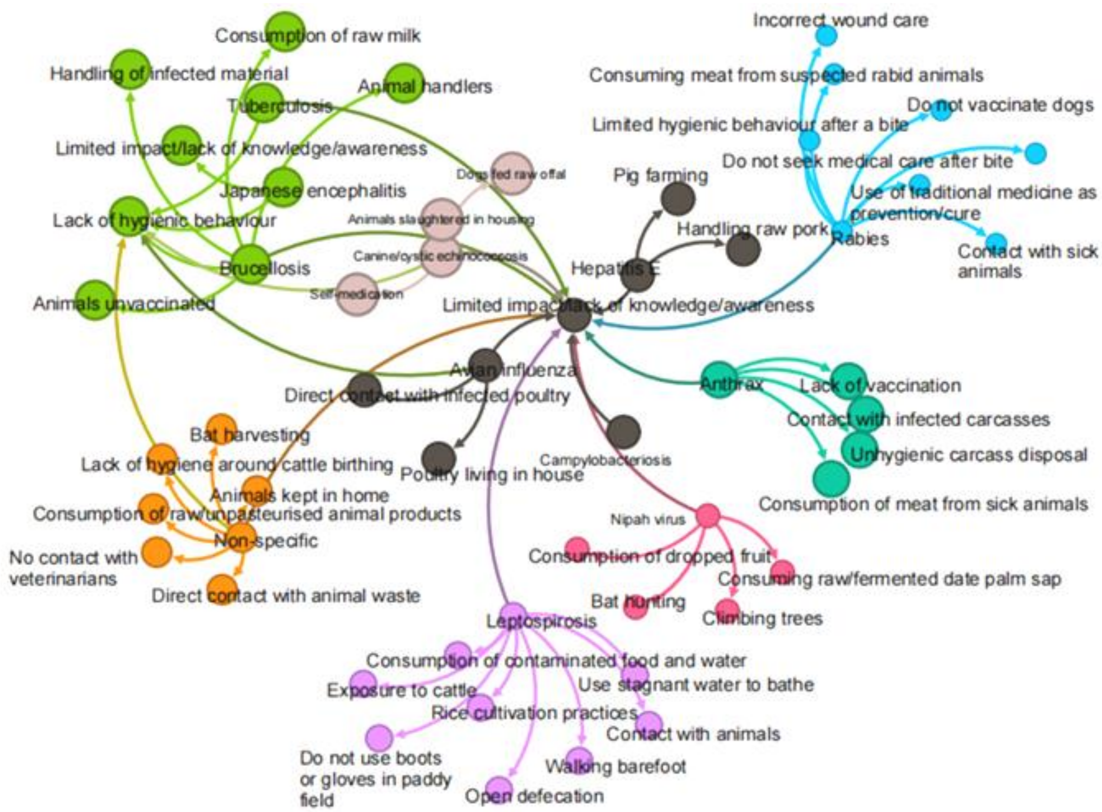

Fig. 1: Network modeling for behavioral anthropogenic vectors interactions with the major zoonotic diseases and their interrelationship.

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).

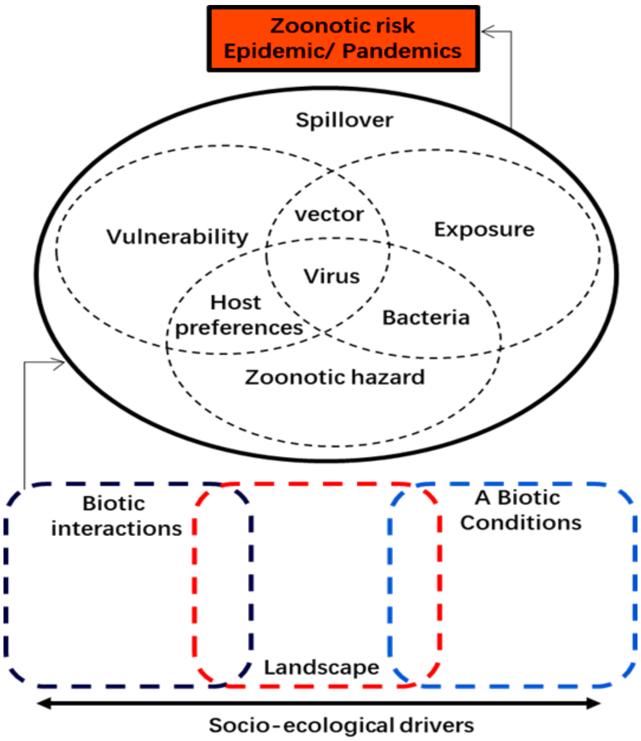

Fig. 2: Thematic flow highlighting the major relationship between zoonosis factors that how socio-ecological drives connected with spill over and zoonotic hazard, a foundation of component ultimately influencing the zoonotic risk.

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).

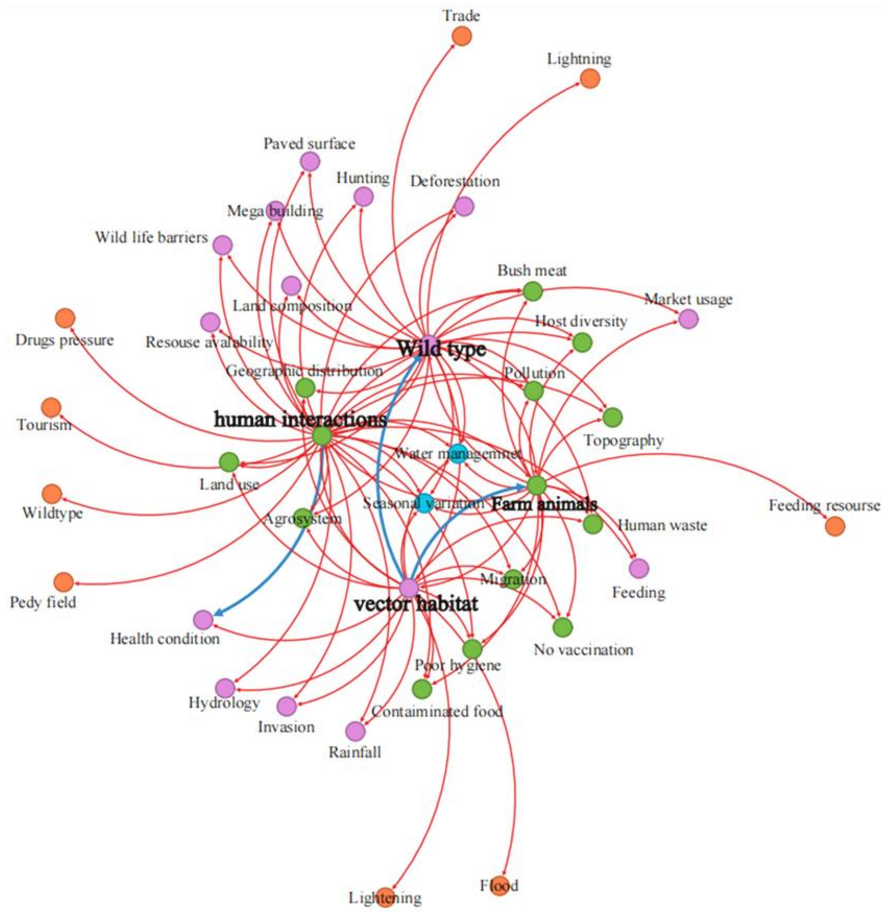

Fig. 3: Network modeling for anthropogenic drivers' interaction with the Human interface, Wild type, farm animals and vector habitat interrelationship. Different colors represent modularity class (37% - 5%), red lines indicate overall interactions and blue lines represent strong interaction.

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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