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.

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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).

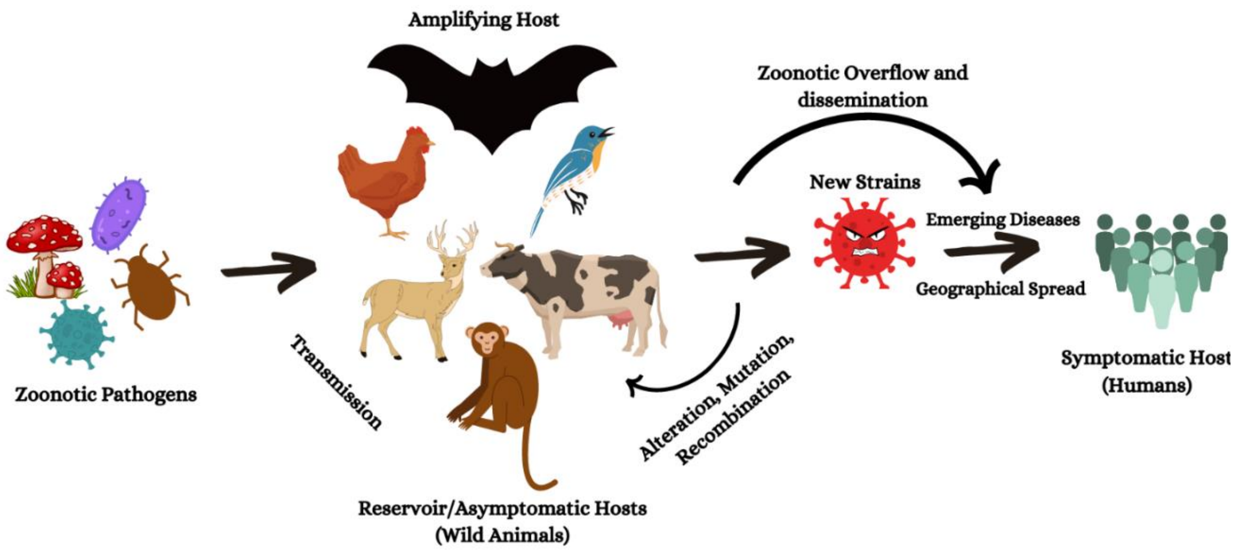

Fig. 1*:* Transmission of Zoonotic Pathogen from Reservoir Host to Humans.

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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