One Health 1

Advancing One human–animal–environment Health for global health security: what does the evidence say?

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In this Series paper, we review the contributions of One Health approaches (ie, at the human–animal–environment interface) to improve global health security across a range of health hazards and we summarise contemporary evidence of incremental benefits of a One Health approach. We assessed how One Health approaches were reported to the Food and Agricultural Organization of the UN, the World Organisation for Animal Health (WOAH, formerly OIE), and WHO, within the monitoring and assessment frameworks, including WHO International Health Regulations (2005) and WOAH Performance of Veterinary Services. We reviewed One Health theoretical foundations, methods, and case studies. Examples from joint health services and infrastructure, surveillance–response systems, surveillance of antimicrobial resistance, food safety and security, environmental hazards, water and sanitation, and zoonoses control clearly show incremental benefits of One Health approaches. One Health approaches appear to be most effective and sustainable in the prevention, preparedness, and early detection and investigation of evolving risks and hazards; the evidence base for their application is strongest in the control of endemic and neglected tropical diseases. For benefits to be maximised and extended, improved One Health operationalisation is needed by strengthening multisectoral coordination mechanisms at national, regional, and global levels.

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Introduction

Human development, the substantial expansion of domestic animal populations (eg, cattle, pigs, poultry, sheep, and goats), and transformed landscapes engineered for human populations are having profound effects on the evolution and epidemiology of infectious and non-communicable diseases of all species. Intimate and rapid global interconnections mean uncontrolled infectious diseases in one part of the world can quickly threaten health across species anywhere. Although technological advances are making public health services better equipped for detecting, preventing, and controlling new infectious diseases and other health hazards, major gaps exist in the conversion of these advances into effective actions and policies at the animal–human–environment interface.[1] National institutions addressing these challenges worldwide are most often not able to adequately address the large array of interconnected risks. Several human–animal–environment health approaches have been applied to improve global health security across a range of health hazards. The ongoing COVID-19 pandemic vividly shows that the emergence of a lethal pathogen of probable animal origin locally affects public health and almost every sector worldwide.

In 2001, the World Health Assembly decided that WHO will work with its member states towards preparedness and response to pandemics. The Food and Agriculture Organization of the UN (FAO), WHO, and the World Organisation for Animal Health (WOAH) support countries to implement international standards and frameworks, such as the International Health Regulations (IHR, 2005), the Terrestrial and Aquatic Codes and Manuals,[2] and the Codex Alimentarius (ie, international food safety standards).[3] The revised IHR came into force in June, 2007, and required all countries to develop core capacities for preventing, detecting, and responding to public health emergencies including those resulting from infectious agents that can adversely affect public health, travel, and trade worldwide. The IHR promoted building robust public health and animal health systems on the basis of good governance and implementation of internationally accepted standards.

In 2010, WHO, WOAH, and FAO launched a strategy for partnership (known as Tripartite Concept Note),[4] recognising a shared responsibility in addressing health risks at the human–animal (wildlife and domestic)–environment interface, with avian influenza, rabies, and antimicrobial resistance as priorities. A worsening global climate crisis and the COVID-19 pandemic have spurred the formal inclusion of the UN Environment Programme (UNEP) into the Tripartite in March, 2022. This newly formed Quadripartite grouping of international agencies is supported scientifically by an independent One Health High-Level Expert Panel (OHHLEP)[5] and other topic-specific scientific communities of practice, and is working on launching and implementing a global One Health Joint Plan of Action (2022–26). The shared views of these international organisations has contributed strongly to the mainstreaming of integrative approaches like One Health (panel 1) that contribute towards global health security, taking advantage of the legal mandate of the IHR as a driving force.[23,24] To support countries in implementing the regulations, while assessing their

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Key messages

- One Health means interdisciplinary (among academic disciplines) and transdisciplinary (between academia and society) collaboration on health at the human–animal–environment interface leading to benefits that could not be achieved if the different sectors worked alone. Clear evidence exists of the benefits in terms of the number of human and animal lives saved and financial savings resulting from a close cooperation among different sectors across a range of hazards and operational functions. Our analysis indicates greater investment should be directed towards prevention and preparedness interventions across the social–ecological systems, in which the evidence base is most firmly established. This approach would lead to a shift of the disease control paradigm upstream, away from an overwhelming focus on surveillance and response in humans—which nowadays still predominates—to greater, more proactive investment in preventive interventions, and in integrating surveillance–response in environmental, animal, and human systems.
- One Health has a high potential to sustainably improve global health security for all by prioritising national and local capacity-building across relevant sectors and disciplines. In resource-constrained settings, this horizontal approach should first focus on endemic One Health issues across the ecosystem, including those with implications for food security, local community health needs, and hazards for which the evidence base is most strongly established, before considering emergent risks of more global concern that occur periodically.
- There are still daunting knowledge and implementation gaps that impede the full operationalisation of One Health for optimal global health security. As more evidence of its effectiveness becomes available, current and future One Health approaches should more fully integrate environmental, wildlife, and agriculture and farming issues across the social–ecological system to better address contemporary challenges like pandemic threats.
- Many national governments have started operationalising One Health in their governance and programmes, as reflected by an increasing degree of compliance with the International Health Regulations (IHR, 2005). This attention has received further impetus during the COVID-19 pandemic. The IHR have been a catalyst to embed cross-sectoral, whole-system approaches to public health emergencies but an evidence-led acceleration of implementation and expansion across a wider spectrum of hazards to the social–ecological system is needed.
- WHO, the World Organisation for Animal Health, the Food and Agricultural Organization of the UN, and the UN Environment Programme (ie, the Quadripartite) lead the One Health technical cooperation at the global level. In 2021, a global One Health High-Level Expert Panel came into operation to support the Quadripartite, help develop the One Health Joint Plan of Action (2022–26), and help advance One Health operationalisation.
- Further primary research and systematic reviews are needed to assess the effectiveness of One Health approaches for specific drivers of disease and hazard or risk categories across the social–ecological system. These studies should include analyses of trade-offs and cobenefits, cost-effectiveness, and comparisons of unisectoral versus multisectoral approaches, and include relevant outcome measures relating to animal and environmental health, in addition to those on human health security.

capacities to address public health risks, WHO developed the IHR Monitoring and Evaluation Framework (IHR MEF),[25] which includes the IHR State Party Self-Assessment Annual Reporting tool for the mandatory annual reporting of the level of compliance with the IHR, and the Joint External Evaluation, which is a voluntary, external peer-reviewed assessment. The WOAH developed the Performance of Veterinary Services (PVS), a monitoring and evaluation tool assessing the performance of a country's veterinary services. However, the IHR and PVS frameworks were not sufficiently operational to support national responses in an internationally coordinated way or adequate for use during the COVID-19 pandemic. The COVID-19 pandemic has shown the weaknesses of global health security; has already resulted in multiple reviews of how institutions, tools, and global approaches assess capacities and build capabilities to address threats at the human–animal–environment interface; and has challenged the assumptions around the operational value of integrated approaches like One Health.[26–28]

See Online for appendix 1

See Online for appendices 1 and 2

In this Series paper, we review the contributions of One Health approaches (ie, at the human–animal–environment interface) to improving global health security across a range of health hazards by use of methods detailed in appendix 1 (p 2). We summarise contemporary evidence assessing the incremental benefits of a One Health approach and how this evidence is reflected in reporting to FAO, WOAH, and WHO (appendices 2 and 3). We identify gaps of operationalisation that remain at the One Health interface to rapidly detect and respond to the risk of new and re-emerging infections and other health hazards. Through examples from the field, we build the case for One Health operationalisation and strengthened multisectoral coordination mechanisms (appendix 1 pp 10–17). As the IHR adopts an all-hazards approach to global health security, our Series paper has adapted the classification of hazards outlined in the WHO Health Emergency and Disaster Risk Management Framework[29] to review the literature and to assess which categories of priority threats to global health security[30] would benefit from a One Health approach.

Panel 1: One Health background and contemporary theory

In the 1960s, the veterinary epidemiologist Calvin Schwabe coined the term One Medicine to focus attention on the commonality of human and animal health interests.[6] Historically, such unifying views are much older, dating back to the late 19th century in academic circles and thousands of years in indigenous societies and early human civilisations.[7,8] In the past few decades, growing interest in sustainable development has pointed towards the inextricable linkage of human, animal, and ecosystem dimensions of health.[9–11] In 2004, the Wildlife Conservation Society coined the phrase One World, One Health to underscore the importance of securing human and animal health, ecosystem integrity, and the protection of conservation areas under the manifesto of the Manhattan Principles,[12] which were updated with the Berlin Principles on One Health in 2019. The Berlin Principles aim to restore ecosystem health and integrity while also addressing current pressing issues (eg, climate change and antimicrobial resistance) and emphasising their links to sustainable development.[13]

One Health appeared for the first time in peer-reviewed medical literature in 2005, to emphasise its potential to strengthen health systems[14,15] by showing value added from a closer cooperation between human and animal health that could not be achieved by the disciplinary approaches alone.[16] With regard to avian influenza, Zinsstag and colleagues[14] stated that, to avert or limit interactions among wildlife, wildlife farming, and livestock, which might be reservoirs for future human influenza pandemics, research for vaccines "should urgently be complemented by modifications to smallholder livestock systems and live-animal markets". They continued to say "However, these implementations should be handled carefully to avoid impending poverty for the hundreds of millions who produce livestock on a small scale."[14] These warnings could be considered a forecast in the face of the current COVID-19 pandemic, but remained largely unheard, with largely insufficient global investment in prevention and preparedness during the past 17 years. The suggestions by Zinsstag and colleagues might still be a narrow view on how these emergent pathogens are established. Certainly it is not just the transmission and interface that matter but also the social–ecological drivers, and the political and economic context in which these occurrences happen, enabling expansion and establishment of pathogens across species and societies, much of which happen in the domestic and peridomestic landscape.[17,18]

Therefore, under the most favourable conditions, One Health as a problem-solving approach engages both academic and non-academic actors in the coproduction of transformational knowledge for societal problem solving.[19,20] Cooperating partners and stakeholders seek a benefit from working together. A necessary but not sufficient requirement for One Health is to fully understand systemically how humans, animals (wildlife and domestic), and their environment are inter-related over various time and space scales. Although several definitions of One Health have been proposed,[21,22] a requirement that we consider sufficient for achieving One Health is the achievement of benefits as a result of the crosstalk and closer multisectoral cooperation on health at the human–animal (domestic and wildlife)–environment interface. The benefits associated with cooperation among individuals, communities, and institutions can be expressed as any added value to the benefits obtained when relevant disciplines work separately, in terms of health of humans, wildlife, domestic animals, and their ecosystems; financial savings; social resilience; and environmental sustainability.[16] The One Health definition developed by the One Health High-Level Expert Panel is a culmination of these past efforts around meaning and scope. The new definition and its underlying principles (equity, sociopolitical parity, social–ecological equilibrium, stewardship, and transdisciplinarity) was endorsed by all members of the Quadripartite and represents the global consensus for the framing, planning, and programme delivery of future One Health initiatives. Key to the effective implementation will be the quantifiable demonstration of the added value of cooperative One Health approaches both in terms of their cobenefits across sectors and through the identification and mitigation of potential risks and trade-offs.

After examining the evidence base of One Health in this Series paper, subsequent papers in this 4-part Series explore other dimensions that are crucial to foster a One Health approach to global health security. In the second paper in this Series, Mwatondo and colleagues[31] show a method for mapping global One Health Networks, explore their proliferation, and highlight key characteristics of successful cross-sectoral collaboration. In the third paper in this Series, Traore and colleagues[32] analyse current monitoring and evaluation tools for assessing health emergency preparedness capacities at the national level, and make recommendations for strengthening these capacities in line with a holistic One Health approach. In the fourth paper in this Series, Elnaiem and colleagues[33] discuss the key challenges in the global and regional governance of One Health, assessing their implications for global health security and offering recommendations for addressing them.

Conceptual relationships of integrative approaches across the social–ecological system: One Health, EcoHealth, and Planetary Health

In response to the increasing recognition of threats across species related to both climate change and changing patterns of disease, several multisectoral and transdisciplinary approaches have emerged in the past few decades. As such, an urgent need remains for a

proper framing of integrative concepts like One Health, EcoHealth, and Planetary Health to promote a better understanding across sectors[34] including, importantly, wildlife health, which often necessitates being distinguished from animal health because the focus of animal health is almost entirely on domestic animals, legally, commercially, and practically (ie, in the management of companion animals, livestock, and aquaculture *vs* ecosystems and natural habitats).[22] Additionally, large sections of separated human and animal health do not require a One Health approach. For example, surgery or specific non-communicable conditions are domains for which no incremental benefit, assessment of trade-offs, or risk mitigation can be expected from a closer cooperation between human and animal health, and between environment specialists and other disciplines. One Health evolved from narrower origins focusing on the cooperation between human and veterinary medicine, for example in zoonoses control towards a conceptual association with related ecosystem approaches to health. Expanded concepts like EcoHealth and Planetary Health as applied across the social–ecological system are detailed in figure 1. One Health remains at the centre of interest, building intersectoral cooperation in areas where its effectiveness is most firmly established and gradually expanding its application to more complex issues and health security hazards across the whole of the social–ecological system, as research, piloting, and practice help further develop the evidence base.[38,39]

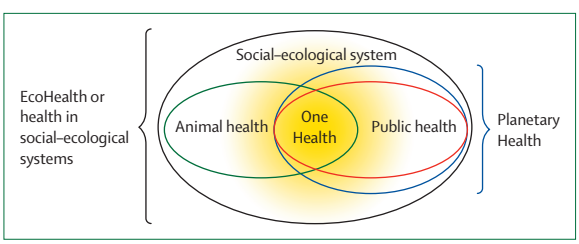

Figure 1: **Boolean conceptual relationships of One Health, EcoHealth, health in social–ecological systems, and Planetary Health on a Venn diagram**
One Health has for the last two decades been largely rooted at the intersection of human (red ellipse) and animal (primarily domestic) health (green ellipse), aiming to show the benefits arising from a closer cooperation of human and veterinary medicine. Nowadays, One Health incorporates broader approaches that consider the interactions between human and animal health and the environment, including plant health, within social–ecological systems[35] (black ellipse). One Health is thus embedded within ecosystem approaches to health, for which a new term, health in social–ecological systems, was coined in 2011.[36] Although the term EcoHealth emphasises the ecological approaches to health, health in social–ecological systems explicitly relates to modern systems theory and new institutional economics.[35] Planetary Health (blue ellipse) sets the ambitious task of understanding the dynamic and systemic relationships between global environmental changes and health, including climate change, transboundary fire emissions, and persistent organic pollutants,[37] but does not explicitly include animal health. One Health includes social and environmental factors, which extend across the social–ecological systems, beyond public and (domestic) animal health, and expands as the evidence base for the effectiveness of the approach grows, as depicted by the enlarging fading yellow circle.

Evidence of the benefits of One Health

Although there is consensus that the One Health approach is crucial for tackling challenging global health security threats, evidence of its incremental benefits is sparse. Applied methods for showing the incremental benefits of the approach and examples of effectiveness are outlined in panels 2 and 3.[16] One Health is characterised by the logical view that by coordinating the people and systems working to improve the health of humans, animals, and the environment, any potential health threat can be identified as early as possible. This coordination results in reduction or even prevention of harm to health and fewer resources required to deal with the long-term repercussions. Evidence exists of the benefits of One Health across a range of health hazards[29] in the delivery of health services; the control of newly emerging and endemic zoonoses in the domestic animal environment; food safety, food security, and nutrition security; integrated disease and antimicrobial resistance surveillance–response systems; water security and sanitation; infrastructure sharing; and communication.[54] For example, joint human and animal routine vaccination services for mobile pastoralists in Chad provide access to health care for populations that would otherwise be excluded and save financial resources by sharing cold chain and transport.[55] Mass vaccination of livestock against brucellosis in Mongolia is not cost-effective for public health alone, but, financially, it is three times more profitable when benefits for livestock production and nutrition security are also included in benefit–cost ratios (panel 2).[47] Combining dog-vaccination campaigns with human postexposure prophylaxis in N'djamena, Chad has been shown to become less costly than human postexposure prophylaxis alone after 10 years[48,49] and might ultimately lead to rabies elimination (panel 2).

The Institute of Medicine in 2009,[56] and later the World Bank in 2012, conceptualised integrated surveillance–response systems in a visionary way, as a time sequence of detection of emerging pathogens in the environment, wildlife, domestic animals, and humans (figure 2A).[58] The model shows ever increasing cumulative societal costs the later a new emerging pathogen of zoonotic origin is detected.[54,57] The ongoing COVID-19 pandemic is an exemplar of the urgent need for this kind of integrated surveillance–response systems, encompassing the environment, entomology, wildlife, domestic animals, and humans, and the catastrophic socio-economic consequences of not implementing such systems. Several examples exist of the potential benefit of more targeted surveillance of vector-borne zoonoses. A regional integrated surveillance–response system of the West Nile virus in mosquitoes, wild birds, horses, and humans in Italy saved more than €1 million between 2009 and 2015, compared with separate human and animal surveillance activities.[59] Wielinga and Schlundt[60] similarly argue that intersectoral surveillance has had a substantial effect on reducing human

Panel 2: Quantitative One Health methods

An understanding of the human–animal health interface is required to show incremental benefits of One Health. We describe both linear and dynamic quantitative approaches that have been used to develop the evidence base and show these incremental benefits in terms of One Health (panel 1).

The association of human health (H) and animal health (A) can be presented as a linear regression $H_i = \alpha + \beta_k A_{jk} + e_{jk}$, where H_i is, for example, the brucellosis seroprevalence status of the ith human community, related to the brucellosis seroprevalence status A_{jk} of the jth animal of the kth species in close spatial-temporal relationship, such as a household or a village. The term α is the intercept and e_{jk} the residual in the notation of linear regression. In this way, we could show that human brucellosis seroprevalence in villages in Kyrgyzstan most strongly depended on the brucellosis seroprevalence of sheep and not of goats or cattle, with behavioural risk factors (eg, being in direct contact with livestock during abortions and consuming raw milk and dairy products) captured in the residual.[40] The relative importance of sheep for the transmission of brucellosis was established by molecular typing of brucellosis strains.[41] The method is interchangeable in that animal health can also be the dependent variable on a human health indicator.

For dynamic relationships like the transmission of directly transmitted zoonotic diseases (stage 2,[42] that is pathogen transmission from animals to humans but not human-to-human transmission), the animal–human interface can be expressed as coupled differential equations in a simplified way, ignoring demographic processes:

$$\frac{dI_h}{dt} = \beta I_a S_h$$

where the instantaneous change of newly infected humans I_h is equal to an animal–human transmission constant β times the number of infectious animals I_a and the number of susceptible humans S_h. Such models allow assessing, for example, the effect of animal mass vaccination on the number of human exposures to brucellosis[43] or rabies.[44] Such models can be expanded to meta-population or contact network models.[45,46] Similar to deterministic differential equation models, these models can also describe the dynamics of human to animal transmission in an interchangeable way.

Cross-sector economic analyses show that benefit–cost ratios (ie, health benefits over intervention costs in livestock) including benefits to both human and animal health are greater than benefit–cost ratios including only benefits to human health.[47] Similarly, the cost-effectiveness (expressed as cost per disability-adjusted life-years averted) of interventions in both animals and humans is higher (ie, it requires less cost per disability-adjusted life-years averted) than the cost-effectiveness of interventions in humans only, if transmission between animals, and consequently transmission from animals to humans, can be interrupted.[47] In the case of directly transmitted stage 2 zoonoses, it can be shown that the societal cumulative cost of interventions in both animals and humans are lower than the cumulative cost of interventions in humans only. This difference in costs is because, in the case of directly transmitted zoonoses, interventions in animals interrupt transmission between animals and consequently from animals to humans, whereas interventions in humans alone do not interrupt transmission from the animal reservoir. The benefits of joint interventions have been shown in N'Djamena, Chad, in relation to rabies control via dog mass vaccination.[48,49] Such analyses should be context specific to assure local validity. If cross-species transmission is rare, human health benefits might be too low to justify intervention costs in animals.[50]

The systemic understanding of human and animal health would benefit from expansions to include parameters of the ecosystems (EcoHealth; figure 1).[9,10] Dynamic changes of human health, animal health, and environmental determinants can again be expressed as coupled differential equations:

$$\frac{dI_h}{dt} = \beta I_a S_h + \gamma E S_h + \varepsilon E S_a$$

where newly infected humans I_h depend directly on the transmission from infected animals I_a (conditional on animal–human transmission constant β and the number of susceptible humans S_h) and exposure to the environment E (conditional on environment–human transmission constant γ and S_h), and indirectly from E and the number of susceptible animals S_a (conditional on environment–animal transmission constant ε). This expanded equation is applicable for example to the transmission dynamics of human exposure to anthrax (*Bacillus anthracis*) from contact with animals, meat consumption, and other environmental sources. Inclusion of ecological determinants in the equation makes the dynamic model more complex and results in increased data variability. In a study on vitamin A deficiency in pastoralists in Chad, a link was observed between human retinol concentrations in serum and consumed milk, but not between retinol concentrations in cow milk and β-carotene concentrations in the pasture grass.[51]

The variability of β-carotene in the grass was too high to find a significant correlation with retinol concentrations in cow milk. This example shows that ecological studies of human and animal health including environmental parameters have the potential for a broader understanding; however, finding relevant environmental determinants is difficult because of the high variability of environmental factors.

The clinical evidence currently available is therefore strongest for stage 2 zoonoses, that is directly transmitted diseases from animals to humans with negligible transmission between

(Continues on next page)

(Panel 2 continued from previous page)

humans, such as rabies or brucellosis. After exposure to an animal with suspected rabies infection has occurred, human lives can be saved by timely application of postexposure prophylaxis. The use of postexposure prophylaxis will, however, not interrupt transmission in the animal reservoir and human exposure to infected animals could continue indefinitely. Human exposure to rabies or brucellosis can only be fully avoided by their elimination in the animal reservoir through mass vaccination or test and slaughter interventions. Ultimately interventions eliminating stage 2 zoonoses in animals are less costly to society than interventions solely directed at humans.[47,48]

salmonella infections by lowering the prevalence of *Salmonella* spp in animals, giving as an example a previous study that described how disease control was achieved in Denmark through integration of control measures in farms and food-processing plants, saving US$25·5 million.[61]

The Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS) is a systems approach that has saved financial and infrastructural resources and reduced the time needed for the detection of newly emerging antimicrobial resistance.[36,62] In 2013, CIPARS showed the effect of regulating antimicrobial use on the number of resistant *Salmonella* isolates identified in humans and chickens.[63] A decrease in the number of *Salmonella enterica* serovar Heidelberg isolates coincided with the introduction of a voluntary ban on the use of ceftiofur in Quebec, Canada, with a subsequent increase after a partial return to ceftiofur use.[63] Without such integrated surveillance systems, establishing the effect and cost-effectiveness of interventions designed to reduce antimicrobial resistance in human and livestock populations would not have been possible.

The World Bank has estimated that the Canadian Science Centre for Human and Animal Health, an institute jointly hosting research laboratories for both human and animal highly contagious diseases, saved 26% in operational costs compared with different facilities hosting separate laboratories for human and animal disease research.[64] The outbreak of Q fever in the Netherlands (2007–09) with several thousand human cases could probably have been largely avoided if veterinary and public health authorities had maintained continuous communication (figure 2A),[65] or if joint human and animal studies had been performed, similar to studies done on brucellosis in Kyrgyzstan (panel 2).[40] These examples show that where capacity exists in both animal (domestic) and human health systems to address these issues, progress is made. However, the under-resourced wildlife–environment interface remains a major challenge in applied One Health approaches. A report of the International Union for Conservation of Nature[66] highlights the enormous data gaps on wildlife zoonosis and the emergence of human pathogens from wildlife sources. Detailed examination of more than 5000 publications in the past three decades by use of strict diagnostic criteria only showed evidence of one to two zoonosis cases per year globally attributed to wildlife trade and zoonosis.[66] No effective mechanism currently exists for early detection of emergent pathogen spillover from wildlife, as the COVID-19 pandemic has shown.

Because food safety and nutrition security encompass human, animal, and environmental concerns, One Health is considered key to multisector coordinated progress.[67] Little research in this area reinforces the importance of coordinated responses but only occasionally supports the benefit of One Health with consistent evidence of effectiveness, whether in terms of directly attributable improvement to health outcomes or financial savings. Meanwhile, the burden of foodborne disease is well established: according to the WHO Foodborne Disease Burden Epidemiology Reference Group (FERG), 31 foodborne hazards were estimated to have caused more than 600 million foodborne illnesses and 420 000 deaths globally in 2010.[68,69] The World Bank has described an example of applying One Health to foodborne disease in the EU coordinated control programmes for salmonellosis.[70] These programmes led to a reduction in the number of salmonellosis cases in humans from more than 200 000 each year before 2004 in 15 member states to less than 90 000 cases in 2014 in 28 member states. EU's integrated approach to food safety is characterised by the involvement of member states and four major institutions (the European Commission, the European Parliament, the European Food Safety Authority, and the European Centre for Disease Prevention and Control), and the methods highlighted as key to the success of such approach range from target reductions of *Salmonella* spp in livestock to the imposition of trade restrictions.[70]

The direct effect of funding provided to integrated systems was assessed by the World Bank using data from FERG.[70] The report compared the adequacy of operational funding for veterinary services in several sub-Saharan African countries, on the basis of WOAH PVS Pathway reports, and found that the burden of foodborne disease caused by animal-source foods was lower in countries with adequate funding than in countries with inadequate resources (208 *vs* 569 disability-adjusted life-years per 100 000 population).[70]

In the same report, the World Bank identified only seven countries from low-income or lower-middle-income countries with adequate operational funding for their veterinary services (on the basis of PVS reports). The burden of foodborne disease in these countries was

192 disability-adjusted life-years per 100 000 people versus 407 per 100 000 people in 48 other low-income and lower-middle-income countries using inadequate funding.[70] By use of 2016 income data, these findings were translated into worldwide annual productivity losses of approximately US$95 billion due to illness, disability, and premature deaths related to unsafe food.[70] Despite these published examples emphasising improvements to food safety and security as a result of an applied One Health approach, the evidence, or its absence, does not allow to directly attribute improvements to any particular measure. This difficulty is unsurprising given the multisectoral, systems-based nature of One Health, which cannot be studied in isolation and therefore cannot easily adjust for the effect of confounding factors.

These examples across the spectrum of disease control from prevention to preparedness, detection, and response clearly show the benefits of One Health approaches for a range of health hazards. To maximise and extend such benefits, we need more effective and sustained operationalisation of One Health. With UNEP now part of the Quadripartite, the opportunity to better understand the environment–wildlife interface should be fully explored. In 2012, WHO estimated that 23% (95% CI 13–34) of global human deaths are due to modifiable environmental factors, such as lack of clean drinking water and sanitation, air pollution, noise, and road safety.[71] Better integrating the environmental sector provides an opportunity to establish an exciting new array of potential partnerships and interventions to improve global health security.

For example, the piloting and scaling up of biological control programmes for emerging and endemic infectious diseases has the potential to strengthen global health security strategies.[72,73] Biological control, which is already widely used to support vector-borne disease control in malaria programmes, can be further expanded to help control endemic neglected diseases such as schistosomiasis, through the introduction of river prawn species that eat cercariae (ie, the hosts of schistosomiasis),[74] or dengue fever, by use of larvivorous fish species and predatory copepods that reduce and prevent dengue virus transmission, as previously shown in Viet Nam.[75] One Health approaches across the social–ecological system are necessary to test these types of interventions and help describe the complex interplay among hosts, pathogens, vectors, and natural predators as part of a disease ecological system. The occurrence of a disease is thus seen in a broader context including the effects on other species within the ecosystem. Environmental science can also help support the control of invasive plant species such as mesquite (*Prosopis juliflora*), which is implicated in sugar feeding, thereby maintaining mosquito populations during the dry season;[76] promotes transmission of malaria, Rift Valley fever virus, and dengue virus; occupies vast areas of grazing land and farmland by outcompeting

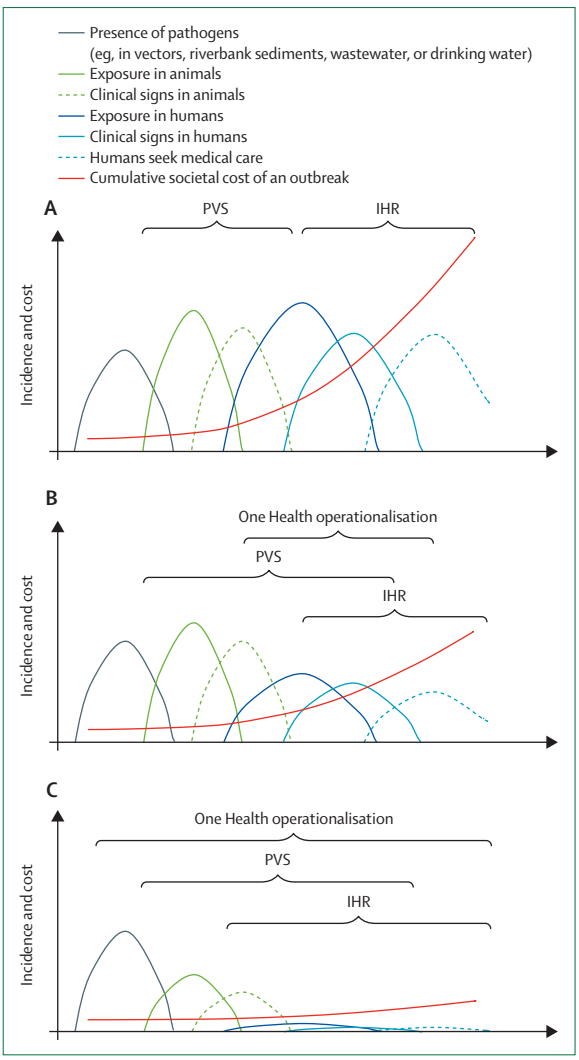

Figure 2: **Vision of One Health governance in global health security**
We used the World Bank framework[57] as a starting point. We modified it to include environmental risk[54] as a vision for One Health in global health security (A–C) and its longer-term effects (eg, disability-adjusted life-years) to society and households. The earlier a novel pathogen, food security risk, or other hazard to the social–ecological system (eg, impending drought) can be detected (reduced time to detection) and the faster information is communicated between animal and human health sectors, the earlier an effective response can be organised, thus preventing exposure and reducing risk of transmission, and the lesser are the cumulative societal, animal, and environmental costs of the outbreak or emergency (B–C). (A) Status quo with very poor collaboration between animal health and human public health; separated surveillance and response systems. (B) One Health governance supports closer collaboration between animal health and human public health; onset of integrated human–animal–environment surveillance and response systems. (C) Full One Health status with closest possible collaboration between animal health and human public health; fully integrated human–animal–environment surveillance and response systems. Framework (C) would be the final desirable expected stage of global health security through a One Health approach. Despite existing environmental threats and some animal exposure, fewer human cases would be observed in this setting and costs could be kept to a minimum.[21] IHR=International Health Regulations. PVS=Performance of Veterinary Services.

native vegetation preferred by livestock, thus leading to poisoning in cattle and goats; and depletes water sources.[77] Originally, mesquite was introduced in south Asia and parts of Africa in the early 20th century to support livestock agriculture by international development agencies, in particular as a forage for small ruminants. Mesquite introduction to new environments produced sectoral benefits, but without consideration of the wider ecological impacts, since the importance of trade-off analysis was not underscored, risk mitigation strategies were not integrated, and the need for wider environmental expertise when testing interventions was not taken into account.

With the COVID-19 pandemic highlighting the strong links among populations density, urban health, and pandemic spread, air quality management for the control of respiratory illnesses and comorbid conditions has become a priority for policy makers.[78] In this context, environmental science together with urban planners can play an important role in advancing a One Health approach, via the introduction of plant and tree species that specifically reduce air pollution.[79] Overall, strategies and plans can be aligned, for example, towards a global solidarity for the control of zoonoses and other diseases across the human–animal–environment interface (figure 2B), analogous to the Global Fund to Fight AIDS, tuberculosis, and malaria.[24] The Quadripartite One Health Joint Plan of Action (2022–26) is an important global initiative in this direction.

Relevance of One Health for IHR (2005) and WOAH PVS

Our analysis of WHO IHR MEF and WOAH PVS reports and associated methodological approach are presented in appendix 1 (pp 2–5). The results suggest an increased use of the term One Health in the global assessment tools and reporting in relation to IHR and PVS, which can be linked to an increased awareness of the relevance of One Health for global health security and an increased use of this terminology in the language of national leaders and politicians. Our analysis also showed that, despite the progress made in integrating One Health for global health security, the IHR MEF would benefit from a separate category in which the operationalisation of One Health is systematically assessed. Other findings include a degree of vagueness in defining One Health when carrying out IHR assessments, which allows for easier mobilisation of global and local stakeholders from different sectors, although it might render the assessment of its operationalisation more challenging. This degree of vagueness is particularly established in the definitions of animal health used by assessment teams, which, in practice, currently largely exclude non-domestic animals.

Furthermore, the current COVID-19 pandemic shows that a global, technical (WHO–FAO–WOAH–UNEP), and political coordination (UN) of pandemics is crucial, especially when taking into account the current global context with multiple actors and interests involved on different scales (panel 3).

After the recommendations in 2020 of the IHR Review Committee and the Independent Oversight and Advisory Committee for the WHO Health Emergencies Programme on the functioning of the IHR regulations, a questionnaire was sent to all WHO member states to capture the initial experiences and lessons learnt in dealing with the COVID-19 pandemic. In 2021, a technical working group composed of global experts from WHO, partner institutions, and member states was set up to review and update both the IHR State Party Self-Assessment Annual Reporting and the Joint External Evaluation tools.

In doing so, the IHR MEF tools are now better aligned to adequately assess country preparedness and response capacity to all public health hazards, via the adoption of a broader vision of One Health that accounts for a holistic framework of health in social–ecological systems, to achieve incremental benefit from closer cooperation among sectors,[36] and the newly Quadripartite-endorsed One Health definition developed by OHHLEP in 2022.[5] With the addition of UNEP to the Tripartite, capacities related to environmental determinants, biodiversity loss, and climate change that consider upstream drivers of infectious disease emergence, as well as other environmental hazards, will also have to be more fully accounted for by the aforementioned tools, and other related ones, to assess national capacity and building capability (as detailed in the third paper in this Series[32]).

Evidence of One Health for global health security

By considering the aforementioned examples of the benefits of One Health and the analysis on the relevance of One Health for IHR (2005), we can summarise how One Health approaches work to address the risks and hazards to global health security (table). First, for emerging infections and novel pathogens, One Health institutional (governance) arrangements and engagement exist; however, effective, integrated surveillance and response programmes that encompass wildlife, domestic animals, and humans are rare.[53,59] Wildlife is one potential source of disease emergence, but not always. Bernstein and colleagues[81] reported approximately 67 million human deaths from zoonotic viral emergence since 1918. Most of these deaths were ascribed to domestic animals, whereas only about 200 000 deaths were linked to direct wildlife zoonosis, largely from synanthropic rodents carrying mammarenaviruses. In the context of emerging pathogens and zoonosis, food systems based on domesticated animals and rapidly increasing numbers of farmed animal populations (eg, 1·5 billion heads of cattle and 24 billion chickens globally at any one time) are arguably a greater matter of concern; however, our poor knowledge about wildlife-related issues should be still addressed.

Improvement of the operationalisation of One Health is clearly needed, as shown by the COVID-19 pandemic.

Panel 3: COVID-19 and One Health operationalisation

The COVID-19 pandemic clearly shows that global health security cannot be disconnected from socioeconomic wellbeing, whether poor or rich. Consequently public health and economic imperatives have to be balanced against the detrimental socioeconomic impact of pandemic prevention measures at local, national, and global levels.[20,80] Vulnerabilities to infectious disease emergence and pandemics like COVID-19 exist at all scales, from local to global, with implications for all sectors of business and society. There appears to be a paradox between health-related and wellbeing-related development goals, and a consumption-driven economic model purporting to help achieve these development goals through ever increasing intensification and efficiency of production. Ultimately, more research is needed on how we can adapt an economy largely driven on consumption towards a more ecologically and socially sound economy, reducing the risk of new pandemics of zoonotic origin while maintaining essential livelihoods and improving equitable access to health-related knowledge, technologies, and counter-measures.[20]

Panel 4: Qualitative One Health methods

Other benefits from One Health cooperation can be difficult to quantify, such as improved insights into complex and context-specific systems, capacity development of institutions and practitioners, better designed regulatory and non-regulatory interventions generating confidence, and the resulting social cohesion. By expanding the integration of health towards broad social–ecological issues like antimicrobial resistance or deforestation, complex interactions can become intractable because of diverging interests and misaligned aims of different actors. Rüegg and colleagues[38] state that "There is a need to provide evidence on the added value of these integrated and transdisciplinary approaches to governments, researchers, funding bodies, and stakeholders." The Network for Evaluation of One Health proposes a qualitative and semi-quantitative evaluation and knowledge framework addressing aspects of One Health operations and infrastructure (ie, thinking, planning, working, sharing, learning, and systemic organisation) within a policy and intervention cycle.[38] This framework involves a number of components. A One Health index is proposed as a spider diagram, whose surface can be calculated and expressed as the so-called One Health-ness of a programme or health system. The Network for Evaluation of One Health has further developed a One Health knowledge integration approach to support international health governance.[52] The One Health index has been applied to the West Nile virus surveillance in Italy.[53] A One Health policy cycle analysis allows for the assessment of different stages of One Health policy development and governance by reviewing systemic thinking and transdisciplinary processes that develop target and transformation knowledge for policy development. This policy cycle is the basis for One Health agenda setting, policy formulation, and decision making, all of which lead to implementation and evaluation as an iterative process.[38,39,52] It is postulated that a truly One Health integrative approach, not yet achieved in any health sector, will reduce the risk of the global community being affected by further pandemics and health crises that impact the world's economies and cause hardship to rich and poor communities and considerable loss of life.

Most of the current research focuses on vaccines and drugs with profit-making potential to help reduce high morbidity and mortality rates, whereas very little focus is given to research on how to prevent future pandemics. A One Health approach proposing integrated disease prevention–surveillance–response systems that encompass wildlife, domestic animals, and humans combined with improved biosecurity and animal welfare has a realistic potential to contribute to the prevention of future pandemics.[58]

Second, for antimicrobial resistance, important institutional efforts and engagement exist and increasing numbers of nations are beginning to implement integrated antimicrobial resistance surveillance programmes analogous to CIPARS. Integrated antimicrobial resistance control programmes based on a One Health approach have certainly benefitted from greatly increased amounts of funding despite the evidence base for these approaches being relatively weak.[82] Third, for endemic infections and neglected tropical diseases, there is a strong evidence base for the operationalisation of One Health, including control programmes and proof of economic benefits. Institutions and engagement are well established, but still require a stronger political will and investment in, for example, rabies[83] or brucellosis elimination.[84] Fourth, institutions and engagement are well established for the operationalisation of One Health for food safety and nutrition security. However, little formal analysis is available of the incremental economic benefits of One Health operationalisation for food safety and nutrition security, which thus requires further research. Finally, there is a clear shortfall of evidence of One Health operationalisation for extreme weather, water security, and environmental degradation despite environmental sciences offering a wide array of expertise, experience, and insight. Across all these hazard groups, the evidence base is most strongly established for prevention and preparedness interventions by use of a One Health approach rather than those relating specifically to response.

Outlook on the future of One Health operationalisation

The conclusions of our five-step analysis (appendix 1 pp 5–9, 17) on the current state of One Health operationalisation for global health security are varied. Although excellent individually, institutions, laws, and

	Absent	Weak	Medium	Strong	Very strong
Emerging infections and novel pathogens	..	Response and service delivery	Prevention, preparedness, detection, and surveillance measures	..	..
Risks and hazards to global health security					
Antimicrobial resistance	..	..	Prevention, preparedness, detection, and surveillance measures	Response and service delivery	..
Endemic infections and neglected tropical diseases	..	..	Response and service delivery	Prevention, preparedness, detection, and surveillance measures	..
Food safety, food security, and nutrition security	..	Response and service delivery	Detection and surveillance measures	Prevention and preparedness measures	..
Extreme weather, water security, and environmental degradation	..	Response and service delivery	..	Prevention, preparedness, detection, and surveillance measures	..

The summarised evidence is based on reviewed literature, JEE and PVS reports, and consensus view of the authors. JEE=Joint External Evaluation. PVS=Performance of Veterinary Services.

Table: **Strength of the evidence base for applied One Health approaches across a range of risks and hazards to global health security**

capacities do not globally integrate environmental risk factors or drivers of all types (eg, air pollution or safe drinking water and sanitation), or do not consider the role of the natural systems (eg, biodiversity and encroachment into natural wildlife habitats) in both the prevention and the promotion of microbial evolution and pathogen emergence. For further institutional and legal aspects of One Health, we refer to the fourth paper in this Series.[33] Substantial efforts are in place to operationalise One Health in many countries (appendix 1 pp 10–17); however, more research and efforts are needed to mainstream the operationalisation of One Health[85] with sustainable (programmed) budgetary implications to ultimately make it effective in the immediate and long term. However, the costs of the pandemic and the recovery from it greatly outweigh the investment costs for One Health operationalisation, which in turn is prevention-focused (figure 2), particularly when viewed across the health of humans, animals, and ecosystems. The profitability and cost-effectiveness, but also qualitative benefits (eg, social wellbeing, spiritual dimensions of health, animal welfare, biodiversity, and healthy environments; panel 4) are important components of our analysis of the spectrum of threats to global health security (table). The analysis indicates that the evidence base of a One Health approach favours shifting the paradigm of disease control upstream to address drivers of disease spillover and other health emergency hazards—that is away from the current focus on detection and response in humans to prevention and preparedness across the social–ecological system by use of multisectoral approaches.[58] This early detection–early response framework can be used as a foundation for the operationalisation of One Health within the IHR (2005) and can be assessed via tools of the IHR MEF, that in the future should be revised to fully integrate the environmental and wildlife dimensions.

Within global health security, not all global health threats[30,86] can be analysed by the early detection–early response framework alone when grouped into hazard categories. Some of these hazards and risks are more amenable or relevant to being addressed through a One Health approach than others and any linked investment should be based on evidence of effectiveness. For example, the zoonotic potential (ie, the potential for animals to infect humans) of brucellosis due to *Brucella melitensis* is more than 100 times higher than that of bovine tuberculosis (*Mycobacterium bovis*). Consequently, when considering human and animal health benefits, the control of brucellosis in the livestock reservoir has a much higher societal profitability than the control of bovine tuberculosis (3:1 *vs* <1 benefit–cost ratios).[16] Advancing One Health operationalisation would also require the use of different methodological approaches in specific animal–human interfaces.[16,87] Animal–human interfaces can use linear (eg, logistic regression)[40] or non-linear models (eg, coupled differential equations),[48,88] and different types of cross-sector economic analyses (eg, benefit–cost and cumulative cost analyses).[47,89] Case examples, like the aforementioned West Nile virus surveillance in Italy, can be generalised for a One Health, cross-sectoral economic analysis of integrated disease surveillance–response systems.[53,59] Novel assessment frameworks, which, for example, assess knowledge integration,[39,52,90] will need to be further developed and tested for complementary usefulness to the IHR MEF. These novel frameworks and assessments need to be at least able to assess cobenefits and trade-offs across sectors and whether the underlying principles of One Health approaches are being applied. The effective implementation of a multisectoral One Health approach could build on the core indicators of the IHR MEF[91] and usefully reference the Tripartite's guide to zoonotic diseases and its operational tools,[92] while framing activities on four aspects (communication, coordination, collaboration, and capacity building) proposed by OHHLEP.[5] Functional regional platforms, multihazard national public health preparedness, training programmes on epidemiology, and disease-specific targets could be assessed as proxies for the current status of national coordination on the operationalisation of One Health.[21,92] If proxy indicators are not in use for more holistic assessments of the health (eg, human and animal health, and sustained environmental services and ecosystems) and the resilience of the whole social–ecological system, these should be developed, and agreed

on, to ensure that the IHR and other global health security initiatives take into account all hazards in their approach, as detailed in the third paper in this Series.[32]

Towards policies and implementation of One Health operationalisation

To guide the global recovery from the COVID-19 pandemic, WHO has released policy recommendations with an emphasis for an integrated approach to build the resilience of health systems and allied sectors for both universal health coverage and health security as interdependent objectives.[93] This initiative, the One Health Joint Plan of Action (2022–26), and a potential pandemic instrument (possibly in the form of a treaty) currently being discussed under the leadership of WHO[94] are clear opportunities to support the operationalisation of One Health globally.

At the national level, One Health operationalisation requires regulations for the prevention, preparedness, and response to epidemics and other health emergencies or hazards that are written in environmental standards, public health laws, and animal (domestic and wild) health laws.[95] These legal aspects should include preparation for early response to crises through mechanisms that engage all relevant government institutions (whole-of-government emergency management), the private sector, and civil society organisations. One Health and its operationalisation should be expanded on the basis of available scientific evidence. A clear purpose of One Health operationalisation should be expressed across ministries and government and the legal basis of a national One Health strategy should be specified with regard to community participation, technical support, multisectoral coordination, communication, and scientific exchange. The composition of organisational structures for One Health operationalisation includes representatives of community organisations, public health (eg, IHR Focal Points), animal (domestic and wild) health, environment (eg, UNEP Focal Points), industry, city and town planning (eg, UN-Habitat, UN Industrial Development Organisation [UNIDO] Focal Points), agriculture, nutrition, and defence at national and provincial levels. The involvement of non-governmental organisations, educators, academia, and the private sector should be specified. The organisation and leadership, for example, in rotation between sectors, should be clarified and schedules for standing committees and taskforces developed. Procedures for coordination, joint prioritisation, implementation, and assessment or feedback are required. Communication and information channels should be clarified among sectors.

Importantly, the funding of One Health operationalisation has to be negotiated among different government sectors, with the potential of cost sharing.[47] Both donor and national funding for the operationalisation of One Health should be focused sustainably on those hazards for which clear benefits of One Health approaches have been shown, and on those local and endemic hazards for which the evidence base on effectiveness is most firmly established, community priorities are addressed, and various sectoral interests are equitably met. Funding support should also provide necessary flexibility to address a wider scope when it can be of practical value (eg, sharing cost between the public health and animal health sectors for interventions in the reservoir of transmission of brucellosis or rabies).

This horizontal approach to One Health operationalisation at the national and subnational level is essential for sustainably building capacity towards global health security. A stronger horizontal integration should be reflected by increasingly harmonised and further developed reporting mechanisms on the implementation of One Health operationalisation within the IHR (2005) and PVS pathways (figure 2C) and by more comprehensive surveillance and monitoring by use of indicators of relevance across the spectrum of hazards in the social–economical system, combining, for example, surveillance data across species.[59]

Conclusions

One Health approaches show quantitative incremental benefits for health services and infrastructure, surveillance–response systems, antimicrobial resistance, food safety, nutrition security, environmental sanitation, and zoonoses control for global health security; however, gaps remain in the realisation of One Health to cover all species of interest. The evidence base is generally strongest for the One Health interventions focused on prevention and preparedness across the spectrum of hazards to global health security. To maximise and extend such benefits for global health security, a wider, global operationalisation of One Health is needed, which should be budgeted in multiannual national plans and include an increased allocation of resources towards prevention and preparedness in addition to response. The existing tools of IHR and PVS reporting are working in principle; however, they were insufficient during the COVID-19 pandemic, and, therefore, they have been reviewed and updated to better support future incidents of global health security. Specific One Health categories in the IHR MEF contribute to increased fostering of One Health operationalisation but they will need further development to better capture wildlife and environmental drivers of risks and hazards. The vagueness of commonly used definitions across the spectrum of hazards and risks, such as zoonoses, needs to be addressed to better frame integrative health concepts and promote understanding across sectors. The Quadripartite, working closely with member states, can potentially play a pivotal role in supporting the expansion, implementation, and guidance of One Health operationalisation at all levels with the launch of the One Health Joint Plan of Action (2022–26). To support implementation, the Quadripartite and advisory groups like OHHLEP[96] would further benefit from the contributions of other UN agencies such as

UN-Habitat or UNIDO to broaden the understanding of ecosystem health and services; industrial, rural, and urban development and their effect on human, animal, and ecosystem health; agriculture; wellbeing; and welfare. Further research is needed to show financial savings, cobenefits, and trade-offs associated with One Health operationalisation (panels 2, 3; appendix 1 pp 10–17) and systematic evidence reviews are required to assess the effectiveness of One Health approaches to address threats to global health security. One Health has a high potential to sustainably improve global health security for all, by first prioritising national capacity building and focusing on local community health needs and hazards before considering those risks of more global concern, especially in resource-constrained settings. As countries seek to recover from the health and socioeconomic impacts of the COVID-19 pandemic, adopting integrated One Health approaches with a full consideration of its underlying principles (panels 1–3) will be key to achieving meaningful progress and building back better.

Contributors

RK, AZ, DH, SdlR, RS, and OD ideated the Series theme of One Health and global health security, developed the articles' outlines, and selected lead authors. JZ developed the first and subsequent drafts and led the writing of this Series paper. AK-G, KH-T, RS, JL, FC, HB, BB, ED, JH, LC, VdRV, SS, OD, and SdlR contributed to content collection and planning. JZ, AK-G, KH-T, FC, VdRV, and SdlR contributed to data collection and analysis. JZ, AK-G, KH-T, ED, and DM contributed to the writing of the case studies. All authors contributed to the writing of the manuscript. JZ, AK-G, KH-T, JL, FC, HB, JH, LC, VdRV, AZ, RK, DH, OD, and SdlR contributed to article revision and pre-final editing.

Declaration of interests

We declare no competing interests. The views and opinions expressed in this Series paper are those of the authors and not of their institutions.

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References

1 Zinsstag J. Animal health research. *Science* 2007; **315:** 1193.
2 World Organisation for Animal Health. Terrestrial animal health code, vol 1, 28th edn. 2019. https://rr-europe.woah.org/wp-content/uploads/2020/08/oie-terrestrial-code-1_2019_en.pdf (accessed Oct 6, 2022).
3 Food and Agriculture Organization of the UN, WHO. Codex Alimentarius. http://www.fao.org/fao-who-codexalimentarius/publications/en/ (accessed May 15, 2022).
4 Food and Agriculture Organization of the UN, World Organisation for Animal Health, WHO. The FAO–OIE–WHO collaboration: a Tripartite concept note. Sept 28, 2010. https://www.who.int/publications/m/item/the-fao-oie-who-collaboration (accessed Sept 30, 2022).
5 WHO. One Health High-Level Expert Panel (OHHLEP). https://www.who.int/groups/one-health-high-level-expert-panel (accessed May 15, 2022).
6 Schwabe CW. Veterinary medicine and human health. Baltimore, MD: Williams & Wilkins, 1984.
7 Bresalier M, Cassidy A, Woods A. One health in history. In: Zinsstag J, Schelling E, Waltner-Toews D, Whittaker M, Tanner M, eds. One Health: the theory and practice of integrated health approaches. Wallingford Oxon: CABI, 2015: 1–15.
8 WHO. Future trends in veterinary public health: report of a WHO study group. Teramo: World Health Organization, 2002. https://apps.who.int/iris/handle/10665/42460 (accessed May 15, 2022).
9 Rapport D, Böhm G, Buckingham D, et al. Ecosystem health: the concept, the ISEH, and the important tasks ahead. *Ecosyst Health* 1999; **5:** 82–90.
10 Rapport D, Costanza R, Epstein PR, Gaudet C, Levins R. Ecosystem health. Malden, MA: Blackwell Science, 1998.
11 Lebel J. Health: an ecosystem approach. Ottawa, ON: International Development Research Centre, 2002.
12 Osofsky SA, Cleaveland S, Karesh WB, et al. Conservation and development interventions at the wildlife/livestock interface: implications for wildlife, livestock and human health. Gland and Cambridge: International Union for Conservation of Nature, 2005.
13 Berlin Principles Working Group. The Berlin Principles on One Health 2019. https://c532f75abb9c1c021b8c-e46e473f8aadb72cf2a8ea564b4e6a76.ssl.cf5.rackcdn.com/2020/02/11/74ik3zxtxp_The_Berlin_Principles_on_One_Health_.pdf (accessed May 15, 2022).
14 Zinsstag J, Schelling E, Wyss K, Bechir Mahamat M. Potential of cooperation between human and animal health to strengthen health systems. *Lancet* 2005; **366:** 2142–45.
15 Woods A, Bresalier M, Cassidy A, Mason Dentinger R. Animals and the shaping of modern medicine: One Health and its histories. Cham: Springer Nature, 2017.
16 Zinsstag J, Schelling E, Waltner-Toews D, Whittaker M, Tanner M. One Health: the theory and practice of integrated health approaches. Wallingford Oxon: CABI, 2015.
17 Johnson CK, Hitchens PL, Pandit PS, et al. Global shifts in mammalian population trends reveal key predictors of virus spillover risk. *Proc Biol Sci* 2020; **287:** 20192736.
18 Gibb R, Redding DW, Chin KQ, et al. Zoonotic host diversity increases in human-dominated ecosystems. *Nature* 2020; **584:** 398–402.
19 Hirsch Hadorn G, Hoffmann-Reim H, Biber-Klemm S, et al. Handbook of transdisciplinary research. Dordrecht: Springer, 2008.
20 Organisation for Economic Co-operation and Development. Addressing societal challenges using transdisciplinary research. June 16, 2020. https://www.oecd.org/science/addressing-societal-challenges-using-transdisciplinary-research-0ca0ca45-en.htm (accessed May 15, 2022).
21 Berthe FCJ, Bouley T, Karesh WB, et al. Operational framework for strengthening human, animal and environmental public health systems at their interface. Washington, DC: World Bank Group, 2018.
22 Queenan K, Garnier J, Rosenbaum Nielsen L, et al. Roadmap to a One Health agenda 2030. *Perspect Agric Vet Sci Nutr Nat Resour* 2017; **12:** 17.
23 De La Rocque S, Tagliaro E, Belot G, et al. Strengthening good governance: exploiting synergies between the Performance of Veterinary Services Pathway and the International Health Regulations (2005). *Rev Sci Tech* 2017; **36:** 711–20.
24 Zinsstag J, Schelling E, Roth F, Bonfoh B, de Savigny D, Tanner M. Human benefits of animal interventions for zoonosis control. *Emerg Infect Dis* 2007; **13:** 527–31.
25 WHO. International Health Regulations (2005): IHR monitoring and evaluation framework. Geneva: World Health Organization, 2018. https://apps.who.int/iris/handle/10665/276651 (accessed Oct 6, 2022).
26 WHO. Report of the Review Committee on the functioning of the International Health Regulations (2005) during the COVID-19 response. April 30, 2021. https://www.who.int/publications/m/item/a74-9-who-s-work-in-health-emergencies (accessed May 19, 2022).
27 The Independent Panel for Pandemic Preparedness and Response. COVID-19: make it the last pandemic. 2021. https://theindependentpanel.org/wp-content/uploads/2021/05/COVID-19-Make-it-the-Last-Pandemic_final.pdf (accessed May 15, 2022).
28 Haider N, Yavlinsky A, Chang Y-M, et al. The Global Health Security index and Joint External Evaluation score for health preparedness are not correlated with countries' COVID-19 detection response time and mortality outcome. *Epidemiol Infect* 2020; **148:** e210.

29 WHO. Health emergency and disaster risk management framework. Report. Geneva: World Health Organization, 2019. https://apps.who.int/iris/handle/10665/326106 (accessed May 15, 2022).

30 WHO. Ten threats to global health in 2019. https://www.who.int/news-room/spotlight/ten-threats-to-global-health-in-2019 (accessed May 15, 2022).

31 Mwatondo A, Rahman-Shepherd A, Hollmann L, et al. A global analysis of One Health Networks and the proliferation of One Health collaborations. *Lancet* 2023; published online Jan 19. https://doi.org/10.1016/S0140-6736(22)01596-3.

32 Traore T, Shanks S, Haider N, et al. How prepared is the world? Identifying weaknesses in existing assessment frameworks for global health security through a One Health approach. *Lancet* 2023; published online Jan 19. https://doi.org/10.1016/S0140-6736(22)01589-6.

33 Elnaiem A, Mohamed-Ahmed O, Zumla A, et al. Global and regional governance of One Health and implications for global health security. *Lancet* 2023; publised online Jan 19. https://doi.org/10.1016/S0140-6736(22)01597-5.

34 Assmuth T, Chen X, Degeling C, et al. Integrative concepts and practices of health in transdisciplinary social ecology. *Socio-Ecol Pract Res* 2020; **2:** 71–90.

35 Ostrom E. A diagnostic approach for going beyond panaceas. *Proc Natl Acad Sci USA* 2007; **104:** 15181–87.

36 Zinsstag J, Schelling E, Waltner-Toews D, Tanner M. From "One Medicine" to "One Health" and systemic approaches to health and well-being. *Prev Vet Med* 2011; **101:** 148–56.

37 Pongsiri MJ, Bickersteth S, Colón C, et al. Planetary health: from concept to decisive action. *Lancet Planet Health* 2019; **3:** e402–04.

38 Rüegg SR, Häsler B, Rosenbaum Nielsen L, et al. A One Health evaluation framework. In: Rüegg SR, Häsler B, Zinsstag J, eds. Integrated approaches to health: a handbook for the evaluation of One Health. Wageningen: Wageningen Academic Publishers, 2018: 38–85.

39 Rüegg SR, McMahon BJ, Häsler B, et al. A blueprint to evaluate One Health. *Front Public Health* 2017; **5:** 20.

40 Bonfoh B, Kasymbekov J, Dürr S, et al. Representative seroprevalences of brucellosis in humans and livestock in Kyrgyzstan. *EcoHealth* 2012; **9:** 132–38.

41 Kasymbekov J, Imanseitov J, Ballif M, et al. Molecular epidemiology and antibiotic susceptibility of livestock *Brucella melitensis* isolates from Naryn oblast, Kyrgyzstan. *PLoS Negl Trop Dis* 2013; **7:** e2047.

42 Wolfe ND, Dunavan CP, Diamond J. Origins of major human infectious diseases. *Nature* 2007; **447:** 279–83.

43 Zinsstag J, Roth F, Orkhon D, et al. A model of animal–human brucellosis transmission in Mongolia. *Prev Vet Med* 2005; **69:** 77–95.

44 Zinsstag J, Lechenne M, Laager M, et al. Vaccination of dogs in an African city interrupts rabies transmission and reduces human exposure. *Sci Transl Med* 2017; **9:** eaaf6984.

45 Laager M, Léchenne M, Naissengar K, et al. A metapopulation model of dog rabies transmission in N'Djamena, Chad. *J Theor Biol* 2019; **462:** 408–17.

46 Laager M, Mbilo C, Madaye EA, et al. The importance of dog population contact network structures in rabies transmission. *PLoS Negl Trop Dis* 2018; **12:** e0006680.

47 Roth F, Zinsstag J, Orkhon D, et al. Human health benefits from livestock vaccination for brucellosis: case study. *Bull World Health Organ* 2003; **81:** 867–76.

48 Zinsstag J, Dürr S, Penny MA, et al. Transmission dynamics and economics of rabies control in dogs and humans in an African city. *Proc Natl Acad Sci USA* 2009; **106:** 14996–5001.

49 Mindekem R, Lechenne M, Alfaroukh IO, et al. Evaluation of knowledge–attitudes–practices of the populations in the health districts of Benoye, Laoukassy, Moundou and South N'Djamena towards canine rabies in Chad. *Pan Afr Med J* 2017; **27:** 24 (in French).

50 Schurer JM, Rafferty E, Farag M, Zeng W, Jenkins EJ. Echinococcosis: an economic evaluation of a veterinary public health intervention in rural Canada. *PLoS Negl Trop Dis* 2015; **9:** e0003883.

51 Crump L, Béchir M, Ngandolo BNR, Daugla DM, Hattendorf J, Zinsstag J. Seasonal dynamics of human retinol status in mobile pastoralists in Chad. *Acta Trop* 2017; **166:** 280–86.

52 Hitziger M, Esposito R, Canali M, Aragrande M, Häsler B, Rüegg SR. Knowledge integration in One Health policy formulation, implementation and evaluation. *Bull World Health Organ* 2018; **96:** 211–18.

53 Paternoster G, Tomassone L, Tamba M, et al. The Degree of One Health implementation in the West Nile virus integrated surveillance in northern Italy, 2016. *Front Public Health* 2017; **5:** 236.

54 Zinsstag J, Crump L, Schelling E, et al. Climate change and One Health. *FEMS Microbiol Lett* 2018; **365:** fny085.

55 Schelling E, Wyss K, Béchir M, Moto DD, Zinsstag J. Synergy between public health and veterinary services to deliver human and animal health interventions in rural low income settings. *BMJ* 2005; **331:** 1264–67.

56 Institute of Medicine and National Research Council. Sustaining global surveillance and response to emerging zoonotic diseases. Washington, DC: The National Academies Press, 2009.

57 World Bank. People, pathogens and our planet: vol 1. Towards a One Health approach for controlling zoonotic disease. Washington, DC: World Bank, 2010. https://openknowledge.worldbank.org/handle/10986/2844 (accessed Oct 6, 2022).

58 Zinsstag J, Utzinger J, Probst-Hensch N, Shan L, Zhou X-N. Towards integrated surveillance–response systems for the prevention of future pandemics. *Infect Dis Poverty* 2020; **9:** 140.

59 Paternoster G, Babo Martins S, Mattivi A, et al. Economics of One Health: costs and benefits of integrated West Nile virus surveillance in Emilia-Romagna. *PLoS One* 2017; **12:** e0188156.

60 Wielinga PR, Schlundt J. Food safety: at the center of a One Health approach for combating zoonoses. *Curr Top Microbiol Immunol* 2013; **366:** 3–17.

61 Wegener HC, Hald T, Lo Fo Wong D, et al. Salmonella control programs in Denmark. *Emerg Infect Dis* 2003; **9:** 774–80.

62 Aenishaenslin C, Häsler B, Ravel A, Parmley J, Stärk K, Buckeridge D. Evidence needed for antimicrobial resistance surveillance systems. *Bull World Health Organ* 2019; **97:** 283–89.

63 Parmley EJ, Pintar K, Majowicz S, et al. A Canadian application of One Health: integration of *Salmonella* data from various Canadian surveillance programs (2005–2010). *Foodborne Pathog Dis* 2013; **10:** 747–56.

64 World Bank. People, pathogens and our planet: vol 2. The economics of One Health. Washington, DC: World Bank, 2012. https://openknowledge.worldbank.org/handle/10986/11892 (accessed May 15, 2022).

65 Enserink M. Infectious diseases. Questions abound in Q-fever explosion in the Netherlands. *Science* 2010; **327:** 266–67.

66 Kock R, Caceres-Escobar H. Situation analysis on the roles and risks of wildlife in the emergence of human infectious diseases. Gland: International Union for Conservation of Nature, 2022.

67 Sodagari HR, Wang P, Robertson I, Habib I, Sahibzada S. Non-typhoidal *Salmonella* at the human–food-of-animal-origin interface in Australia. *Animals (Basel)* 2020; **10:** E1192.

68 Havelaar AH, Kirk MD, Torgerson PR, et al. World Health Organization global estimates and regional comparisons of the burden of foodborne disease in 2010. *PLoS Med* 2015; **12:** e1001923.

69 Li M, Havelaar AH, Hoffmann S, et al. Global disease burden of pathogens in animal source foods, 2010. *PLoS One* 2019; **14:** e0216545.

70 Jaffee S, Henson S, Unnevehr L, Grace D, Cassou E. The safe food imperative: accelerating progress in low- and middle-income countries. Washington, DC: World Bank, 2019.

71 Prüss-Ustün A, Wolf J, Corvalán C, Bos R, Neira M. Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks. Geneva: World Health Organization, 2016. https://www.who.int/publications/i/item/9789241565196 (accessed May 15, 2022).

72 Thomas MB. Biological control of human disease vectors: a perspective on challenges and opportunities. *Biocontrol (Dordr)* 2018; **63:** 61–69.

73 Okamoto KW, Amarasekare P. The biological control of disease vectors. *J Theor Biol* 2012; **309:** 47–57.

74 Sokolow SH, Jones IJ, Jocque M, et al. Nearly 400 million people are at higher risk of schistosomiasis because dams block the migration of snail-eating river prawns. *Philos Trans R Soc Lond B Biol Sci* 2017; **372:** 20160127.

75 Nam VS, Yen NT, Holynska M, Reid JW, Kay BH. National progress in dengue vector control in Vietnam: survey for *Mesocyclops* (Copepoda), *Micronecta* (Corixidae), and fish as biological control agents. *Am J Trop Med Hyg* 2000; **62:** 5–10.

76 Muller GC, Junnila A, Traore MM, et al. The invasive shrub *Prosopis juliflora* enhances the malaria parasite transmission capacity of *Anopheles* mosquitoes: a habitat manipulation experiment. *Malar J* 2017; **16:** 237.

77 William K, Jafri L. Mesquite (*Prosopis juliflora*): livestock grazing, its toxicity and management. *J Biores Manag* 2015; **2:** 49–58.

78 Wu X, Nethery RC, Sabath BM, Braun D, Dominici F. Air pollution and COVID-19 mortality in the United States: strengths and limitations of an ecological regression analysis. *Sci Adv* 2020; **6:** eabd4049.

79 Barwise Y, Kumar, P. Designing vegetation barriers for urban air pollution abatement: a practical review for appropriate plant species selection. *NPJ J Clim Atmos Sci* 2020; **3:** 12.

80 Haider N, Yavlinsky A, Kock R. Response to 'Evaluation of modelling study shows limits of COVID-19 importing risk simulations in sub-Saharan Africa' (*Epidemiology and Infection* - HYG-LE-10513-May-20). *Epidemiol Infect* 2020; **148:** e112.

81 Bernstein AS, Ando AW, Loch-Temzelides T, et al. The costs and benefits of primary prevention of zoonotic pandemics. *Sci Adv* 2022; **8:** eabl4183.

82 Escher NA, Muhummed AM, Hattendorf J, Vonaesch P, Zinsstag J. Systematic review and meta-analysis of integrated studies on antimicrobial resistance genes in Africa—a One Health perspective. *Trop Med Int Health* 2021; **26:** 1153–63.

83 Cleaveland S, Lankester F, Townsend S, Lembo T, Hampson K. Rabies control and elimination: a test case for One Health. *Vet Rec* 2014; **175:** 188–93.

84 Zinsstag J, Kasymbekov J, Schelling E, Bonfoh B. It's time to control brucellosis in central Asia. 2012. https://nmc.unibas.ch/online-courses/one-health/2017/6_9_Brucellosis_Policy_Brief_Revision_2017.pdf (accessed May 15, 2022).

85 Zinsstag J, Mackenzie JS, Jeggo M, Heymann DL, Patz JA, Daszak P. Mainstreaming One Health. *EcoHealth* 2012; **9:** 107–10.

86 WHO. 10 global health issues to track in 2021. Dec 24, 2021. https://www.who.int/news-room/spotlight/10-global-health-issues-to-track-in-2021 (accessed May 15, 2022).

87 Future Learn. One Health: connecting humans, animals and the environment. 2015. https://www.futurelearn.com/courses/one-health (accessed May 15, 2022).

88 Mindekem R, Kayali U, Yemadji N, Ndoutamia AG, Zinsstag J. Impact of canine demography on rabies transmission in N'djamena, Chad. *Med Trop (Mars)* 2005; **65:** 53–58 (in French).

89 Mindekem R, Lechenne MS, Naissengar KS, et al. cost description and comparative cost efficiency of post-exposure prophylaxis and canine mass vaccination against rabies in N'Djamena, Chad. *Front Vet Sci* 2017; **4:** 38.

90 Rüegg SR, Häsler B, Zinsstag J. Integrated approaches to health: a handbook for the evaluation of One Health. Wageningen: Wageningen Academic Publishers, 2018.

91 Errecaborde KM, Belot G, Traore T, Skrypnyk A, Gongal G, de La Rocque S. Paving the path for health security and emergency preparedness by pairing national One Health road maps with multisectoral implementation tools and approaches. *Wkly Epidemiol Rec* 2021; **96:** 27–31.

92 WHO, Food and Agriculture Organization of the UN, World Organisation for Animal Health. Taking a multisectoral, One Health approach: a Tripartite guide to addressing zoonotic diseases in countries. 2019. https://apps.who.int/iris/handle/10665/325620 (accessed May 15, 2022).

93 WHO. Building health systems resilience for universal health coverage and health security during the COVID-19 pandemic and beyond: WHO position paper. Geneva: World Health Organization, 2021. https://www.who.int/publications/i/item/WHO-UHL-PHC-SP-2021.01 (accessed May 15, 2022).

94 Fukuda-Parr S, Buss P, Ely Yamin A. Pandemic treaty needs to start with rethinking the paradigm of global health security. *BMJ Glob Health* 2021; **6:** e006392.

95 Nuttall I, Miyagishima K, Roth C, de La Rocque S. The United Nations and One Health: the International Health Regulations (2005) and global health security. *Rev Sci Tech* 2014; **33:** 659–68.

96 UN Environment Programme. UNEP joins three international organizations in expert panel to improve One Health. Nov 12, 2020. https://www.unep.org/news-and-stories/story/unep-joins-three-international-organizations-expert-panel-improve-one-health (accessed May 15, 2022).