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REVIEW ARTICLE OPEN ACCESS

Emerging Zoonotic Viral Diseases in India: One Health Perspective

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Abstract

Emerging zoonotic viral diseases pose significant public health challenges due to their high fatality rates, potential for widespread outbreaks, and profound socioeconomic impact. Human, animal, and environmental health interconnectedness highlights the need for a collaborative One Health (OH) approach to control and prevent these diseases. With its diverse ecosystems and rapid urbanization, India has witnessed several major zoonotic outbreaks over the past two decades, including Nipah virus, Kyasanur Forest Disease (KFD), H1N1 influenza, and the global COVID-19 pandemic. These outbreaks underscore the urgent need for integrated surveillance systems, early detection strategies, and sustainable interventions to mitigate future risks. Contributing factors such as deforestation, climate change, unregulated wildlife trade, and intensive farming practices exacerbate the spread of zoonotic diseases. This manuscript emphasizes the importance of a multidisciplinary OH approach, drawing on evidence-based strategies for disease surveillance, vaccination, vector control, and community engagement. By addressing these challenges through coordinated efforts, India can strengthen its preparedness and response to emerging zoonotic viral diseases while promoting public and ecological health.

Keywords: Zoonotic Diseases, One Health, Nipah Virus, Kyasanur Forest Disease, Surveillance, India, Climate Change

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INTRODUCTION

Human activities and stressed ecosystems create opportunities for the emergence and spread of viral diseases. The stress factors such as habitat fragmentation, animal trafficking, agriculture, cattle farming, urbanization, mining industries, climate change, and environmental degradation.[1,2] In recent years, the global community has borne witness to the profound ramifications of emergent viral diseases such as Zika, COVID-19, and Ebola. These diseases not only engender significant threats to human health but also exert considerable impacts on the environmental and animal well-being.[3] This paradigm embodies a collaborative attempt to acknowledge the intricate interrelations among human, animal, and environmental health domains. Through interdisciplinary cooperation, experts from diverse fields can identify and address the fundamental causes of emergent viral diseases, including factors such as deforestation, climate

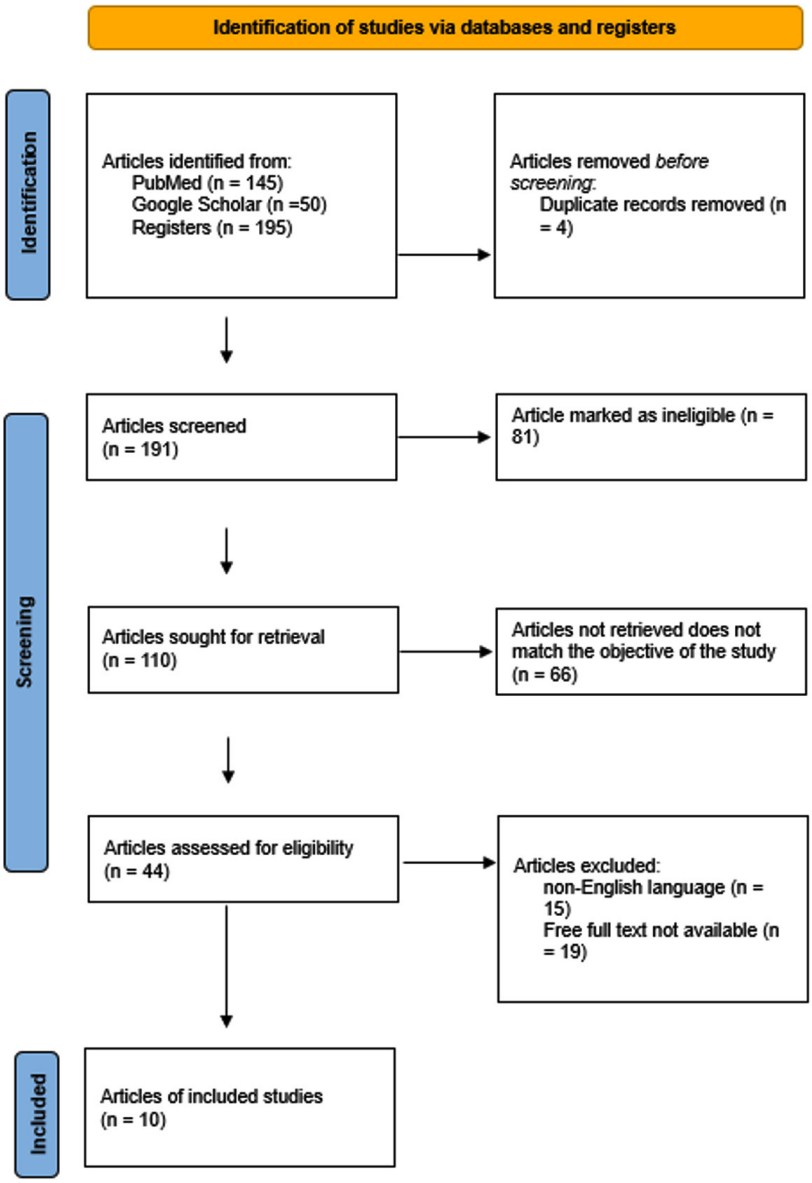

Figure 1. PRISMA[9]

perturbations, and the proliferation of globalized networks.[4] The efficacy of the OH framework has been substantiated through its successful implementation across numerous nations, bringing advancements in disease surveillance, prophylaxis, and mitigation strategies.[5]

Antimicrobial resistance (AMR) stands out as one of the most significant global health challenges within the OH framework.[6] AMR is linked to all three components due to the excessive use of antimicrobials across diverse sectors, including human medicine, livestock farming, and agriculture. Bacteria acquire resistance genes and mobile genetic elements in response to selection pressure from antimicrobials. These genes can be transferred to other bacteria within the same genus or to new species.[7] Due to factors such as mismanagement, lack of infection control, agricultural waste, environmental pollution, and the migration of persons and animals, antimicrobial-resistant bacteria have an increased capability to spread to humans, animals, and the environment.[8] This study aims to evaluate the historical and contemporary impact of emerging viral diseases on human and animal populations, considering the potential for zoonotic transmission.

Review

Search strategy

Inclusion criteria

Inclusion criteria were (i) studies that focus on zoonosis, emerging viral diseases, and one health approach, (ii) studies published in the past decade, (iii) studies that match the objective of this study, and (iv) studies written in the English language.

Exclusion criteria

Exclusion criteria were (i) Studies written as editorials, book chapters, case series, short communication, or letter to editor; (ii) studies unavailable in full-text; (iii) studies published are not in English language; and (iv) studies whose findings were considered does not match the objective of the study.

Data Extraction

PubMed and Google Scholar search engines were used, Mesh terms were (("zoonoses"[MeSH Terms] OR "zoonoses"[All Fields] OR ("zoonotic"[All Fields] AND "diseases"[All Fields]) OR "zoonotic diseases"[All Fields]) AND ("one health"[MeSH Terms] OR ("one"[All Fields] AND "health"[All Fields]) OR "one health"[All Fields]) AND ("virus diseases"[MeSH Terms] OR ("virus"[All Fields] AND "diseases"[All Fields]) OR "virus diseases"[All Fields]) AND

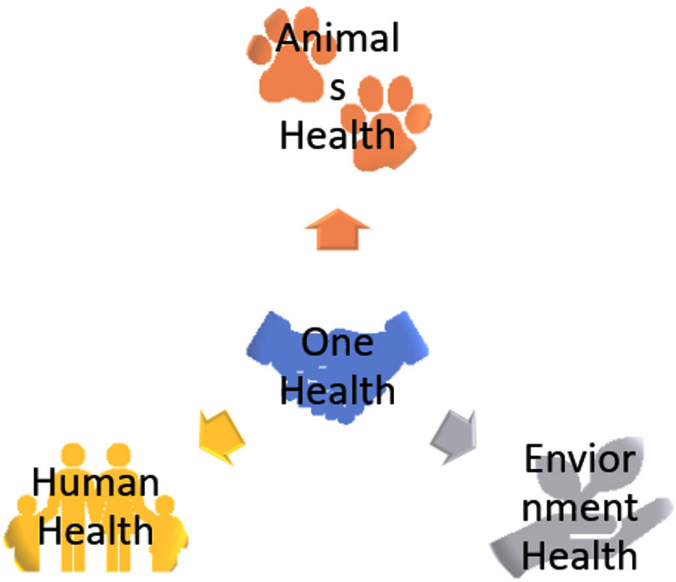

Figure 2. One Health Approach[1,20]

("collaborate"[All Fields] OR "collaborated"[All Fields] OR "collaborates"[All Fields] OR "collaborating"[All Fields] OR "collaboration"[All Fields] OR "collaborations"[All Fields] OR "collaborative"[All Fields] OR "collaborative s"[All Fields] OR "collaboratively"[All Fields] OR "collaboratives"[All Fields] OR "collaborator"[All Fields] OR "collaborators"[All Fields]) AND ("india"[MeSH Terms] OR "india"[All Fields] OR "india s"[All Fields] OR "indias"[All Fields]))(Figure 1) (Table 1).

Figure 3. The timeline illustrates the progression of One Health initiatives in India[35,37-40]

Study included

The reviewed studies collectively highlight the significant role of the OH approach in addressing complex health challenges at the human-animal-environment interface. Kumar *et al*. emphasized the zoological origins of SARS-CoV-2 and stressed the need for a one-health strategy to mitigate future epidemics.[10] Likewise, Filho *et al*. explain the increasing impact of climate change on the spread of zoonotic diseases and emphasize the need for integrated health interventions.[11] Mourya *et al*. further demonstrated the effectiveness of one-health interventions. Prejit *et al*. documented the management and control of successful epidemics of zoonotic diseases in India through cooperation efforts.[12,13] Chatterjee *et al*. and de la Rocque *et al*. highlighted the critical gap in policy and the importance of implementing a health plan to improve global health security.[14,15] The detailed study by Tazerji *et al*. on the transmission of SARS-CoV-2 in animals and Dasgupta *et al*. on the need for inter-disciplinary cooperation in India, we further highlight the importance of a multidisciplinary approach to the management of zoonotic diseases.[16,17] Finally, Wacharapluesadee *et al*. long-term surveillance study of Nipah virus in Thailand illustrates the sustained benefits of coordinating.

One health approach

One Health approach is a team effort to recognize that the health of animals, humans, and the environment are all connected and that one affects the others.[20] Experts in human health, animal health, environmental science, ecology, and public health work together to find and solve the root causes of new viral diseases, which is why the One Health approach includes specialists from different fields.[21]

The OH approach is not a new concept. It has been recognized since the early 20th century, but it gained renewed attention in the 1990s following the outbreak of zoonotic diseases such as SARS and avian influenza. This approach is now widely recognized as an effective way to tackle emerging viral diseases and other health issues that affect multiple species.[22]

This approach has several advantages, including improved disease surveillance, prevention, and control. It also encourages a more complete and integrated approach to health, acknowledging the connection between the health of people, animals, and the environment[1] (Figure 2).

The link between emerging viral diseases and the environment

Emerging viral diseases are interconnected with changes in the environment, a relationship grounded in the complex relationship between ecological systems, human activities, and infectious agents.[23] Scientific evidence highlights the pivotal role of environmental alterations, including deforestation and climate change, in driving the emergence and transmission of zoonotic diseases those that originate in animals and spill over into human populations.[24]

Deforestation, often driven by agricultural expansion and urbanization, disrupts natural habitats and ecological balance, bringing humans into closer contact with wildlife species that may harbor novel pathogens.[25] This increased proximity heightens the risk of zoonotic spillover events, wherein pathogens transfer from animals to humans, potentially resulting in outbreaks or pandemics. Similarly, climate change influences the distribution and behavior of vector species, such as mosquitoes and ticks, altering the transmission dynamics of vector-borne diseases and expanding their geographical range.[26]

Globalization and intensified travel patterns have profoundly transformed the landscape of disease transmission, facilitating the rapid spread of infectious agents across borders and continents. The COVID-19 pandemic serves as a poignant illustration of how interconnectedness and international mobility can amplify the dissemination of a novel virus.[27] The emerging evidence suggests that the SARS-CoV-2 virus, which is responsible for COVID-19, probably originates from bats and may be transmitted to humans by the intermediate host, possibly pangolin, on a wet market in Wuhan, China.[28] Subsequent international travel facilitated the global spread of the virus, leading to a devastating pandemic.[29]

The approach of one health has become a comprehensive framework for understanding and addressing the complex interdependence between human health, animal health, and environmental

Table 1. Summary of research on one health strategies and their impact

No.	Author(s)	Year	Population	Intervention /Exposure	Outcome Measures	Main Findings	Strengths	Limitations	Relevance to Review
1	Kumar et al.[10]	2022	Various animal species	Infection with SARS-CoV-2	SARS-CoV-2 infection rates and transmission among animals	The review highlights the zoonotic origin, its transmission, and the need for a OH approach.	A comprehensive review of various animal studies on SARS-CoV-2	No new experimental data; relies on existing studies	Provides a thorough understanding of the role of animals in COVID-19 transmission and emphasizes the need for an OH approach
2	Filho et al.[11]	2022	Not specific to any population	Impact of climate change on zoonotic diseases	Analysis of literature and bibliometric trends	Climate change alters the conditions for pathogens and vectors, leading to increased spread of zoonotic diseases such as West Nile and Usutu viruses; the USA, UK, Canada, Australia, Italy, and Germany are the most active in research.	Comprehensive bibliometric analysis, and visualization of data using VOSviewer	Relies on existing literature, no new experimental data	Highlights the complex impact of climate change on zoonotic diseases and the need for OH approach
3	Mourya et al.[12]	2021	Various populations in India	Outbreak investigations and OH approach implementation	Disease spread, outbreak response, and control measures	Collaboration and coordination among stakeholders were crucial in managing outbreaks and; a significant reduction in impact through early detection and preventive measures.	Detailed review but no new experimental data; relies on existing cases and outbreak reports	Detailed review but no new experimental data; relies on existing cases and outbreak reports	Provides insights into the practice of the OH approach in managing zoonotic diseases.
4	Prejit et al.[13]	2022	Population of Wayana, Kerala	OH approach for Kyasanur Forest Disease (KFD) control	Degree of OH-ness, outbreak control effectiveness	The OH approach was effective in controlling the KFD outbreak with high scores in a systemic	Comprehensive evaluation of the OH approach using the Network for	Limited to one district and one disease; results may not be	Demonstrates the effectiveness of the OH approach and provides a model for future

						organization and OH thinking; and identified areas for improvement in OH sharing and learning.	Evaluation of One Health (NEOH) framework	generalizable	implementation in similar contexts
5	Chatterjee et al.[14]	2016	Various stakeholders in India	Policy analysis and review	Policy gaps and recommendations	The paper discusses the missed opportunities in integrating One Health approaches in India's national health policies, emphasizing the need for intersectoral coordination to address emerging infectious diseases.	Critical analysis of policy framework, highlighting gaps and missed opportunities	Focuses on policy analysis, lacks empirical data	Provides a policy perspective on the importance and integration in national health strategies.
6	de la Rocque et al.[15]	2021	Various countries	One Health roadmap implementation	Evaluation of IHR capacities and health security	The study highlights the importance of operationalizing OH roadmaps to improve IHR capacities and health security, identifying gaps and recommending improvements for better coordination at the human-animal-environment interface.	Comprehensive analysis of IHR capacities and OH implementation	Limited to analysis, lacks implementation data	Provides a framework for improving OH implementation and enhancing global health security
7	Tazerji et al.[16]	2020	Various animal species	Transmission of SARS-CoV-2 from humans to animals	SARS-CoV-2 infection rates among animals, genomic and phylogenetic analyses	The study reviews reported cases of SARS-CoV-2 transmission to animals, emphasizing the need for further research to understand the dynamics of the disease in humans and animals.	Detailed genomic and phylogenetic analysis of SARS-CoV-2 isolates from animals	Relies on existing reports and studies, no new experimental data	Provides insights into the trans-missiondynamics of SARS-CoV-2 between humans and animals, highlighting the need for a OH approach

8	Dasgupta et al.[17]	2021	Various populations in India	OH policy implementation	Policy recommendations, framework for OH Committees	The study emphasizes the need for intersectoral collaboration and the establishment of OH Committees at state and district levels to address public health challenges effectively.	Comprehensive policy recommendations, practical framework for implementation	Focuses on policy analysis, lacks empirical data	The importance of a coordinated OH approach in addressing zoonotic diseases and other public health challenges in India
9	Wacharapluesadee et al.[18]	2018	Various animal species in Thailand	Surveillance of Nipah virus	Nipah virus infection rates, surveillance effectiveness	The study reviews two decades of OH surveillance of Nipah virus in Thailand, highlighting the effectiveness of a coordinated surveillance approach in detecting and managing outbreaks.	Long-term surveillance data, comprehensive analysis of Nipah virus trends	Limited to surveillance data, no new experimental data	Demonstrates the effectiveness of long-term OH surveillance in managing zoonotic disease outbreaks
10	Taaffe et al.[19]	2023	Various populations in India	Intersectoral coordination and collaboration	Local intersectoral activities and collaboration examples	The review identifies key themes and examples of local OH activities, demonstrating that intersectoral collaboration primarily occurs through specific research activities, during outbreaks, and community outreach efforts. Limited formal coordination among veterinary, medical, and environmental professionals at the district/sub-district levels is noted.	Comprehensive landscape assessment, highlighting real-world examples of intersectoral coordination	Limited to published literature and personal experiences, potential bias	Provides insights into the current landscape of OH activities at the local level in India, emphasizing the need for formalized and sustained intersectoral coordination

health. The goal of a health approach is to identify and mitigate the root causes of emerging viral diseases by promoting cooperation between experts from a variety of fields, such as medicine, veterinary sciences, ecology, and public health.[1] This collaborative effort involves proactive surveillance, early detection, and preventive interventions aimed at mitigating the risks posed by environmental factors, thereby reducing the likelihood of future outbreaks and pandemics.

In short, the bridge between emerging viral diseases and the environment highlights the urgent need for interdisciplinary cooperation, evidence-based interventions, and sustainable practices to safeguard human health and ecological integrity.[30] By adopting a comprehensive and integrated approach, informed by scientific and ethical studies, we can address the complex challenges associated with new infectious diseases and promote the resilience of the global health system to environmental changes.[31]

Indian Government

The Government of India plays an important role in the implementation of a one health approach that addresses the interdependence of human, animal, and environmental health and mitigates the risks of emerging infectious diseases. As a diverse and populous nation facing numerous health and environmental challenges, the Indian government's actions and policies have significant implications for public health and ecological integrity.[32]

In terms of public health, the Indian government is tasked with enhancing disease surveillance, early detection, and response capabilities to combat infectious pathogens. This involves strengthening laboratory infrastructure, expanding diagnostic capacity, and developing robust public health systems capable of rapidly detecting and containing outbreaks. Additionally, promoting research and innovation in fields such as epidemiology and virology is essential for understanding the dynamics of disease emergence and transmission.[33]

Furthermore, the Indian government plays an important role in environmental governance and biodiversity conservation, addressing factors such as habitat destruction and deforestation that contribute to the emergence of zoonotic diseases. Policies aimed at conserving ecosystems, preserving wildlife habitats, and promoting sustainable land-use practices are integral to a OH approach. Initiatives to regulate the wildlife trade, promote responsible agriculture, and mitigate climate change impacts are also essential for minimizing ecological drivers of disease emergence.[34]

In terms of international collaboration, the Indian government engages with global health organizations and regional alliances to exchange knowledge and resources related to OH initiatives. Participation in forums such as the World Health Assembly and the Convention on Biological Diversity allows India to contribute to collective efforts to address emerging health and environmental challenges.[35]

However, challenges such as resource constraints, infrastructure gaps, and socio-economic disparities pose obstacles to effective OH implementation in India. To tackle these challenges, strong political support is needed, along with investment in building skills and community involvement. This will help ensure fair access to healthcare services and environmental resources for everyone.[36]

The Indian government's role in implementing a OH approach is multifaceted, encompassing public health, environmental management, and international collaboration. By prioritizing interdisciplinary cooperation, evidence-based policymaking, and community participation, the Indian government can help in the prevention, detection, and control of emerging viral diseases while promoting the health and resilience of ecosystems and communities across the country (Figure 3).[35]

History of Viral diseases outbreak reported in India

Zoonotic viral diseases have a long history of impacting humans and animals, with notable outbreaks occurring throughout the ages. Rabies, a disease that dates back to ancient times, affects dogs, bats, and wild carnivores and is primarily transmitted by saliva.[41] In the 1950s, Japanese Encephalitis emerged, affecting birds and pigs, transmitted by Culex mosquitoes.[42] Kyasanur Forest Disease, discovered in 1957, primarily affects monkeys and is transmitted by ticks.[43]

Table 2. Emerging, remerging zoonotic viral diseases in India

Zoonotic Viral Disease	Year of Detection/ Outbreak	Affected Animals	Vector
Rabies	Historical (ancient)	Dogs, bats, wild carnivores	Direct transmission (saliva/bite)[41]
Japanese Encephalitis (JE)	1950s	Pigs, birds	Mosquito (culex species)[42]
Kyasanur Forest Disease (KFD)	1957	Monkeys	Ticks (Haemaphysalis spinner)[43]
Chandipura Virus	1965	Not specific	Sandflies (Phlebotomus species)[53]
Dengue Fever	1960s	Non-human primates	Mosquito (aedes albopictus, aedes aegypti)[44]
Chikungunya	2006 (major outbreak)	Non-human primates	Mosquito (aedes albopictus, aedes aegypti)[45]
Avian Influenza (Bird Flu)	2006	Poultry, wild birds	Direct transmission (Bird secretions)[46]
Nipah Virus	2001 (West Bengal), 2018 (Kerala)	Bats (fruit bats)	Direct transmission (bat secretions)[54]
H1N1 Influenza (Swine Flu)	2009	Pigs	Direct transmission (Respiratory droplets)[48]
Crimean-Congo Hemorrhagic Fever (CCHF)	2011	Livestock (cattle, sheep, goats)	Ticks (Hyalomma species)[49]
Zika Virus	2017	Non-human Primates	Mosquito (Aedes aegypti, Aedes albopictus)[50]
SARS-CoV-2 (COVID-19)	2020	Bats, Pangolins (Suspected)	Direct transmission (Respiratory droplets)[51]

The 1960s saw the emergence of Dengue Fever, transmitted by Aedes mosquitoes and affecting non-human primates.[44] Chikungunya, another mosquito-borne disease, caused a major outbreak in 2006, primarily affecting non-human primates.[45] Avian Influenza, or Bird Flu, emerged in 2006, impacting poultry and wild birds through direct transmission.[46] The Nipah Virus, identified in 2001 and 2018, is associated with fruit bats and direct contact with bat secretions.[47]

In 2009, the H1N1 Influenza, or Swine Flu, emerged, primarily affecting mainly pigs and spreading through respiratory droplets.[48] Crimean-Congo Hemorrhagic Fever, identified in 2011, affects livestock and is transmitted by ticks.[49] Zika Virus gained prominence in 2017, transmitted by Aedes mosquitoes and impacting non-human primates.[50] Recently in 2020, SARS-CoV-2, which causes COVID-19, emerged, possibly from bats and pangolins, spreading through respiratory droplets in humans.[51] These diseases underscore the ongoing challenge of zoonotic infections and the importance of understanding their dynamics for effective prevention and control measures (Table 2).

Collaboration between veterinary, environmental, and public health sectors to monitor bat populations, educate communities, and implement surveillance and control measures to prevent future outbreaks come under a OH approach.[52]

Emerging, remerging zoonotic viral diseases in India

Implications for future

The imperative for active disease management necessitates a collaborative approach to surveillance, vaccination, vector control, wildlife management, environmental stewardship, community engagement, and policy formulation, all supported by research and capacity-building initiatives.[55] Integrated monitoring systems are necessary for human, animal, and vector surveillance to detect disease emergence easily. Simplified by enhanced data sharing among health, veterinary, and environmental agencies, timely dissemination of information is essential for effective response.[56]

Vaccination campaigns targeting both animals and high-risk human associates joined

Table 3. Key strategies for one health approach in disease prevention

Area	Strategies
Surveillance and Early Detection	• Integrated monitoring means creating systems to keep track of diseases in people, animals, and insects that spread diseases. • Data sharing means improving teamwork between agencies that focus on human health, animal health, and the environment so they can quickly share important information.[62]
Vaccination and Treatment	• Vaccination Campaigns can conduct vaccination programs in animals (e.g., rabies, avian influenza) and at-risk human populations. • Access to antiviral drugs can improve healthcare through early treatment.[63]
Wildlife and Livestock Management	• Zoning and biosecurity can be implemented in livestock biosecurity measures and wildlife management strategies. • Educate communities on the safe handling of domestic and wild animals.[64]
Vector Control and Management	• Source reduction of breeding sites for vectors such as mosquitoes or ticks. • Biological control by using biological agents or natural predators to reduce vector populations.[55]
Community Engagement and Education	• Public Awareness to educate communities on preventive practices, safe animal handling, and recognizing disease symptoms. • Cultural Adaptation to give messages and strategies to local cultural practices for better adoption.[65]
Environmental and Ecological Management	• Deforestation control can limit habitat disruption and manage land use changes to minimize wildlife-human contact. • Water management to reduce contamination and ensure proper waste disposal.[26]
Policy and Legislation	• Establish strong legal regulatory frameworks for disease control, wildlife trade, and livestock management. • Cross-sector cooperation to promote multi-disciplinary coordination between health, agriculture, and environmental sectors.[60]
Research and Capacity Building	• Research on disease ecology helps us understand how diseases spread between different species. • Training programs to build capacity in epidemiology, veterinary science, and environmental health for sustained expertise.[66]

with improved access to antiviral therapeutics, establishment is an essential component of disease management strategies. Together, vector control measures, including source reduction and biological agents, aim to restrain vector-borne disease transmission.[57] Implementation of zoning protocols and biosecurity measures in livestock and wildlife management, alongside community education on safe animal handling, foster disease containment.[58]

Environmental management interferences, such as deforestation control and water sanitation measures, moderate habitat disruption and minimize pathogen spillover. Community engagement initiatives, emphasizing preventive practices and culturally adapted messaging, increase public awareness and adopt behavioural change.[59] Policy frameworks, surrounding disease control, wildlife trade, and interdisciplinary cooperation, provide the regulatory support necessary for effective implementation.[60]

The research aims to explain disease ecology dynamics across species and capacity-building initiatives in epidemiology, veterinary science, and environmental health to support institutional resilience against emergent threats. This collaborative approach, supported by scientific accuracy and interdisciplinary collaboration, embodies a positive attitude toward the protection of public health and ecological integrity in the evolving infectious disease challenges (Table 3).[61]

CONCLUSION

The one health approach connects the health of people, animals, and the environment, making it essential for managing new diseases that can spread from animals to humans in India. Success requires teamwork across various fields, effective monitoring, vaccination efforts, controlling disease-carrying insects, managing wildlife, and engaging communities. The Indian government plays a crucial role by creating policies, collaborating with other countries, and building the necessary skills to address these health issues. Tackling challenges like antibiotic resistance and environmental damage through sustainable practices can help prevent future outbreaks of zoonotic diseases. By adopting a comprehensive and evidence-based strategy, India can enhance public health and foster a healthier balance between people and nature.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS' CONTRIBUTION

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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None.

DATA AVAILABILITY

All datasets generated or analyzed during this study are included in the manuscript.

ETHICS STATEMENT

Not applicable.

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