

Perspectives

From Silos to Systems: Reimagining Zoonotic Neglected Tropical Disease Management through the Lens of One Health

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ABSTRACT

Background: Zoonotic neglected tropical diseases (zNTDs) pose significant global public health challenges, particularly in low-income and middle-income countries. Traditional siloed approaches to zNTD management have proven inadequate for addressing the complex interplay between human, animal, and environmental health factors. **Objective:** This review examined the limitations of fragmented strategies and explored the potential of integrated one-health approaches for more effective zNTD control. **Methods:** This narrative review covered publications from 2000 to 2023, sourced from databases including PubMed and Scopus, emphasizing studies that met inclusion criteria of peer-reviewed research focused on zNTDs through a One Health lens. **Results:** A comprehensive analysis of the current literature and case studies was conducted to evaluate the multifaceted drivers of zoonotic pathogen spillover, assess the economic and health impacts of zNTDs, and identify successful implementation of the One Health strategy in endemic regions. This review highlights the inadequacies of siloed disease management approaches, which often lead to inefficient resource allocation and missed opportunities for synergistic intervention. Successful case studies have demonstrated the effectiveness of the One Health strategy in improving disease surveillance, enhancing cross-sectoral collaboration, and achieving sustainable health outcomes. The potential of emerging technologies and innovations to support integrated approaches has also been explored. **Conclusion:** Transitioning from siloed to systemic approaches in zNTD management requires overcoming institutional barriers, fostering cross-sector collaboration, and implementing multitiered frameworks that operate at the local, national, and global levels. Investing in cross-sectoral capacity development and leveraging technological innovations are crucial for building a workforce capable of addressing the complex challenges posed by zNTDs. Adopting the One Health principle offers a promising path toward more comprehensive, efficient, and sustainable strategies for zNTD prevention.

KEYWORDS

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INTRODUCTION

Zoonotic neglected tropical diseases (zNTDs) continue to pose a significant threat to public health, especially in low-income and middle-income countries [1]. zNTDs are a group of infectious diseases that primarily affect impoverished populations and are transmitted between animals and humans. At least one billion people worldwide are burdened by zNTDs in tropical and subtropical regions. The transmission of these diseases involves complex interactions between humans, animals, and the environment, with many diseases showing increasing prevalence annually [2]. Despite advances in zNTD control, traditional silo approaches to zNTD management that focus on human health interventions have proven insufficient to address the multifaceted nature of the disease [3]. Fragment strategies often overlook important ecological components and zoonotic factors, leading to suboptimal outcomes and persistent disease transmission.

In addition, traditional silos result in inefficient resource allocation, repetitive efforts, and missed opportunities for synergistic interventions [4]. This, along with the lack of integrated surveillance systems and data-sharing mechanisms, has hindered our understanding of disease transmission dynamics and the development of effective control measures [5]. Given these challenges, there is an urgent need to explore innovative integrated approaches to zNTD management that can effectively address the complex interplay among human, animal, and environmental health factors. This paper aims to systematically assess zNTD management using One Health strategies by targeting specific disease drivers, socio-economic impacts, and case-study evaluations of implementation practices. The insights and recommendations presented are relevant not only to policy makers and health practitioners working in zNTD-endemic regions but also to the wider global health community seeking to build more resilient and responsive health systems in the face of emerging zoonotic threats.

PERSPECTIVE

Overview of Zoonotic NTDs

Zoonotic neglected tropical diseases (NTDs) represent a subset of NTDs that are transmitted from animals to humans and pose substantial challenges to global public health. These diseases have gained increasing attention because of their potential to cause widespread outbreaks and pandemics. These diseases, which include but are not limited to rabies, echinococcosis, Ebola, Zika, and cysticercosis, disproportionately affect impoverished populations in tropical and subtropical regions [2]. These diseases not only cause significant morbidity and mortality but also perpetuate cycles of poverty through reduced productivity, increased healthcare costs, and social stigma [6,7]. For example, rabies, a viral zoonosis, is associated with an estimated 59,000 human deaths annually, with 95% of cases occurring in Africa and Asia [8–11].

Similarly, cysticercosis, caused by the pork tapeworm *Taenia solium*, is a leading cause of acquired epilepsy in endemic areas, resulting in substantial neurological morbidity and economic losses [12–14]. Additionally, zoonotic diseases such as Zika, Ebola, COVID-19, and Mpox have illustrated how quickly local outbreaks can escalate into international health emergencies, highlighting the need for robust monitoring and response systems [1,7,15,16].

To date, the control of zoonotic NTDs has been further complicated by ecological and socioeconomic factors, including climate change, urbanization, and changing agricultural practices, which can alter host pathogen dynamics and disease transmission patterns [17]. Additionally, the often neglected status of these diseases on national and international health agendas has led to underreporting and inadequate surveillance systems, hindering the accurate assessment of their true burden and effective resource allocation (Hotez et al., 2009). The significance of zoonotic NTDs lies not only in their impact on human health but also in their ability to disrupt ecosystems and economies, particularly in resource-constrained settings where they often thrive [1].

Transmission dynamics of zoonotic NTDs

The transmission dynamics of NTDs involve complex interactions between humans, animals, and environmental factors on a global scale. These diseases, including echinococcosis,

cysticercosis, and leishmaniasis, pose significant public health challenges, particularly in resource-limited settings [2]. Understanding their transmission pathways is crucial, as they often involve intricate ecological relationships and socioeconomic determinants. Central to zoonotic NTD transmission is the concept of spillover, wherein pathogens cross species barriers from animal reservoirs to human hosts. This process is influenced by environmental conditions, human behavior, and the biology of both pathogens and their hosts [19]. Climate change has emerged as a critical driver of these dynamics, affecting vector distribution and pathogen survival rates [17]. With climate change altering weather patterns, mosquito vectors are expanding into previously non-endemic areas, leading to increased mosquito-borne diseases incidence in unexpected locales. Consequently, the geographical range of many zoonotic NTDs is expanding, which has led to the emergence of diseases in previously unaffected areas.

Anthropogenic activities, such as deforestation, urbanization, and agricultural intensification, further complicate the transmission landscape by modifying ecosystems and increasing human-wildlife contact. These changes can create novel ecological niches that favor disease transmission and disrupt natural host-pathogen equilibria. Global trade and travel facilitate the rapid spread of pathogens across international borders, thereby challenging traditional disease control strategies. Socioeconomic factors significantly shape the burden of zoonotic NTDs. Poverty, inadequate healthcare infrastructure, and limited access to clean water and sanitation have contributed to increased vulnerability in many endemic regions [1,20]. Cultural practices and occupational exposure can influence transmission risks, highlighting the need for context-specific interventions that address both the biological and social determinants of the disease.

The transmission dynamics of specific zoonotic NTDs vary widely. For example, rabies is transmitted primarily through infected animal bites, typically dogs, and is almost always fatal once clinical symptoms appear [21,22]. Vector-borne diseases, such as dengue fever, Zika virus, and chikungunya, are transmitted by *Aedes* mosquitoes and affect millions annually [23,24]. These diseases are highly sensitive to environmental factors such as temperature, rainfall, and humidity, which influence mosquito abundance and viral replication [6,24–26]. The COVID-19 pandemic has affected efforts to control zNTDs, particularly dengue fever. Lockdown measures and overwhelmed healthcare systems have diverted resources from routine vector control programs and surveillance activities [27–29].

These disruptions have raised concerns about potential increases in dengue cases in some regions [28,30,31]. Moreover, the pandemic has exacerbated existing public health challenges, as healthcare infrastructures redirected their focus towards managing COVID-19 caseloads. Consequently, resources such as funding, personnel, and laboratory capabilities were significantly reduced for zNTD programs, compromising routine disease control and prevention measures. For instance, vector control activities, such as outdoor spraying and community engagement initiatives, were severely curtailed due to restrictions on movement and social distancing protocols [32]. Additionally, public health data collection and real-time disease monitoring faced setbacks as routine surveillance systems experienced disruptions. The comprehensive reporting of zNTD cases, particularly dengue, became challenging due to limited laboratory testing and data processing delays [33].

This hampered the accurate tracking of outbreak patterns and restricted the timely deployment of targeted interventions. The intersection of COVID-19 with zNTDs like dengue also unveiled underlying vulnerabilities in healthcare systems, especially in tropical regions where simultaneous outbreaks overburdened the capacity to deliver essential health services. Furthermore, the economic repercussions of the pandemic led to increased poverty rates, reducing communities' access to healthcare services and increasing their susceptibility to zNTDs. Such socio-economic impacts are particularly pronounced in low-income areas, where priorities shifted towards immediate survival rather than disease prevention.

The pandemic served as a wake-up call for enhancing integrated health surveillance systems capable of managing multiple health threats efficiently. This includes adopting innovative strategies like digital health platforms for community engagement and leveraging telemedicine to ensure healthcare continuity for zNTD patients during crises. The complex transmission dynamics of zoonotic NTDs necessitate integrated approaches that encompass vector control,

surveillance, and community-based interventions. A nuanced understanding of these dynamics is imperative for developing effective prevention and control strategies to alleviate the burden of these diseases and to safeguard public health.

Characteristic zoonotic NTDs affecting vulnerable populations

Zoonotic neglected tropical diseases (zNTDs) exhibit distinct characteristics in their impact on vulnerable populations worldwide, predominantly affecting low- and middle-income countries where poverty, inadequate healthcare infrastructure, and limited access to sanitation exacerbate their prevalence [1,7]. These diseases disproportionately burden rural communities, which are often in close proximity to animal reservoirs, where occupational and environmental factors increase exposure risk [34]. Women and children are particularly susceptible, with gender roles and childcare practices influencing transmission patterns. A key feature of zNTDs is their chronic and debilitating nature, which leads to long-term disabilities that perpetuate cycles of poverty and marginalization [3]. Diseases such as lymphatic filariasis, leishmaniasis, and Chagas disease often result in disfigurement, disability, and decreased quality of life, affecting millions of people globally [35,36]. The chronicity of these conditions not only impacts physical health but also has profound psychological and social consequences.

Stigma associated with zNTDs significantly contributes to the marginalization of affected individuals and communities [37,38]. Misconceptions about disease causes and transmission modes often lead to social isolation, loss of livelihood, and barriers to accessing healthcare and support services [21,38,39]. This stigmatization further compounded social and economic challenges, hindering access to treatment and support. The economic impact of zNTDs is substantial and affects both individuals and society. These diseases impair productivity by causing disability, preventing individuals from engaging in work, attending school, or participating in community activities [36,40]. At the societal level, zNTDs impose a significant economic burden on health care costs, decrease agricultural productivity, and decrease workforce productivity, thereby perpetuating cycles of poverty and hindering socioeconomic development in endemic regions.

Environmental factors play crucial roles in the transmission and spread of zNTDs. Poor environmental conditions, including inadequate sanitation, unsafe water sources, and overcrowded living conditions, contribute to disease persistence. Environmental degradation, urbanization, and climate change can exacerbate transmission by altering disease vector habitats and reservoir host populations, thereby increasing human exposure risk [41]. The complex life cycles of zNTD pathogens and their adaptability to diverse ecological niches further contribute to their persistence in vulnerable communities, necessitating multifaceted intervention strategies that address both the biological and social determinants of disease transmission and impact.

Neglected tropical diseases zoonoses with pandemic potential

Zoonotic neglected tropical diseases (zNTDs) are significant global health problems because of their ability to transmit from animals to humans and their potential to trigger pandemics [42]. In recent years, several zNTDs have demonstrated pandemic potential. Nipah virus, first identified in Malaysia in 1999, has caused localized outbreaks with high mortality rates and remains a concern owing to its ability to spread through human-to-human transmission. Similarly, the Ebola virus, which primarily affects Central and West Africa, has demonstrated a capacity for international spread, as evidenced by the 2014-2016 West African epidemic [34,43].

The Filoviridae family of Ebola viruses poses a pandemic threat due to zNTD. The high case fatality rate of this virus, ranging from 25-90%, is coupled with its transmission through direct contact with bodily fluids, underscoring its alarming potential [1,39,40,44]. The 2014-2016 West African Ebola outbreak resulted in more than 28,000 cases and 11,000 deaths, highlighting the capacity of the virus to rapidly overwhelm healthcare systems and cross borders [45]. This highlights the need for a resilient global health system that can detect and respond to rapidly emerging zoonotic threats.

The COVID-19 pandemic caused by SARS-CoV-2, a virus of possible zoonotic origin, further emphasizes the devastating potential of zoonotic diseases to cause global disruption [46]. These

events have drawn renewed attention to other zNTDs with pandemic potential, such as henipavirus infections, highly pathogenic avian influenza, certain arboviruses such as Zika and chikungunya [47], and the emerging MPOXV (formerly monkeypox virus). Infection with the nipah virus, which is transmitted primarily from fruit bats of the genus *Pteropus*, presents another significant threat to zNTD. The virus causes severe respiratory and neurological symptoms, with outbreaks characterized by rapid spread and high mortality rates [48,49]. The outbreaks in Malaysia from 1998-1999 and the outbreak in Kerala, India, in 2018 demonstrated the ability of the virus to cause massive loss of life and economic disruption [48,50,51].

In addition, avian influenza, especially the H5N1 and H7N9 strains, has posed a pandemic threat because of its genetic adaptability. Although primarily circulating among birds, certain strains have demonstrated the capacity to cause severe diseases in humans [52]. The ability of viruses to undergo genetic rearrangements, potentially resulting in new strains with improved transmissibility or virulence, is a major concern [53,54]. This genetic plasticity requires ongoing surveillance and preparedness efforts to reduce the risk of global pandemics. Recent studies have highlighted the ongoing threat posed by highly pathogenic avian influenza (HPAI) strains such as H5N1. For example, a novel H5N1 clade 2.3.4.4b virus was detected in wild birds in Chile [53], and similar strains have been isolated from cats in South Korea [55]. These findings underscore the capacity of the virus to spill over into various species, thereby increasing the risk of human infection [56]. Furthermore, the detection of H5N1 in dairy farm workers in the US highlights the zoonotic potential of this virus and the need for heightened biosecurity measures [56,57].

Factors contributing to potential zNTD pandemics include ecological changes, increased human-animal contact, global travel and trade, and inadequate health infrastructure in endemic regions. Climate change also alters the geographic distribution of disease vectors, potentially exposing new populations to zNTDs [58]. Addressing zNTDs with pandemic potential requires a multifaceted approach. Enhanced surveillance systems, particularly human-animal linkages, are critical for early detection and rapid response to emerging threats. Strengthening healthcare systems in endemic areas is essential for managing existing disease burdens and preparing for potential outbreaks. Research and development efforts should focus on developing diagnostics, therapeutics, and vaccines for ZNTDs with pandemic potential as well as improving the understanding of their transmission dynamics and ecological drivers [59,60].

Multifaceted drivers of zoonotic pathogen spillover

The spillover of zoonotic pathogens into human populations is influenced by a complex interplay between ecological, socioeconomic, and biological factors [61]. Habitat destruction, climate change, and biodiversity loss are critical ecological drivers. Deforestation and land use changes force wildlife into closer contact with humans, increasing the risk of pathogen transmission. Climate change alters vector and host habitats, facilitating disease spread, as evidenced by the expansion of dengue fever and avian influenza [24,26].

The destruction of forests in Bali has been linked to the spread of dengue fever, as changes in land use facilitate the breeding of *Aedes* mosquitoes [61]. The loss of biodiversity can reduce ecosystem resilience and potentially amplify outbreaks [19]. Socioeconomic factors, including globalization and urbanization, significantly impact zoonotic spillover [62]. International trade and travel facilitate rapid disease dissemination, whereas urban overcrowding creates transmission hotspots [63,64]. The urbanization of regions in Indonesia, for example, has complicated dengue fever control efforts by increasing mosquito breeding sites and human-vector contact [65,66].

Biological and behavioral factors encompass host-vector dynamics and wildlife-human interactions. Changes in animal populations due to ecological disruptions influence disease dynamics, whereas activities such as hunting and the wildlife trade increase direct human-animal contact, increasing spillover risk. The Nipah virus outbreak in Malaysia, linked to pig farming and bat encroachment, exemplifies the consequences of such interactions [67]. Addressing these challenges requires an integrative approach. The One Health framework, which recognizes the interconnectedness of human, animal, and environmental health, promotes collaborative efforts across sectors [68].

The implementation of comprehensive public health strategies, including surveillance, vector control, and community education, is crucial for preventing outbreaks. The success of dengue control measures in Bali underscores the importance of integrated vector management and community engagement [64]. By systematically addressing these multifaceted drivers through coordinated interventions and research, we can more effectively mitigate the risks of future zoonotic disease outbreaks and protect global public health [69,70].

Importance of addressing zNTDs worldwide

Addressing zoonotic neglected tropical diseases (zNTDs) is crucial to global health and development. Over 60% of emerging infectious diseases in humans have zoonotic origins, and this trend has been exacerbated by factors such as environmental changes, urbanization, and increased human-animal interactions [6,44,71]. Environmental degradation, such as deforestation and habitat fragmentation, has been shown to increase the likelihood of zoonotic spillover. As human activities encroach on wildlife habitats, the interface between animals and humans expands, facilitating pathogen transmission [19]. Climate change further exacerbates this issue by altering the distribution of vectors and reservoir hosts, potentially introducing zoonotic pathogens into new regions [72].

The economic impact of zoonotic NTDs is profound [36,40,45,65,73]. Outbreaks can result in substantial healthcare costs, loss of productivity, and long-term economic burdens on affected communities. For example, the Nipah virus outbreak in Malaysia from 1998-1999 resulted in significant agricultural losses due to the culling of infected pigs and trade restrictions, costing the economy an estimated \$350 million [48,50,51]. Similarly, the Ebola virus outbreak in West Africa (2014-2016) [45] not only caused significant morbidity and mortality but also led to an estimated \$2.2 billion GDP loss across Guinea, Liberia, and Sierra Leone [45]. Moreover, zoonotic diseases, such as filovirus infections, among bushmeat hunters in Guinea present ongoing exposure risks that necessitate sustained public health interventions [64]. The risk of zoonotic spillover from wildlife to humans is compounded by practices such as bushmeat hunting and live animal markets, which create opportunities for pathogen transmission [63,73].

Therefore, it is imperative to adopt a proactive approach to mitigate the risks associated with zoonotic NTDs. This includes enhancing surveillance systems, improving diagnostic capabilities, and fostering interdisciplinary collaboration through the One Health approach, which integrates human, animal, and environmental health strategies [69]. The One Health approach is critical for addressing the interconnectedness of human, animal, and environmental health, emphasizing the need for collaborative efforts across sectors to prevent and control zoonotic diseases [31,69,70]. Quantitative modeling has also been proposed to support programmatic decisions and accelerate progress toward 2030 NTD targets. These models can help predict disease outbreaks, assess the impact of interventions, and optimize resource allocation [39]. For example, mathematical models have been used to understand the dynamics of zoonotic diseases and inform control strategies, demonstrating their utility in public health planning [74].

A "silo" approach to disease management

The management of neglected tropical zoonotic diseases (NTDs) faces significant challenges due to the prevalence of siloed approaches in disease control strategies. This fragmented methodology, characterized by isolated efforts and a lack of cross-sector collaboration, has proven inadequate in addressing the complex nature of zoonotic NTDs. Currently, many tropical regions struggle with limited resources and insufficient coordination among the human health, veterinary, and environmental sectors, hindering effective disease management [34]. The silo approach perpetuates a narrow focus on individual diseases or specific interventions, often neglecting the interconnected ecological and socioeconomic factors that influence disease transmission and persistence [8].

Traditional disease management strategies predominantly rely on vertical programs that target single pathogens or vectors. Although these approaches have achieved some success in controlling specific diseases, they fail to address the broader ecosystem of zoonotic NTDs and their shared risk factors. The limitations of such vertical interventions become particularly evident in

resource-constrained settings, where multiple NTDs coexist and compete for scarce healthcare resources (Hotez et al., 2009). Moreover, silo mentality often leads to duplication of efforts, inefficient resource allocation, and missed opportunities for synergistic interventions that can simultaneously target multiple diseases.

The fragmented approach to zoonotic NTD management has far-reaching consequences for the effectiveness of control efforts worldwide. By focusing on individual diseases in isolation, policymakers and health practitioners often overlook the potential of integrated strategies that could yield more substantial and sustainable results. This lack of coordination impedes the development of comprehensive surveillance systems, limits the sharing of critical data and expertise across sectors, and hampers the implementation of holistic interventions that address the root causes of disease transmission [75]. Furthermore, the siloed approach fails to adequately consider the One Health perspective, which recognizes the intricate connections between human, animal, and environmental health in the context of zoonotic diseases.

To overcome these challenges, there is a growing recognition of the need for integrated, multisectoral approaches to zoonotic NTD management. Such strategies emphasize collaboration between public health, veterinary services, environmental agencies, and community stakeholders to develop comprehensive control programs. Breaking down silos and fostering interdisciplinary cooperation makes it possible to implement more effective interventions that simultaneously address multiple diseases and their shared risk factors. This shift toward a more holistic approach not only promises improved health outcomes but also offers potential cost savings and increased sustainability in disease control efforts [75].

One health concept in the context of zoonotic neglected tropical diseases

The One Health concept, in the context of neglected tropical zoonotic diseases (NTDs), represents a paradigm shift in disease management, emphasizing the interconnectedness of human, animal, and environmental health. This approach recognizes that the well-being of these three domains is inextricably linked and that addressing complex health challenges requires a holistic, interdisciplinary perspective [42]. The core principles of One Health include collaboration across sectors, shared responsibility, and the integration of multiple disciplines to achieve optimal health outcomes for all species and ecosystems. The interconnections among human, animal, and environmental health are particularly evident in zoonotic NTDs.

These diseases often emerge at the interface of human-animal interactions and are influenced by environmental factors such as climate change, deforestation, and urbanization [76]. For example, the transmission of vector-borne zoonoses such as leishmaniasis is closely tied to environmental conditions that affect vector habitats, whereas diseases such as echinococcosis are perpetuated through complex cycles involving domestic animals, wildlife, and human activities. Understanding these intricate relationships is crucial for developing effective preventive and control strategies.

The urgency and potential of applying the One Health approach to neglected tropical zoonotic diseases in endemic regions and globally cannot be overstated. Traditional siloed approaches have often fallen short of addressing the multifaceted nature of these diseases, leading to suboptimal outcomes and inefficient resource utilization [75]. In contrast, the One Health strategy offers the promise of more comprehensive and sustainable solutions. For example, integrated surveillance systems that monitor disease trends in both human and animal populations can provide early warning signals for potential outbreaks, enabling timely and targeted interventions [77].

Concrete evidence of the effectiveness of the One Health approach in managing neglected tropical zoonotic diseases emerged from various endemic regions. In Tanzania, a one-health-based rabies control program that combined dog vaccination with improved access to postexposure prophylaxis for humans resulted in a significant reduction in rabies cases and deaths [8]. Similarly, in Chad, an integrated human and animal health vaccination program for nomadic pastoralists led to improved vaccination coverage for both humans and livestock, demonstrating the synergistic benefits of cross-sector collaboration [42].

The potential of One Health extends beyond direct disease control to address broader societal challenges. By promoting collaboration among the public health, veterinary, and environmental

sectors, the One Health initiative can contribute to strengthening health systems, improving food security, and enhancing community resilience in endemic areas [34]. Moreover, this approach aligns with global health priorities, including sustainable development goals, by addressing the complex interplay between health, poverty, and ecosystem integrity. Recognizing the interdependence of human, animal, and environmental health and fostering cross-sector collaboration, the One Health approach has the potential to yield more effective, efficient, and sustainable solutions to these complex health issues.

Transformation from a "Silo" Approach to a systemic approach

The transformation from a "silo" approach to a systemic approach in managing NTDs represents a paradigm shift in global health strategies. While promising, this transition faces significant challenges that must be addressed to fully realize the potential of the One Health framework. Identifying and overcoming these barriers are crucial for the effective integration of various sectors and disciplines in disease management. One of the primary obstacles to transitioning to a one-health approach is the entrenched nature of institutional silos. Traditional organizational structures, funding mechanisms, and academic disciplines have long operated independently, creating barriers to cross-sector collaboration [78]. These silos are reinforced by distinct professional cultures, terminologies, and priorities, which can impede effective communication and cooperation. Additionally, limited resources and competition for funding often lead to protectionism within sectors, further hindering collaborative efforts [75].

Several strategies have been proven to be effective in overcoming these challenges and integrating various sectors and disciplines. First, fostering a shared vision and common language across disciplines is essential. This can be achieved through interdisciplinary training programs and joint workshops that bring professionals from public health, veterinary medicine, environmental sciences, and social sciences [42]. Second, developing integrated surveillance systems that combine data from the human, animal, and environmental health sectors can provide a more comprehensive understanding of disease dynamics and facilitate coordinated responses [77]. Establishing formal mechanisms for cross-sector collaboration, such as joint committees or task forces, can help institutionalize the One Health approach within existing structures.

Several case studies have demonstrated the successful application of a single health principle in zoonotic disease management. In Chad, an integrated human and animal vaccination program for nomadic pastoralists significantly improved vaccination coverage for both humans and livestock. This approach not only enhances health outcomes but is also more cost-effective than separate human and animal health interventions are [42]. In Tanzania, a One Health approach to rabies control, which combines dog vaccination with improved access to postexposure prophylaxis for humans, led to a substantial reduction in human rabies cases and deaths [8].

In Southeast Asia, the PREDICT project exemplifies the large-scale implementation of the One Health Approach. This initiative focused on the early detection of zoonotic diseases with pandemic potential and successfully integrated wildlife surveillance, laboratory systems, and outbreak response capacities across multiple countries. The project's collaborative framework enabled the identification of numerous novel viruses and strengthened regional capacities for disease detection and response [79].

These success stories highlight the potential of systemic approaches to address complex health challenges. However, sustaining and scaling up these efforts require continued commitment from policymakers, funding agencies, and practitioners. Emphasizing the economic benefits of integrated approaches, such as cost savings from shared resources and improved health outcomes, can help garner support for One Health initiatives [80]. The transformation from siloed to systemic approaches for managing zoonotic NTDs is a complex but necessary process. By addressing institutional barriers, fostering cross-sector collaboration, and learning from successful case studies, the global health community can move toward more effective, efficient, and sustainable strategies for disease control and prevention.

Implementation of One Health in the management of zoonotic NTDs

The implementation of One Health in managing neglected tropical zoonotic diseases requires a comprehensive framework that operates at the local, national, and global levels. This multitiered approach ensures coherence and effectiveness in addressing the complex challenges posed by zoonotic NTDs. At the local level, community engagement and participatory approaches are crucial and involve stakeholders, such as local health workers, veterinarians, environmental specialists, and community leaders, in disease surveillance, prevention, and control activities. This grassroots involvement facilitates the early detection of disease outbreaks and promotes sustainable interventions tailored to local contexts. At the national level, the framework calls for the establishment of interministerial committees or task forces that bring together representatives from health, agriculture, the environment, and other relevant sectors to develop integrated policies, allocate resources, and coordinate responses to zoonotic threats. These national bodies also play a vital role in harmonizing local efforts with broader national health strategies and international commitments.

The global level of the framework focuses on fostering international collaboration, knowledge sharing, and resource mobilization. This includes partnerships between countries, international organizations, and nongovernmental entities to address transboundary disease challenges, develop global standards and guidelines, and support capacity building in endemic regions. Key components of the global framework include the World Health Organization's Tripartite Collaboration with the Food and Agriculture Organization and the World Organization for Animal Health, which provides a platform for coordinating global One Health initiatives. Additionally, the framework emphasizes the importance of aligning the One Health strategy with global health security agendas and development goals to ensure comprehensive and sustainable approaches to zoonotic NTD management. The framework stresses the need for robust communication channels, standardized data-sharing protocols, and mechanisms for joint planning and decision-making to enable effective coordination and rapid response to emerging threats [81,82]. [Figure 1](#) illustrates the multilevel framework for implementing One Health, showing the interconnections between the global, national, and local levels and highlighting key activities at each level.

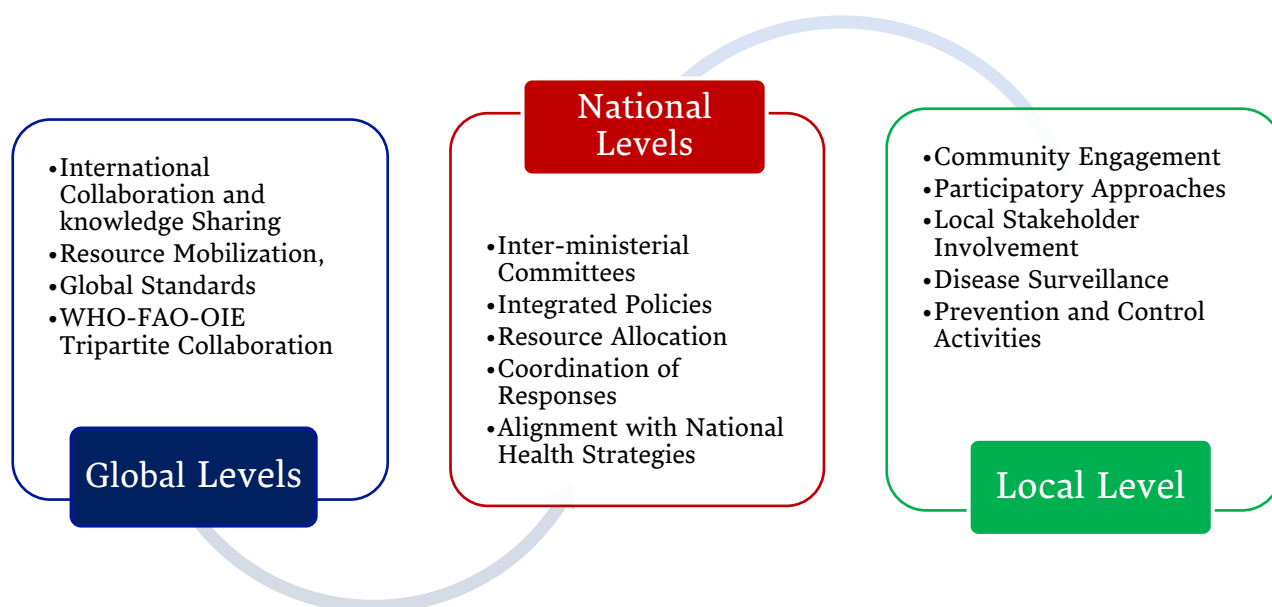


Figure 1. One Health Implementation Framework

Technology and innovation play pivotal roles in supporting and enhancing the One Health approach for managing NTDs. These advancements facilitate more efficient data collection, analysis, and sharing across the human, animal, and environmental health sectors, enabling a more comprehensive understanding of disease dynamics and a faster response to outbreaks. Geographic information systems (GISs) and remote sensing technologies, for instance, allow for

the mapping of disease patterns, vector habitats, and environmental risk factors, thereby providing valuable insights for targeted interventions. Mobile health (mHealth) applications have revolutionized field data collection and real-time reporting, empowering community health workers and veterinarians to contribute to surveillance efforts even in remote areas. Advances in molecular diagnostics, such as point-of-care tests and portable sequencing devices, enable the rapid and accurate identification of pathogens in both clinical and field settings, which are crucial for the early detection and containment of zoonotic threats. Big data analytics and machine learning algorithms are being increasingly applied to integrate diverse datasets, predict disease outbreaks, and optimize resource allocation in NTD control programs.

Blockchain technology is emerging as a potential tool for ensuring the integrity and traceability of data across multiple stakeholders and addressing issues of trust and data ownership in collaborative One Health initiatives. Digital platforms and cloud computing services facilitate knowledge sharing and collaboration among researchers, practitioners, and policymakers across geographic locations and disciplines. Innovations in vaccine development and delivery, such as the development of thermostable vaccines and novel adjuvants, are enhancing the feasibility of integrated human–animal vaccination campaigns in challenging environments. Drones and other autonomous systems are being explored for their potential to deliver medical supplies to hard-to-reach areas and conduct environmental surveys.

Importantly, these technological advancements must be implemented with consideration of local contexts, infrastructure limitations, and capacity building to ensure their sustainable adoption and impact. As the field of One Health continues to evolve, emerging technologies such as artificial intelligence, Internet of Things (IoT) sensors, and advanced modeling techniques promise to further enhance our ability to predict, prevent, and respond to zoonotic NTDs in a more integrated and efficient manner [83]. [Figure 2](#) illustrates the various technologies and innovations that support the One Health approach.



Figure 2. Technology and Innovation in One Health

Cross-sectoral capacity development and training are fundamental to the successful implementation of the One Health approach for managing zNTDs. This comprehensive strategy aims to bridge knowledge gaps, foster collaboration, and build a workforce capable of addressing the complex challenges posed by zNTDs at the human–animal–environment interface. The core of this approach is the development of interdisciplinary curricula that integrate concepts from public health, veterinary medicine, environmental sciences, and social sciences. These programs,

implemented at both the undergraduate and postgraduate levels, equip future professionals with a holistic understanding of zoonotic disease dynamics and skills to work effectively across sectors. Short-term training workshops and field courses play crucial roles in providing hands-on experience and practical skills in areas such as integrated disease surveillance, outbreak investigations, and community engagement. These training opportunities often involve simulations and case studies that mirror real-world scenarios, allowing participants to apply the One Health principle in a controlled setting.

Professional exchange programs and joint field missions facilitate knowledge transfer and the development of collaborative networks among practitioners from different sectors and regions. To ensure sustainability, trainer programs are implemented to increase the local capacity for ongoing education and skill development. Digital learning platforms and e-learning modules are being increasingly utilized to reach a wider audience and provide flexible and accessible training options, particularly in resource-limited settings. The mentorship program pairs experienced health practitioners with early career professionals, fostering long-term skill development and career growth.

Importantly, capacity development efforts extend beyond technical skills to include training in leadership, communication, and policy engagement, enabling professionals to effectively advocate for the One Health approach at various levels of decision-making. Collaborative research projects and joint publications are encouraged to promote cross-sectoral thinking and evidence-based practices. Regular assessments of training needs and outcomes help to continuously refine and adapt capacity development strategies to the evolving challenges in zNTD management. By investing in cross-sectoral capacity development and training, countries and regions can build a skilled workforce capable of implementing integrated and sustainable approaches for zNTD control and prevention, ultimately contributing to improved health outcomes for both human and animal populations in endemic areas [58,84].

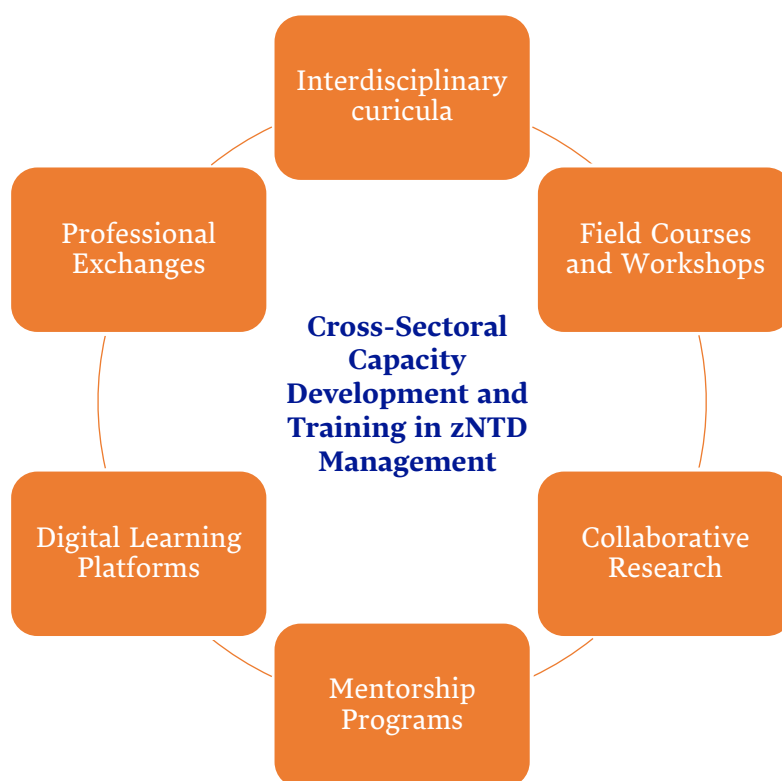


Figure 3. Cross-sectoral capacity development and training in zNTD management

The diagram in [Figure 3](#) illustrates the various components of cross-sectoral capacity development and training in zNTD management, represented as interconnected elements surrounding a central concept. These capacity development initiatives are crucial for creating a workforce that can effectively implement a single health approach in zNTD management. They

foster a shared understanding of the complex interactions between humans, animals, and environmental health and equip professionals with the skills to collaborate across traditional disciplinary boundaries. By promoting interdisciplinary thinking and cross-sectoral collaboration, these training programs contribute to more comprehensive and sustainable approaches to zNTD control and prevention [85–87].

The success of these capacity development efforts relies on strong partnerships between academic institutions, government agencies, nongovernmental organizations, and international bodies. These collaborations ensure that training programs are aligned with local and global health priorities and are responsive to evolving challenges in zNTD management [88]. Furthermore, the integration of indigenous knowledge and local expertise into training programs enhances their relevance and effectiveness in diverse cultural and ecological contexts. As the field of One Health continues to evolve, ongoing evaluation and adaptation of capacity development strategies are essential. This includes assessing the impact of training programs on professional practices, health outcomes, and policy development. By continuously refining and expanding cross-sectoral capacity development initiatives, the global health community can build a robust workforce capable of addressing the complex challenges posed by zoonotic NTDs, ultimately contributing to improved health and well-being of both human and animal populations in endemic areas.

Lessons learned

From this perspective, several key lessons have emerged in the management of zNTDs. The complex interplay among human, animal, and environmental health underscores the critical importance of adopting a one-health approach to address these diseases effectively. The limitations of traditional siloed approaches highlight the need for integrated, multisectoral strategies that breakdown barriers between disciplines and foster collaboration among public health, veterinary services, and environmental agencies. The economic impact of zNTDs, exemplified by outbreaks such as the Nipah virus and Ebola, emphasizes the urgency of proactive measures and robust surveillance systems.

The role of environmental factors, including deforestation, climate change, and urbanization, in driving zoonotic spillovers necessitates a holistic approach to disease management that considers ecological dynamics. Furthermore, the potential of emerging technologies and innovations such as GISs, mHealth applications, and advanced diagnostics offers promising avenues for enhancing disease surveillance, prediction, and control efforts. Finally, the importance of cross-sectoral capacity development and training emerges as a crucial component in building a skilled workforce capable of implementing integrated approaches to zNTD management, ultimately contributing to improved health outcomes in endemic areas.

CONCLUSIONS

The perspective of zNTDs underscores their significant impact on global public health, particularly in resource-limited settings. These diseases, including rabies, echinococcosis, and cysticercosis, not only cause substantial morbidity and mortality but also perpetuate cycles of poverty through reduced productivity and increased health care costs. The complex transmission dynamics of zNTDs involve intricate interactions among human, animal, and environmental factors, necessitating a comprehensive management approach. The One Health concept has emerged as a crucial framework for addressing zNTDs, emphasizing the interconnectedness of human, animal, and environmental health. This approach advocates cross-sectoral collaboration, integrated surveillance systems, and multidisciplinary strategies to effectively combat these diseases. The transformation from siloed to systemic approaches in zNTD management, although challenging, offers promising solutions for more sustainable and efficient disease control. Despite the comprehensive framework, real-world application in resource-limited settings is hindered by issues such as limited infrastructure and socio-economic barriers. To address this, scalable technologies like mobile health apps and low-cost diagnostics should be prioritized to ensure sustainable implementation. Technological innovations such as GISs, mHealth applications, and

advanced diagnostics play pivotal roles in enhancing surveillance, prediction, and control efforts. Furthermore, cross-sectoral capacity development and training are fundamental for building a skilled workforce capable of implementing integrated approaches to zNTD management. By adopting holistic strategies and fostering global collaboration, the international community can make significant strides to mitigate the burden of zNTDs and improve health outcomes in endemic areas.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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AUTHOR CONTRIBUTIONS

Conceptualization: RPA., IMDM; Methodology: RPA., IMDM; Software: IMDM; Validation: RPA., IMDM., S.; Formal analysis: RPA., IMDM; Investigation: IMDM., S., RPA., TYPG; Resources: S., RPA., TYPG; Data Curation: S., RPA., TYPG; Writing - Original Draft: IMDM., S., RPA., TYPG; Writing - Review & Editing: IMDM., S., RPA., TYPG; Visualization: IMDM; Supervision: S.

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ABBREVIATIONS

CDC: Centers for Disease Prevention and Control, COVID-19: Coronavirus Disease 2019, FAO: Food and Agriculture Organization, GIS: Geographic Information System, HPAI: Highly Pathogenic Avian Influenza, IoT: Internet of Things, mHealth: Mobile Health, MPOXV: Monkeypox Virus, NTD: Neglected Tropical Disease, SARS-CoV-2: Severe Acute Respiratory Syndrome Coronavirus 2, WHO: World Health Organization, zNTD: Zoonotic Neglected Tropical Disease. The text also references specific disease strains such as H5N1 and H7N9, which are influenza A virus subtypes, characterized by their hemagglutinin (H) and neuraminidase (N) surface proteins.

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