zoonotic diseases

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Review

Holistic Approaches to Zoonoses: Integrating Public Health, Policy, and One Health in a Dynamic Global Context

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Simple Summary: Zoonotic diseases—illnesses that spread between animals and humans—pose a major threat to global health. The increasing frequency of zoonotic outbreaks is driven by factors such as globalization, climate change, urbanization, and antimicrobial resistance. The One Health (OH) paradigm, which integrates human, animal, and environmental health, is essential for controlling these diseases effectively. This review highlights the impact of zoonoses on public health, particularly in a highly interconnected world, and discusses successful programs, such as Rwanda's National One Health Program and the Rabies Elimination Program in the Philippines. These initiatives demonstrate that a coordinated interdisciplinary approach is crucial for early disease detection, improved outbreak responses, and stronger health systems. Strengthening global surveillance, enhancing policies, and increasing intersectoral collaboration are essential steps inmitigating the risks of zoonotic diseases and ensure global health security.

Abstract: Zoonotic diseases pose a significant global health threat, driven by factors such as globalization, climate change, urbanization, antimicrobial resistance (AMR), and intensified human–animal interactions. The increasing interconnectedness of human, animal, and environmental health underscores the importance of the OH paradigm in addressing zoonotic threats in a globalized world. This review explores the complex epidemiology of zoonotic diseases, the challenges associated with their management, and the necessity for cross-sector collaboration to enhance prevention and control efforts. Key public health strategies, including surveillance systems, infection control measures, and community education programs, play crucial roles in mitigating outbreaks. However, gaps in governance, resource allocation, and interdisciplinary cooperation hinder effective disease management, particularly in low- and middle-income countries (LMICs). To illustrate the

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effectiveness of the OH approach, this review highlights successful programs, such as the PREDICT project, Rwanda's National One Health Program, the EcoHealth Alliance, and the Rabies Elimination Program in the Philippines. These initiatives demonstrate how integrating human, animal, and environmental health efforts can enhance early detection, improve outbreak responses, and reduce public health burdens. Strengthening global health governance, enhancing surveillance infrastructure, regulating antimicrobial use, and investing in research and technological innovations are essential steps toward mitigating zoonotic risks. Ultimately, a coordinated, multidisciplinary approach is vital for addressing the dynamic challenges posed by zoonotic diseases and ensuring global health security in an increasingly interconnected world.

Keywords: zoonoses; epidemiological surveillance; One Health; antimicrobial resistance; global health; infectious disease preparedness

1. Introduction

Zoonotic diseases, or zoonoses, are infectious diseases that can spread between animals and humans in both directions. Bacteria, viruses, parasites, and fungi are the causative agents of these diseases, affecting people of all ages and backgrounds [1–3]. Zoonotic diseases are mostly transmitted to humans through direct contact with infected animals, the consumption of contaminated food or water, or vector-borne pathways. Conversely, humans can also transmit diseases to animals, a phenomenon known as reverse zoonosis or anthropozoonosis, where pathogens originally adapted to humans infect animal hosts, potentially altering their epidemiology and virulence [4]. This bidirectional transmission underscores the complex interactions among humans, animals, and their environments. Most pathogens that cause zoonotic diseases originate from wildlife reservoirs or domestic animals, and transmission is influenced by factors such as the pathogen type, host susceptibility, environmental conditions, and human–animal interactions. Certain zoonotic pathogens, such as influenza viruses and bacterial infections like Staphylococcus aureus, have demonstrated the ability to circulate between humans and animals, presenting risks to both public health and animal populations [5,6]. Zoonoses area serious public health concern worldwide, as they account for around 60% of new human infectious diseases and have been responsible for numerous outbreaks throughout history, resulting in severe morbidity and mortality [7].

Zoonosis can lead to severe health crises, as evidenced by the recent COVID-19 pandemic, which demonstrated how a zoonotic virus can disrupt healthcare systems and economies worldwide [8]. The emergence of new zoonotic pathogens has necessitated robust surveillance systems to promptly detect and respond to outbreaks. The interconnectedness of global travel and trade exacerbates the rapid spread of these diseases [7,9]. In recent years, several zoonotic diseases have emerged, resulting in significant challenges for public health. Ebola virus disease and H5N1 avian influenza are examples of zoonotic diseases that have caused significant outbreaks globally. These diseases highlight the risks inherent in human–animal interactions, particularly through wildlife markets and habitat encroachment, emphasizing the critical importance of surveillance and preventive measures [10,11]. Other notable zoonotic threats include Nipah virus, which spreads from bats to pigs and then to humans, causing severe respiratory illness and encephalitis, and Mpox (Monkeypox), transmitted from animals (including rodents) to humans, with an increasing number of cases reported in non-endemic regions [8,12].

Because of the numerous links between human, animal, and environmental health, addressing zoonotic diseases requires a holistic approach. The concept of "One Health" recognizes this interdependence, emphasizing the importance of collaboration across sectors in managing and preventing zoonotic hazards, and advocates for a holistic approach to addressing global health issues [13]. This holistic approach acknowledges that health challenges in one sector can substantially impact others. For example, the spread of zoonotic viruses frequently coincides with environmental changes and human behavior, requiring a coordinated response from public health systems, veterinary services, and environmental management services [14]. In recent decades, the increasing occurrence of emerging infectious diseases, AMR, and environmental changes and degradation has underscored the limitations of traditional isolated health approaches [14]. Collaborative efforts among epidemiologists, veterinarians, ecologists, and public health officials enable the mapping of disease hotspots, contributing to targeted interventions [15]. This paper aims to explore integrated approaches to zoonotic diseases through public health strategies, policymaking, and the OH Framework. It examines the predisposing factors and consequences posed by zoonoses in a dynamic global context, discusses various public health approaches, analyzes policy and governance aspects, and highlights the importance of integrating these elements in effective zoonotic disease management.

2. Addressing Challenges in a Dynamic Global Context

Zoonotic diseases transmitted between animals and humans pose a significant global public health challenge. The dynamic nature of the contemporary world has amplified the frequency, impact, and complexity of zoonotic diseases. Factors such as globalization, urbanization, climate change, AMR, and intensified human–animal interactions contribute to the emergence and re-emergence of zoonoses (Table 1), making their management a critical priority for public health systems worldwide [16]. Globalization has increased the movement of people, goods, and animals, creating pathways for zoonotic pathogens to spread rapidly across regions and continents. Diseases such as SARS and COVID-19 highlight how international travel and trade can facilitate the evolution of pandemics [17]. Without these measures, outbreaks that begin in localized areas can quickly escalate into global health crises. Urbanization and population growth exacerbate the challenges posed by zoonoses. As more people move to urban areas, habitats are altered and the boundaries between human settlements and wildlife diminish. This encroachment into natural ecosystems increases human exposure to wildlife reservoirs of zoonotic pathogens [18]. Additionally, the expansion of urban centers often lacks the proper infrastructure to manage waste, water, and sanitation, creating breeding grounds for vectors such as mosquitoes and ticks and reservoirs like rodents that transmit zoonotic diseases. For example, the spread of leptospirosis in densely populated urban areas is strongly associated with poor sanitation and inadequate infrastructure. Moreover, the urban sprawl encroaches on wildlife habitats, increasing human–wildlife interactions and amplifying the likelihood of zoonotic transmission.

Table 1. Factors influencing zoonotic disease emergence.

Factor	Description	Source(s)
Globalization	Increased movement of people, goods, and animals across borders facilitates the rapid spread of pathogens.	[17]
Urbanization	Encroachment into natural ecosystems increases human exposure to wildlife reservoirs of zoonotic pathogens; lack of infrastructure can create breeding grounds for vectors.	[18]

Table 1. *Cont.*

Factor	Description	Source(s)
Climate Change	Altered temperatures, precipitation, and extreme weather events impact ecosystems, wildlife migration, and vector distribution, increasing the risk of pathogen spillover.	[19]
Agricultural Practices	Intensified livestock farming, deforestation, and unsafe food handling create opportunities for pathogens to jump between species.	[20]
Antimicrobial Resistance (AMR)	Misuse of antibiotics in human and animal medicine leads to the emergence of resistant pathogens, complicating disease management.	[21]
Socioeconomic Inequities	Limited access to healthcare, diagnostic tools, and public health infrastructure in low- and middle-income countries hinders early detection and management.	[22]

Climate change is another key driver influencing the dynamics of zoonotic diseases. Rising global temperatures, altered precipitation patterns, and extreme weather events affect ecosystems, wildlife migration patterns, and the geographical distribution of vectors and pathogens [19]. Changes in these environmental conditions allow certain zoonotic diseases such as dengue fever to spread to new regions that were previously unaffected. Furthermore, climate-induced habitat loss forces wildlife into closer proximity to human populations, increasing the opportunities for pathogen spillovers. Thus, addressing zoonoses in a dynamic global context requires incorporating climate change mitigation and adaptation strategies into public health planning. Agricultural practices and food systems play a critical role in the emergence of zoonotic diseases. Intensified livestock farming, deforestation for agriculture, and unsafe food handling practices create opportunities for pathogens to jump between species [20]. For example, industrial farming systems that house animals in crowded, unsanitary conditions can facilitate the transmission of zoonotic pathogens, such as avian influenza and swine flu. These transmissions are further influenced by critical factors like the recombination of pathogens and avian migration routes, which can spread diseases across regions and species [23,24]. Strengthening biosecurity measures, promoting sustainable agricultural practices, and ensuring food safety standards are essential steps in addressing these challenges. Compounding these challenges is the growing threat of AMR, which can complicate efforts to control certain zoonotic diseases. While not all resistant pathogens are zoonotic, AMR can facilitate the persistence and spread of zoonotic bacteria such as *Salmonella*, *Campylobacter*, and *Escherichia coli* [21,25]. A significant contributor to this issue is the misuse of antibiotics in both human medicine and animal agriculture, particularly the inappropriate use of antibiotics classified as critically important for human health by the World Health Organization (WHO) [26]. These antibiotics, which should be reserved for severe human infections, are often restricted or not accessible for treating animals. In livestock production, antibiotics are often excessively used for growth promotion and disease prevention, leading to the emergence of resistant pathogens. These microbes can spread to humans through direct contact, food consumption, or environmental pathways [27]. For instance, resistant strains of *Salmonella* and *Campylobacter* have been linked to unregulated antibiotic use in poultry farming, underscoring the interconnected nature of human, animal, and environmental health [28,29].

The global implications of AMR are significant. As zoonotic diseases become increasingly resistant to treatment, health systems face greater burdens, particularly LMICs that have limited access to alternative therapies. AMR not only undermines routine medical interventions but also heightens the risk of outbreaks that are more severe and difficult to

contain. Addressing this issue requires a One Health approach to strengthen regulations on antimicrobial use in agriculture, promote alternatives such as vaccines, and enhance global surveillance systems to monitor resistance patterns. Economic and social inequities further complicate global responses to zoonotic diseases. In many low- and middle-income countries (LMICs), limited access to healthcare, diagnostic tools, and public health infrastructure hinders the early detection and management of zoonotic outbreaks. Marginalized communities, who often rely on livestock and natural resources for their livelihoods, are disproportionately affected by zoonoses [22]. Therefore, addressing these diseases requires equitable access to healthcare resources, investment in community-based health initiatives, and capacity-building efforts to strengthen the local health systems.

Lessons from the COVID-19 pandemic highlight the importance of proactive, coordinated efforts to prevent future zoonotic spillovers through strengthened global health governance and interdisciplinary collaboration. Addressing zoonotic challenges requires integrated strategies that consider human, animal, and environmental health, emphasizing international cooperation and sustainable policies.

3. Public Health Approaches to Zoonotic Diseases

The burden of zoonotic diseases is considerable and requires significant attention and intervention. Key strategies for managing zoonoses include robust surveillance systems, comprehensive infection and disease prevention measures, and community education initiatives (Table 2).

Table 2. Public health approaches to zoonotic disease control.

Approach	Description	Source(s)
Surveillance Systems	Monitoring and early detection of zoonotic pathogens in animals and humans to inform strategic interventions and mitigate impact of outbreaks.	[30]
Infection and Disease Prevention	Preventive methods such as vaccination and sanitation programs (WASH) to prevent disease occurrence.	[31]
Community Education	Awareness campaigns and training programs to educate the public about risk factors and prevention methods.	[32]

3.1. Surveillance and Monitoring Systems

Disease surveillance systems are an essential element of the OH approach, consisting of monitoring, early detection, and data availability to facilitate informed decision-making and lessen the impacts caused by outbreaks involving zoonotic diseases [30]. These systems produce critical data that serve as the foundation for strategic initiatives to confine, manage, and mitigate the impact on vulnerable human and animal populations. The early detection of zoonotic pathogens among animals is crucial to prevent spillover into human populations, leading to severe diseases such as Ebola, Nipah, and yellow fever [33]. However, zoonotic disease management must extend beyond human health to embrace the full scope of the OH Framework, which prioritizes the interconnected health of humans, animals, plants, and ecosystems [34]. Climate change, habitat destruction, and agricultural intensification not only increase the risk of zoonotic spillover but also threaten vulnerable wildlife populations and biodiversity [35,36]. These environmental stressors can push species toward extinction and create conditions that facilitate reverse zoonosis, where pathogens are transmitted from humans back to animals, further destabilizing ecosystems [37]. For example, reverse zoonosis has been observed in species such as primates and mustelids, with documented cases of tuberculosis in elephants, SARS-CoV-2 in minks, and influenza viruses in ferrets, exacerbating conservation and public health challenges [38–40]. Moreover,

shifts in the habitats of disease vectors like mosquitoes and ticks due to changing climate patterns affect both human and animal populations [41]. Therefore, enhancing surveillance systems to monitor zoonotic and reverse zoonotic infections, alongside ecosystem health indicators, is critical for fostering sustainable and resilient health systems globally [42]. OH preparedness should aim to protect not only human health but also promote sustainable, resilient health for all living organisms and their environments [43].

3.2. Infection and Disease Prevention

Preventive methods are interventions that aim to prevent the occurrence of diseases, such as zoonotic illnesses, and they include but are not limited to vaccination and sanitation. A vaccine is an immunobiological substance administered before exposure to infectious agents to provide sufficient immunization against the pathogen when the individual is naturally infected with the agent [31]. Vaccination is the most effective strategy for controlling infectious diseases in both public and veterinary settings. For instance, veterinary immunization was able to eradicate rinderpest in 2011 [44]. Water, sanitation, and hygiene (WASH) programs are primary approaches to mitigating infectious pathogens, specifically those that are transmitted through water or through the fecal–oral route [31]. Contaminated water can be a significant pathway for zoonotic diseases; therefore, clean water is a fundamental method to prevent these infections. Hence, WASH programs provide an essential sanitation infrastructure that safely removes human and animal waste from the environment [45]. Furthermore, WASH approaches often include educational components that inform communities about the importance of sanitation and hygiene in preventing disease to empower individuals in adopting practices that protect their health status and the health of their animals [45].

3.3. Community Education

Education and awareness campaigns play a vital role in managing zoonotic diseases, significantly contributing to the improvement of intervention systems [32]. Health education takes various forms, including training programs for both the public and healthcare professionals, informational brochures, mobile applications, and television advertisements. These initiatives help to disseminate knowledge about risk factors and potential reservoirs of zoonotic diseases [46]. Bridging awareness–practice gaps requires a comprehensive understanding of the negative health outcomes associated with zoonotic pathogens. Increased funding for disease monitoring is essential to support the development of specialized training programs aimed at preventing and controlling zoonotic diseases. Furthermore, enhancing the surveillance systems for livestock-associated zoonotic diseases is crucial. Improved surveillance provides a better understanding of transmission factors, facilitating the effective implementation of prevention and control measures, particularly in rural communities [47]. In the digital era, mobile applications and other technological tools have become powerful platforms for providing disease-specific information and improving public health outreach. For example, during the Ebola outbreak in Nigeria in 2014, digital tutorials available through mobile apps effectively educated users about the causes, diagnostic methods, and transmission pathways of the disease [32].

4. Policy and Governance in Zoonotic Disease Control

Controlling zoonotic diseases, which can be transmitted between animals and humans, is an important public health concern that requires collaborative effort from multiple sectors. Some key international institutions, such as the WHO, World Organization for Animal Health (WOAH), and Food and Agriculture Organization (FAO), have developed a comprehensive framework to address these challenges through the OH approach. The Tripartite

Zoonosis Guide (TZG) is a collaborative framework created by the WHO, the OIE, and the FAO to encourage an intersectoral approach to zoonotic disease control. While the TZG provides valuable tools for improving collaboration at the human–animal–environment interface, its effectiveness depends on countries' capacity to adapt these tools to their unique health systems and policy environments [48,49]. The guidance emphasizes that countries must improve their national skills in areas like surveillance, risk assessment, emergency planning, and coordinated response tactics [50,51]. The Generalizable One Health Framework (GOHF) outlines a five-step strategy for implementing OH concepts across various governance levels [52]. This framework not only fosters collaboration among sectors responsible for human, animal, and environmental health but also highlights the challenges of operationalizing such coordination in regions with limited resources or competing health priorities. The GOHF offers a comprehensive toolkit that integrates existing resources to enhance countries' capacities for effectively controlling zoonotic infections [52]. The Food Safety and Zoonotic Diseases Policy by the WHO supports member states in managing food safety risks associated with zoonotic diseases throughout the food chain [53]. However, while this policy emphasizes strengthening core capacities under the International Health Regulations (IHR) and fostering multi-sectoral collaboration, the implementation of these regulations often faces challenges related to compliance, monitoring, and enforcement in low-resource settings [53]. In partnership with the FAO, the WHO develops international food standards, and in collaboration with WOAH, coordinates efforts to prevent zoonotic diseases [53]. While EMPRES-AH plays a critical role in mitigating risks and promoting proactive management strategies, its success is contingent on sustained funding, political commitment, and the capacity of national health systems to integrate its recommendations into local practice [54]. This program uses the OH concept to ensure complete disease management. The combined efforts of the WHO, WOAH, and FAO through frameworks such as TZG and GOHF are critical for the efficient management of zoonotic diseases worldwide. However, the real-world impact of these frameworks often varies depending on national-level governance structures, resource availability, and intersectoral coordination mechanisms. These organizations hope to minimize the prevalence of zoonosis and its impact on public health, economies, and livelihoods around the world by fostering multisectoral collaboration and strengthening state competencies.

The management of zoonotic diseases presents substantial regulatory and practical challenges, particularly in LMICs. Many LMICs struggle with inadequate surveillance frameworks, which are crucial for the early detection and response to zoonotic threats. Weaknesses in these systems often result in underreporting and delayed responses to outbreaks [7,55]. A lack of trained staff, financial resources, and infrastructure impedes the implementation of effective zoonosis control strategies. This scarcity is exacerbated by conflicting health objectives, where limited resources are often diverted towards addressing immediate public health priorities such as maternal health, non-communicable diseases, and malnutrition [56,57]. As a result, zoonotic disease control is frequently deprioritized, leading to gaps in surveillance, delayed outbreak responses, and insufficient cross-sectoral collaboration [58]. The governance of zoonotic disease control is frequently fragmented due to unclear policy mandates, overlapping responsibilities, and a lack of coordinated frameworks among sectors. Limited collaboration between public health, veterinary, agricultural, and environmental stakeholders hampers the development of cohesive strategies to manage zoonotic risks [59–61]. This disconnected approach leads to inefficient communication, delays in outbreak detection and response, and duplicated efforts in surveillance and control, ultimately compromising the effectiveness of zoonotic disease prevention measures [7]. Policymakers frequently lack awareness regarding the severity and economic impact of zoonotic illnesses, which can further hinder resource allo-

cation and political commitment towards addressing these diseases (Figure 1). Insufficient political commitment may lead to a lack of financing and support for critical initiatives [7]. Effective management of zoonosis requires integrated approaches that link human, animal, and environmental health sectors [59]. However, establishing such integrated systems is challenging due to existing bureaucratic barriers and the need for intersectoral collaboration [60,62]. Several strategies can be implemented to address these issues. Developing robust surveillance frameworks that integrate data from human and animal health sectors is essential for timely detection and response [62]. Raising awareness about the economic burden of zoonosis can help to secure political support for funding and resource allocation toward control programs [7]. For instance, the Global Health Security Agenda (GHSA) facilitates joint training programs for healthcare workers, veterinarians, and environmental scientists to strengthen cross-sectoral response capacities [63,64]. Additionally, frameworks like the One Health Joint Plan of Action (OH JPA) encourage coordinated data sharing and joint risk assessments between sectors, enhancing early detection and rapid responses to zoonotic threats [63,64]. Addressing these gaps in policy enforcement and execution will help countries to enhance their ability to control zoonotic diseases successfully, eventually preserving public health and increasing global health security. The rise of zoonotic diseases, which can be transmitted from animals to humans, has become a major health problem worldwide, as evidenced by the COVID-19 pandemic. International collaboration is critical for addressing these concerns through various programs and frameworks, including GHSA and TZG. GHSA is a multilateral program that aims to improve global health security by encouraging governments to collaborate in the prevention, detection, and response to infectious disease threats [48]. One of its key components is the Zoonotic Disease Action Package (ZDAP), which emphasizes a One Health approach that connects the human, animal, and environmental health sectors [65–67]. The integration of health sectors through frameworks such as GHSA and TZG improves global health security while also preparing countries for potential pandemics. By encouraging collaboration across disciplines and sectors, the global community can address the challenges posed by zoonotic diseases better.

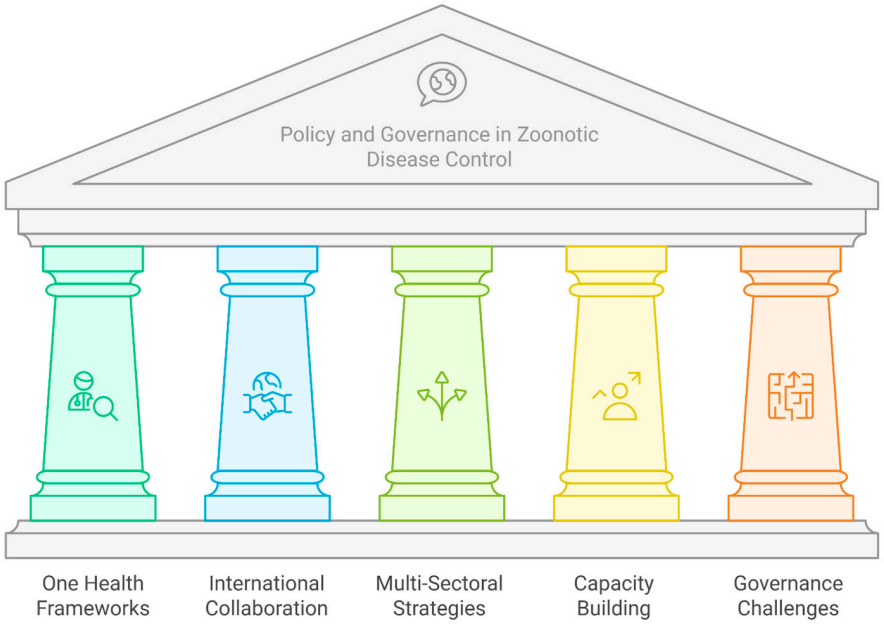

Figure 1. Pillars of zoonotic disease governance: One Health, collaboration, multi-sector strategies, capacity building, and challenges.

5. Integrating Public Health, Policy, and One Health

Addressing zoonotic diseases requires an integrated approach linking human, animal, and environmental health (Table 3). This integrated approach, central to the OH Framework, fosters collaboration across disciplines and sectors to prevent, detect, and respond to zoonotic threats more effectively. By aligning public health strategies, policy initiatives, and the principles of One Health, robust systems can be established to strengthen global health resilience [51]. The Tripartite Collaboration among the WHO, the FAO, and the WOAH facilitates cross-sectoral cooperation, ensuring seamless collaboration between human health, veterinary medicine, environmental science, and policymaking [52]. This collaborative model underscores the importance of sharing expertise, resources, and surveillance data to globally monitor zoonotic diseases. Countries, especially those in LMICs, become better equipped to detect outbreaks early and mount coordinated responses when supported by international partnerships and capacity-building initiatives from organizations like the WHO, FAO, and WOAH [49].

Table 3. Integrated frameworks and initiatives.

Framework/Initiative	Description	Source(s)
Tripartite Zoonosis Guide (TZG)	A collaborative framework by WHO, WOAH, and FAO for multi-sectoral approach to zoonotic disease control, providing guidance and tools to improve collaboration.	[48,49]
Generalizable One Health Framework (GOHF)	A five-step strategy for implementing One Health concepts at various governance levels, aimed at increasing cross-sector collaboration.	[52]
Global Health Security Agenda (GHSA)	Multilateral program for global health security, including ZDAP which emphasizes a One Health approach to connect human, animal, and environmental health sectors.	[68]
PREZODE (Preventing Zoonotic Disease Emergence)	An innovative international initiative focused on understanding zoonotic disease emergence, developing methods for prevention, early detection, and resilience to ensure rapid response.	[69]
PREDICT Project	A global One Health initiative that strengthened surveillance and lab capabilities by fostering transdisciplinary collaboration.	[70]
Rwanda's National One Health Program	A national-level coordinated system involving Ministries of Health, Agriculture, and Environment that resulted in improvements in surveillance, rapid response, and community education.	[71]
EcoHealth Alliance	An organization that uses ecological data to predict and prevent zoonotic disease outbreaks by addressing deforestation, wildlife trade, and human–wildlife interactions.	[72]
Rabies Elimination Program in the Philippines	A program that successfully reduced human rabies cases by integrating public health and veterinary efforts through mass dog vaccination campaigns, public awareness initiatives, and improved access to post-exposure prophylaxis.	[73]

At the national level, frameworks such as the Joint Risk Assessment (JRA) help evaluate zoonotic disease risks by incorporating inputs from the human and veterinary health sectors. For instance, multidisciplinary task forces that integrate epidemiological data, animal health surveillance, and environmental monitoring have been successfully implemented in countries like Rwanda and Bangladesh, leading to earlier outbreak detection and better prediction of zoonotic disease spread [74–76]. Similarly, national OH platforms in countries such as Rwanda and Bangladesh have successfully institutionalized cross-sector collaboration, promoting proactive measures to combat zoonotic diseases [71,75]. Furthermore, the GHSA supports countries in strengthening their capacities to prevent,

detect, and respond to health threats, emphasizing a One Health approach, which urges governments to align health and policy efforts with environmental sustainability. These frameworks ensure that zoonotic disease management remains a priority across sectors, promoting resilience at both local and global scales [68].

Public health policies must reflect the principles of OH to ensure sustainable and effective responses to zoonotic diseases. Policies that address AMR, promote biosecurity in agriculture, and invest in disease surveillance systems are critical components of this integration [29]. For example, legislation regulating the use of antibiotics in livestock production in regions such as the European Union (EU) and Scandinavian countries has been instrumental in reducing the emergence of resistant zoonotic pathogens [77–79]. The EU-wide ban on the use of antibiotics as growth promoters in animal feed was implemented in 2005, although resistance of some emerging foodborne pathogens like Salmonella and Campylobacter has not decreased [80]. Similarly, Denmark's "Yellow Card" initiative monitors antibiotic use in livestock, implementing strict thresholds and penalties for non-compliance [81].

Governments play a pivotal role in aligning policies across sectors by providing adequate funding, establishing regulatory frameworks, and promoting research and innovation [82]. Implementation strategies include integrating surveillance systems for human and animal health, enforcing strict monitoring of antibiotic usage, and promoting public–private partnerships to ensure compliance and accountability. In addition, international agreements, such as the IHR, provide a foundation for coordinated responses to zoonotic threats while fostering policy alignment across countries, with several initiatives demonstrating the significant benefits of integrating public health, policy, and One Health principles to combat zoonotic diseases [83].

5.1. The PREDICT Project

The PREDICT project, launched under the USAID Emerging Pandemic Threats Program, was led by the Wildlife Conservation Society in partnership with key global organizations, including UC Davis, EcoHealth Alliance, Metabiota, and the Smithsonian Institution. It serves as a landmark example of a global One Health initiative. Running from 2009 to 2020, PREDICT significantly strengthened global surveillance and laboratory diagnostic capacities for both known and newly emerging viruses, including filoviruses (ebolaviruses), influenza viruses, paramyxoviruses, and coronaviruses [70]. The initiative was implemented across 30+ countries in Africa, Asia, and Latin America, including Vietnam, Laos, Cambodia, Bolivia, Peru, Congo, and Mongolia. In Vietnam and Laos, the project supported the early detection of novel influenza strains and enhanced diagnostic laboratory capacities [84,85]. Meanwhile, in Cambodia and Congo, it facilitated the identification of zoonotic reservoirs for viruses such as Ebola and coronaviruses [3,86]. These interventions not only strengthened local disease monitoring but also improved global health security by fostering regional collaborations and capacity building in high-risk areas. PREDICT advanced OH-based health surveillance by fostering interdisciplinary collaboration between human health professionals and animal health experts, including veterinarians, wildlife health specialists, epidemiologists, and ecologists, alongside laboratory scientists. The project focused on risk assessment at high-risk human–animal interfaces, such as wildlife trade, contributing directly to emerging pandemic preparedness and GHSA [87]. Through its initiatives, PREDICT has detected over 949 novel viruses, characterized as previously unidentified viral isolates with distinct genetic sequences and phylogenetic profiles not found in existing viral databases. These include Bombali ebolavirus, Zaire ebolavirus, Marburg virus, and MERS-related coronaviruses, among other previously unknown viruses. In addition, the project trained a workforce of more than 6800 zoonotic disease specialists and

laboratory scientists across over 60 national laboratories, universities, and partner laboratories. This extensive capacity-building effort has provided critical resources for responding to biological threats like COVID-19, highlighting the importance of interdisciplinary approaches in preventing spillover events and enhancing global pandemic resilience [70]. PREDICT's long-term contributions underscore the value of integrated disease surveillance and provide a scalable blueprint for future OH initiatives aimed at reducing the risks associated with emerging infectious diseases [70].

5.2. Rwanda's National One Health Program

Rwanda has positioned itself as a leader in implementing a national-level OH framework. Through its National One Health Strategic Plan, the country has developed a well-coordinated system involving key ministries, including Health, Agriculture, and Environment [71]. This multisectoral collaboration has driven substantial improvements in zoonotic disease surveillance, emergency response capabilities, and community education on disease prevention. For example, integrated surveillance systems have effectively mitigated the spread of rabies and brucellosis, further demonstrating the effectiveness of policy-driven, cross-sector collaboration in preventing zoonotic outbreaks [71].

5.3. The EcoHealth Alliance

The EcoHealth Alliance works at the intersection of environmental and public health using ecological data to predict and prevent zoonotic disease outbreaks. Through projects that address deforestation, wildlife trade, and human–wildlife interactions, the EcoHealth Alliance has successfully reduced zoonotic risks in regions prone to spillover events [72]. Their work in Southeast Asia, for instance, led to the identification of key pathways for Nipah virus transmission, enabling local governments to implement targeted interventions [72].

5.4. Rabies Elimination Program in the Philippines

The Philippines' success in eliminating rabies highlights the importance of integrating public health and veterinary efforts. Through coordinated mass dog vaccination campaigns, public awareness initiatives, and improved access to post-exposure prophylaxis, the program reduced human rabies cases significantly [73]. This effort exemplifies how combining policy implementation, community engagement, and One Health principles can yield measurable public health outcomes [73]. Integrating public health policies—such as zoonotic disease surveillance, antimicrobial resistance management, vaccination programs, and health education initiatives—requires sustained commitment at the global, national, and local levels. Strengthening collaborative frameworks, investing in capacity building, and fostering research-driven policies is essential for addressing the complexities of zoonotic diseases. Governments, international organizations, and community stakeholders must work in tandem to align resources and strategies across sectors. Ultimately, the successful integration of these components enhances disease prevention, improves outbreak preparedness, and fosters sustainable solutions that address the root causes of zoonotic disease emergence. By embracing a holistic and unified approach, resilient systems capable of protecting both human and animal populations in an increasingly interconnected world can be built.

6. Future Directions and Recommendations

The prevention of zoonotic diseases emphasizes interdisciplinary collaboration between animal health, public health, and the environment sector [88]. Wild animals are hosts to many pathogens that cause outbreaks of novel diseases. However, the probability of this emergency can be reduced by establishing proper policy frameworks focused on an inte-

grated One Health and Planetary Health approach. This approach combines public health infrastructure, specialist skills, and science to enhance performance in predicting disease risks and implement interventions effectively during epidemics by ensuring rapid response times, evidence-based strategies, and coordinated efforts across public health, veterinary, and environmental sectors [89]. Strengthening political commitment, national planning, and regional coordination through intersectionality and global solidarity is essential to foster collaboration between various sections of health systems and develop innovative strategies and information networks to enhance knowledge sharing, particularly at the wildlife and livestock levels [90]. AMR has raised a global call for action through the establishment of the WHO Global Action Plan on Antimicrobial Resistance, which emphasizes an OH strategy focusing on improving awareness, strengthening surveillance, reducing infection, optimizing the use of antimicrobials, and promoting sustainable investment [91]. Ongoing interventions include the Global Antimicrobial Resistance Surveillance System (GLASS), which facilitates standardized data collection and reporting across countries [92]. To mitigate AMR genes, adherence to One Health strategies is required through expediting global advancement, innovating to ensure future security, cooperating for increased efficacy, investing in sustainable solutions, and fortifying global governance and accountability [93]. Therefore, to implement systematic monitoring to prevent outbreaks due to zoonoses, an efficient surveillance system is paramount for rapid risk assessment, improving laboratory diagnostic capacities, and responding to a range of zoonotic diseases, such as influenza, Ebola, and Nipah virus at the animal–human level [88,94].

Community education efforts play a vital role in raising awareness of zoonotic risks and minimizing contact with wildlife, which is essential for preventing spillover events (Figure 2). These initiatives focus on identifying high-risk behaviors and conducting serological studies to analyze seasonal patterns associated with these risks. For instance, the use of bamboo skirts to limit the spread of the Nipah virus has been instrumental in enhancing biosecurity at livestock farms by reducing wildlife–livestock–human interactions. Additionally, promoting handwashing and encouraging the use of personal protective equipment (PPE) when handling wildlife have further strengthened preventive measures. Such efforts have significantly curtailed the ability of wildlife to transmit zoonotic viruses to humans [57]. However, funding problems are the main challenges associated with the implementation of these programs [89]. Additionally, illegal wildlife trafficking and wild animal hunting exacerbate zoonotic risks by increasing human exposure to wildlife pathogens, disrupting ecosystems, and undermining conservation efforts [95]. Addressing a zoonotic outbreak requires a synchronized crisis response that includes preventive medicine specialists, legal advisors, and corporate communication teams. The primary objective is to form a crisis team, accompanied by proactive communication to guarantee public accessibility and mitigate speculation [96]. These detection and prevention programs in the early stage of epidemics result in considerable savings by lowering morbidity and mortality rates [97]. In addition, fostering collaboration between LMICs and international agencies (e.g., WHO, FAO, UNEP) is essential for developing and conducting joint research to bridge gaps in zoonotic disease prevention and control [89].

Technological advancements are increasingly being leveraged to combat infectious zoonotic diseases in this digital age. Automation of zoonotic disease detection using technologies like AI offers significant improvements over traditional human analysis. AI's ability to process large datasets rapidly and accurately, which would otherwise require substantial time manually, and its capacity to detect subtle signals indicating early-stage outbreaks make it an innovative tool for preventing zoonotic pathogen transmission [98]. IoT-based sensors enable real-time environmental monitoring, allowing for the early detection of zoonotic pathogens and rapid responses. Applications include wildlife biosensors

for ecological disturbances, agricultural IoT for livestock health tracking, and wearable sensors for human vital signs. Key advantages of these technologies include instant identification, seamless integration of data streams, scalability, and cost-effectiveness compared to manual methods [98]. However, several challenges hinder the widespread adoption of these tools, including issues with data quality, technical difficulties, and regulatory constraints such as the General Data Protection Regulation (GDPR) [99], which imposes strict guidelines on the collection, processing, and sharing of personal health data from wearable devices used in zoonotic disease monitoring. Addressing these barriers requires targeted interventions such as improving infrastructure and connectivity, particularly in rural areas, and providing healthcare professionals with specialized training to effectively utilize these technologies. Enhanced collaboration and data-sharing between researchers, public health organizations, and technology companies are also vital for maximizing the potential of AI in zoonotic disease research. Strong data governance frameworks are essential for ensuring data security and the protection of privacy. However, challenges such as privacy concerns, inconsistent data standards, and poor interoperability hinder effective data-sharing. To improve collaboration, the OH should include standardized data-sharing protocols, governance agreements, and interoperable platforms for seamless exchanges across the human, animal, and environmental health sectors [100]. Additionally, fostering public–private partnerships with clear data ownership guidelines will help to build trust and cooperation in the surveillance of zoonotic diseases [98,101].

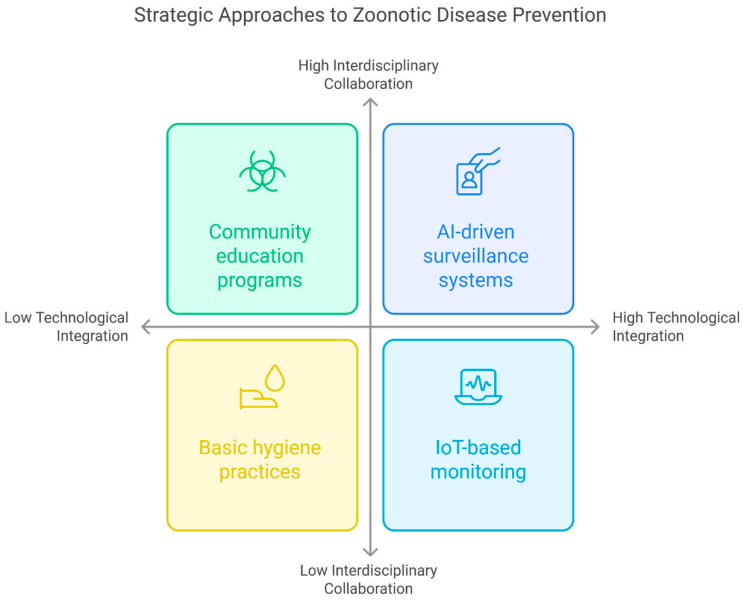

Figure 2. Strategic approaches to zoonotic disease prevention categorized by levels of interdisciplinary collaboration and technological integration.

7. Conclusions

Zoonotic diseases present complex challenges that require an integrated approach across multiple sectors. This review has demonstrated that effective management demands synergy between public health strategies, policy frameworks, and the OH paradigm bridging the gaps between the human, animal, and environmental health sectors. Evidence shows that factors such as globalization, climate change, and AMR complicate the management and control of zoonoses. AMR exacerbates zoonotic risks by reducing the effectiveness of treatments and facilitating the transmission of resistant pathogens between humans, animals, and the environment, necessitating strong response mechanisms within the OH framework. Successful implementation, such as the PREDICT project and Rwanda's National One Health Program, demonstrates the effectiveness of this in-

tegrated approach through enhanced disease surveillance, rapid response mechanisms, and cross-sector collaboration. The integration of surveillance systems, policy frameworks, and cross-sector collaboration remains crucial for preventing and controlling zoonotic outbreaks. Strengthening political commitment, enhancing surveillance capabilities, and leveraging technological advancements will be vital for building resilient systems capable of addressing future zoonotic challenges. This integrated approach, supported by sustainable funding mechanisms and international collaboration, is fundamental to promoting holistic health resilience across human, animal, and environmental systems.

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