

One Health and the Environment:



Veterinarian vaccinating a cow at a livestock farm.

From Conceptual Framework to Implementation Science

by Oladele A. Ogunseitan



Young man receiving a COVID-19 vaccine during an immunization clinic at a vaccination center.

The One Health Conceptual Framework

Emergence of the Environmental Context of One Health

The insignia of several agencies dedicated to health and healing depict an animal, a snake, coiled around a potent staff. Various interpretations have been offered to explain the symbolic meaning of the *Rod of Asclepius*, but its representation of intertwined human health and animal health suggests a long history of relatively recent attempts, including the One Health framework, to define human health in the context of interconnectedness with other organisms.¹ The debate about what health means for the human population is rekindled during periods of increasingly apparent and frequent impacts of disease outbreaks and pandemics, biodiversity loss, climate change, deforestation, unsustainable population growth, and forced migration. The One Health concept is often framed as a pathway to sustainability because it links biodiversity, particularly regarding wildlife and agricultural animals, to human health, with the environment playing an intermediary role.² However, some investigators have argued that environmental sustainability is undervalued and understudied in the One Health framework.³ In response, the United Nations Environment Program (UNEP) recently joined the tripartite Food and Agriculture Organization (FAO), World Organization for Animal Health (OIE), and World Health Organization (WHO) to recommend establishment of a One Health High-Level Expert Council, including all four agencies and key international experts on human, animal, environment and social sciences. This council aims to “collect, distribute and publicize reliable scientific information on the links between human, animal and environmental health in order to assist public officials make appropriate decisions to address future crises and to inform citizens.”⁴ The ongoing COVID-19 pandemic, which likely originated through the spillover of a coronavirus (SARS-Cov-2) from an animal reservoir to

human populations⁵ and certainly spread and perpetuated through transmission by environmental media, is a powerful reminder of the transformative potential of the One Health framework, and provides a timely opportunity to investigate gaps in the framework with particular emphasis on scholarship and institutional barriers that marginalize the environmental context as a late invitee to the tripartite (Figure 1).

The practical application of research linking human health to animal health can be traced to the work of Edward Jenner (1749–1823), whose role was pivotal in the development of vaccination after observing the relationship between smallpox and cowpox.⁶ However, it was Rudolf Virchow (1821–1902) who coined the term *zoonosis* to define the spillover of pathogens from animals to humans, a main concern of the One Health conceptual framework.⁷ In 1947, the establishment of the Division of Veterinary Public Health by the U.S. Centers for Disease Control and Prevention (CDC) initiated the imperative for institutional oversight of zoonotic diseases, even as the academic and professional infrastructures for animal health and human health sought their independent identities. By introducing the phrase “One Medicine,” Calvin Schwabe (1927–2006) strengthened the professional collaboration and academic foundation for One Health, although the transition from “One Medicine” to “One Health” remained a fledgling concept until 2007, when the American Veterinary Medical Association and the American Medical Association established a bond to strengthen their collaboration, and representatives of the more than 100 countries and more than 20 international organizations convened in the wake of avian and pandemic influenza to secure the One Health concept.⁸

Institutional Limitations of One Health and Environment

To fully grasp the scope of One Health and the limitations of the institutional context of the framework, it is



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important to understand the intersection of knowledge gaps and policy differences among the foundational agencies. The World Health Organization currently defines One Health generically as an “approach to designing and implementing programmes, policies, legislation and research in which multiple sectors communicate and work together to achieve better public health outcomes.” This definition is arguably indistinguishable from those adopted by multidisciplinary frameworks such as the socioecological model of public health and its emphasis on systems thinking. One Health is perhaps best recognized through the dominance of specific academic and professional disciplines that have embraced the framework, including, for example, veterinary medicine. Formal inclusion of the environmental context in One Health did not occur until 2008, when the Food and Agricultural Organization (FAO), Office International des Epizooties (OIE, or World Organization for Animal Health), and the World Health Organization (WHO), UNICEF, the World Bank, and the United Nations System Influenza Coordination collaborated to develop a strategic framework for reducing risks of infectious diseases at the animal–human–ecosystem interface. Soon after, in 2009, the CDC established the One Health Office, and the U.S. Agency for

Figure 1. Farms are major nodes in the spillover of pathogens from animal populations to human populations, and vice versa. In the case of an experimental pig farm designed to minimize the risk from zoonoses and antibiotic resistance in southeast Asia, wastewater and solid waste manure are properly treated, and visitors to the location are warned about the biosecurity precautions, including disinfection of shoes before entry.



Photographs from the author, Oladele A. Ogunseitan.

International Development (USAID) began investing in programs to build infrastructure and workforce for One Health capacities at the local, national, and regional levels for early detection of emerging pandemic threats. More than a decade since, the direct inclusion of the environmental context within the One Health tripartite shows marginal participation, demonstrable in part by the absence of the United Nations Environment Program (UNEP) in the implementation of One Health initiatives until 2017 in the case of antimicrobial resistance, which rapidly became a looming threat to derail a century of progress to curb infectious pathogens. It wasn't until 2021 that UNEP was formally invited to join the One Health "tripartite alliance" consisting of FAO, OIE, and WHO to form a more inclusive quartet.⁹ However, the role of environmental sustainability and ecosystem services in One Health remains cloudy even now, in the middle of the COVID-19

pandemic. In parallel with United Nations efforts to better integrate UNEP into the alliance for One Health, other international sectors recognized the global problem presented by climate change as perhaps the most significant environmental challenge confronting humanity, and its absence or marginal treatment in the One Health framework. The COVID-19 pandemic was likely already incubating on October 25, 2019, when Germany's Climate and Environmental Foreign Policy Division of the Federal Foreign Office collaborated with Wildlife Conservation Society to convene a "One Planet, One Health, One Future" conference that resulted in a Call-to-Action codified as the "Berlin Principles," a set of 10 items emphasizing the integration of ecosystem health and integrity and urgent topics including climate change and antimicrobial resistance.¹⁰

The emergence and evolution of various high-level alliances, forums,

working groups, principles, academic journals, and training programs in One Health is clearly recognizable. It is important to now ask what went wrong in the One Health framework that contributed to the colossal failure to prevent a pandemic such as COVID-19, or at least to diagnose and curb the pathogen spillover event soon after the outbreak.¹¹ I argue here that the emergence of One Health as a multidisciplinary academic and professional concept has struggled to progress toward implementation in part because of the late integration of environmental context and sustainability science. There is need for more thought and action to dissolve the research silos to fully realize the potential for implementing One Health ideas, starting with development of capacity for methodological infrastructure and competent workforce in integrative surveillance, particularly in the environmental networks that support human and animal health.

Progressing From One Health Concept to Implementation Science

An Inclusive Agenda for Implementation Science of One Health and the Environment

Implementation science is typically considered the systematic study of the gap between efficacy, the outcome of an intervention under ideal conditions, and effectiveness, the realistic outcome under normal conditions, which may vary widely between geographical locations under the influence of political, socioeconomic, behavioral, and cultural attributes. A review of more than 50 peer-reviewed articles labeled with implementation science revealed a wide range of definitions and concepts, but with the common theme of progressing from the generation of evidence to the interpretation and of knowledge to practice in a scientific way.¹² Particularly, the One Health framework is heavily dominated by theoretical constructs about why close collaboration between specialists in human health, animal health, and ecosystem/environmental health should generate effectiveness of strategies to prevent pathogen spillover events and zoonotic disease outbreaks. It is difficult to argue against such theories, but the scientific evidence of the effectiveness of such collaboration and the translation of knowledge to practice are even more difficult.

The inaugural editorial for a new journal entitled *One Health & Implementation Research* emphasized multidisciplinary and transdisciplinary work within the One Health approach, to be enabled by collaboration with communities and policymakers, among other stakeholders.¹³ Broad recognition of the need to progress from concepts and definitions to actions that may have been occluded without the One Health paradigm was highlighted at the 2010 meeting.¹⁴ The meeting was hosted by the CDC at the request of and in close collaboration with the tripartite FAO, OIE, and WHO, and focused on policy and economic dimensions. The relatively

early interest in transitioning from conceptual framework to implementing One Health strategies seemed to have stalled in the interim between the disease outbreaks of the last decade, including MERS, SARS, and Zika, and the current COVID-19 pandemic. The devastation of the global economy due to the COVID-19 pandemic will rekindle interest of investors in One Health. Such investments should be guided by new knowledge and strategies captured by complementarity with sustainability science and implementation science, both equally powerful transdisciplinary frameworks that explicitly account for the integration of local knowledge and collective action.

The agenda for One Health implementation science is both urgent and broad, spanning the spectrum of how disease outbreak surveillance is integrated across animal, human, and environmental contexts, to strategic management of ecosystem services and human nutrition, and how we design cities of millions of people who at any time may come under quarantine or shelter-in-place orders. We must revive how we inspect commercial food environments, and the definition of individual personal space and operation of public transportation. The perspective that pathogen spillover events will occur independently or sequentially is probably too optimistic. The pessimistic view is that overlapping outbreaks and pandemics will not provide sufficient time and opportunities to learn important lessons and use our knowledge to prepare for the next big one. Cultivating the tenets of implementation science within One Health can improve preventive strategies designed for environmental surveillance and early warning systems, while also reducing the time lapse between emergency signals and outbreak response.

Clinical aspects of human and animal health care systems make them amenable to the applications of implementation science, which is reflected in the majority of research literature on the topic. However, environmental health science has progressed more slowly toward the adoption of implementation science. The

U.S. National Institute of Environmental Health Sciences (NIEHS) acknowledges the difficulty of implementation of evidence-based interventions across populations. But this difficulty can be addressed through carefully designed research studies if environmental health is to fulfill the promise of the next frontier of implementation science. The second theme of the strategic plan of the NIEHS is to promote translation of data to knowledge to action. This theme is particularly relevant to natural disaster response and climate change. Among the earliest applications of implementation science to global environmental problems is research on clean cooking fuels to prevent the large burden of respiratory diseases in middle- and low-income countries, highlighting the One Health context of the linkages between deforestation and human health. The intersection of local knowledge, technological innovation, social-ecological resources, and behavioral and cultural factors make the clean fuel case an important template for implementing evidence-based interventions.¹⁵

Abiotic components of environmental systems are potentially influential but not necessarily required for the spillover of pathogens from animal populations to human hosts. For example, direct contact infections are relatively easy to document when humans handle animals through wildlife hunting, wet market transactions, and food processing. Numerous zoonotic pathogens, including those responsible for notorious outbreaks, are transmitted through such direct pathways. Thus, surveillance field epidemiology in the One Health framework emphasizes sampling and monitoring of animal populations and attempts to link data from hospitals regarding incidence of reportable diseases to centralized population health data systems. Rabies is a good example of such zoonotic diseases with direct spillover and minimal or no role for environmental transmission. In such cases, mass vaccination of animal reservoirs is the evidence-based intervention, and the local configuration of community campaigns is the subject of implementation science studies.¹⁶

In the following sections, specific examples are presented to highlight gaps in the implementation of One Health-oriented solutions to major environmental challenges.

Environmental Change and Zoonoses

For many other zoonotic diseases where environmental systems directly influence pathogen spillover from animal populations to human hosts, the role of environmental surveillance has not been adequately integrated into the One Health framework from the perspective of implementation science. For examples, water-borne cryptosporidiosis and soil-borne coccidioidomycosis are case studies for truly integrative surveillance infrastructure for One Health that must include environmental microbiology and monitoring of physical environmental parameters. The etiologic agent of cryptosporidiosis is the parasitic protozoa of the *Cryptosporidium* genus, which is distributed worldwide. *Cryptosporidium* is transmitted through the fecal–mouth route primarily in natural aquatic ecosystems, through urban water distribution systems, or through food, in part because the pathogen can resist water-purification strategies such as chlorination. Cryptosporidiosis occurs problematically in young or immunocompromised humans and can infect a wide range of wildlife and domesticated animals. The symptoms, mild to severe diarrhea, can be difficult to pin to this One Health poster disease without effective environmental surveillance based on advanced molecular biological diagnostic tools.¹⁷

Each year in the United States, approximately 200 people die from valley fever (coccidioidomycosis) caused by infections with soil-borne *Coccidioidomyces* fungi. Valley fever is endemic in the southeastern region of the United States and in regions of Central and South America. *Coccidioidomyces* species are sensitive to soil temperature, acidity, and other physicochemical environmental conditions. Environmental exposure to the fungal spores is enhanced through disturbance of

dry soil and dust, which occurs during drought conditions or construction projects. In addition to humans, valley fever occurs in animals, particularly domesticated dogs and wild coyotes. Farm animals, including sheep and horses, are also vulnerable. The geographical zone occupied by coccidioidomycosis has been shown to be sensitive to climate change, and implementation of preventive strategies must include environmental surveillance to complement existing programs in hospital reports of diagnosis in humans and veterinary cases, all purportedly essential skills associated with implementation of One Health-oriented interventions.¹⁸

Environmental Context of Antibiotic Resistance

Before the COVID-19 pandemic, antibiotic resistance was largely considered the most significant emerging infectious disease threat to public health in the United States, and in many ways also to global health security. According to the U.S. Centers for Disease Control and Prevention, antibiotic-resistant infections account for more than 2.8 million cases in the United States each year, among which more than 35,000 people die. The notorious multiply resistant *Clostridioides difficile* infected 223,900 patients in 2017, killing at least 12,800 people. The economic cost of treating multiply resistant pathogens exceeds \$4.6 billion annually. It is well recognized that the excessive use of antibiotics in hospitals and prophylactic use of antibiotics in agriculture are major drivers of the spread of antibiotic resistance among human bacterial pathogens, and several incentives and policy interventions are being implemented to combat antibiotic resistance in those circumstances. However, the environmental context of antibiotic resistance has not progressed much beyond research to implementable practice in terms of routine environmental surveillance and interventions designed to disrupt the emergence and spread of resistant pathogens in, for example, wastewater from farms and households. In many national action plans to combat antibiotic resistance, the

environmental context may be acknowledged, but there are no coordinated strategies to implement solutions, although public awareness is growing regarding the dangers of discarding expired antibiotics into sewer systems or landfills.¹⁹

Toxic Environmental Pollutants

Environmental toxicology has long been a major cornerstone of environmental surveillance and epidemiology. Outdoor air quality monitors have been installed in many regions of the United States plagued by particulate matter and other noxious emissions from mobile (e.g., automobiles) and stationary (e.g., industrial smokestacks) sources. Childhood exposure to lead (Pb) is monitored through mandated screening of blood lead levels, and the U.S. CDC National Health and Nutrition Examination Surveys (NHANES) includes markers for environmental exposures to pesticides, persistent organic chemicals, and “forever chemicals” that have led to interventions that are implemented nationally through regulatory policies and public education. It is rare, however, to encounter an integrative One Health approach for these environmental health initiatives. The recent wildfires driven by climate change in the western regions of the United States have prompted emergency interventions, and the sale of indoor air quality monitors has increased, but the impacts on wildlife animals have not been clearly linked in these responses. Similarly, the major initiatives to remove toxic lead from numerous human consumer products such as gasoline, electronics, and batteries are only recently being extended to bullets used by wildlife hunters, because of the legacy of biomagnification of lead poisoning. Perhaps the most significant environmental gap in the One Health framework for implementation science is the role of toxic pesticides in agriculture, landscape management, and domestic home-level applications. The gap can be traced to the original focus of the One Health framework in attempts to predict and control zoonotic infections. It is clear that both humans and animals depend on plants for survival, and their

livelihoods are intricately connected through plant health. In the current One Health framework, plants have been included in the environment subframe, with the result of marginalizing the effectiveness of the framework in dealing with major risks such as mycotoxins in animal and human food, pesticide residues, and other toxic disease contaminants.²⁰

Emerging Environmental Pollutants

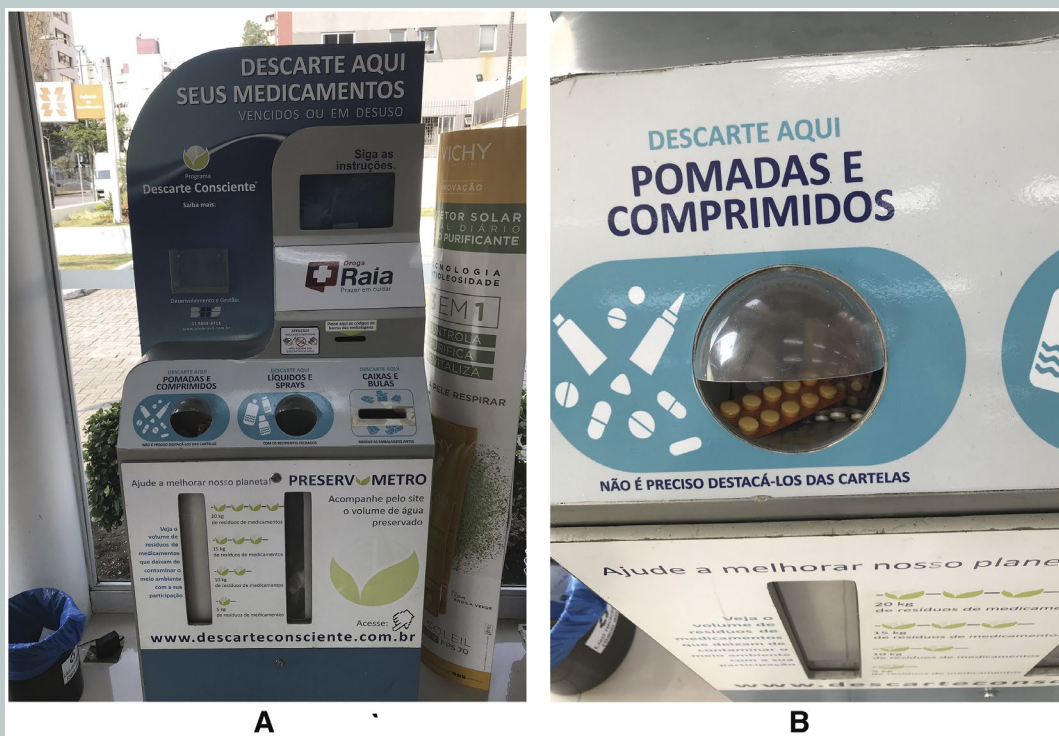
Much attention is currently being focused on the problem of microplastics in the environment and their potential impact on human health. This emerging topic has not yet been framed as an opportunity for the One Health framework to implement broad-ranging prevention strategies. In 2019, the World Health Organization called for more research to

assess the impacts of microplastics in the environment and their effects on human health. This call followed a report that documented the prevalence of microplastics in drinking water. The impact of microplastics on the health of marine life has not been prominent, a situation that should change with the full integration of the environment domain in One Health implementation science framework. In the marine environment, the health of several animal species has been shown to be compromised by ingestion of microplastics, although the demonstration has focused on the physical form of the plastics. The real damage could be due to toxic chemicals associated with plastic components, including endocrine-disrupting chemicals.²¹ Wastewaters from pharmaceutical manufacturing facilities and agricultural farms are major sources of

pharmaceutical products released into the environment, including human and animal hormones that potentially disrupt growth and development in a wide variety of nontarget species. Pharmaceutical and personal care products in aquatic environments have been shown to affect, for example, morphological development of amphibians, reptiles, and other aquatic organisms.²² Environmental surveillance to inform solutions such as regulatory policies to phase out certain chemicals or to monitor their presence in human tissues (e.g., bisphenol-A) need to be extended to domestic and wild animal populations under a reformed One Health framework that fully integrates the environmental domain in its implementation (Figure 2).

The examples presented here are not exhaustive and do not indicate a deliberate

Figure 2. An example disease prevention strategy within the One Health framework is public education and facilitation to avoid environmental contamination with pharmaceutical products such as antibiotics, hormones, and potential endocrine-disrupting chemicals. In this situation in Brazil, a waste medication disposal structure is prominently displayed at a grocery store that also dispenses medication.



Photographs from the author, Oladele A. Ogunseitan.



Microplastics found in sand on beaches causes environmental pollution and affects the ecosystem.



Sea turtles can eat plastic bags, mistaking them for jellyfish.

been used to warn human communities of dangers lurking in the environment. For reasons associated with the ethical treatment of nonhuman species and the warning efficiency, many traditional sentinel species have been replaced by highly sensitive sensors. For example, in 1986, British law required miners to replace live canary birds, which were introduced for that purpose in 1911, with electronic carbon monoxide sensors, which were determined to be more sensitive.²³ Research on and development of biomarkers of environmental health have advanced significantly over the past century. However, integration of environmental health instruments into the One Health framework has lagged in comparison to integration of clinical data human and animal health in the prevention of zoonotic diseases (Figure 3 and Figure 4).

The argument for expanding the research scope of One Health research beyond infectious zoonotic diseases is difficult to make in the aftermath of the COVID-19 pandemic for which the world was ill-prepared, despite having more than two decades of attempts to define and operationalize One Health through the agenda for global health security. The presumptive failure of One Health in the COVID-19 pandemic case does not justify a search for another paradigm. Rather, it is a reason to redouble efforts to refine the scope and principles of One Health and to move the rhetoric closer to the emerging framework of implementation science. The full integration of the environmental context is deemed essential for the implementation of solutions informed by the One Health concept. The linkages between biodiversity and all its phylogenetic branches (animal, plant, and microbial) and human health are modified by physicochemical environmental systems, which alone are the subject of the emerging field of *planetary health*. Climate change, the impetus for planetary health is the defining environmental sustainability issue of our times, and the connection of the phenomenon to the habitats of humans, animals, and plants is evident. Increasingly, climate change is also recognized as a major factor in the habitats and movement of microorganisms, including pathogens. It is imperative that we improve current

neglect of the environmental context of the One Health framework and its implementation but indicate a collective intimidation by the complexity of the challenge posed by disentangling the role of environmental systems in promoting, buffering, or mediating diseases at the intersection of humans and animals. To overcome that initial intimidation requires reassessment of One Health framework objectives for research, education, and practice to implement sustainable solutions to population health problems that are increasingly global in scope.

Toward an Integrative One Health Environment

Bridging Gaps in the Research Scope of One Health Environment

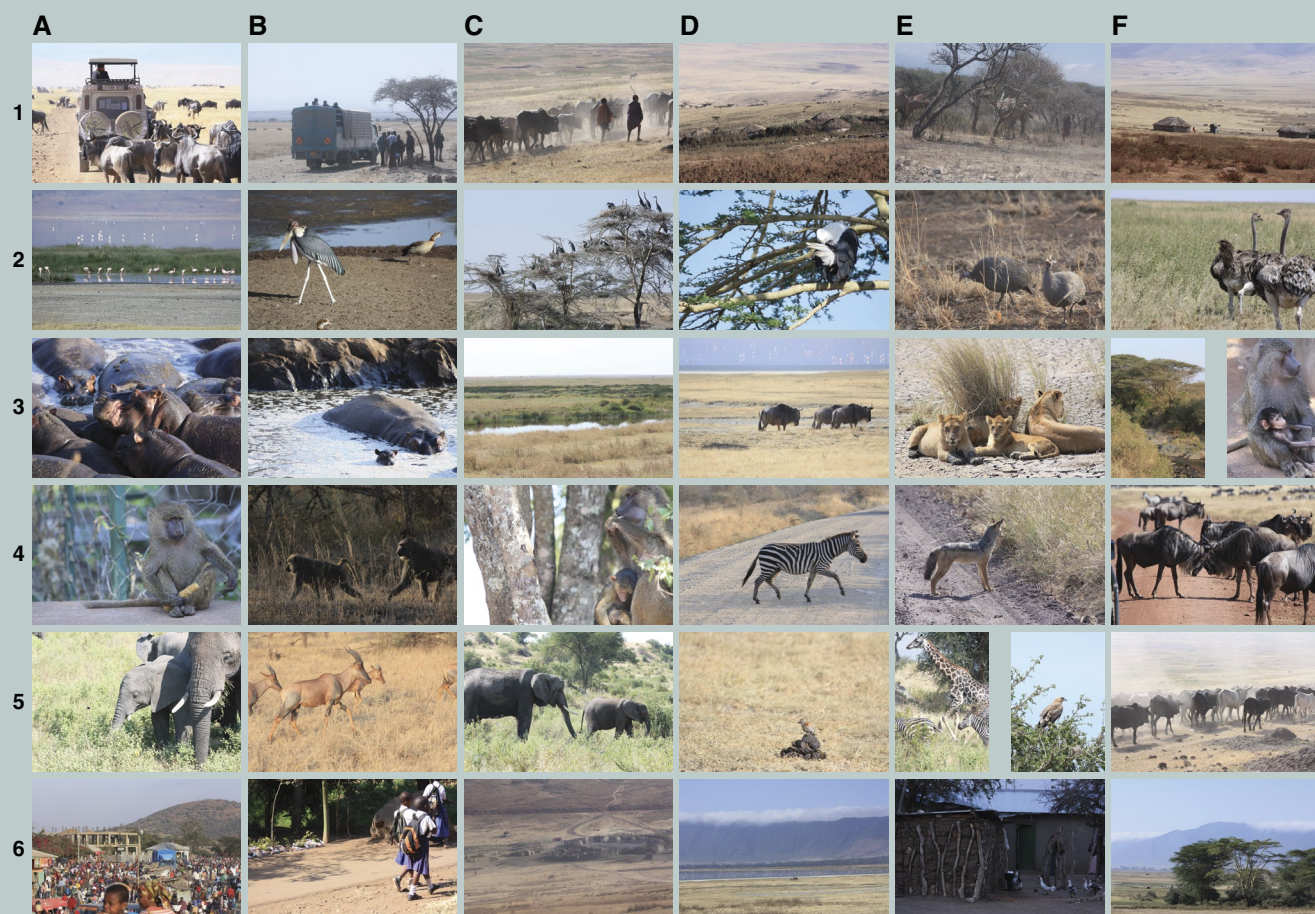
Research development with implementation of early warning system is the holy grail of One Health's concept to stabilize global health security through preventing pathogen spillover from animal populations to human hosts. Applications of the One Health approach include the use of sentinel animal species, which have long

Figure 3. In highly visited and curated animal parks such as Foz do Iguaçu in South America, contact between humans and wildlife occurs constantly, and there is a frequent need for environmental surveillance and waste management.



Photographs from the author, Oladele A. Ogunseitan.

Figure 4. In tourist havens that also serve as habitats for local communities and a wide range of biological diversity, as in the depicted case of Tanzania's Ngorongoro Park, the potential for pathogen spillover events is high, justifying the implementation of strong environmental surveillance programs to inform coordinated early warning systems.



Photographs from the author, Oladele A. Ogunseitan.

understanding of how environmental systems mediate the outcome of population health problems analyzed within the One Health framework, and the role of variable environmental parameters in implementing evidence-based solutions.²⁴

A way to bridge the research gap is to provide financial incentives in terms of research grants and scholarship to scientists and students collaborating on One Health projects. Currently, One Health-oriented research is fragmented across funding agencies, at least in the United States. The standard model used by the National Institutes of Health to fund individual investigator-initiated scientific projects may not be ideal. Instead, the interdisciplinary funding models that also emphasize institutional capacity development, such as the National Center for Advancing Translation Science, are more appropriate. The infusion of research funding to address the COVID-19 pandemic will likely dissipate when the pandemic is eventually conquered. Then will be the time not simply to reallocate the funds to other sectors, but to institutionalize a prospective National Center for One Health Implementation Science.

Bridging Educational Gaps in One Health Environment

The initial step to improve the situation of environmental domain in the One Health framework is defining what a One Health professional ought to know about environmental systems. There may be no need to shift the focus of One Health from zoonotic diseases, if it is accepted that the trajectories of such diseases are influenced by issues such as climate change and exposures to toxic chemicals that compromise immune response. Integrating such understanding into educational programs focused on One Health will require major investments from multilateral agencies working to move toward implementation of sustainable solutions.

In most parts of the world, there are three categories of opportunities for training the personnel to protect populations from infectious disease threats of zoonotic origins. The first category is the academic institutions, universities, and colleges, where we educate the researchers, teachers,

and professionals, particularly in the degree programs in health sciences, human medicine and nursing, veterinary medicine, public health, environmental science, and pharmacy, among others. In most cases, the training delivered in university classrooms is incomplete, and we require the second category or opportunity, which is within the workforce. Hence, we have internships and residency training for most of the workforce, and we have continuing professional development. The third category, which is underappreciated with minimal investment, is the opportunity existing in local communities that are intimately connected to local environments. This is of course the oldest form of education about zoonoses, in which how to navigate the intersection of animals, human livelihood, and environmental conditions has been passed down from generation to generation over long periods of time. The local professions in this category are the farmers, hunters, food preparers, and market vendors. This is about the local guardians of water and solid waste management, and how communities maintain the quality of the local environment.

About two decades ago, it became increasingly clear that there are major gaps in these three categories of opportunities for training. The effect of these gaps is recognizable in the major zoonotic outbreaks that occurred over this period, including swine flu, bird flu, Ebola, MERS, SARS, and quite likely COVID-19. At the universities, there are gaps in training of health professionals—veterinarians, public health practitioners, doctors, nurses, agriculturists. We have rudimentary interprofessional education sprinkled through heavily packed and impacted curricula. There are gaps between what we teach in universities and the functions of employed front-line workers and programmatic leaders, whereby graduates are not quite ready to hit the ground running when they are employed to prevent zoonotic pathogen spillovers and outbreaks.

Historically, educational gaps have been bridged by mergers of disciplines into independent departments. Examples include molecular biology and biophysics. Degree programs in One Health are beginning to appear in the curricula of major universities, but there is no organization

that provides quality assurance, and core competencies are still being debated. An international consensus on these competencies and how to implement their delivery and assessment through credentialing and continuing professional development is necessary, and the institutionalization and quality assurance of such a credential should be prioritized by the professional training schools entrusted with delivering potential employees capable of working collaboratively to secure global health.

Bridging Translational Gaps in One Health Environment

Finally, there are gaps in translating what we know how to do in the ministries of health, ministries of wildlife and environment, food or drug administration, and community engagement and local knowledge. The One Health framework acknowledged these gaps and is trying to fill them with competency-based interdisciplinary training at the university level for the future workforce and continuing professional development within the current workforce. Field experiences, including field or environmental epidemiology training that cuts across the health professions with strong community engagement, are part of the solution. The international agencies at the helm of One Health (WHO, OIE, FAO, UNEP) should continue to collaborate with increased emphasis on implementation of cross-cutting solutions. The term “tripartite” should be jettisoned not only to signal the inclusion of UNEP, but also to leave the door open for other partners. Similar collaboration needs to be nurtured at the country level across ministries or departments of health, environment, agriculture, and (for the United States), Food and Drug Administration. Selecting cross-cutting problems such as antibiotic resistance is a way to stimulate these collaborations beyond the rhetoric toward effective action.

Bridging the gaps between scientific knowledge and action informed by One Health to implement preventive strategies including policies and program development requires integration of various interdisciplinary and interprofessional frameworks that currently compete for attention in scholarly




A Southern California brush fire approaches houses in a nearby community. Recent wildfires driven by climate change in the western regions of the United States have prompted emergency interventions, but the impacts on wildlife animals have not been clearly linked in responses.

journals, in funding agencies, and in the agenda of international negotiation forums. For example, the absence of One Health context in the United Nations Sustainable Development Goals (SDGs) compromises the likelihood of meeting targets for health encoded in SDG-3, “Ensure healthy lives and promote well-being for all at all ages,” in part because challenges such as nutrition are inextricably linked to ecosystem health, animal health, wildlife diversity, and population distribution.²⁵ In this context, One Health science and sustainability science share an agenda that needs better articulation to highlight synergistic opportunities, including the need to address the inequalities in access to health care and social support systems that exacerbate impacts of risk factors such as disease outbreaks and climate change. The patterns of health inequality revealed by the trajectory of COVID-19 pandemic, in countries rich and poor, and the difficulty of negotiating a transformative policy solution to climate change mitigation that became apparent during the 26th Conference of Parties to the United Nations Climate Program have shown a

clear need for convergence of scientific frameworks and advocacy coalition.²⁶

If we achieve improvements within these three categories and successfully bridge pathways across the gaps, the world will have a successful early warning system of monitoring and surveillance to prevent pathogen spillovers (and where we cannot do so), to prevent zoonotic outbreaks from becoming pandemics.

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NOTES

1. Symbolic and literal expressions about health, illness, and wellness are abundant in historical records. Examples include R. A. Wilcox and E. M. Whitham, “The Symbol of Modern Medicine: Why One Snake Is More Than Two,” *Annals of Internal Medicine* 138 (2003): 673–77; I. Badash et al., “Redefining Health: The Evolution of Health Ideas from Antiquity to the Era of Value-Based Care,” *Cureus* 9, no. 2 (2017): e1018; J. Schouten, “The Rod and Serpent of Asklepios, Symbol of Medicine, Reviewed,” *Annals of Internal Medicine*, 67, no. 3 (1967): 681–82.
2. There is a broad range of opinions and perspectives in published literature about the scope of One Health, with its strengths, weaknesses, opportunities, and challenges. A sample of the literature is presented here: R. Coker et al., “Towards a Conceptual Framework to Support One-Health Research for Policy on Emerging Zoonoses,” *Lancet Infectious Diseases* 11, no. 4 (2011): 326–31; J. Lebov et al., “A Framework for One Health Research,” *One Health* 3 (2017): 44–50; T. Xie, W. Liu, B. D. Anderson, X. Liu, and G. C. Gray, “A System Dynamics Approach to Understanding the One Health Concept,” *PLoS ONE*

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3. For example, see S. Y. Essack, "Environment: The Neglected Component of the One Health Triad," *Lancet Planetary Health* 2, no. 6 (2018): e238–39.
4. United Nations Environment Program, "One Health," <https://www.unep.org/news-and-stories/story/unep-joins-three-international-organizations-expert-panel-improve-one-health> and <https://multilateralism.org/wp-content/uploads/2020/11/2020-11-11-Press-release-meeting-AfM-12-November-2020-final-version-EN.pdf> (accessed 5 September 2021).
5. World Health Organization, "WHO-China Commission on COVID-19," <https://www.who.int/publications/i/item/who-convended-global-study-of-origins-of-sars-cov-2-china-part> and <https://www.who.int/docs/default-source/coronavirus/who-china-joint-mission-on-COVID-19-final-report.pdf> (accessed 5 September 2021).
6. S. Riedel, "Edward Jenner and the History of Smallpox and Vaccination," *Proceedings (Baylor University Medical Center)* 18, no. 1 (2005): 21–25.
7. M. Schultz, "Rudolf Virchow," *Emerging Infectious Diseases* 14, no. 9 (2008): 1480–81.
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