Review Article
Yonsei Med J 2025 Apr;66(4):203-210
https://doi.org/10.3349/ymj.2024.0108

Yonsei Medical Journal
YMJ
pISSN: 0513-5796 · eISSN: 1976-2437

Navigating the Interconnected Web of Health: A Comprehensive Review of the One Health Paradigm and Its Implications for Disease Management

Andrea Hernandez[1], Jaehyun Lee[1,2], and Hojeong Kang[1]

[1]School of Civil and Environmental Engineering, Yonsei University, Seoul;
[2]Climate and Environmental Research Institute, Korea Institute of Science and Technology, Seoul, Korea.

Disease outbreaks pose serious threats to humans, as highlighted by the recent pandemic, underscoring the need for an institutionalized multi-sectoral approach like One Health, encompassing human, animal, and environmental health. One Health has demonstrated efficacy in addressing emerging issues such as antimicrobial resistance and zoonotic disease spillover. While integrating the human-animal sector has yielded positive outcomes, the majority of zoonotic spillovers originate from wildlife, emphasizing the crucial role of environmental surveillance within global One Health systems. Additionally, climate change intensifies the frequency and emergence of infectious diseases and spillover events. Tackling the complexity and interconnectedness of health challenges necessitates integrated solutions that incorporate broader structural factors, aiding in the prevention, detection, and mitigation of disease outbreaks. Embracing One Health through multi-sectoral preparedness can effectively confront the escalating threats of pandemics and other emerging diseases.

Key Words: Climate change, zoonosis, antimicrobial resistance, pandemic

INTRODUCTION

Traditionally, the investigation and treatment of diseases have predominantly fallen within the purview of medical science, confined to a narrow framework. However, a growing body of scientific evidence now points to the intricate web of ecosystem-mediated diseases, exemplified by the escalating threats posed by zoonoses and antimicrobial resistance (AMR). This burgeoning awareness emphasizes the need for multifaceted approaches to address complex challenges. In response, the "One Health" paradigm has emerged as a pivotal strategy to confront intricate problems.[1] Central to this concept is the recognition of the interconnectedness among humans, animals, and the environment, a perspective gaining prominence due to the heightened risks and challenges presented by the increased frequency and severity of disease outbreaks. "One Health" is defined by the World Health Organization (WHO) as an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals, and ecosystems. Specific examples of the impact of animals on human health include COVID-19, rabies, avian influenza, and vector-borne diseases, such as malaria and Lyme disease. Conversely, human behaviors, such as habitat destruction, overuse of antibiotics in livestock, and the human-mediated spread of invasive species, have adversely affected animal health. Potential adverse impacts of each component are presented in Fig. 1.

This review seeks to establish a foundational understanding of the One Health concept by elucidating the current knowledge and insights surrounding it. Specifically, we spotlight zoonoses and AMR as prime examples of the One Health concept. Additionally, we explore how climate change and agricultural malpractice can disrupt the entire system, ultimately impacting human health. Finally, we provide recommendations and outline future research directions in this critical area.

Received: May 13, 2024 **Revised:** January 7, 2025
Accepted: January 9, 2025 **Published online:** February 5, 2025
Corresponding author: Hojeong Kang, PhD, School of Civil and Environmental Engineering, Yonsei University, 50 Yonsei-ro, Seodaemun-gu, Seoul 03722, Korea.
E-mail: hj_kang@yonsei.ac.kr

•The authors have no potential conflicts of interest to disclose.

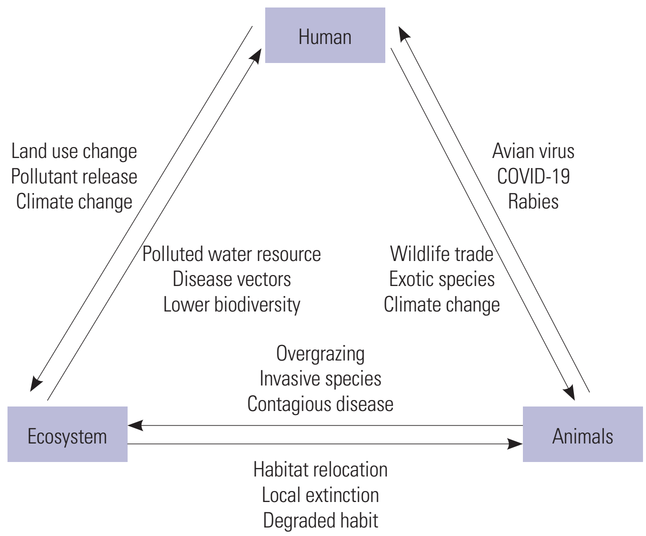

Fig. 1. A conceptual framework of interactions among three components of One Health concept.

HISTORICAL DEVELOPMENT OF ONE HEALTH CONCEPT

In recent decades, the One Health approach has garnered substantial recognition and endorsement.[2] The intrinsic relationship between public health and the environment has been acknowledged since ancient times; Hippocrates, in Ancient Greece, contended that geographical conditions and climate could influence health outcomes and diseases.[3] In the 19th century, Rudolf Virchow introduced the term "zoonosis" and emphasized the similarity in health outcomes between animals and humans, highlighting the pivotal role of environmental factors in human health.[3] Sir William Osler, Virchow's student and an epidemiologist, coined the term "one medicine" to closely associate veterinary sciences with human health outcomes.[4]

The term "One Health" gained widespread usage during the outbreak of severe acute respiratory disease in 2003, and it was further emphasized during the highly pathogenic avian influenza H5N1 outbreak in 2004, leading to the formulation of the "Manhattan Principles" at a Wildlife Conservation Society meeting.[5] These principles underscored the crucial acknowledgment of the interconnected health of humans, animals, and the environment.

In 2010, the WHO, the Food and Agriculture Organization, and the Organization for Animal Health (OIE) formed the "Tripartite Alliance" to recognize their shared responsibility in addressing health risks at the human-animal-environment interface. In March 2022, the partnership evolved into the "Quadripartite" with the inclusion of the United Nations Environment Programme, establishing a Global One Health Joint Plan of Action for 2022–2026.[6]

The One Health concept encompasses various disciplines, with the recognition that the overlap between the health of humans, animals, and the environment is constantly expanding, making it an ever-evolving dynamic concept.[3] The Quadripartite's One Health Joint Plan of Action is structured around six interdependent action tracks aimed at preventing, detecting, and responding to health threats while enhancing the health of humans, animals, plants, and the environment.[6] Six action tracks proposed in the One Health Joint Plan of Action are as follows: the first is enhancing One Health capacities to strengthen health systems by establishing foundational mechanisms, tools, and capacities, and creating an enabling environment for effective implementation. The second action track is reducing the risks from emerging and re-emerging zoonotic epidemics and pandemics. This is to reduce the risk of local and global impacts of zoonotic pathogens by understanding drivers, identifying upstream interventions, and strengthening surveillance systems. The third one is controlling and eliminating endemic zoonotic, neglected tropical and vector-borne diseases. The main target of this action is community-centric risk-based solutions. The fourth action track is strengthening the assessment, management, and communication of food safety risks. This is about the nexus of the human-animal-plant-environmental interface through food production and consumption. The fifth one is curbing the silent pandemic of AMR, which is to limit the emergence and spread of resistant pathogens. The final action track is integrating the environment into One Health. This is based on the acknowledgement that the health of humans, domestic and wild animals, and the environment are closely linked and interdependent. In 2020, the multidisciplinary One Health High-Level Expert Panel was established to enhance cross-sectoral collaboration, attracting around 17000 learners globally within 2 years through open-access training courses.[7] Global initiatives to address public health emergencies at the human-animal-environment interface include the International Health Regulations by the WHO, the Performance of Veterinary Services Pathway by the OIE, and the incorporation of One Health principles into the United Nations' 2030 Agenda for Sustainable Development Goals.[8] Through One Health, the Quadripartite aims to enhance each country's ability to respond to escalating health threats and to surveil and prevent disease outbreaks by integrating human health and environmental data.

Many countries, both developed and developing, have implemented policy programs to address One Health-related issues (Table 1). Some of these programs tackle global challenges, while others focus on local endemic problems specific to certain regions.

ONE HEALTH CONCEPT IN THE CONTEXT OF THE OUTBREAK OF DISEASES

Infectious diseases represent some of the most formidable

https://doi.org/10.3349/ymj.2024.0108

Table 1. Examples of Policy Programs of Various Countries with Titles and Key Foci

Country	Title	Key foci
USA	National Action Plan for Combating Antibiotic-Resistant Bacteria	Reducing antimicrobial resistance through improved surveillance, stewardship, and the development of new diagnostics and treatments
	CDC One Health Office	Coordinating efforts to tackle zoonotic diseases, including rabies, brucellosis, and influenza
EU	EU One Health Action Plan on Antimicrobial Resistance	A holistic approach to fighting AMR by addressing its environmental, human, and animal components
	Avian Influenza Preparedness	Coordinated response and surveillance of avian influenza outbreaks across member states
China	Pandemic Preparedness and Wildlife Trade Regulation	Following COVID-19, China enacted stricter laws regulating wildlife trade and consumption to reduce zoonotic spillovers
	National Avian Influenza Control Program	Preventing and controlling avian influenza outbreaks in poultry and humans
Canada	Pan-Canadian Framework for Action on Antimicrobial Resistance	Addressing AMR through a One Health approach targeting human, animal, and environmental health
	Wildlife Disease Surveillance	Monitoring diseases such as chronic wasting disease in deer and West Nile virus in birds and mosquitoes
Australia	Australian National Antimicrobial Resistance Strategy	Reducing the impact of AMR through integrated human, animal, and environmental measures
	Hendra Virus Management	Controlling outbreaks of Hendra virus, which spreads from horses to humans
India	National Action Plan on Antimicrobial Resistance	Strengthening regulations on antibiotic use in humans and livestock
	Rabies Elimination Program	Controlling rabies through mass dog vaccination and public education
Bangladesh	One Health Bangladesh	Zoonotic disease control, with a special focus on Nipah virus, avian influenza, and antimicrobial resistance
Kenya	Zoonotic Disease Unit	Tackling zoonotic diseases such as Rift Valley fever, rabies, and anthrax
	Rabies Elimination Strategy	Achieving zero human deaths from rabies through mass dog vaccination and public health education

AMR, antimicrobial resistance.

health and security challenges confronting the world, a trend anticipated to persist for decades. The WHO reports that over 60% of emerging infectious diseases are of zoonotic or animal origin, with approximately 70% originating in wildlife.[6] In 2018, the WHO Research and Development Blueprint recognized the emergence of an enigmatic threat referred to as "Disease X," identified as the foremost health risk. In 2020, Disease X materialized as the COVID-19 outbreak.[9] The ominous term "Disease X" underscores the potential emergence of currently unknown pathogens from unidentified spillover events, resulting in outbreaks that pose global threats to human health.[10] Notably, the pandemic underscored the lack of an effective mechanism for early detection of emergent pathogen spillover from environmental sources such as wildlife[1] and highlighted the vulnerability to the rapid spread of disease through international air travel and other transport systems.[11]

Zoonotic diseases, shared between animals and humans, pose significant risks to both animal and human health, profoundly impacting economies and livelihoods. These diseases spread through contact between humans and animals and with their environment, manifesting as foodborne, waterborne, vector-borne, or transmitted through direct or indirect contact and environmental contamination.[9] The One Health concept advocates for collaboration across sectors to enhance the surveillance, detection, and control of diseases.[5] From an economic standpoint, controlling zoonotic disease outbreaks and implementing early prevention measures benefit governments globally. The World Bank estimates economic losses from six major outbreaks of highly fatal zoonoses during 1997–2009 at US$80 billion, emphasizing that preventive measures could have reduced the cost to approximately US$6.7 billion.[8]

Zoonotic diseases can be transmitted to humans through various contact-dependent and contact-independent scenarios. One significant cause of zoonotic disease outbreaks is when animals from livestock production serve as intermediate hosts, facilitating the adaptation of pathogens acquired from wildlife and the environment.[11] For instance, domestic pigs may act as intermediate vessels, enabling genetic recombination of influenza A viruses from wild birds, resulting in new influenza strains transmitted to human populations.[11] The majority of newly identified human viral infections in the last decade have had a zoonotic origin, emphasizing the influence of animals on human disease.[5] As such, developing technology for early diagnosis and control of zoonotic disease outbreaks is of paramount importance.[12]

An illustrative case is the outbreak of hemorrhagic fever in Uganda during 2007 and 2008, caused by the Marburg virus, a close relative of Ebola, known for high transmissibility and human mortality rates.[13] The outbreak affected gold miners at the Kitaka mine and tourists visiting the Python Cave, both habitats of Egyptian fruit bats, the natural reservoirs of the virus. An initial response focused solely on exterminating bat colonies, disrupting the ecosystem. However, a subsequent study, following the recovery of bat populations, revealed higher levels of the virus and infection potential than before.[13] This intervention, concentrating on the human health outcome without considering the broader One Health aspects, worsened the situation in the long term.

EFFECTS OF GLOBAL CLIMATE CHANGE ON ZOONOSIS

Anthropogenic interference with ecosystems heightens the risk of zoonotic spillovers, while climate change-induced extreme weather events exacerbate the impact of these spillovers on human health. Factors such as elevated temperatures, rising sea levels, flooding, increased precipitation, and droughts directly contribute to disease outbreaks by amplifying the transmission of vector-borne and waterborne diseases. Simultaneously, they disrupt healthcare systems and sanitation protocols, intensifying health disparities.[14] The disruption of ecosystems by extreme weather events significantly impacts biodiversity, a crucial factor in preventing infectious disease outbreaks and pandemics.[11]

Climate change facilitates the geographical expansion of infectious disease pathogens, enabling them to find new habitats and extend their range into previously unaffected regions.[1] Notably, vector-borne diseases such as Zika and Dengue, typically confined to tropical climates due to temperature requirements, are now encroaching into temperate climates due to rising temperatures.[12] Instances of cholera in Europe imported from regions experiencing heightened epidemic activity due to climate change underscore the role of human migration in disease transmission.[15] The shifting geographic range of vectors and the shortened pathogen incubation period are key mechanisms through which climate change influences disease transmission.[15]

An illustrative case is the emergence of the phocine distemper virus, known for causing mortality in Atlantic seals, in sea otters in the North Pacific Ocean. Reduced sea ice, attributed to global warming, is identified as a potential driver, as it increases contact between Arctic and sub-Arctic mammals, fostering the spread of this unprecedented disease.[16] The rapid melting of permafrost and deepening of the active layer raise concerns about exposing pathogenic viruses and bacteria, potentially leading to the resurgence of previously eradicated diseases.[17] *Bacillus anthracis*, the causative agent of anthrax, stands out as a notable bacterial pathogen present in permafrost.[18] This organism has a global distribution and poses potential risks to human health.[19] A notable outbreak of anthrax in Siberia in 2016, linked to the exposure to infected animal carcasses previously preserved in permafrost, resulted in the death of 2000 reindeer and one human case.[20] While human viral pathogens have been detected in permafrost, the risk of infection from these sources is considered negligible. Viruses are susceptible to environmental pressures, particularly during thawing, which significantly reduces their viability.[21] Consequently, as of the current date, there are no documented instances of viral infections in humans attributed to pathogens released from thawed permafrost.

ANTIMICROBIAL RESISTANCE

AMR is acknowledged as a primary cause of global mortality, exerting the most significant impact on low-income countries and resource-limited settings. This pervasive and escalating threat is propelled by the overuse and misuse of antimicrobials across the human, animal, and plant sectors.[6] AMR presents a multifaceted and intricate challenge, affecting humans, animals, plants, and the environment.[8] The extensive use of antimicrobial agents in the livestock industry establishes favorable conditions for the selection of microorganisms resistant to multiple drugs, fostering the emergence of new pathogenic strains and amplifying the risk of spillover events. A report commissioned by the U.K. government in 2016 estimated that without intervention, AMR could cause up to 10 million annual deaths globally by 2050, with a potential reduction in gross domestic product by 2%–3%.[12] The role of drug resistance in the genesis of outbreaks and epidemics is expected to garner increased attention in the coming decades, alongside anthropogenic pressures on the environment and animal species.[11]

For over six decades, antibiotics have been instrumental in treating diseases in humans and livestock, with their use in animals for disease treatment and growth promotion surpassing that in human medicine.[22,23] The livestock industry's reliance on antibiotics, particularly tetracyclines, has led to significant environmental concerns. Due to the low biodegradation rates within livestock, a substantial portion of administered antibiotics, ranging from 30% to 90%, is excreted in manure, which is then used as fertilizer, introducing large quantities of antibiotics into agricultural lands.[24,25] This cycle contributes to the pervasive presence of antimicrobial substances in the soil, affecting human health and natural ecosystems. The stability of these compounds in the environment increases their residual presence during crop growth periods, posing a potential risk to food safety and public health.[26,27] Environmental exposure to antibiotics is a significant issue, as it leads to an increase in antibiotic-resistant bacteria and the expression of resistance genes, warranting extensive research.[22,28,29] Despite the recognized need, research on the toxicity of antibiotics on crops remains relatively limited, underscoring the importance of studying the impact of various antibiotics and their concentrations

https://doi.org/10.3349/ymj.2024.0108

on crop growth. Among these, tetracycline, chlortetracycline, and oxytetracycline are of particular concern due to their prevalent use and relatively high residue levels in agricultural soils (0.003–100 mg kg^{-1}),[30-32] highlighting an urgent need for further investigation and the development of strategies to mitigate the spread of AMR in the agriculture field.

The overuse of antimicrobials in aquaculture has also resulted in antibiotic resistance in the surrounding water, sediments, and fish-associated bacterial strains.[6] Proximity to fish farming sites has revealed high incidences of antibiotic-resistant bacterial populations, particularly resistant to quinolones, tetracyclines, and penicillins.[33] Antibiotic resistance can readily disseminate within aquatic microbial communities, reaching human pathogenic bacteria and triggering spillover events with repercussions for human health outcomes.[6] The well-documented use of antibiotics in aquaculture contributes to the dispersion of antibiotic residues in the marine environment, escalating the rates of antibiotic resistance in aquatic bacteria, and critically facilitating the transfer of resistance to human pathogens. The presence of AMR in estuaries has been noted on a continental scale, underscoring the imperative for multiscale approaches that incorporate ecosystem considerations.[34]

Identifying antimicrobial-resistant contaminants in fresh produce through cross-sectional studies worldwide underscores the intricate ways AMR can affect human health.[35,36] This situation highlights the influence of dietary choices on the gastrointestinal carriage and colonization of antimicrobial-resistant organisms, as seen in studies linking the consumption of contaminated fruits and vegetables to increased diversity of resistant microflora in vegetarians.[37,38] Furthermore, experimental research with animal models, such as studies showing a higher prevalence of streptomycin-resistant and multi-drug-resistant E. coli in sheep grazing on antibiotic-treated pastures, illustrates the environmental vectors of AMR transmission. These findings emphasize the critical need for implementing sustainable practices in agriculture and aquaculture, promoting responsible antibiotic use, and curbing the ecological spread of antibiotics and resistance. Such strategies are vital for addressing the AMR challenge, ensuring the safety and sustainability of food production systems for future generations, and aligning with global efforts to protect public health.

SOLUTIONS BASED ON ONE HEALTH CONCEPT

To counter the escalating frequency of spillover events leading to health crises, One Health offers preventive measures to mitigate zoonosis and AMR. Livestock vaccination against brucellosis and leptospirosis has demonstrated effectiveness in reducing disease burdens.[12] An effective strategy to curb zoonotic disease outbreaks and AMR is the mass vaccination of animal populations, offering a cost-effective and feasible alternative to the overuse of antimicrobials.[12]

Successful cases underscore the efficacy of One Health approaches in addressing disease threats. In the United States in 2014, an outbreak of Highly Pathogenic Avian Influenza Virus (HPAI) introduced by migratory birds triggered the largest recorded animal disease emergency. A collaborative effort, the Interagency Steering Committee for Avian Influenza Surveillance in Wild Migratory Birds, established a complex surveillance system, enabling early identification of HPAI viruses in wild birds. This system, facilitated by interagency collaboration, served as an early warning mechanism, preventing the transmission of the virus to poultry and mitigating the threat of a zoonotic spillover event.[13] This successful collaboration emphasized the importance of the One Health approach in achieving ecosystem conservation, disease prevention, and the health of wildlife, food-animals, and humans.

The Quadripartite currently advocates a multi-sectoral One Health approach to address the "silent pandemic" of AMR. The term "silent pandemic" underscores the information disparity globally, with high-resource countries providing data on AMR while low-resource countries face under-detection, leading to increased deaths due to ineffective antibiotic treatments. Under the Global Action Plan on AMR, the Global Early Warning System for health threats and emerging risks at the human-animal-ecosystem interface (GLEWS+) was established for early warning, detection, and risk assessment.[8] While these systems aim for global unification of data, there are examples of countries successfully addressing AMR through the One Health perspective.

In 1995, Denmark implemented the Danish Antimicrobial Resistance Monitoring Programme (DANMAP) to mitigate zoonotic threats and AMR. With a national action plan under the One Health perspective, DANMAP monitored antibiotic residues, bacterial resistance, reduced antimicrobial use in livestock, and surveilled disease spread. The success of this action plan contributed to increased scientific knowledge on AMR, with Denmark significantly reducing AMR in agricultural settings and improving clinical health outcomes.[1] The European Union's "farm to fork" action plan, initiated in 2010, further advanced food safety and sustainability based on DANMAP's surveillance.[1] New Zealand, as an isolated "closed system," serves as a case study for the successful application of One Health through governance and scientific collaboration. The "One Health Aotearoa (OHA)" alliance in New Zealand focuses on mitigating AMR, improving water quality, and curbing the effects of zoonotic disease spillover. The success of OHA was exemplified during a gastroenteritis outbreak in Havelock North in 2016, classified as one of the world's largest reported waterborne outbreaks. OHA researchers, employing a One Health surveillance system, traced the outbreak to sheep feces contaminating drinking water bores, successfully containing the outbreak.[39] The OHA system integrates collaboration between the national veterinary laboratory, the New Zealand microbiology network, and a centralized surveillance system for notifiable diseases called EpiSurv, illustrating the importance of cross-disciplinary responses under One Health surveillance in effectively managing new outbreaks.

Several scientific investigations employing the One Health concept have been successfully conducted, as outlined in Table 2.

OUTLOOK AND RECOMMENDATION

To successfully incorporate One Health through multi-sectoral collaboration, it is imperative to provide proper training to individuals working in distinct sectors. This training is vital for raising awareness regarding the interconnectedness of humans, animals, and the environment. Incorporating One Health professional training programs into the curriculum for veterinary, human, and environmental scientists can bridge educational gaps, fostering collaboration across multiple disciplines.[8] Evaluating the operationalization of One Health within the International Health Regulations, including a distinct category, can enhance the implementation of national action plans and serve as guidelines for countries.[4] Crucially, integrating One Health into the curricula of medical and veterinary schools can profoundly influence students to approach new challenges in a multi-sectoral manner. A study conducted at Georgetown University demonstrated that the inclusion of One Health-related subjects and activities in the curriculum can be achieved efficiently and cost-effectively.[40] The incorporation of a One Health elective for third-year medical students covered topics such as emerging infectious diseases, zoonoses, vector-borne diseases, epidemiology, disease preparedness, the human-animal-environment interface, and the impact of climate change on public health.[40] The survey conducted before and after the course revealed that students recognized the vital importance of a holistic approach to healthcare, where the human-animal-environment interface is considered. They emphasized the increasing importance of interdepartmental and interdisciplinary collaboration in the face of emerging challenges.[40] This study underscores the achievability of successfully integrating One Health preparedness at a low cost, emphasizing the importance of closing educational gaps through increased knowledge of One Health strategies as a cornerstone of education.

A more effective One Health approach to reduce spillover events of the virus could have involved prohibiting human access during high-risk times, such as birthing seasons, along with enhanced personal protective equipment and health screening when access was allowed. Instead of disrupting the ecosystem, the One Health approach provides an opportunity to collaboratively work with the ecosystem to minimize the risk of spillover events.[13]

The environment, often neglected in One Health triad responses, assumes critical importance due to its role in exacerbating antibiotic resistance and zoonoses under climate change.[31] Despite its dynamic nature, the environment remains the least explored and integrated aspect of One Health systems.[41] Addressing climate change, habitat fragmentation, pollution, and environmental degradation is essential to safeguard ecosystem function and human health.[13] The success of One Health integration in New Zealand highlights the potential for a multi-sectoral approach to address issues beyond infectious diseases, such as climate change.[39] Integrating environmental

Table 2. Examples of Studies That Implemented One Health Concept

Region	Disease	Approach	Outcome	References
Malaysia	Nipah virus	Identified fruit bats as the natural reservoir, with spillover to pigs and subsequently to humans	Insights led to changes in farming practices, reducing interactions between livestock and bats	Chua, et al. (2000) Science 288:1432-5[43]
Mongolia	Brucellosis	Collaborative efforts among veterinarians, public health professionals, and livestock owners	Mass vaccination reducing incidence of brucellosis in both humans and livestock	Zinsstag, et al. (2005) The Lancet 366:2142-5[45]
Kenya	Rift valley fever	Combined satellite imagery for environmental monitoring, animal health surveillance, and human disease tracking	Early warning systems were developed to predict outbreaks based on weather patterns	Anyamba, et al. (2009) PNAS 106:955-9[46]
Southeast Asia	Avian influenza	Multi-sectoral collaborations between veterinary and public health authorities	Early detection and rapid containment strategies	Gilbert, et al. (2014) Nature Communications 5:4116[47]
Australia	Hendra virus	Conducted ecological studies on bat populations and developed horse vaccines	Vaccination programs for horses significantly reduced human exposure	Field, et al. (2015) PLoS One 10:e0144055[48]
USA	Lyme disease	Examined interactions among deer, ticks, and human populations, considering deforestation	Recommendations for land management and tick control strategies	Ostfeld, et al. (2018) Ecology 99:1562-73[49]
Global	COVID-19	Integrated genomic, epidemiological, and ecological studies identified bats as a likely reservoir	The need for stronger wildlife trade regulations and global pandemic preparedness	Andersen, et al. (2020) Nature Medicine 26:450-2[50]

https://doi.org/10.3349/ymj.2024.0108

surveillance into One Health systems will gain importance as climate change amplifies the frequency and incidence of disease outbreaks.

AMR is a growing concern in food-animal and livestock production, acknowledging the interconnectedness of animal and human health. However, AMR is increasingly problematic in aquaculture settings due to a lack of regulations and rising temperatures linked to climate change. The One Health approach proposes characterizing and surveilling resistant bacterial strains, enhancing aquaculture sector hygiene, minimizing antimicrobial usage, and including environmental surveillance in sediments and surrounding water to address AMR.[33] Success in curbing AMR through surveillance in other sectors necessitates extending these approaches to aquaculture.

We propose several research directions to further advance the One Health concept. First, emerging technologies, including machine learning (ML) models, advanced molecular biology tools, and remote sensing techniques, should be integrated to address multi-scale medical challenges on a global scale. This integration is particularly critical as ML algorithms are capable of analyzing highly complex systems with diverse input features, which frequently encompass high-throughput sequencing data and spatially explicit information collected at regional or continental scales.[42] Second, fostering transdisciplinary research and education is imperative to strengthen the One Health framework. This need is underscored by a recent survey indicating that only 56% of medical schools in the United States incorporate One Health-related topics into their curricula.[40] Addressing this gap requires collaborative research efforts across diverse academic disciplines, publication of findings in journals with broad readerships, development of novel syllabi and courses in medical schools, and organization of interdisciplinary conferences. For instance, numerous academic societies focused on microbial ecology predominantly emphasize either natural ecosystems or medical perspectives, thereby limiting interdisciplinary dissemination of knowledge. Third, the effective implementation and benefits of the One Health concept heavily rely on public health efficiency and cost-effectiveness. Nevertheless, reliable metrics for evaluating One Health outcomes remain insufficient. Current assessments predominantly depend on modeled projections rather than empirical data derived from implemented interventions.[44] Consequently, establishing a standardized framework for evaluation metrics is urgently required to facilitate widespread adoption and support of the One Health approach among stakeholders. Finally, sub-disciplines that serve as intermediaries among diverse fields, including medicine, environmental science, and ecology, should receive increased support to enhance One Health research and its practical implementation. Disciplines such as epidemiology, ecosystem ecology, and environmental toxicology represent promising candidates for fulfilling this role.

ACKNOWLEDGEMENTS

This study is supported by the Ministry of Environment of Korea [2022003640002, RS-2023-00232066 and NRF (RS-2024-00335917)].

AUTHOR CONTRIBUTIONS

Conceptualization: Hojeong Kang and Andrea Hernandez. Data curation: all authors. Formal analysis: all authors. Funding acquisition: Hojeong Kang. Investigation: all authors. Methodology: all authors. Project administration: Hojeong Kang. Resources: Hojeong Kang. Software: all authors. Supervision: Hojeong Kang. Validation: all authors. Visualization: Jaehyun Lee. Writing—original draft: Hojeong Kang and Andrea Hernandez. Writing—review & editing: all authors. Approval of final manuscript: all authors.

ORCID iDs

Andrea Hernandez https://orcid.org/0009-0002-6783-6315
Jaehyun Lee https://orcid.org/0000-0003-0883-1207
Hojeong Kang https://orcid.org/0000-0002-2088-6406

REFERENCES

1. Humboldt-Dachroeden S, Mantovani A. Assessing environmental factors within the One Health approach. Medicina (Kaunas) 2021;57:240.
2. No author. Promoting the science of One Health. Nat Commun 2023;14:4735.
3. Capua I, Cattoli G. One Health (r)Evolution: learning from the past to build a new future. Viruses. 2018;10:725.
4. Zinsstag J, Kaiser-Grolimund A, Heitz-Tokpa K, Sreedharan R, Lubroth J, Caya F, et al. Advancing one human-animal-environment health for global health security: what does the evidence say? Lancet 2023;401:591-604.
5. Shaheen MNF. The concept of one health applied to the problem of zoonotic diseases. Rev Med Virol 2022;32:e2326.
6. FAO, UNEP, WHO, WOAH. One Health Joint Plan of Action (2022-2026): working together for the health of humans, animals, plants and the environment. Rome: FAO, UNEP, WHO, WOAH; 2022.
7. de la Rocque S, Errecaborde KMM, Belot G, Brand T, Shadomy S, von Dobschuetz S, et al. One Health systems strengthening in countries: tripartite tools and approaches at the human-animal-environment interface. BMJ Glob Health 2023;8:e011236.
8. Barton Behravesh C. Introduction. One Health: over a decade of progress on the road to sustainability. Rev Sci Tech 2019;38:21-50.
9. FAO, OIE, WHO. Taking a multisectoral, one health approach: a tripartite guide to addressing zoonotic diseases in countries. Paris: OIE; 2019.
10. Chatterjee P, Nair P, Chersich M, Terefe Y, Chauhan AS, Quesada F, et al. One Health, “disease X” & the challenge of “unknown” unknowns. Indian J Med Res 2021;153:264-71.
11. Ellwanger JH, Fearnside PM, Ziliotto M, Valverde-Villegas JM, Veiga ABGD, Vieira GF, et al. Synthesizing the connections between environmental disturbances and zoonotic spillover. An Acad Bras Cienc 2022;94:e20211530.
12. Gudipati S, Zervos M, Herc E. Can the One Health approach save us from the emergence and reemergence of infectious pathogens in the era of climate change: implications for antimicrobial resistance? Antibiotics (Basel) 2020;9:599.

13. Sleeman JM, Richgels KLD, White CL, Stephen C. Integration of wildlife and environmental health into a One Health approach. Rev Sci Tech 2019;38:91-102.
14. World Health Organization. Compendium of WHO and other UN guidance on health and environment, 2022 update. Geneva: World Health Organization; 2022.
15. Bezirtzoglou C, Dekas K, Charvalos E. Climate changes, environment and infection: facts, scenarios and growing awareness from the public health community within Europe. Anaerobe 2011;17:337-40.
16. VanWormer E, Mazet JAK, Hall A, Gill VA, Boveng PL, London JM, et al. Viral emergence in marine mammals in the North Pacific may be linked to Arctic sea ice reduction. Sci Rep 2019;9:15569.
17. Cohen J. Lurking in the deep freeze? Science 2023;381:1406-7.
18. Liskova EA, Egorova IY, Selyaninov YO, Razheva IV, Gladkova NA, Toropova NN, et al. Reindeer anthrax in the Russian Arctic, 2016: climatic determinants of the outbreak and vaccination effectiveness. Front Vet Sci 2021;8:668420.
19. Carlson CJ, Kracalik IT, Ross N, Alexander KA, Hugh-Jones ME, Fegan M, et al. The global distribution of Bacillus anthracis and associated anthrax risk to humans, livestock and wildlife. Nat Microbiol 2019;4:1337-43.
20. Popova AY, Demina YV, Ezhlova EB, Kulichenko AN, Ryazanova AG, Maleev VV, et al. [Outbreak of anthrax in the Yamalo-Nenets autonomous district in 2016, epidemiological peculiarities]. Probl Part Dangerous Infect 2016;4:42-6. Russian
21. Shoham D, Jahangir A, Ruenphet S, Takehara K. Persistence of avian influenza viruses in various artificially frozen environmental water types. Influenza Res Treat 2012;2012:912326.
22. Knapp CW, Dolfing J, Ehlert PA, Graham DW. Evidence of increasing antibiotic resistance gene abundances in archived soils since 1940. Environ Sci Technol 2010;44:580-7.
23. Gelband H, Laxminarayan R. Tackling antimicrobial resistance at global and local scales. Trends Microbiol 2015;23:524-6.
24. Eichhorn P, Pérez S, Bechtholt A, Aga DS. Fragmentation studies on the antibiotic avilamycin A using ion trap mass spectrometry. J Mass Spectrom 2004;39:1541-53.
25. Bártíková H, Podlipná R, Skálová L. Veterinary drugs in the environment and their toxicity to plants. Chemosphere 2016;144:2290-301.
26. Sarmah AK, Meyer MT, Boxall AB. A global perspective on the use, sales, exposure pathways, occurrence, fate and effects of veterinary antibiotics (VAs) in the environment. Chemosphere 2006;65:725-59.
27. Du L, Liu W. Occurrence, fate, and ecotoxicity of antibiotics in agro-ecosystems. A review. Agron Sustain Dev 2012;32:309-27.
28. Kang YK, Kwon K, Ryu JS, Lee HN, Park C, Chung HJ. Nonviral genome editing based on a polymer-derivatized CRISPR nanocomplex for targeting bacterial pathogens and antibiotic resistance. Bioconjug Chem 2017;28:957-67.
29. Kuppusamy S, Kakarla D, Venkateswarlu K, Megharaj M, Yoon YE, Lee YB. Veterinary antibiotics (VAs) contamination as a global agro-ecological issue: a critical view. Agric Ecosyst Environ 2018;257:47-59.
30. Hamscher G, Sczesny S, Höper H, Nau H. Determination of persistent tetracycline residues in soil fertilized with liquid manure by high-performance liquid chromatography with electrospray ionization tandem mass spectrometry. Anal Chem 2002;74:1509-18.
31. Martínez-Carballo E, González-Barreiro C, Scharf S, Gans O. Environmental monitoring study of selected veterinary antibiotics in animal manure and soils in Austria. Environ Pollut 2007;148:570-9.
32. Massé DI, Saady NM, Gilbert Y. Potential of biological processes to eliminate antibiotics in livestock manure: an overview. Animals (Basel) 2014;4:146-63.
33. Pepi M, Focardi S. Antibiotic-resistant bacteria in aquaculture and climate change: a challenge for health in the mediterranean area. Int J Environ Res Public Health 2021;18:5723.
34. Zhu YG, Zhao Y, Li B, Huang CL, Zhang SY, Yu S, et al. Continental-scale pollution of estuaries with antibiotic resistance genes. Nat Microbiol 2017;2:16270.
35. Hölzel CS, Tetens JL, Schwaiger K. Unraveling the role of vegetables in spreading antimicrobial-resistant bacteria: a need for quantitative risk assessment. Foodborne Pathog Dis 2018;15:671-88.
36. Miller SA, Ferreira JP, LeJeune JT. Antimicrobial use and resistance in plant agriculture: a One Health perspective. Agriculture 2022;12:289.
37. Sannes MR, Belongia EA, Kieke B, Smith K, Kieke A, Vandermause M, et al. Predictors of antimicrobial-resistant Escherichia coli in the feces of vegetarians and newly hospitalized adults in Minnesota and Wisconsin. J Infect Dis 2008;197:430-4.
38. Losasso C, Di Cesare A, Mastrorilli E, Patuzzi I, Cibin V, Eckert EM, et al. Assessing antimicrobial resistance gene load in vegan, vegetarian and omnivore human gut microbiota. Int J Antimicrob Agents 2018;52:702-5.
39. Harrison S, Baker MG, Benschop J, Death RG, French NP, Harmsworth G, et al. One Health Aotearoa: a transdisciplinary initiative to improve human, animal and environmental health in New Zealand. One Health Outlook 2020;2:4.
40. Docherty L, Foley PL. Survey of One Health programs in U.S. medical schools and development of a novel one health elective for medical students. One Health 2021;12:100231.
41. Essack SY. Environment: the neglected component of the One Health triad. Lancet Planet Health 2018;2:e238-9.
42. Keshavamurthy R, Dixon S, Pazdernik KT, Charles LE. Predicting infectious disease for biopreparedness and response: a systematic review of machine learning and deep learning approaches. One Health 2022;15:100439.
43. Chua KB, Bellini WJ, Rota PA, Harcourt BH, Tamin A, Lam SK, et al. Nipah virus: a recently emergent deadly paramyxovirus. Science 2000;288:1432-5.
44. Baum SE, Machalaba C, Daszak P, Salerno RH, Karesh WB. Evaluating one health: are we demonstrating effectiveness? One Health 2016;3:5-10.
45. Zinsstag J, Schelling E, Wyss K, Mahamat MB. Potential of cooperation between human and animal health to strengthen health systems. Lancet 2005;366:2142-5.
46. Anyamba A, Chretien JP, Small J, Tucker CJ, Formenty PB, Richardson JH, et al. Prediction of a Rift Valley fever outbreak. Proc Natl Acad Sci USA 2009;106:955-9.
47. Gilbert M, Golding N, Zhou H, Wint GRW, Robinson TP, Tatem AJ, et al. Predicting the rist of avian influenza AH7N9 infection in live-poultry markets across Asia. Nat Commun 2014;5:4116.
48. Field H, Jordan D, Edson D, Morris S, Melville D, Parry-Jones K, et al. Spatiotemporal aspects of Hendra Virus infection in Pteropid bats (flying-foxes) in Eastern Australia. PLoS ONE 2015;10:e0144055.
49. Ostfeld RS, Levi T, Keesing F, Oggenfuss K, Canham CD. Tick-borne disease risk in a forest food web. Ecology 2018;99:1562-73.
50. Andersen KG, Rambaut A, Lipkin WI, Holmes EC, Garry RF. The proximal origin of SARS-CoV-2. Nat Med 2020;26:450-2.

https://doi.org/10.3349/ymj.2024.0108