One Health 20 (2025) 100959

Contents lists available at ScienceDirect

One Health

journal homepage: www.elsevier.com/locate/onehlt

One Health interventions and challenges under rural African smallholder farmer settings: A scoping review

Evanson R. Omuse [a,b], Honest Machekano [b], Bonoukpoè M. Sokame [a], Daniel M. Mutyambai [a], Thomas Dubois [a], Sevgan Subramanian [a], Frank Chidawanyika [a,c,*]

[a] International Centre of Insect Physiology and Ecology (ICIPE), P.O. Box 30772-00100, Nairobi, Kenya
[b] Department of Zoology and Entomology, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa
[c] Department of Zoology and Entomology, University of the Free State, P.O. Box 339, Bloemfontein 9300, South Africa

ARTICLE INFO

Keywords:
Capacity building
Food security
Environmental tipping points
Participatory development
Planetary health
Public health

ABSTRACT

The global human population is rapidly increasing, escalating interactions of people, animals and the environment. This has led to more convoluted health challenges, for which African smallholder farmers bear the brunt. The One Health (OH) approach recognises the interconnectedness of these health challenges and thus follows a transdisciplinary approach involving diverse stakeholders to address them. Although there have recently been global concerted efforts and studies on OH, an information gap exists in Africa, particularly regarding smallholder farmers and their needs. Additionally, evaluation frameworks and outcome metrics for OH initiatives are still unclear. Thus, this study was conducted to critically map the available evidence of OH initiatives in the lens of African smallholder settings and identify gaps and opportunities for optimally targeted interventions. An extensive article searches yielded 1479 references, with only 21 studies from 11 countries qualifying for this review. Implementation of OH initiatives involved the collaboration of diverse stakeholders at local, national, regional and global levels. Most of the reported stakeholders of the OH initiatives were largely UN agencies, CGIAR centres, non-governmental organizations and universities. More than half of the studies focused on zoonotic and human-animal shared diseases. Conversely, few studies focused on human or animal food and nutrition security; land degradations; livelihoods and well-being; antimicrobial resistance, water sanitation and hygiene; food safety; soil health; crop health; biodiversity loss; climate change and gender equity. Effective capacity building, risk mitigation, social benefits, economic benefits, improved animal health and welfare, improved human health and well-being and improved ecosystem health and resilience were identified as OH outcomes. Based on the many evidence gaps, the OH initiatives must address health challenges mostly encountered by smallholder farmers with an increased focus on food security and safety, especially under the ongoing climate change. However, the successful implementation of OH initiatives was constrained by weak governance and coordination structures, poor communication and information sharing, lack of integrated surveillance system, limited community engagement, lack of political will, inadequate resources and logistical support, limited multi-disciplinarity and divergent priorities. Additionally, the lack of consensus on evaluation framework and outcomes highlights the need for an integrated standard framework for developing and implementing OH initiatives and harmonised outcome evaluation metrics to avoid under- or over-estimation of OH benefits.

1. Introduction

1.1. Overview of the One Health concept

The global human population is increasing rapidly and the interactions of people, animals and the environment are gradually becoming tipping points for health challenges. With increasing contemporary health problems, the fragmented framework and conventional linear approach to addressing human, animal, plant and environmental health issues have become unsustainable [1–3]. One Health (OH), is defined as a collaborative and unifying transdisciplinary multisectoral approach for fostering sustainable health of humans,

* Corresponding author at: International Centre of Insect Physiology and Ecology (ICIPE), P.O. Box 30772-00100, Nairobi, Kenya.
E-mail address: fchidawanyika@icipe.org (F. Chidawanyika).

https://doi.org/10.1016/j.onehlt.2024.100959
Received 3 June 2024; Received in revised form 20 December 2024; Accepted 20 December 2024
Available online 2 January 2025

animals, plants and the environment [4]. Thus, the OH approach provides equitable consideration of the health of humans, animals (both domestic and wild) and the environment (including plants) due to their inextricably inter-dependent nature [4]. Inevitably, the OH approach entails the cooperation of different actors, disciplines and practices in key sectors such as sustainable crop-livestock agriculture, and environmental and biodiversity conservation for human wellbeing [4].

Given the promised and realized outcomes of the OH approach, it is unsurprising that it has become a strong entry point for achieving nearly all United Nations Sustainable Development Goals (SDGs) [1]. Since its inception, the concept of OH has often been discussed in the context of zoonotic disease control with diseases such as Ebola, the food-borne bovine spongiform encephalopathy (BSE), salmonella, severe acute respiratory syndrome (SARS) and antimicrobial resistance (AMR) taking centre stage [3]. Plant health and environmental concerns typically receive less attention in OH studies [5,6]. However, plants are central to ecosystems as primary producers supporting human and animal health and their health might be affected by abiotic factors such as climate change as well as biotic factors such as the pests and pathogens they may host [7,8]. Not only substantial yield losses of key staple crops have been observed but also food safety aspects of these crops have been compromised by climate change, pests and pathogens [9]. For instance, mycotoxin-producing fungi commonly observed in cereals, peanuts, cottonseed and tree nuts have caused negative implication to both humans and animals [10], further presenting challenges to our endeavour to access to safe, nutritious and healthy plant-based foods. While agriculture, in particular smallholder crop production constitutes the largest sector supporting the livelihoods of the majority of people in sub-Saharan Africa, substantial yield gaps coupled with food safety challenges persist [10,11]. Current conventional production methods characterised by reliance on chemical fertilizers and synthetic pesticides has been reported to reduce soil health and productivity [12,13]. Several studies have also documented the spread of and consequent negative effects of synthetic pesticides in humans as well as ecosystems, threatening biodiversity in all its forms [12–14]. One way to address yield gaps and food safety is scaling up regenerative agriculture and sustainable intensification such as vegetable push-pull technology and black soldier fly frass fertilizer coupled with integrated pest management (IPM) under OH framework [15,16]. Hoffman et al. [17] opined that plant health practices through the OH approach can result in optimal net benefits associated with plant protection, and food and nutrition security with minimal deleterious impacts on humans, animals and ecosystems. Fasina et al. [18] proposed that the OH approach in African countries should be expanded beyond zoonotic diseases to include other pressing issues such as climate change, nutrition and food safety, policy and planning, welfare and wellbeing, AMR, vector-borne diseases, toxicosis and pesticide use predicated on social and cultural, geographic and economic contexts. Despite the growing body of knowledge on these challenges, African smallholder farmers remain highly vulnerable to OH issues spanning from emerging and endemic diseases to food insecurity and safety, against the backdrop of the ongoing climate and its associated ramifications [19–24].

1.2. Challenges faced by African smallholder farmers that require One Health approach

Food and nutritional security: Approximately 80 % of the farmland in Africa is under smallholder farming [25]. Most of these smallholder farmers operate in rural areas and depend on their agricultural produce for food and nutritional security [25,26]. Hence, smallholder farmers are an integral part of economic development and conservation of natural resources in Africa [27]. Nevertheless, most of these farmers suffer undernutrition and micronutrient deficiencies with enduring physiological, social and economic impacts [28]. Furthermore, sustainable food security among smallholder farmers in most African countries is hampered by rapid population increase, weak economic growth, high inflation and limited adaptive capacity to climate change [21,29,30]. Due to poor economies, maladministration and incoherent policy frameworks, there is low investment in strategic areas such as research, farming inputs and infrastructure as well extension services, which often leads to low farm productivity and ultimately food insecurity [31,32]. Consequently, poor farm productivity coupled with a rising population leads to increased land use change and intensification to meet the shortfalls of agricultural production, thereby, compromising environmental integrity and biodiversity conservation.

Zoonotic diseases and shared animal-human diseases: Many rural African communities endure the scourge of diseases including zoonotic ones [19,33]. Previous outbreaks of zoonotic diseases and animal-human shared diseases have been associated with traditional livestock farming practices that lack veterinary services and increased human-wildlife interaction due to overpopulation and encroachments of natural resources [34–36]. Consumption of tainted animal products such as milk and meat is also another key driver of disease outbreaks [36,37]. With a lack of diagnostic and veterinary services, such outbreaks can rapidly spread [36]. Furthermore, poor awareness and lack of medical professionals in rural communities are rampant in Africa exacerbating disease outbreaks [36].

Indeed, nearly 61 % of the known human infectious diseases are of animal origin and even the newly emerging ones are highly likely to be zoonotic [38]. Rabies, Rift Valley fever, milk-borne bovine tuberculosis and brucellosis and water-borne zoonoses as rampant diseases requiring priority OH interventions in Tanzanian small ruminant pastoralist communities [39]. In Nigeria, cattle pastoralist communities identified trypanosomiasis, contagious bovine pleuropneumonia, foot and mouth disease and fascioliasis as some of the important diseases requiring OH solutions [40]. Although vaccination is considered an effective control option for zoonoses [41], it is not widely adopted by smallholder farmers because of prohibitive costs, limited awareness, inadequate government support and/or inaccessibility of services [41,42].

Food Safety: Although often overlooked, food safety remains one of key areas of societal concern. Ubiquitous microbial pathogens such as salmonella and rotavirus, parasites (tapeworm) and naturally occurring toxins (e.g., mycotoxins) remain the major causes of food-borne illnesses. This is further compounded by synthetic toxins such as pesticide residues, adulterants (e.g., melamine), antibiotic drug residues and heavy metals that persist in food systems [8,43–45]. The dearth of government regulatory frameworks and lack of consumer awareness inevitably leaves the problem unabated [46]. For instance, most food-borne hazards in African nations are associated with informal markets characterised by poor hygiene and storage conditions and a lack of routinely examination for adherence to acceptable standards [46]. With poor sanitation, consumption of raw or uncooked products can become risky in such conditions as contamination can be sourced directly from the markets [46]. Under field conditions, fungi including *Aspergillus* spp. produce mycotoxins such as aflatoxins, which contaminate products such as cereals and nuts [47]. These mycotoxins are potent carcinogens that cause health problems to smallholder farmers while negatively impacting livestock and poultry [43]. Additionally, most smallholders are increasingly applying toxic pesticides on their agricultural lands, however, insufficient technical knowledge and lack of protective equipment increase pesticide poisoning through direct contact exposure [48,49] or residual activity in fresh produce following ingestion [50]. The lack of food and feed safety standards not only adversely impacts human or animal health [51] but also results in economic losses associated with embargos on contaminated products in prime domestic and international markets [52].

Antimicrobial resistance: In Africa, pathogen control in livestock and poultry production relies mostly on antimicrobials [53]. However, inadequate diagnostic tools and injudicious usage of the antimicrobials have resulted in higher incidences of AMR in commonly used antibiotics such as tetracyclines, aminoglycosides and penicillin [54,55]. Indeed, AMR in African smallholder livestock and poultry production systems

has been linked to indiscriminate use of antimicrobials, poor surveillance and regulatory frameworks and generally poor husbandry [56,57]. In the end, farmers are affected by poor farm productivity of animal-based products such as meat, milk, eggs and fish which are key for dietary diversity and other key nutritional outcomes [58,59]. Inevitably, AMR also negatively affects household income due to poor productivity and increased treatment costs in cases where more potent but expensive drugs are required. Overall, AMR in animals also poses public health risks since the build-up of reservoirs of drug-resistant microbiota can eventually spread to humans through contaminated food or the environment, making treatment of infections among humans even more complex leading to severe illnesses and sometimes ultimately death [56,57].

Plant pests and diseases: Climate change have predisposed various crops to various plant pests and diseases including invasive ones [60–62]. The subsequent increased pest pressure coupled with poor crop yield under the climate stressors erodes food and nutritional security [23,62,63]. For resource-poor smallholder farmers who solely rely on farming, coping strategies under climate extremes are limited [19,29,64]. Thus, the incursion of pests further compromises rural development and OH outcomes. Moreover, where resources are available, increased pest pressure often encourages indiscriminate usage of chemical pesticides leading to poor environmental integrity, food safety and ultimately compromised OH outcomes [16,65–67]. There is, therefore, an increased need for IPM strategies such as crop diversification and effective surveillance for both local and area-wide management of pest outbreaks.

Land degradation and loss of soil fertility: According to ELD Initiative & UNEP [68], 33 % of the global land surface has been affected by desertification and about one-third of the arable land has been affected by soil erosion over the past 40 years with Africa being severely affected. Low fertility and unsustainable soil management practices have been regarded as the major constraints in agricultural productivity among African smallholder farmers [69]. Such land degradation has been attributed to deforestation, overgrazing, overexploitation by conventional agriculture intensification, climate change, increased aridity and population pressure that leads to land use changes [70]. Drechsel et al. [71] conducted a study in 37 countries in Africa and confirmed that there is a significant interlink between population pressure, reduced fallow periods (natural soil nutrient recovery time) and soil nutrient depletion (including erosion and loss through crop harvest), indicating unsustainable dynamism between human populations, current agriculture practices and the environment. Additionally, low soil fertility among African smallholder farmers has been aggravated by limited access to quality soil test services and limited knowledge of suitable organic amendments [72].

Another outcome of land degradation is the emergence of invasive plants, which primarily outcompete native vegetation and reduce the necessary ecosystem services important for human well-being. For instance, invasive plants such as *Parthenium hysterophorus* L. inflict further OH challenges by supporting vectors of important diseases [73], causing allergic reactions and tainting livestock produce such as milk and meat [74]. The displacement of native vegetation by invasive plants can reduce the grazing index of field pastures leading to low livestock productivity [75] in addition to reducing biodiversity [76]. Of concern is how ecosystem corridors crucial for the conservation and dispersal of beneficial organisms such as natural control of pests are lost leading to increased pest challenges in agricultural landscapes [60].

Human-wildlife conflicts and loss of biodiversity: Human-wildlife conflicts and loss of biodiversity are the culmination of increased human population and land use change. Furthermore, limited access to land and alternative sources of livelihood leave communities resorting to unsustainable hunting practices [39]. In some cases, the hunting practices include destruction of habitats and grazing lands through fires and harvesting of firewood leading to lower biodiversity and wildlife traversing human settlements for food and shelter where both crops and livestock are lost. The increased human-wildlife interactions also predispose humans to zoonotic diseases [39]. Indeed, the ecological and behavioural changes that increase wildlife contact with humans have been associated with zoonotic infections including SARS, Ebola, Lyme disease and Lipah virus [34]. Thus, the inclusion of wildlife in the OH framework not only conserves biodiversity but promotes public health and well-being [35].

Climate change: Climate change remains a primary driver affecting OH outcomes, directly or indirectly. In many countries, changing climates have already been associated with detrimental effects on economic and social development [77]. Talukder et al. [22] recently reviewed the health impacts of climate change on African smallholder farmers where increases in transmission and outbreak of infectious diseases and non-communicable diseases such as dengue, malaria, cholera, zika virus, leptospirosis, diarrhoea and dysentery were all linked to climate change. Moreover, acute respiratory infections and heat-related health impacts such as cardiovascular disease, cancers, hypertension and respiratory issues are also known to increase under warming temperatures [22]. The World Health Organization (WHO) reported that water-borne diseases and vector-borne diseases accounted for 40 % and 28 %, respectively, of climate-related health emergencies while floods accounted for 33 % of the most frequent climate-related disasters in Africa [78].

In the case of food insecurity, climate change has been associated with decreasing crop yield and loss of indigenous varieties of crops [23,29,63]. This is largely due to poor agronomic performance under climate extremes such as drought and flooding [29]. Climate warming has also been associated with increased geographic expansion of invasive pests coupled with multivoltinism [61], which all lead to increased pest pressure ultimately poor crop productivity, and increased post-harvest losses [63,79]. Talukder et al. [22] reported that the incidences of food insecurity that follow crop losses also contributed to cases of mental health such as depression and anxiety among smallholder farmers. The vulnerability to climate shocks among most African countries is exacerbated by a lack of coping strategies [29]. For example, Mauerman et al. [80] reported that a multi-season drought that occurred from 2009 to 2011 in Northern Kenya resulted in livestock losses, reduced household income from livestock, increased expenditure on water and increased herd recovery durations (3–4 years). With limited alternative sources of livelihood to cushion against the climate shocks, farmers are left highly vulnerable.

1.3. The problem

From the foregoing, the compelling evidence and growing need for OH approaches in Africa to address increasingly intricate health challenges cannot be overstated. To date, African countries have largely endorsed OH approaches following the 2008 Libreville Declaration at the first Inter-Ministerial Conference on Health and Environment [81]. The third Inter-Ministerial Conference on Health and Environment was subsequently held in Gabon in 2018, which yielded a 10-year Strategic Action Plan for health and environmental interventions in Africa from 2019 to 2029 [81]. In addition, a tripartite partnership of the Food and Agriculture Organization (FAO), World Organization for Animal Health (WOAH/OIE) and WHO was formed in 2010 to tackle zoonotic diseases in many countries [82]. As a result, several OH initiatives and activities covering different disciplines by local, national, regional and international actors have been identified in Africa [18]. Despite these increasing campaigns for paradigm shifts to transdisciplinary and multisectoral approaches to tackle a variety of health challenges, OH initiatives remain poorly adapted to local and context-specific needs across Africa [18]. Furthermore, few community-based OH initiatives have been implemented in Africa posing questions about their feasibility and compatibility with cultural norms and values [83]. Institutional, resource and socio-cultural challenges previously highlighted in national OH frameworks [84,85] are likely to be encountered as drawbacks

to optimal outcomes of OH initiatives in the rural African settings. African smallholder farmers face a complex web of interconnected challenges spanning human, animal, plant and environmental health. Here, using African smallholder farmers as the focal group, we sought to investigate OH needs, interventions and implementation challenges to enhance outcomes through local context-specific frameworks.

Standardized frameworks for assessing OH initiatives remain elusive largely due to a lack of consensus and integration of different health disciplines [86]. However, previous studies have adopted various frameworks for assessing OH initiatives incorporating both qualitative and quantitative outcomes (e.g., Delesalle et al. [87]). Despite the increasing endorsement of One Health (OH) approaches, existing frameworks remain inadequately adapted to local and context-specific needs. For instance, zoonotic diseases continue to threaten rural livelihoods, food and nutrition security remains precarious, and environmental degradation exacerbates these issues [88,89]. Fragmented health interventions and limited community engagement further hinder sustainable outcomes. This scoping review addresses the urgent need to identify gaps, challenges, and opportunities for implementing OH initiatives tailored to the unique socio-economic and cultural contexts of African smallholders.

1.4. Aim

This scoping review aimed to identify and explore OH interventions, outcomes, implementation frameworks and challenges with focus on African smallholder farmers. This scoping review identifies gaps and opportunities for successful implementations of OH initiatives or related programs based on systematic evaluation of outcomes related to OH pillars (human, animal, plant and environmental health).

2. Materials and methods

A scoping review and synthesis of the literature were carried out to identify potential OH approaches or initiatives used to address complex global health challenges that are directly linked to African smallholder farmers. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was adopted [90]. The review procedure involved a database search to identify relevant articles, screening of the relevance of articles and extraction of data. The search was performed from November 2023 to February 2024.

2.1. Search strategy

The databases used for this study included Web of Science, Google Scholar, CABI Digital Library, PubMed and grey literature in reputable research organizations' websites. The search terms were based on three concepts 'one health', 'smallholder farmer' and 'Africa'. For instance, on the Web of Science, the search terms were ALL = (one health OR ecohealth) AND (smallholder farmer OR small-scale farmer) AND (Africa). Random searches were performed using a combination of strings of keywords using Boolean operators "OR" and "AND" (Table 1). The same search strategy was performed in all selected databases. (See Table 2.)

2.2. Article screening

The details of the articles (main author, journal name, article title and abstract) were retrieved and saved in MS Excel. Duplicated articles from various sources were removed and the remaining articles were screened in two steps. In the first step, only the title and abstract were screened for inclusion. In the second step, full texts of articles that met inclusion criteria during the first screening were retrieved for further screening. Studies were selected for evaluation if they met the following inclusion and exclusion criteria.

No time limit was considered given this is the first review documenting the OH approach in African smallholder agricultural settings.

Table 1
Search terms based on domains (keywords) for scoping review on One Health interventions and outcomes under African smallholder farmers' settings.

Concept	Search terms
One health	One health OR Ecohealth OR One Welfare OR planetary health OR one medicine OR human health OR environment health OR animal health OR plant health OR ecosystem health OR multidisciplinary OR multisectoral OR integrated approach OR Community-Based
Smallholder farmer	Smallholder farmer OR small-scale farmer OR small-scale agriculture OR smallholder agriculture OR small-scale livestock keeper OR pastoralist OR poor farmer OR poor resourced farmer OR resource-constrained farmer OR vulnerable farmers OR subsistence farming
Africa	(Africa OR Algeria OR Angola OR Benin OR Botswana OR Burkina Faso OR Burundi OR Cabo Verde OR Cameroon OR Central African Republic OR Chad OR Comoros OR DRC OR Congo OR Cote d'Ivoire OR Ivory Coast OR Djibouti OR Egypt OR Equatorial Guinea OR Eritrea OR Eswatini OR Ethiopia OR Gabon OR Gambia OR Ghana OR Guinea OR Guinea-Bissau OR Kenya OR Lesotho OR Liberia OR Libya OR Madagascar OR Malawi OR Mali OR Mauritania OR Mauritius OR Morocco OR Mozambique OR Namibia OR Niger OR Nigeria OR Rwanda OR Sao Tome and Principe OR Senegal OR Seychelles OR Sierra Leone OR Somalia OR Sudan OR Tanzania OR Togo OR Tunisia OR Uganda OR Zambia OR Zimbabwe)

Table 2
Inclusion and exclusion criteria in article screening.

Inclusion criteria	Exclusion criteria
Original research (article that described primary research).	Review articles
Article describing OH initiatives by highlighting OH issues, OH interventions and outcomes	Article describing OH issues and OH interventions but lacked OH outcomes. Article with limited information on OH approaches.
Article focusing on Africa (the article described studies performed in the African continent, African regions or countries within Africa).	Article with studies performed outside Africa.
Article describing study related to smallholder farmers or was performed in smallholder agriculture settings.	Article not performed under smallholder agricultural settings.
Article that was written in English or French.	Article not written in English or French.
Study that is available through unrestricted access.	Article not available in full text (including an article that is not availed in full text by the authors upon request).

2.3. Data extraction and synthesis

The selected 21 articles were uploaded to Mendeley reference software (Elsevier, Amsterdam, Netherlands) to store and organize the literature for citing. The selected studies were summarized as follows. Each article was assessed for its OH context and sectors (human, animal and environment, or intersections of these), types of targeted beneficiaries in the context of area implementation (rural, urban, peri-urban or combinations of these), scale of implementation (multi-country, national and subnational), key stakeholders/actors, interventions, outcomes and implementation challenges.

One Health themes were further organized to align with current and overarching global challenges that can be resolved using the OH approach [4]. These challenges included but were not limited to zoonotic diseases, antimicrobial resistance, food safety and security, vector-borne diseases, environmental contamination, climate change, biodiversity loss, human-wildlife interactions and other health threats shared by people, animals and the environment.

Stakeholders/actors were further clustered as international non-governmental organizations (NGOs), international development

partners, regional development partners, universities, national agricultural research and extension systems (NARES), local governments, private sector, local NGOs, community-based organizations (CBOs) and local private agricultural extension services.

One Health initiatives were classified based on the systematic framework, developed for the implementation of health policies, by the World Federation of Public Health Associations (WFPHA) [91]. The same framework has been previously adopted by Delesalle et al. [87] in a scoping review on large-scale OH initiatives for infectious diseases and antimicrobial resistance. Components of the WFPHA framework included (1) governance (e.g., legislation, strategy, policy, financing, organization); (2) knowledge (e.g., surveillance, monitoring and evaluation, research and evidence, innovation, dissemination and uptake); (3) prevention (e.g., primary prevention, vaccination, screening, management and planning); (4) protection (e.g., control, emergency preparedness, environmental health, climate change and sustainability-adaptation and mitigation); (5) promotion (e.g., environmental determinants, social and economic determinants, resilience, behaviour and health literacy), (6) people-centred care (e.g., healthcare), (7) advocacy (e.g., community engagement and empowerment, communications) and (8) capacity building (e.g., workforce development, workforce planning, teaching and training).

We adopted an approach commonly used in health outcomes research that recognises four evaluation methods based on how outcomes were sourced, viz., technical (clinical) observation, perception (patient-reported) outcomes, technical performance (measurements) and economic implications [92]. Technical observations involve the assessment of outcomes of interventions where data are not measured but are described based on expectations. Perceived outcomes are those that are reported by target beneficiaries of an intervention based on their observations and experiences. Technical performance encompasses measurable outcomes after administering an intervention (e.g., mortality rates, disease burden, vaccination coverage, number of beneficiaries, etc.). Economic evaluation is the financial implications of an intervention (e.g., cost minimization, cost-effectiveness, cost-utility, cost-benefit, etc.).

The outcomes (benefits) were grouped based on overarching themes such as technical, social, economic and health (human, animal and environmental) benefits. Further, we grouped the challenges into emerging principal themes.

Geographic information system software version 3.34.3 [93] was used to map the geographical distribution of the studies. Word cloud showing stakeholders or actors of OH initiatives was generated using Displayr (https://westeurope.displayr.com).

3. Results

3.1. Search results

Fig. 1 illustrates the screening process of articles for inclusion in this study. Approximately 1479 studies were initially identified. After removing duplications, 1214 articles were screened for titles and abstracts and 114 were retrieved for full-text screening. Only 21 studies met the eventual eligibility criteria and therefore qualified for this review.

3.2. Geographical distribution of studies

The geographic distribution of the reviewed studies disproportionately varied across the African countries (Fig. 2). Uganda had the most studies ($n = 5$) followed by Kenya ($n = 3$), Ethiopia (n = 3), Tanzania (n = 3), Rwanda ($n = 2$), Chad (n = 2), Malawi (n = 2), South Africa (n = 2), Morocco ($n = 1$), Mali (n = 1) and Cote d'Ivoire (n = 1) (Fig. 2).

3.3. Scale of One Health implementation and targeted beneficiaries

Most of the reviewed studies were undertaken at district level ($n = 6$) [45,94–98], while others were carried at multi-district ($n = 4$) [44,99–101], village (n = 4) [102–105], county (n = 2) [106,107] and provincial level (n = 3) [108–110]. Only two studies were undertaken at

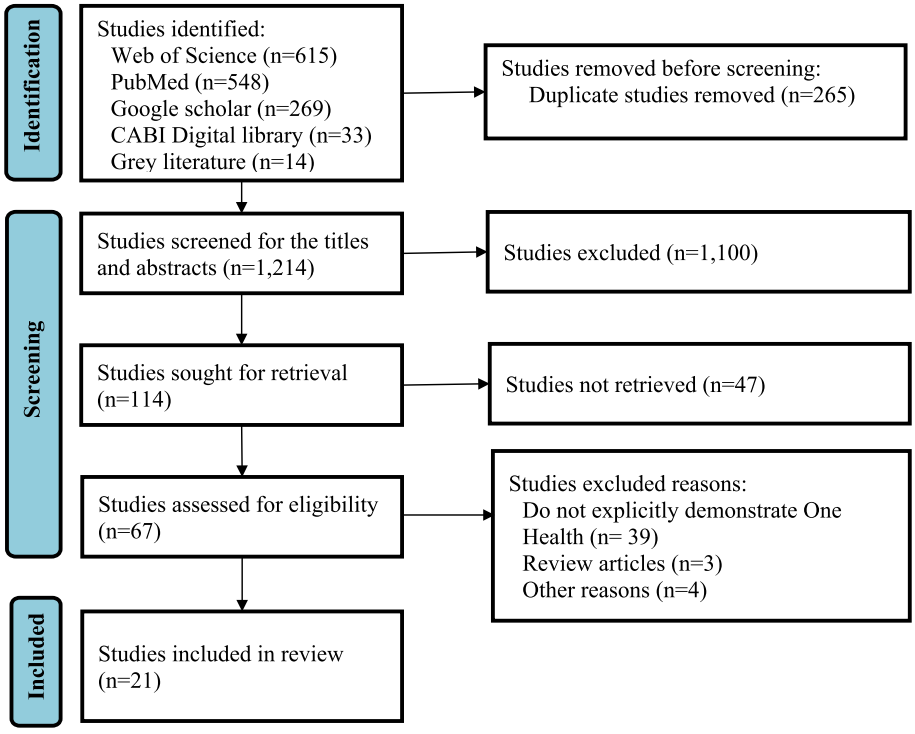

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow chart showing the search, retrieval and selection of relevant studies on One Health interventions and outcomes under African smallholder farmer settings.

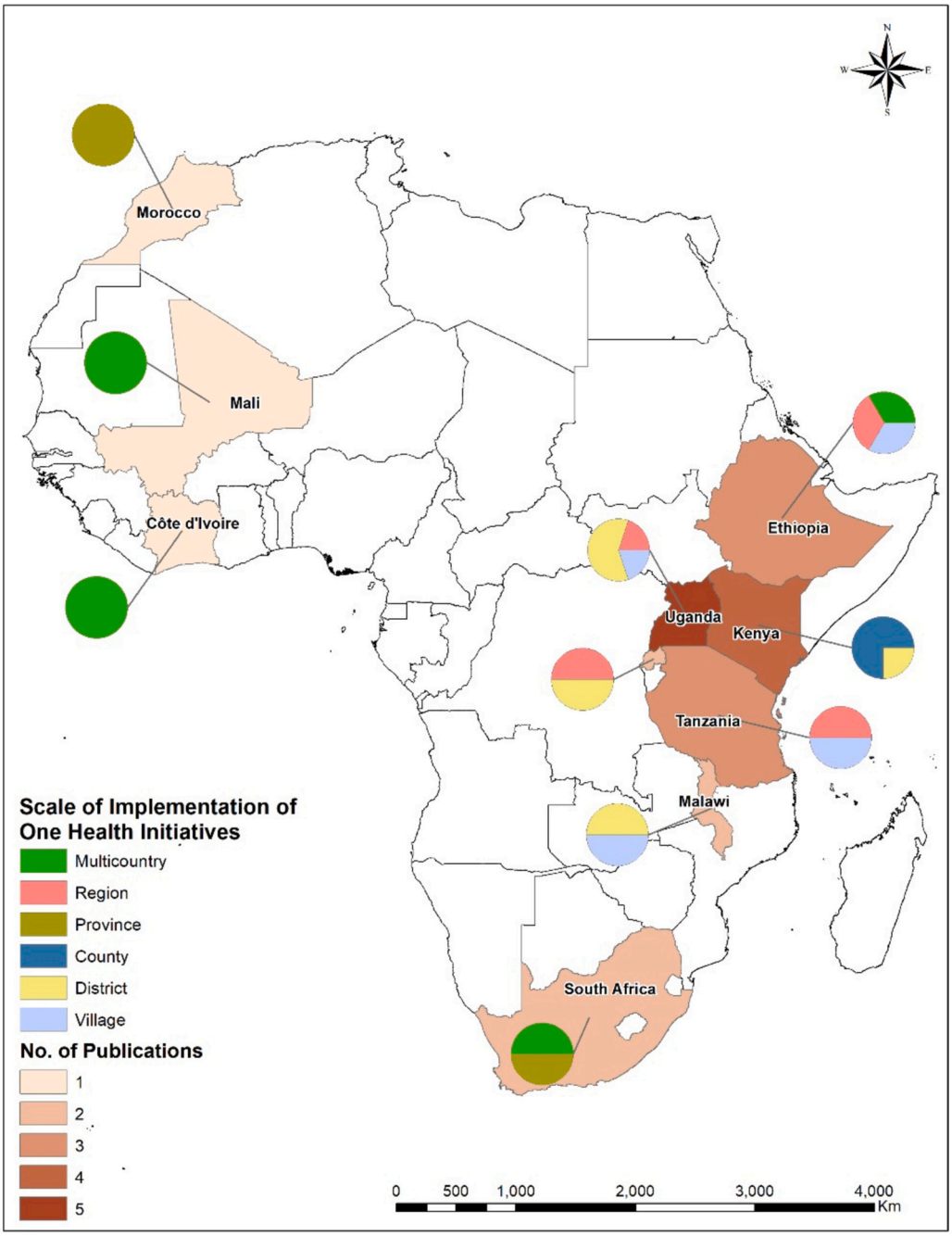

Fig. 2. Geographic scope and distribution of studies that were eligible for the review on One Health interventions and outcomes under African smallholder farmer settings.

multi-country levels [111,112].

Regarding target beneficiaries, six studies focused on rural smallholder livestock farming or pastoralist communities [44,96,103,104,107,110]. Four studies targeted rural smallholder farming communities with mixed farming systems [45,95,113]. Two targeted rural smallholder communities farming crops [94,105]. Other studies focused on the general rural communities targeting women [98] and pregnant women and children [106]. Studies also were implemented based on emerging issues affecting general communities such as targeting rural communities from regions with many outbreaks of zoonotic diseases [99], urban and rural communities with high dog-to-human ratios [100], rural communities with high reported cases of dog-transmitted zoonoses [108], urban and rural communities with high rates of neglected tropical diseases (NTDs) [97], urban communities with high incidence of human rabies [109], urban and peri-urban consumers of animal-source foods [101]. Multi-country studies were conducted due to issues recognized at national levels such as the high zoonosis burden reported [111,112].

3.4. Stakeholders and actors involved in One Health implementation

The ultimate beneficiaries (individual smallholder farmers, households, communities, farmers associations) of OH initiatives are mentioned in all studies; therefore, we deliberately did not include these categories as OH stakeholders or actors. About 143 stakeholders and actors were listed in the review as implementors of OH initiatives (Fig. 3). The stakeholders for the implementation of OH initiatives broadly include various national governments including ministries,

Fig. 3. Stakeholders and actors implementing One Health initiatives for smallholder farmers in Africa based on 21 selected studies. Based on the Word Cloud Analysis, the size of the font in the phrase represents the frequency of stakeholder involvement in OH initiatives in different articles (highest frequency = 8 and the lowest frequency = 1).

departments and agencies (38), Universities (28), international non-governmental organizations (NGOs) (21), local governments (19), international development partners (10), UN agencies (5), consultative group on international agricultural research (CGIAR) centres (5), NARES (5), local private partners (4), local NGOs (3), community-based organizations (CBOs) (2), private agricultural extension services (1), regional development partners (1) and regional NGO (1). From the reviewed articles, the most implementing partners of OH initiatives in Africa were WHO, Swiss Tropical and Public Health Institute (Swiss TPHI), FAO, WOAH/OIE, United States Agency for International Development (USAID), International Livestock Research Institute (ILRI), World Vision, Makerere University and Sokoine University of Agriculture.

3.5. One Health disciplines and overarching One Health challenges

In the OH disciplines, out of the 21 studies, four studies focused on the OH triad: humans-animals-environment interphase [45,95,96,113], five on humans-environment interphase [94,97,98,105,106] and twelve on human-animal interphase [44,99–101,103,104,107–112].

From the review, 11 themes were identified for OH. Fourteen (14) studies focused on zoonotic disease and animal-shared diseases, including endemic and re-emerging zoonotic diseases was the dominant theme covered by 14 studies [44,45,96,99–101,107–112], while infectious diseases such as African swine fever [103] and soil-transmitted helminths [97,104]. Six studies focused on food and nutrition security [45,94,95,105,106,113], five focused on water security including water access, sanitation and hygiene (WASH) [97,98] and water-borne disease [45], four focused on land and environmental degradation [45,94,95,105] and three focused on livelihoods and well-being [94,95,113]. Antimicrobial resistance [45,111], animal feed and nutrition security [45,95], food safety (including mycotoxins, pesticide poisoning and vet drug contamination [45] and foodborne pathogens [44]) were each reported in two studies. Finally, weeds and insect pests [95], loss of biodiversity [94], climate change [98] and gender inequality [98] were each reported in single studies. The OH sectors and OH themes retrieved from the reviewed studies are summarized in Fig. 4. Presence of limited studies on plant health such as plant diseases, pests, weeds and loss of biodiversity as well as environmental degradation including loss of soil fertility underscore how environmental health remains underexplored area under the auspice of OH.

3.6. Types of One Health initiatives

One Health initiatives in the 21 selected studies aligned with more than one component of the WFPHA systematic framework (Table 3). Following the set inclusion criteria, all the reviewed studies focused on the smallholders, therefore, all implemented OH initiatives fell within the "people-centred" component (which was not included in Table 3). Most of the interrelated components were merged, that is, governance and capacity building as well as protection and prevention. Under governance and capacity building components, studies on collaborations were the most represented (n = 16), followed by workforce development [such as defining responsibilities and training of health sectors (n = 6) and inclusion of a wider workforce through partnerships (n = 5)], sustainability development (n = 9) and infrastructure and logistical support (n = 3). Knowledge category comprised mainly of dissemination and uptake (n = 15) followed by research and evidence [through participatory approach (n = 4) and multidisciplinary research (n = 4)] and surveillance, monitoring and evaluation (n = 8) with the

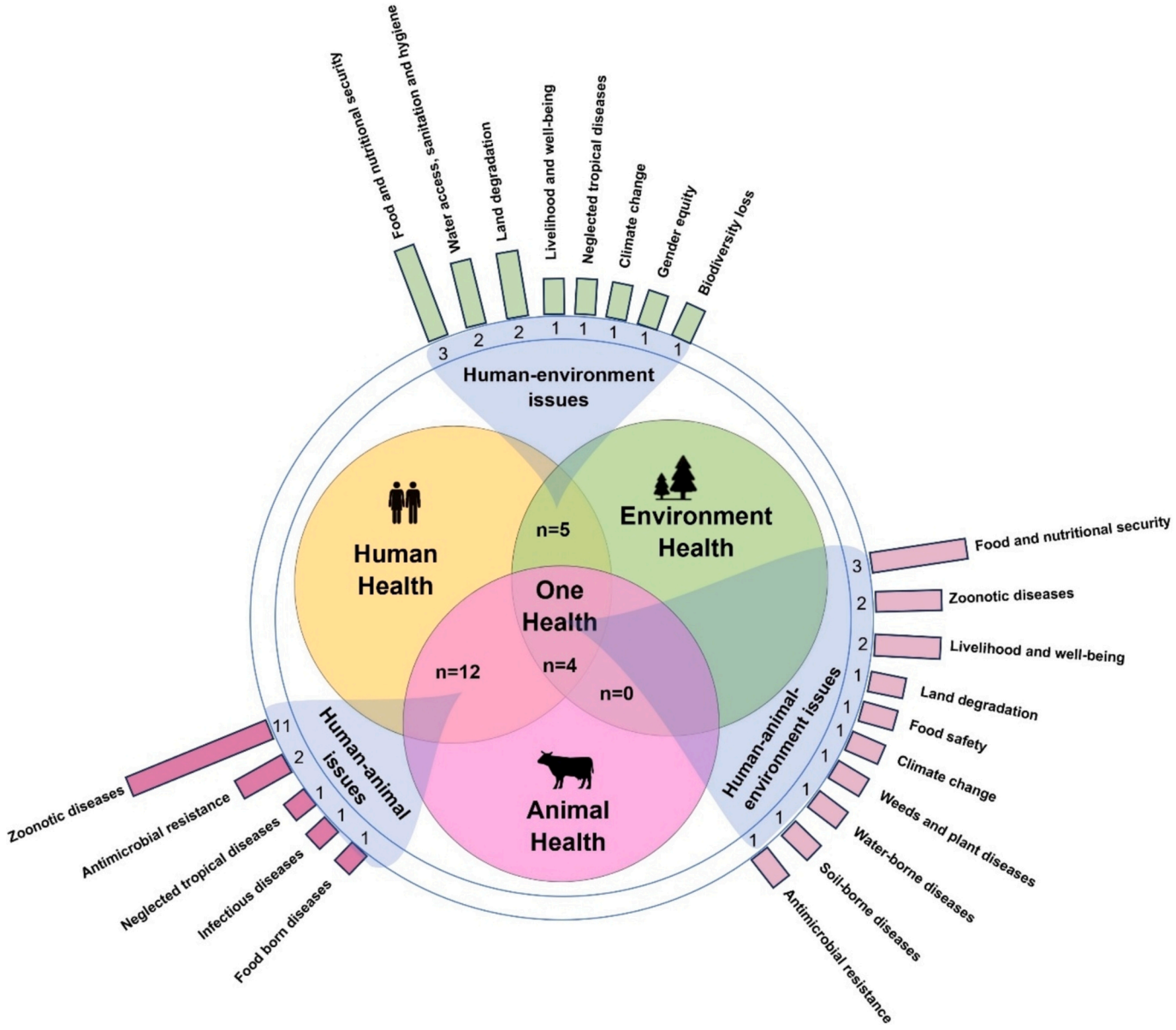

Fig. 4. Illustration of One Health (OH) sectors and emerging themes retrieved from the 21 reviewed studies on OH interventions and outcomes under African smallholder farmer settings. Several studies focusing on at least two health sectors are represented at the intersections of human, animal and environmental health. The number of OH emerging issues addressed by different intersectoral collaborations are illustrated in the graphs.

least number of OH initiatives being grouped as risks and innovations (n = 5).

Protection and prevention components constituted mostly the primary prevention [e.g., mass vaccination (n = 10) or performing biosecurity measures by health professionals such as baiting of stray dogs and cats (n = 1)] followed by secondary prevention [e.g., deworming, administering post-exposure prophylaxis schemes and curative treatments (n = 6)]. Public education and awareness creations (n = 1), transdisciplinary surveillance (n = 1) and emergence preparedness (n = 1) were least reported under protection and prevention components.

Promotion initiatives mostly targeted the provision of initial inputs or material support or free services to the communities to promote buy-in and adoption (n = 9) followed by behaviour and health literacy (n = 5). Socio-economic determinants and geographical inequalities such as smallholding communities in hard-to-reach areas were mentioned in three (n = 3) studies. Promotion initiatives that increase overall accessibility to OH interventions through training and prevention infrastructure and services were also reported (n = 3). Finally, few studies focused on healthy environmental determinants such as pesticide use and soil degradation (n = 2), gender inequality (n = 1) and healthy settings (n = 1).

One Health initiatives under the advocacy mostly targeted strategic communication (n = 5), and least on community engagement and empowerment (n = 2), extended networks and partnership for collaborative work (n = 2) and orienting OH initiatives around other multiple needs of the communities (n = 1).

3.7. Evaluation methods and outcome metrics of One Health initiatives

A summary of various interventions, evaluation methods and outcome metrics of OH initiatives from the 21 studies reviewed are presented in Table 4. Studies employed more than one evaluative method for outcome assessments. Ten (10) studies employed the perception approach while nine studies presented the outcomes based on the technical observations. One Health outcomes from technical observation and perception were only provided conceptually or

Table 3
Types of One Health (OH) initiatives found in 21 studies included the review of OH interventions and outcomes under African smallholder farmer settings. The World Federation of Public Health Association (WFPHA) systematic framework for healthy policy was adopted to evaluate the OH initiatives.

Components of OH initiatives and overarching themes identified
1. **Governance and capacity building**
- *Collaborations:* Formation of multisectoral, multidisciplinary team and multilevel coordination structures for priority setting, planning, strategizing and implementation [45,94,96–98,100,101,103,105–107,109,111–113].
- *Workforce development:* Defining responsibilities and training workforce of different health sectors to get a broader understanding of cross-cutting issues and improve their technical capacity [44,45,94,100,109,111].
- *Workforce development:* Incorporating a wider workforce through partnership e.g., a participatory approach where community collective influence is required [99,103,105,112,113].
- *Infrastructure and logistical support:* Establishment of multidisciplinary laboratories and quarantine facilities [112] or multidisciplinary mobile clinics for community-targeted service delivery [45].
- *Sustainability development:* Professional development to develop skills and knowledge through continued training programmes e.g., training of students [45,98,99,112] or training local stakeholders [94,100,106,111,112].
2. **Knowledge**
- *Research and evidence:* Participatory approach to co-create and exchange ideas with the community about addressing OH issues [45,95,103,113].
- *Research and evidence:* Multidisciplinary qualitative and quantitative research to assist priority setting, e.g., the burden of diseases [45,96,107] and systems analysis [110].
- *Surveillance, monitoring and evaluation:* Continuous and systematic collection, analysis and interpretation to track OH impact or progress [44,96–98,104,105,111].
- *Dissemination and uptake:* Awareness creation through training, education, demonstrations, media coverage or other channels adapted for the target community [44,45,94–96,98–100,103,105–109,112].
- *Risks and innovations:* Identify risks and opportunities and promote community-based innovations and research, e.g., diversification of animal feed by planting multipurpose trees [103,113], cropping systems combining cereals, agroforestry and small doses of inorganic fertilizer [94], legume intercrops with maize [105] or legumes, maize and forage grass intercrops [95].
3. **Protection and prevention**
- *Public education and awareness:* Promote the use of biosecurity measures and behaviour change among communities for protection against disease outbreaks such as NTDs, infectious diseases or zoonotic diseases [44,96–99,103,108].
- Transdisciplinary surveillance aiming at measuring and improving OH outcomes such as continuous meat inspection [96,107].
- *Emergency preparedness:* Planting trees to protect the water catchment to improve water access and security [98].
- *Primary prevention:* Conduct prevention through mass vaccination of animals or humans against potentially zoonotic diseases [45,96,100,104,107–109,111,112] or use insecticides-impregnated dog collars to prevent dog owners against leishmaniasis [108].
- *Primary prevention:* Perform and demonstrate biosecurity measures such as baiting of stray dogs and cats and correct disposal of canine carcasses to protect the public against disease outbreaks such as zoonotic diseases [107].
- *Secondary prevention:* Conducting preventive treatment, e.g., deworming, administering post-exposure prophylaxis schemes and treatment [96,100,104,107,108,112].
4. **Promotion**
- *Gender inequality:* Promotion of gender equity [98].
- *Socio-economic determinants and geographical inequalities:* Reduce inequality in the context of socio-economic and geographical locations by targeting smallholding communities such as pastoralists/livestock keepers living in rural and hard-to-reach areas [107,111] or rural farmers practising mixed farming [45].
- *Accessibility:* Increase community access to OH initiatives such as training and prevention infrastructure and services including diagnosis, vaccination and preventive treatments [45,107,110,112].
- Provision of initial inputs or material support or free services to the community to promote buy-in while ensuring sustainability e.g., biofortified sweet potato vines [106], seeds for Desmodium for push-pull technology [95] or free mass vaccination and treatments against diseases [100,104,108,109,112], free joint human-animal health advisory services [45], or free community WASH facilities [98].
- *Healthy environmental determinants:* Promote cropping practices that reduce the use of chemical pesticides and address environmental degradation [45,95].
- *Behaviour and health literacy:* Developing and promoting behaviours that avert health risks for example eating nutritious food or taking biosecurity measures [44,45,98,104,107], safe use of veterinary drugs and pesticides [45].
- *Healthy settings:* Developing healthy settings in different places such as schools, hospitals, butcheries and communities by installing WASH facilities [98].
5. **Advocacy**
- Community engagement and empowerment initiatives through the promotion of local ownership e.g., the establishment of a water use committee to manage water systems by ensuring water access and security to the community [98], creation of community contracts about disease control [103].
- Strategic communication for dissemination, cross-learning platforms and mobilizing change to increase OH uptake and outcomes [45,98,103,109,112].
- Establishing networks and partnerships for collaborative work with other actors in health sectors to reinforce OH initiatives [98,107].
- Orienting OH initiatives around other multiple needs of the community including the provision of other public services (e.g., national identification cards and birth certificates) or medical camps with additional medical outreach services (e.g., nutrition screening, outpatient treatment, immunization of children, public health education, laboratory diagnosis, antenatal care and HIV testing and counselling) to improve the impact of OH initiatives such as increased immunization coverage [107].

descriptively by stakeholders and targeted beneficiaries, respectively and did not have apparent outcome metrics. There is a lack of documented outcome metrics for such kind of evaluation methods. We, therefore, provided metrics for outcomes that were evaluated based on economic efficiency and technical performance. The economic evaluation was employed in five studies with cost minimization, cost-effectiveness, cost-efficiency, break-even point, cost-effectiveness per disability-adjusted life years (DALY) averted and cost-effectiveness per life saved being used as outcome metrics. Nine studies employed technical performance (measurements) as an evaluation method for OH outcomes with the following outcome metrics: mortality rate, disease incidence, vaccination coverage, number of beneficiaries, DALY, years of life lost (YLL) saved, implementation success rate, infection rate, time saved, school attendance and bacterial load.

3.8. Benefits of One Health initiatives

One Health initiatives resulted in multiple benefits that were broadly classified as technical, economic, social, human health, animal health, environmental health and information outcomes. The majority (50 %) of reviewed studies mentioned capacity building (e.g., increased knowledge, coordination, skills and community empowerment) as OH benefits. Nine studies reported effective risk mitigation (e.g., decrease in disease burdens) as OH benefits. Social benefits (e.g., increased number of beneficiaries, increased access to service delivery, increased number of school-going children, improved working security) were listed in nine

Table 4
Summary of the One Health (OH) initiatives, type of evaluation methods, outcome metrics, benefits and type of benefit reported from studies included in the review on OH interventions and outcomes under African smallholder farmer settings.

Intervention initiative	Evaluation method and outcome metrics	Benefits/indicators of success reported	Type of benefits	Reference
Established the National OH Steering Committee bringing together four key ministries with objectives of integrated multisectoral surveillance systems, joint research projects and enhancing multidisciplinary capacities for detecting and responding to specific challenges such as rabies control.	Technical observation	Trained and equipped community animal health workers or veterinary paraprofessionals to provide extension and animal health services.	Capacity building	Braam et al. [111]
		Effectively support for animal health in rural and remote areas.	Personal or social benefit	
		Improved OH surveillance, prevention and treatment activities.	Effective risk mitigation	
Multilevel coordination for prevention and control of zoonotic diseases through transdisciplinary research, meat inspection, rabies control, zoonotic disease extension services; Provision of medical camps for people for medical outreach (nutrition screening, outpatient treatment, immunization of children, public health education, laboratory diagnosis, antenatal care and HIV testing and counselling); Provision of veterinary support (livestock vaccination, deworming; treatment and baiting for stray canines).	Perception	Improved access to human health, animal health and administrative services in rural and hard-to-reach areas; Improved access to care and holistic care; Improved the availability of both human and animal drugs; Improved mobilization of communities for outreaches; Increased turnout leading to increased immunization coverage; Improved zoonotic disease extension activities.	Personal or social benefit	Griffith et al. [107]
		Frequent meetings led to effective measures to quickly respond to disease outbreak events.	Effective risk mitigation	
		Reduced the distance and cost required to travel to receive services by participants; Much higher impact due to pooling of resources by ministries; Cost sharing between departments of animal health and human health solve logistical challenges, e.g., vehicle and fuel cost.	Economic benefits	
Provision of Dairy Dynamic Management education, research and outreach program; Extension specialists supported smallholder dairy farmers in performing proper husbandry and animal health practices for mastitis control and reduction of bacterial counts in the udder; Farmers' education on conducting hygienic milking procedures, equipment hygiene, animal husbandry and animal health.	Technical performance: bacterial load, implementation success rate	Significant reduction of mean total bacterial counts and prevalence of bacterial species in quarters over the 16-week training; More than 90 % of smallholder farmers performed hygienic milking protocols.	Effective risk mitigation	Garcia et al. [44]
Engaged public and private sector stakeholders with diverse technical expertise and community connections to pair water installation projects with education, training and community events; Disseminate OH message to separate water sources for people and animals to reduce zoonotic waterborne diseases; Installation rainwater harvesting tanks at a primary school and maternal health centre; Creation of a centrally located water kiosk (business enterprise) that sells clean water at reduced cost; Establishment of Water Use Committees (WUCs) comprised of delegated community members to manage local water systems.	Technical observation	Improved water, sanitation and hygiene (WASH) behaviours; Lowed impacts on mother-to-child HIV transmission, risk and treatment; Decreased the dependence on potentially contaminated and unimproved water sources; Improved availability of clean water for both drinking and for health care operations for over 2000 people; Water availability helped women to maintain their menstrual hygiene.	Improved human health	Nankanja et al. [98]
		A new network of water access points reduced the time and money spent on water collection; Improved health and financial conditions.	Economic benefits	
		Lowered student absenteeism.	Personal/Social benefits	
		WUCs addressed community priority issues, hired the kiosk attendant and organized meetings to discuss water rates, revenue review and sustainable management plans; Women were empowered with leadership roles in maintaining community interest.	Capacity building	
		Collaboration with other stakeholders in tree planting and environmental education activities that restore watersheds.	Ecosystem health	
A local partner team from the agroforestry, fruit and vegetable, natural resource development, livestock production, animal health and gender departments were involved in community mobilization, co-facilitation and documentation of community conversation sessions on diversifying animal feed sources through planting multipurpose trees (avocado, mango, papaya, neem and improved grass and fodder species).	Perception	Strengthened capacity for diversified feed production (forage, tree, fodder and grass availability); Sustainable animal feed sources; Improved availability and accessibility of animal feed in different seasons; Improved productivity; Good animal-human interactions due to comfortable living environment; Healthy animals due to reduced disease incidence.	Improved animal health	Alemayehu et al. [113]
Integrating control programs for two neglected tropical diseases (NTDs): mass drug administration (MDA) for soil-transmitted helminths in humans and mass dog rabies vaccination (MDRV). Creation of awareness on soil-transmitted helminths and/or rabies and	Economic evaluation: cost-effectiveness	Integrated delivery resulted in a 33 % lower cost per deworming dose and a 16 % lower cost per rabies vaccination.	Economic benefit	Lankester et al. [104]
	Technical performance: school attendance, time saved, vaccination coverage	Coverage was not reduced when interventions were integrated because a high proportion (81.7 % and 80.4 %) of households participated in MDA and MDRV, respectively, resulting in obtaining	Improved animal and human health	

(*continued on next page*)

Table 4 (*continued*)

Intervention initiative	Evaluation method and outcome metrics	Benefits/indicators of success reported	Type of benefits	Reference
integrated control approach. Treatments were given free of charge.		"two for one" health treatments per individual, saving time, saving effort and participation costs; 63.8 and 67.3 % dogs were vaccinated in integrated interventions and mass dog rabies vaccination.		
		Increased number of children enrolling on school after interventions. Treatment reached 76 % and 37 % who have and have not enrolled primary school children, respectively; 33 % less time was required for a single person and a dog to attend and receive integrated interventions than to attend each separate intervention.	Personal/social benefits	
Participatory approaches through the co-creation of a community contract on biosecurity measures for controlling infectious diseases. Broader inclusion of stakeholders in animal disease control; Adapting disease prevention or control actions according to local people's priorities; Promotion of local ownership of disease control; Creation of a communication and meeting platform for different stakeholders to enhance cooperation; Creation of awareness for behavioural changes on biosecurity measures	Perception	The intensified communication and cooperation around pigs in the communities reinforced the sense of group identity; The capacity-building offered at the first meeting supported implementation and appeared to be more important than the physical contract; The community and stakeholders felt empowered and described how they shared their knowledge; Participants educated their peers and acted as catalysts for wider biosecurity change in their communities.	Capacity building	Erika et al. [103]
	Technical performance: implementation success rate	Success rate of implementation of many biosecurity measures increased. For instance, the success rate for farmer subgroups was 0/6 and 5/7 at the second follow-up from 0/6–4/7 at the first follow-up while for the trader subgroups, the success rate ranged from 0/5–2/3 at the first follow-up, increasing from 0/5–5/6.	Effective risk mitigation	
Formed the supervisory and technical committees; Vaccinators were recruited among local animal health workers and veterinarians and were trained on animal handling, vaccination and registration technique; Canine vaccination and OH communication; Administration of both canine vaccination and post-exposure prophylaxis (PEP) to exposed victims; Maximal communication between human and animal health workers (OH paradigm). Free mass vaccination campaign for dogs.	Technical performance: disease incidence, vaccination coverage, DALY averted	Rabies incidences declined to 0.07/1000 in 2014 from 0.7/1000 in 2012; The decrease in animal rabies incidence led to a decline in PEP use; Overall dog vaccination coverage was 71 %; The vaccination campaign only slightly (10 %) increased the number of confirmed vaccinated animals throughout the mass vaccination intervention; Yearly number of DALY averted with PEP alone was 454, whereas PEP + dog vaccination (plus communication) led to a total of 659 DALY averted each year; Maximum OH communication plus dog vaccination will take only 10 years after the start of the intervention for the break-even point to be reached. This is due to a reduction in inappropriate use of PEP (dog confirmed vaccinated and in good health during the observation period).	Effective risk mitigation	Mindekem et al. [109]
	Economic evaluation: cost-effectiveness, cost-efficiency, break-even point, cost-effectiveness per DALY averted	Canine vaccination is financially the best option for animal rabies control and rabies prevention in humans; Canine mass vaccination is less costly than PEP over 15–20 years; Vaccination of the animal vector was about 30 % less costly over 20 years and this cost efficiency would be improved by strengthening communication between animal and human health workers; Estimated costs for 100 % of human rabies deaths to be prevented by PEP only, vaccination + PEP + communication would be advantageous after 6 years and canine vaccination with PEP after 8 years; Cost-effectiveness per DALY averted was higher for canine mass vaccination than sole use of PEP.	Economic benefits	
Access to disease prevention infrastructure intervention such as crushing pens to allow handling during dipping, vaccination and inspection of cattle; Access to disease management training intervention such as vaccination; Access to nutrition management training intervention; Access to communal dips intervention	Technical observation	Improved cattle health through disease prevention and control of parasites; Improved herd numbers; Improved human health through less exposure to zoonotic diseases from cattle; Improved cattle nutrition and carcass health; Better pasture feed quality and quantity; Improved cattle reproductive performance	Improved animal health	van Heerden et al. [110]
		Increasing income from weaner sales; Improved farmers' economic health due to fewer expenses to purchase their dipping solution.	Economic benefits	
		Reduced environmental impact.	Ecosystem health	
		Reduced disease burden.	Effective risk mitigation	

(*continued on next page*)

Table 4 (*continued*)

Intervention initiative	Evaluation method and outcome metrics	Benefits/indicators of success reported	Type of benefits	Reference
Treatment villages: anti-rabies vaccination, deworming with praziquantel against Echinococcus granulosus and fitting of a deltamethrin (0.76 g) insecticide-impregnated collar (Scalibor®, Intervet) against sandflies to prevent canine leishmaniasis of owned dogs and population health education; Control villages: anti-rabies vaccination of owned dogs and population health education alone.	Technical performance: vaccination coverage, infection rate	Vaccination coverage of 65.0 % of the total canine population was achieved in treatment villages; Canine leishmaniasis infection decreased by 4 % (from 17.2 to 13.2 % seroprevalence) in treated villages while it increased by 11.4 % (from 12.1 to 23.8 % seroprevalence) in the control villages within the high-risk seasons; Decrease in E. granulosus infection rate in dogs in treated villages compared with those in control villages; Low infection rates of E. granulosus of 1.6 % and 3.0 % in treated and control villages, respectively.	Effective risk mitigation	El Berbri et al. [108]
	Economic evaluation: cost-minimization, cost-effectiveness	The integrated intervention reduced costs, such as those of health education, staff accommodation, salaries and allowances, and transportation, which could be shared between the three diseases; The delivery costs for the single disease interventions are at least 30 % higher per dog treated than when interventions are integrated.	Economic benefits	
Water, Sanitation and Hygiene (WASH) interventions	Perception	Political coverage reached 100 % in WASH before 2020; Availability of reviewed National neglected tropical diseases Strategic plan; Existence of technical staff and SWGs for programme coordination and implementation; Improved mapping of NTDs countrywide leading to data sharing; Well-coordinated social cluster ministries for WASH activities.	Capacity building	Mukankaka [97]
Joint mobile crop-livestock advisory services with partnership include representatives of the crop and livestock sectors; Agriculture and veterinary department staff talked to farmers and answered their questions on plant health, agronomy such as field management and soil fertility, animal health, nutrition, and husbandry practices, among others.	Technical observation	Plant and livestock consultations in the same place saved time for farmers and provided opportunities for cross-learning both benefitting farmers and clinic staff; Joint clinics improved referral systems and targeted delivery of technology such as animal vaccines and clean cassava cuttings; Crop–livestock clinics provided an avenue for finding out what farmers know and don't know about OH issues – crucial information to design solution; The mobile mode of operation led to a new decision regarding biosecurity.	Capacity building	Danielsen et al. [45]
		Mobile clinics improved service delivery (saved time and improved access to more farmers); More female farmers and other vulnerable groups attended clinic sessions held close to their homes.	Personal/social benefits	
		Holding clinic sessions closer to farmers' homesteads enabled clinic staff to make occasional follow-up visits in the field to assess the extent of a certain problem, verify a diagnosis or collect a sample for further analysis.	Effective risk mitigation	
		Crop and livestock staff shared operational costs, knowledge and insights in a way that they would not normally be able to do under little resources.	Economic benefits	
	Technical performance: number of beneficiaries	Over 1000 crop officers and university students were trained as plant doctors; Over 1000 farmers attended and women made up 43 % of attendees.	Capacity building	
Promotion of push-pull technology (PPT) programme by different stakeholders; Awareness creation through information materials, training and demonstrations; Provision of inputs and follow-up	Perception	Villagers confirmed that their overall well-being has increased due to PPT mainly referring to positive effects on food security, milk production, income/savings and employment; Improved social aspects such as social ties, friendship and exchange of information.	Personal/social benefits	Fischler, [95]
		Farmers practising PPT observed a significant reduction in the incidence of Striga, stemborer and soil erosion and increased soil fertility and soil moisture; Increase of cereal yields (mainly maize) by threefold to fourfold on average; PPT does not depend on external inputs such as pesticides and mineral fertilizer and is therefore environmentally friendly, likely to increase agrobiodiversity and contribute to the provision of ecosystem services.	Ecosystem health	
Collaboration and partnerships in project countries: Chad, Mali and Cote d'Ivoire for the elimination of dog rabies; Capacitation of veterinary services in all study countries, through infrastructural, logistical and administrative support for animal	Technical observation	Increased access to rabies diagnosis; Improved work security through the provision of PEP for all veterinary personnel working for the study.	Personal/social benefits	Léchenne et al. [112]
		Increased technical capacity of core project partners including mainly administrative (office	Capacity building	

(*continued on next page*)

Table 4 (*continued*)

Intervention initiative	Evaluation method and outcome metrics	Benefits/indicators of success reported	Type of benefits	Reference
rabies surveillance; Public sensitization strategy was designed and implemented in each country; Human vaccine for PEP was provided free of charge; Increased sharing of network among project partners and collaborators through meetings and workshops.		equipment) and logistical aspects; Knowledge transfer through training, sharing of findings and expertise within the modelling consortium of stakeholders; Improved public awareness building; To ensure the sustainability of control efforts on the national level beyond the project timeframe, local stakeholders were motivated to form OH committees; Capacity building: training of one postdoctoral fellow, one PhD and four master students.		
	Technical performance: disease incidences, YLL saved	Elimination of dog rabies in N'Djamena, the capital city of Chad; The free availability of vaccine will likely save nearly 500,000 lives over 15 YLL.	Effective risk mitigation	
Training and transforming the knowledge of young interdisciplinary and cross-sectoral teams of professionals at the start of their careers and give them the ability to detect, prevent and respond to infectious diseases.	Perception	The students appreciated the training citing skills gained in communication, teamwork and collaboration; Students felt gratitude and accomplishment by designing interventions to some of the communities' challenges. The communities learnt and appreciated the concept of OH; Increased awareness of general disease prevention and health promotion; Improved sanitation and hygiene in schools, slaughter areas and markets; Enhanced interaction between communities and their leaders.	Capacity building	Buregyeya et al. [99]
Promote Mama SASHA (Sweetpotato Action for Security and Health in Africa) project, an integrated orange-fleshed sweet potato (OFSP) and health service-delivery strategy focusing on healthy mothers during pregnancy, healthy eating, vitamin A, infant feeding, benefits and growing OFSP; The multi-disciplinary team established, maintained and distributed biofortified OFSP vines to pregnant women to seek recommended early antenatal care and postnatal care services; Pregnant women were provided information, education and communication materials on OFSP benefits and agronomic advice.	Technical observation	Improved knowledge on healthy eating and nutrition; Increased adoption of orange-fleshed sweet potato; More women visit maternal healthcare.	Capacity building	Cole et al. [106]
	Perception	Participants' perceptions of enhanced maternal and child health coupled with greater food security; Mothers felt their children were less susceptible to disease and more energetic; Frontline health workers perceived higher antenatal care attendance and increased contact with mothers, their partners and children.		
Collaboration of medical, veterinary and wildlife officers to perform diagnosis, surveillance, treatment and campaigns on anthrax, Rift Valley Fever (RVF), East Coast Fever (ECF), contagious bovine pleuropneumonia (CBPP), Peste des petits ruminants (PPR), brucellosis and trypanosomiasis.	Perception	The multidisciplinary team succeeded in collecting data about rinderpest; Disease outbreaks were effectively controlled according to 48.1 % of community members; 14.9 % of community members said more people became aware of disease control; 3.7 % of community members said that the diseases were diagnosed and controlled.	Effective risk mitigation	Kayunze et al. [96]
Collaboration of ICRAF built partnerships with government departments, farmer associations, NGOs and CBOs to promote cropping systems which combine cereal crops, agroforestry (including fertilizer trees, fruit trees, fodder trees and fuel-wood trees) and small doses of inorganic fertilizers to produce food-crop yields greater than inorganic fertilizers alone on degraded soils, as well as recuperating soil nutrients over years; Provision of planting materials to the farming communities and training of agricultural extension officers; Provision of soil information; train on integration agroforestry trees in the local farming systems, water conservation to the farmers in the communities.	Technical observation	Increased food-crop yields on degraded soils; Improved the livelihoods of farm families, lower risks associated with fertilizer price increases and drought; Restoration of soil nutrients over years; Improved biodiversity and nutrient and water cycling in the agro-ecosystem; Improved soil nutrient and water cycling	Ecosystem health	Beedy et al. [94]
		Improved household food security and nutrition; Improved livelihood; Increased the yield of the major staple crop, maize by nearly 100 % under smallholder conditions.	Improved human health	
		The capacity building of national partners, academics and students through curriculum revision projects; Strengthened partnerships among stakeholders; Built capacity of farmers and extension staff; Mainstreamed agroforestry in university curricula and cross-cutting priority areas including gender equality, governance and HIV/AIDS.	Capacity building	

(*continued on next page*)

Table 4 (*continued*)

Intervention initiative	Evaluation method and outcome metrics	Benefits/indicators of success reported	Type of benefits	Reference
	Technical performance: number of beneficiaries	A total of 184,463 farmers were reached through the project.	Personal/social benefits	
The research team of a nutritionist, sociologist, agronomist, community development specialist and community members to promote legume intercrops with maize to increase soil fertility, food security and child nutrition; Organization of farmer meetings, training, farm visits and on-farm trials.	Technical observation	Increased availability of food and a diversified diet; Improvement of child growth; Increased consumption of legumes in the project area; Improved food security and nutrition; Improved child nutrition.	Improved human health	Kerr et al. [105]
		Households gained knowledge on the processing and use of different foods and healthy feeding practices for young children.	Capacity building	
	Perception	Farmers reported improved maize growth, soil status and increased yield of maize and edible legumes.	Ecosystem health	
	Technical performance: number of beneficiaries, adoption rate	Almost 3000 farmers from 77 villages participated; The adoption of legume use reached almost 100-fold; Women's participation increased over time, from 29 % in 2001 to more than 50 % in all subsequent years (50 to 92 %).	Personal/social benefits	
Mass dog anti-rabies vaccination campaigns; Establishment of human and material resources, infrastructure for implementation and intersectoral working relationships; Training of district veterinary officers, district medical officers, health workers and laboratory staff; Sustained delivery of health information on rabies was to community leaders, students, teachers and the public; Provision of PEP free of charge to bite victims.	Technical observation	Awareness campaigns encouraged increased health seeking by dog bite victims and PEP accessibility improved.	Capacity building	Mpolya et al. [100]
		The overall reduction in bite patients led to less use of PEP.	Economic benefits	
	Technical performance: vaccination coverage, number of dog bites, rabies incidence	Average of 65 % dog vaccination coverage in villages where campaigns were conducted; Decline or total elimination of rabies (or rabies-associated deaths) at the local scale in the subsequent years; The proportion of rabies-positive samples decreased over time; Bites declined from 2700 in 2012 onward.	Effective risk mitigation	
	Economic evaluation: cost, cost-effectiveness	A cost-effectiveness study estimated that the cost per human PEP administered was approximately $22.41, while the cost per life saved ranged on average from $862 to $7859.	Economic benefit	

CBOs = Community–Based Organizations. DALY = disability-adjusted life years. ICRAF = World Agroforestry Centre. Mass dog rabies vaccination (MDRV). Mass drug administration (MDA). NGOs = non-governmental organizations. NTDs = Neglected Tropical diseases. OH = One Health. PEP = post-exposure prophylaxis. PPT = Push pull technology. YLL = years of life lost. WASH = Water, Sanitation and Hygiene. WUCs = Water Use Committees.

studies. Eight studies reported the economic benefits of OH initiatives such as cost minimization through improved resource sharing among sectors, cost-effective reduction of disease risks and burden or overall economic growth. Improvement in animal health and human health or wellbeing (e.g., reduced risks of diseases, improved holistic care, improved food safety, improved nutrition, improved animal productivity) were mentioned as OH benefits in seven studies. Improvement in ecosystem health and resilience including improved soil fertility, climate adaptation and biodiversity conservation constituted OH outcomes in four studies.

3.9. Implementation challenges

Successes in the implementation of OH initiatives in Africa have been reported. However, understanding several challenges reported during the implementation of OH initiatives is critical for developing effective policies and strategies to address these challenges in Africa and beyond. Implementation challenges were listed in five studies [94,99,101,107,111]. The challenges have been discussed under the following thematic areas: governance, communication and information sharing, integrated surveillance system, community engagement, political will, resources, infrastructure and facilities, multi-disciplinary workforce capacity and divergent priorities.

Under governance, weak sectoral cooperation was predominantly highlighted [96,97,101,107,111], while lack of clear responsibilities [101,111] and difficulties in establishing effective coordination across ministries [107] were also discussed as implementation challenges. Communication and information sharing challenges were associated with weak intersectoral information sharing and communication channels among health professionals [96,97,101,111,112] and lack of both common reporting lines and data management frameworks [101]. Lack of a centralized surveillance, monitoring and response system for effective integrated surveillance system was discussed in one of the articles [111].

Limited community engagement led to low uptake of OH initiatives. This has been discussed in light of less community involvement and ownership of such initiatives [96,99,107,111] and inadequate public awareness on concept of OH such as many animal owners being unfamiliar with zoonotic diseases [96,111]. Lack of political led to limited cohesive approach in government policies and regulations in addressing public health challenges [101] and poor integration and underfunding of OH structure at the subnational level [111].

Resource related challenges included insufficient financial and human resources [94,96,97,101,111], different funding scales of sectors [96,97], delayed disbursement of funding [94]. Infrastructure and facilities challenges were associated with lack of multidisciplinary laboratories [45,101,112], inadequate transport facilities [45,94,96,107,112], lack of personal protective equipment [101] and infrastructural weaknesses of public services [112]. Inadequate interdisciplinary training [96,101,112], lack of relevant knowledge or skills needed for collaboration [96,101,112], lack of interdisciplinary teamwork [96,101,112], limited staffing [96,101,112] and unattractive salaries [96] resulted in limited multi-disciplinary workforce capacity.

Different priorities have been demonstrated as OH implementation challenge. For example, governments refocusing on other priorities such as poverty reduction/alleviation programmes [111]. Sectors having varied programme priorities that always are inclined to organizational objectives [94,97]. In case of donors' involvement, the OH initiatives may need to undergo policy change and changing priorities to optimise between donors' strategic goals and both government policies and

smallholder farmer's targets [94,96,97].

4. Discussion

This study identified current crucial OH interventions, stakeholders, and outcomes related to smallholders in Africa together with their evaluation based on the WFPHA systematic framework. Building on previous reviews on OH approaches [86,87,114,115], we provide key intervention areas, evaluation scope and implementation challenges under smallholder farmers' settings in Africa.

4.1. Geographical distribution of studies

One Health, being a relatively new concept, has been implemented disproportionately across the African continent. This corroborates previous reports mapping the OH landscape in Africa showing OH initiatives being comparatively more in Eastern Africa followed by Southern Africa and least in Central and West Africa [18]. Apart from OH being a new concept, we could not ascertain how the magnitude of OH needs, funder priority areas, government viewpoints or approvals, or traditional research constraints such as war or conflict influenced the distribution of the studies.

4.2. Stakeholders and actors involved in One Health implementation

This review identified 143 different stakeholders and actors including; various CGIAR centres ICARDA, ILRI, CIAT and CIP; UN agencies (e.g., WHO, FAO), international NGOs (e.g. World Vision); intergovernmental organizations (e.g. WOAH/OIE), international development partners (e.g., Biovision Foundation, USAID, World Bank, Netherlands government); regional development partners; universities (e.g., Swiss TPHI, Makerere University, Sokoine University of Agriculture); various national governments' ministries, departments and agencies; national agricultural research and extension systems (NARES); local governments; local private sectors; local NGOs; CBOs; and private agricultural extension services. The target beneficiaries including individuals, local communities and farmers' organizations are important players in the successful implementation of OH interventions, as they play a central role in the identification of health challenges and development of locally adapted solutions. Additionally, incorporating the perspectives of local stakeholders including farmers, governments and community leaders in community-based approaches and empowerment initiatives in turns promote local ownership that is crucial for the success of OH initiatives.

Despite the broad interest from various stakeholders, there are several necessary steps required to strengthen the multi-pronged nature required for more impactful and successful OH interventions [101,111]. For example, there remains a gap first in the research attention then also in the depth and reach of collaboration networks. Coherent formal guidelines and frameworks that account for roles and responsibilities, and communication strategies are required to further strengthen regional cooperation. There is a need for further development of regional knowledge exchange hubs and data sharing for coherent communication among stakeholders including smallholder farmers. This can be further improved by employing digital tools that integrate both data collection and communication. To expand the multisectoral engagement, cultural sensitivity and local buy-in, knowledge transfer and capacity-building initiatives can be improved using local languages for successful implementation at the grassroots level. Beyond the four health themes, there is a need to include important fields such as social science to understand sociocultural barriers. For research and enhanced multisectoral engagement, sustainable funding and resource sharing leveraging both local (e.g. private sector) and collaborative international funders will be key for regional research in Africa where funding is often a constraint for research.

4.3. Emerging One Health themes

This review shows that most OH initiatives focused on partnerships of human-animal health sectors, with little attention given to human-environment health sectors including agriculture. About two-thirds of the OH initiatives in the reviewed studies focused on zoonotic diseases, with very little on other pressing global health challenges. The lack of reported issues emanating from the animal-environmental interface in this study underlines the need for more collaboration between animal and environmental (including plant, and wildlife) health sectors. The need to improve the focus on environmental themes has been previously reported by Barret and Bouley [116] and later by Delesalle et al. [87] who cited a lack of collaborative OH initiatives involving animal and environmental sectors.

In the studies which were the focus of this review, twelve broad groups of OH themes were identified as currently receiving attention in Africa, albeit to varying degrees of implementation and success:

1. Zoonotic and infectious diseases: Endemic and re-emerging zoonotic diseases constituting OH challenges included rabies, Rift Valley Fever, visceral leishmaniasis, cystic echinococcosis and mastitis [44,45,99,100,108–112]. Shared human and animal infectious diseases addressed by OH included viral infections such as African swine fever and infectious soil-transmitted parasitic worms such as whipworm (*Trichuris trichuria*), roundworm (*Ascaris lumbricoides*), hookworms (*Ancylostoma duodenale, Necator americanus*) and hydatid worm (*Echinococcus granulosus*) [97,104]. Infectious animal diseases rampant in small ruminants addressed using OH included *Peste des petits* ruminants and bacterial infections such as contagious caprine pleuropneumonia and contagious bovine pleuropneumonia [103,108].

2. Human food and animal feed and nutrition security such as the need for increased forages and productivity of agri-food systems [94,95,105,106,113].

3. Livelihood and well-being such as the need for enhanced healthy living and profitability of agri-food systems [94,95,113].

4. Water security such as water access, sanitation and hygiene and waterborne diseases [45,97,98].

5. Antimicrobial resistance resulting from antibiotic misuse for human and livestock diseases [45,111].

6. Land degradations including soil erosion and poor soil fertility due to poor management practices [94,105].

7. Food safety including reduction in mycotoxins, pesticide residues, veterinary drug contamination, and foodborne pathogens such as bovine tuberculosis, brucellosis and mastitis [44,45].

8. Crop health: weeds such as Striga and insect pests such as stemborers and fall armyworm [100].

9. Biodiversity loss due to non-discriminatory use of pesticides and increased deforestation [103].

10. Climate change impacts and its ramifications including flooding and drought [103].

11. Gender inequity resulting in the need to empower women in the community [103].

None of the reviewed studies focused on malaria, chikungunya virus or dengue virus despite being diseases of public health importance in most developing countries including those in Africa [117]. During the past decades, the OH approach has been shown to result in a reduction in malaria incidence elsewhere [118,119]. For instance, using the OH approach such as transdisciplinary photovoice led to a significant reduction of malaria in rural communities in Malaysia [118]. Similar OH initiatives will be key to strengthen the campaigns against vectors and the proliferation of diseases in Africa.

4.4. Types of One Health initiatives

Based on a WFPHA systematic framework, all implemented OH initiatives mentioned in the reviewed studies were "people-centred", with most having components of governance, capacity building, protection,

prevention, knowledge creation and dissemination, promotion and advocacy. For successful implementation, OH initiatives may require incorporating most components of the WFPHA systematic framework. Governance and capacity building through increased collaborations of different disciplines/sectors, defining responsibilities and training of health sectors, community involvement, and prudent resource allocation are key during the initial implementation of OH initiatives. For instance, Danielsen et al. [45] reported joint mobile crop-livestock advisory services through a partnership of crop and livestock sectors led to the cost-effective sharing of operational costs. The project also involved a participatory approach promoting co-creation and exchange of ideas through cross-learning and training of communities in remote areas on OH issues and interventions. Other OH studies have proposed different frameworks for OH initiatives. For instance, Queenan et al. [2] and the World Bank [120] have recognized seven components that may be crucial for the implementation of the OH approach at the national level, namely, (1) governance and management (includes political goodwill, (2) networks and partnerships, (3) capacity development on OH (includes training professionals in different disciplines), (4) surveillance, disaster preparedness and response, (5) communication and advocacy, (6) operational research (includes multidisciplinary research) and (7) monitoring and evaluation. Additionally, Rüegg et al. [121] proposed an evaluation framework for OH initiatives which includes the Network for Evaluation of One Health (NEOH) anchored in four elements, namely, (1) contextualizing the OH initiative, (2) assessing expected outcomes conferring to the theory of change (TOC) and providing unexpected outcomes, (3) assessing the "OH-ness" in terms of operations and infrastructure needed for implementation of OH initiative, and (4) comparing the degree of "OH-ness" and the OH outcomes.

4.5. One Health outcomes

One Health initiatives in the reviewed studies yielded a wide range of benefits including social, economic, effective risk mitigation, human, animal and environmental health benefits:

Social benefits: OH initiatives have improved access to holistic care in rural and hard-to-reach areas [45,107,111]. The initiatives also resulted in improved mobilization of communities for outreaches and availability of both human and animal health services [107]. The introduction of mobile clinics improved service delivery, saved time and led to more female farmers and other vulnerable groups attending clinic sessions held close to their homes [45]. Implementation of WASH programs in schools was shown to reduce student absenteeism [98]. Farmers who have adopted push-pull technology reported improved social aspects such as social ties, friendship, social support systems and exchange of information [95].

Economic benefits: The coordination and collaboration across sectors in providing OH services save and offer cost-sharing opportunities for critical resources. One Health approach is thus highly applicable in some countries and remote areas where governments are struggling with limited resources. The provision of OH services close to the communities reduces the time and money spent to access the services, therefore, improving the financial conditions of the ultimate beneficiaries [45,98,107]. Much higher impact can be realized when critical resources are being pooled by the health sectors. For instance, cost-sharing across health sectors championing integrated service interventions is ideal for solving logistical challenges such as vehicle and fuel costs and reducing the costs for materials, health training, staff salaries, allowance and accommodation [104,107,108]. Mindekem et al. [109] and Mpolya et al. [100] demonstrated that cost-effectiveness per DALY averted and life saved are high in integrated service delivery such as mass dog anti-rabies vaccination campaigns. Mindekem et al. [109] opined that this cost efficiency was further improved by strengthening communication between animal and human health. One Health initiative has been proven to significantly improve farmers' economic status due to fewer expenses for inputs and seeking health services [110].

Effective risk mitigation: The multidisciplinary team coupled with frequent meetings led to effective OH surveillance and improved implementation of prevention and treatment activities [44,103,107,111]. For instance, mass anti-rabies vaccination led to increased vaccination coverage, reduced dog bites, decline or total elimination of rabies and rabies-associated deaths of humans at the local scale [100] and in N'Djamena, the capital city of Chad [112].

Human health and well-being: One Health approach has been demonstrated to improve WASH behaviours, lowering transmission, risk and treatment of water-borne diseases [97,98]. Scaling up of agroecological cropping practices through a multidisciplinary approach and involvement of smallholder farmers led to improved household food security and nutrition and livelihood [94,105]. For instance, villagers practising push-pull technology reported improved overall well-being due to increased food security, milk production, income/savings and employment [95]. Mass dog vaccination campaigns effectively led to anti-rabies vaccination coverage and subsequent reduction of rabies-associated mortality [100,104,109].

Capacity building: Multidisciplinary training and equipping health partners, academics and students through curriculum revision projects are critical for the implementation and sustainability of OH interventions [45,94,100,111]. Empowering the community by training, awareness creation and direct involvement in OH interventions through leadership roles, contracts and jobs [98,103,105].

Animal health and welfare: OH intervention resulted in improvement in animal health and welfare in several ways. For instance, the strengthened capacity of farmers to diversify feed production (forage, tree, fodder and grass) led to sustainable animal feed sources and consequently improved productivity [113]. The comfortable and healthy living environment for animals promotes good animal-human interactions and reduces disease incidence and exposure of humans to zoonotic diseases [110,113]. Improved cattle nutrition and carcass health due to better pasture feed quality and quantity lead to improved cattle reproductive performance [110]. Mass dog anti-rabies vaccination campaigns improved vaccination coverage and overall dog health [104].

Environmental health: Soil degradation and climate change are some of the environmental constraints to agriculture. Farmers practising agroecological practices such as push-pull technology, maize legume intercropping and agroforestry could produce high food-crop yields on degraded soils. These farmers observed a significant improvement in soil health status and soil moisture [94,95,105]. Additionally, these agroecological practices lowered risks associated with pesticides and mineral fertilizers including high prices and low agrobiodiversity [94,95]. Push-pull technology also reduces parasitic weeds like striga and devasting lepidopteran pests such as stem borers [95]. Nankanja et al. [98] leveraged WASH implementation initiatives to collaborate with other stakeholders and mobilize youths in tree planting and environmental education activities that restore watersheds.

4.6. Evaluation method and outcome metrics

Whereas the reviewed studies on OH have reported OH outcomes, most of them lacked metrics to evaluate the OH outcomes, systematically. Additionally, given that OH is a new concept, there is a lack of reported standard evaluation methods and outcome metrics to estimate OH benefits. Consequently, there is a need to adopt and integrate outcome metrics and associated evaluation methods from different disciplines. By adopting human health disciplinary approaches commonly used in health outcomes research, we found that at least one evaluation method was adopted for measuring OH outcomes. Technical and economic performance and their associated quantitative metrics to measure OH outcomes have recently been discussed [86,87,114,115,120]. Although technical observation and perception were used in some of the studies, they are qualitative and have been least mentioned/used in previous analyses, making it difficult to perform effective evaluations of OH initiatives.

The present study identified OH metrics used in technical performance evaluation including mortality rate, disease incidence, vaccination coverage, number of beneficiaries, DALY averted, YLL averted, implementation success rate, infection rate, time saved, school attendance and bacterial load while those used in the economic evaluation included cost minimization, cost-effectiveness, break-even point, cost-effectiveness per DALY averted and cost-effectiveness per life saved. We found that OH initiatives can result in short-term outcomes such as increased vaccination and disease burden to long-term outcomes such as DALY averted and YLL saved. Worth noting, that DALY averted and YLL saved are important metrics in evaluating outcomes in public health. DALY is a health outcome metric developed by WHO which measures both the disease burden and severity (expressed as morbidity and mortality). For instance, in integrated canine vaccination and PEP program, Mindekem, et al. [109] found that increased vaccination coverage can result in 659 DALY averted each year compared to 454 DALY averted in the use of PEP alone. Additionally, the author reported that the cost-effectiveness per DALY averted was higher for integrated intervention than the use of PEP alone. YLL allows for the estimation of risk burden resulting in human deaths due to lack or inadequate interventions. For instance, Léchenne et al. [112] observed that nearly 500,000 lives over 15 YLL were saved by the increased free availability of dog vaccines against rabies.

Most OH outcomes reported in each study were largely on human and animal health. All-inclusive outcome metrics that considered the OH triad were lacking in reviewed studies, for instance, outcome metrics to measure the ecosystem impact of OH initiatives. We observed heterogeneity of evaluation methods and outcomes metrics within similar clusters of OH initiatives. For example, in three separate rabies control programs, Lankester et al. [104] used school attendance, time saved, dog vaccination coverage and cost-effectiveness as outcome metrics, Mindekem, et al. [109] employed disease incidence, vaccination coverage, DALY averted, cost-effectiveness, cost-efficiency, break-even point and cost-effectiveness per DALY averted as outcome metrics while El Berbri et al. [108] used vaccination coverage, infection rate, cost-effectiveness and cost-efficiency as outcome metrics. Therefore, this further underscores the need for a cohesive and standardized framework designed and endorsed by different disciplines for clusters of OH initiatives.

4.7. Implementation challenges

Governance and coordination: Strong governance and leadership are critical for the effective implementation of OH initiatives in Africa. However, coordination was lacking among various stakeholders to support the effective implementation of OH initiatives. Lack of governance, low institutional capacity, weak sectoral cooperation and inadequate disciplinary representation have driven stakeholder hesitancy to engage, thus further jeopardizing multi- and transdisciplinary collaborations [96,97,101,107,111]. Lack of clear responsibilities often leads to conflict among sectors due to competition for resources, influence and leadership roles in the implementation of OH initiatives [101,111]. Difficulties with coordination across ministries affected planning which became apparent when outreaches were scheduled for different times [107]. Lack of coordination structures not only constrains consensus on priority-setting [96] but also hampers communication and effective response to emergence such as disease outbreaks [101]. Differences in health policies also constrain strong coordination across sectors [96].

Communication and information sharing: Open and transparent communication among actors and strategic communication with communities are needed for successful OH implementation in Africa. However, weak intersectoral information sharing and communication channels among health professionals hinder the operationalization of the OH strategy [96,97,101,111,112]. This was amplified by a lack of common reporting lines and a data management framework [101]. The lack of a coordinated reporting channel is often associated with late reporting and underreporting, therefore, hampering response efforts [94,101].

Integrated surveillance system: Integrated surveillance systems often improve risk mitigation through early detection and quick response. Nevertheless, the lack of a centralized surveillance, monitoring, and response system has been reported during the implementation of OH initiatives [111].

Community engagement: Most OH initiatives may not be sustainable due to less community involvement and ownership of the initiatives when they are excluded from planning and programming consultations [96,99,101,107]. For instance, many community members are unfamiliar with OH issues due to inadequate public awareness resulting in poor buy-in [96,111].

Political will: Good political will is required for effective OH implementation at sub-national, national and international levels. However, OH in Africa are often characterised by inadequate political commitment to and ownership which constrains cooperation and coordination across core sectors. Government policies and regulations lack a cohesive approach to address public health challenges to impact human, animal and environmental health, sustainably [101]. For example, in Ethiopia, OH structure is being practised at the regional and zonal levels but poorly integrated and often underfunded at the subnational level [111].

Resources: In Africa, implementation of OH initiatives is faced with insufficient or poorly allocated financial and human resources, thus, leading to limited sustainable health outcomes for animals, humans and the environment [94,96,97,111]. Effective implementation of the OH strategy has often been crippled by a lack of collaborative funding for health sectors [96,97] and late disbursement of funding [94]. Inadequate resources hampers the dissemination of results and raising public awareness [96]. Inadequate resources also result in inconvenient times for the implementation of activities [96]. Limited resources and investment led to understaffing where only a few animal health professionals were actively involved in the implementation of the OH strategy [101,111].

Infrastructure and facilities: Infrastructure and logistical support such as multidisciplinary laboratories, quarantine facilities, vehicles or multidisciplinary mobile clinics are enablers for successful implementation [45,112]. However, the lack of infrastructure such as multidisciplinary laboratories with medical drugs storage facilities, equipment and reagents as well as personal protective equipment is considered a large implementation challenge [101]. Infrastructural weaknesses of public services including communication network coverage and transportation facilities in the project countries hampered the effective implementation of the OH strategy [112]. Limited transport facilities for health professionals and materials in the field were also reported as a challenge [94,96,107]. Few infrastructures and facilities reduce disease testing and surveillance, data collection and distribution of vaccines, and medicines [111].

Inter-disciplinary workforce capacity: One Health being a relatively new concept to health sectors required more training and time in the field [107]. However, inadequate interdisciplinary training, lack of relevant knowledge or skills needed for collaboration, lack of multidisciplinary teamwork, limited staffing and unattractive salaries are challenges to implementing OH strategy [96,101,112].

Priorities: Some OH initiatives are faced with diverging priorities before the sustainable outcomes are fully realized. For instance, governments always tend to divert focus on other priorities such as poverty reduction [111]. Also, varied institutional priorities of sectors such as a lack of cohesive organizational objectives in addition to donor-driven priorities tend to limit the sustainable health outcomes of OH initiatives [94,97]. For instance, donor-driven priorities are always anchored on basic research while applied research is neither recognized nor rewarded [96].

4.8. Limitation

While we attempted to broaden our search terms, some studies which

may have initiatives under the auspices of OH but not labelled by these search terms as such may have been missed. Additionally, the authors recognize that most studies on OH initiatives did not mention the smallholder farmers or were based on national strategic plans focusing on the general public, therefore, limiting the final number of articles used in this review. Nevertheless, we believe that the low number of relevant articles is also empirical evidence of the lack of research attention on OH initiatives to date, calling for more such work to be conducted in smallholder farming areas in sub-Saharan Africa.

5. Conclusion

Given increasingly complex global health challenges, the OH approach becomes a critical vehicle to harness multisectoral efforts for better development outcomes. In the case of smallholder farmers in Africa, our review shows that there is still limited documented evidence of OH initiatives with only a few countries beginning to make concrete steps. For instance, there is a lack of household and farm-adapted metrics to measure outcomes with much current focus still on medical and veterinary OH approaches. Importantly, many of the excluded studies described OH imperatives with only suggestions for pathways for redress and not necessarily field implementation (e.g. Alhaji et al. [56]). Other studies described ongoing projects focusing on smallholder farmers where OH initiatives have been well-defined with only projected outcomes (e.g. Alders et al. [122]). Clear underlying provenance to the OH initiative may be difficult to comprehend, but the outputs and outcomes of the OH initiative can be assessed. Of the studies reviewed, most OH initiatives focused on zoonotic diseases with other global pressing challenges receiving little attention. This study underscores, the need for increased focus on the ecosystems especially on the health of plants since they are major food sources and support social and economic lives for most small-scale farmers. Challenges to the successful implementation of OH initiatives included weak governance and coordination structures, poor communication and information sharing, lack of integrated surveillance system, limited community engagement, lack of political will, inadequate resources, inadequate infrastructure and logistical support, limited multi-disciplinary workforce capacity and varied priorities by government, health sectors and donors. The results show a need for different health sectors to design a standard framework for the implementation of OH initiatives. Additionally, there is a need for harmonised evaluation methods and metrics for measuring OH outputs and outcomes, to avoid underestimation or overestimation of OH benefits.

Ethics statement

No ethical approval was required for this specific study.

CRediT authorship contribution statement

Evanson R. Omuse: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Honest Machekano:** Writing – review & editing, Supervision. **Bonoukpoè M. Sokame:** Writing – review & editing. **Daniel M. Mutyambai:** Writing – review & editing, Supervision. **Thomas Dubois:** Writing – review & editing. **Sevgan Subramanian:** Writing – review & editing, Funding acquisition. **Frank Chidawanyika:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

All authors: Evanson R. Omuse, Honest Machekano, Bonoukpoè M. Sokame, Daniel M. Mutyambai, Thomas Dubois, Sevgan Subramanian, Frank Chidawanyika, declare no conflict of interest.

Acknowledgements

The authors gratefully acknowledge the financial support for this research by the following organizations and agencies: The Ingvar Kamprad Elmtaryd Agunnaryd (IKEA) foundation through the "Scaling regenerative black soldier fly farming along with vegetable push-pull cropping systems in rural Kenya, Rwanda and Uganda" project (Grant number: 1175); the Swedish International Development Cooperation Agency (SIDA); Biovision Foundation through the project Increasing diffusion and impact of the vegetable-integrated push-pull technology (VIPPT) in eastern Africa from a 'One Health' perspective (Grant number: BV - DPP-012-2023-2025) the Swiss Agency for Development and Cooperation (SDC); the Australian Centre for International Agricultural Research (ACIAR); the Norwegian Agency for Development Cooperation (NorAD); the German Federal Ministry for Economic Cooperation and Development (BMZ); and the Government of the Republic of Kenya. The views expressed herein do not necessarily reflect the official opinion of the donors.

Data availability

No data was used for the research described in the article.

References

[1] One Health High-Level Expert Panel (OHHLEP), D.T.S. Hayman, W.B. Adisasmito, S. Almuhairi, C.B. Behravesh, P. Bilivogui, S.A. Bukachi, N. Casas, N. C. Becerra, D.F. Charron, A. Chaudhary, 2023, Developing one health surveillance systems. One Health 17, 100617. doi:https://doi.org/10.1016/j.onehlt.2023.100617.

[2] K. Queenan, J. Garnier, L.R. Nielsen, S. Buttigieg, D.D. Meneghi, M. Holmberg, J. Zinsstag, S. Rüegg, B. Häsler, R. Kock, Roadmap to a one health agenda 2030, CAB Rev. Perspect. Agric. Vet. Sci. Nutr. Nat. Res. Forum 12 (2017) 1–17, https://doi.org/10.1079/PAVSNNR201712014.

[3] S.R. Rüegg, B. Häsler, L.R. Nielsen, S.C. Buttigieg, M. Santa, M. Aragrande, M. Canali, T. Ehlinger, K. Queenan, I. Chantziaras, E. Boriani, M. Radeski, M. Bruce, H. Keune, H. Bennani, C.I. Speranza, L.P. Carmo, R. Esposito, M.-E. Filippitzi, K.M. McIntyre, B.J. McMahon, M. Peyre, L.C. Falzon, K.L. Bardosh, C. Frazzoli, T. Hald, G. Marcus, J. Zinsstag, A one health evaluation framework, in: S.R. Rüegg, B. Häsler, J. Zinsstag (Eds.), Integrated Approaches to Health: A Handbook for the Evaluation of One Health, Wageningen Academic Publishers, Wageningen, 2018, pp. 14–21, https://doi.org/10.3920/978-90-8686-875-9.

[4] WHO, One Health. https://www.who.int/news-room/fact-sheets/detail/one-health, 2024 (accessed 15 April 2024).

[5] D. Destoumieux-Garzón, P. Mavingui, G. Boetsch, J. Boissier, F. Darriet, P. Duboz, C. Fritsch, P. Giraudoux, F. Le Roux, S. Morand, C. Paillard, The one health concept: 10 years old and a long road ahead, Front. Vet. Sci. 5 (2018) 306018, https://doi.org/10.3389/FVETS.2018.00014/BIBTEX.

[6] E.P.J. Gibbs, The evolution of one health: a decade of progress and challenges for the future, Vet. Rec. 174 (2014) 85–91, https://doi.org/10.1136/VR.G143.

[7] R. Mendes, P. Garbeva, J.M. Raaijmakers, The rhizosphere microbiome: significance of plant beneficial, plant pathogenic, and human pathogenic microorganisms, FEMS Microbiol. Rev. 37 (2013) 634–663, https://doi.org/10.1111/1574-6976.12028.

[8] W. Agnès, V.P. Isabelle, C.M. Anne-Marie, S. Adam, V. Philippe, Interactions of Salmonella with animals and plants, Front. Microbiol. 5 (2014) 1–18, https://doi.org/10.3389/FMICB.2014.00791.

[9] S. Savary, L. Willocquet, S.J. Pethybridge, P. Esker, N. McRoberts, A. Nelson, The global burden of pathogens and pests on major food crops, Nat. Ecol. Evol. 3 (2019) 430–439, https://doi.org/10.1038/s41559-018-0793-y.

[10] D.M. Rizzo, M. Lichtveld, J.A.K. Mazet, E. Togami, S.A. Miller, Plant health and its effects on food safety and security in a one health framework: four case studies, One Heal. Outlook. 3 (2021) 1–9, https://doi.org/10.1186/S42522-021-00038-7.

[11] FAO, The Economic Lives of Smallholder Farmers, FAO, Rome, 2015, https://doi.org/10.13140/RG.2.1.3223.9440.

[12] H.N. Pahalvi, L. Rafiya, S. Rashid, B. Nisar, A.N. Kamili, Chemical fertilizers and their impact on soil health, in: G.H. Dar, R.A. Bhat, M.A. Mehmood, K.R. Hakeem (Eds.), Microbiota and Biofertilizers, Springer, Cham, 2021, pp. 1–20, https://doi.org/10.1007/978-3-030-61010-4_1.

[13] T.L. Fess, V.A. Benedito, Organic versus conventional cropping sustainability: a comparative system analysis, Sustainability 10 (2018) 272, https://doi.org/10.3390/SU10010272.

[14] M.F. Ahmad, F.A. Ahmad, A.A. Alsayegh, M. Zeyaullah, A.M. AlShahrani, K. Muzammil, A.A. Saati, S. Wahab, E.Y. Elbendary, N. Kambal, M. H. Abdelrahman, S. Hussain, Pesticides impacts on human health and the environment with their mechanisms of action and possible countermeasures, Heliyon 10 (2024) e29128, https://doi.org/10.1016/J.HELIYON.2024.E29128.

[15] T. Falkenberg, S. Ekesi, C. Borgemeister, Integrated Pest management (IPM) and one health - a call for action to integrate, Curr. Opin. Insect Sci. 53 (2022) 100960, https://doi.org/10.1016/J.COIS.2022.100960.

[16] F. Chidawanyika, B. Muriithi, S. Niassy, F.O. Ouya, J.O. Pittchar, M. Kassie, Z. R. Khan, Sustainable intensification of vegetable production using the cereal 'push - pull technology': benefits and one health implications, Environ. Sustain. 6 (2023) 25–34, https://doi.org/10.1007/s42398-023-00260-1.

[17] V. Hoffmann, B. Paul, T. Falade, A. Moodley, N. Ramankutty, J. Olawoye, R. Djouaka, E. Lekei, N. de Haan, P. Ballantyne, J. Waage, A one health approach to plant health, CABI Agric. Biosci. 3 (2022) 1–7, https://doi.org/10.1186/S43170-022-00118-2/TABLES/1.

[18] F.O. Fasina, O.G. Fasanmi, Y.J. Makonnen, C. Bebay, B. Bett, K. Roesel, The one health landscape in sub-Saharan African countries, One Health 13 (2021) 100325, https://doi.org/10.1016/J.ONEHLT.2021.100325.

[19] V. Dzingirai, S. Bukachi, M. Leach, L. Mangwanya, I. Scoones, A. Wilkinson, Structural drivers of vulnerability to zoonotic disease in Africa, Philos. Trans. R. Soc. B Biol. Sci. 372 (2017) 20160169, https://doi.org/10.1098/RSTB.2016.0169.

[20] C.A. Harvey, Z.L. Rakotobe, N.S. Rao, R. Dave, H. Razafimahatratra, R. H. Rabarijohn, H. Rajaofara, J.L. MacKinnon, Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar, Philos. Trans. R. Soc. B Biol. Sci. 369 (2014) 20130089, https://doi.org/10.1098/RSTB.2013.0089.

[21] E.K. Derbile, S.Z. Bonye, G.Y. Yiridomoh, Mapping vulnerability of smallholder agriculture in Africa: vulnerability assessment of food crop farming and climate change adaptation in Ghana, Environ. Challenges. 8 (2022) 100537, https://doi.org/10.1016/J.ENVC.2022.100537.

[22] B. Talukder, G.W. van Loon, K.W. Hipel, S. Chiotha, J. Orbinski, Health impacts of climate change on smallholder farmers, One Health 13 (2021) 100258, https://doi.org/10.1016/J.ONEHLT.2021.100258.

[23] D.M.S. Baptista, M.M. Farid, D. Fayad, L. Kemoe, L.S. Lanci, M.P. Mitra, T. S. Muehlschlegel, C. Okou, J.A. Spray, K. Tuitoek, F. Unsal, Climate Change and Chronic Food Insecurity in Sub-Saharan Africa, International Monetary Fund, Washington, DC, 2022.

[24] H.E. Thompson, L. Berrang-Ford, J.D. Ford, Climate change and food security in sub-Saharan Africa: a systematic literature review, Sustainability 2 (2010) 2719–2733, https://doi.org/10.3390/SU2082719.

[25] FAO, Smallholders and Family Farmers. https://www.fao.org/family-farming/detail/en/c/273864/, 2024. (Accessed 27 April 2024).

[26] K.E. Giller, T. Delaune, J.V. Silva, M. van Wijk, J. Hammond, K. Descheemaeker, G. van de Ven, A.G. Schut, G. Taulya, R. Chikowo, J.A. Andersson, Small farms and development in sub-Saharan Africa: farming for food, for income or for lack of better options? Food Secur. 13 (2021) 1431–1454, https://doi.org/10.1007/S12571-021-01209-0/FIGURES/7.

[27] A. Kamara, A. Conteh, E.R. Rhodes, R.A. Cooke, The relevance of smallholder farming to African agricultural growth and development, Afr. J. Food Agric. Nutr. Dev. 19 (2019) 14043–14065, https://doi.org/10.18697/AJFAND.84.BLFB1010.

[28] IFAD, Enabling Poor Rural People to Overcome Poverty: Smallholders, Food Security, and The Environment, IFAD, Rome, 2013.

[29] K. Thabane, H. Bright, C.H. Paramaiah, N. Zinyengere, S. Hachigonta, The vulnerability of smallholder farmers to climate change: evidence from Maphutseng, Lesotho, Int. J. Environ. Dev. 11 (2014) 19–41, https://doi.org/10.5897/INGOJ2013.0280.

[30] C. Delgado, K. Tschunkert, D. Smith, Food Insecurity in Africa: Drivers and Solutions, Stockholm International Peace Research Institute, Stockholm, 2023.

[31] P. Nyambo, P. Nyambo, Z. Mavunganidze, V. Nyambo, Sub-Saharan Africa smallholder farmers agricultural productivity: risks and challenges, in: H. A. Mupambwa, A.D. Nciizah, P. Nyambo, B. Muchara, N.N. Gabriel (Eds.), Food Security for African Smallholder Farmers. Sustainability Sciences in Asia and Africa, Springer, Singapore, 2022, pp. 47–58, https://doi.org/10.1007/978-981-16-6771-8_3.

[32] A.H. Wudil, M. Usman, J. Rosak-Szyrocka, L. Pilař, M. Boye, Reversing years for global food security: a review of the food security situation in sub-Saharan Africa (SSA), Int. J. Environ. Res. Public Health 19 (2022) 14836, https://doi.org/10.3390/IJERPH192214836.

[33] Y.B. Ngoshe, E. Etter, J.P. Gomez-Vazquez, P.N. Thompson, Knowledge, attitudes, and practices of communal livestock farmers regarding animal health and zoonoses in far northern KwaZulu-Natal, South Africa, Int. J. Environ. Res. Public Health 20 (2022) 511, https://doi.org/10.3390/IJERPH20010511.

[34] M.P. Muehlenbein, Human-wildlife contact and emerging infectious diseases, in: E. Brondízio, E. Moran (Eds.), Human-Environment Interactions, Springer, Dordrecht, 2013, p. 79, https://doi.org/10.1007/978-94-007-4780-7_4.

[35] D.J. Decker, D.T. Evensen, W.F. Siemer, K.M. Leong, S.J. Riley, M.A. Wild, K. T. Castle, C.L. Higgins, Understanding risk perceptions to enhance communication about human-wildlife interactions and the impacts of zoonotic disease, ILAR J. 51 (2010) 255–261, https://doi.org/10.1093/ilar.51.3.255.

[36] A.H. Desta, Pastoralism and the issue of zoonoses in Ethiopia, J. Biol. Agric. Healthc. 6 (2016) 21–27, https://doi.org/10.1186/s13570-023-00274-8.

[37] N.B. Alhaji, A.M. Adeiza, E.A. Godwin, A.E. Haruna, M.B. Aliyu, I.A. Odetokun, An assessment of the highly pathogenic avian influenza resurgence at human-poultry-environment interface in north-Central Nigeria: sociocultural determinants and one health implications, One Health 16 (2023) 100574, https://doi.org/10.1016/J.ONEHLT.2023.100574.

[38] L.H. Taylor, S.M. Latham, M.E.J. Woolhouse, Risk factors for human disease emergence, Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 356 (2001) 983–989, https://doi.org/10.1098/RSTB.2001.0888.

[39] H. Amuguni, R. Mdegela, C. Rioux, J. Killewo, A university driven approach to engaging communities in solving complex health problems at the human-animal-environmental interface: a one health demonstration site survey in Kilosa District, Tanzania, Environ. Nat. Resour. Res. 7 (2017) 82, https://doi.org/10.5539/ENRR.V7N1P82.

[40] A. Suleiman, E.L. Jackson, J. Rushton, Challenges of pastoral cattle production in a sub-humid zone of Nigeria, Trop. Anim. Health Prod. 47 (2015) 1177–1185, https://doi.org/10.1007/S11250-015-0845-0.

[41] M.H. Abdilatif, J.O. Onono, F.K. Mutua, Analysis of pastoralists' perception on challenges and opportunities for sheep and goat production in northern Kenya, Trop. Anim. Health Prod. 50 (2018) 1701–1710, https://doi.org/10.1007/S11250-018-1613-8.

[42] C.R. Gustafson, E. VanWormer, R. Kazwala, A. Makweta, G. Paul, W. Smith, J. A. Mazet, Educating pastoralists and extension officers on diverse livestock diseases in a changing environment in Tanzania, Pastoralism 5 (2015) 1–12, https://doi.org/10.1186/S13570-014-0022-5/FIGURES/3.

[43] T.P. Lanyasunya, L.W. Wamae, H.H. Musa, O. Olowofeso, I.K. Lokwaleput, The risk of mycotoxins contamination of dairy feed and milk on smallholder dairy farms in Kenya, *Pakistan*, J. Nutr. 4 (2005) 162–169, https://doi.org/10.3923/PJN.2005.162.169.

[44] S.N. Garcia, J.P.M. Mpatswenumugabo, P. Ntampaka, S. Nandi, J.S. Cullor, A one health framework to advance food safety and security: an on-farm case study in the Rwandan dairy sector, One Health 16 (2023) 100531, https://doi.org/10.1016/J.ONEHLT.2023.100531.

[45] S. Danielsen, C. Alokit, C. Aliamo, I. Mugambi, A. Aliations, How crop–livestock clinics are advancing one health: a pilot case from Uganda, One Health Cases 2022 (2022) ohcs20220002, https://doi.org/10.1079/onehealthcases.2022.0002.

[46] K. Roesel, D. Grace, Food Safety and Informal Markets: Animal Products in Sub-Saharan Africa, first ed., Routledge, London, 2014.

[47] N.K. Njeru, C.A.O. Midega, J.W. Muthomi, J.M. Wagacha, Z.R. Khan, Influence of socio-economic and agronomic factors on aflatoxin and fumonisin contamination of maize in western Kenya, Food Sci. Nutr. 7 (2019) 2291, https://doi.org/10.1002/FSN3.1070.

[48] M.T. Mergia, E.D. Weldemariam, O.M. Eklo, G.T. Yimer, Small-scale farmer pesticide knowledge and practice and impacts on the environment and human health in Ethiopia, J. Heal. Pollut. 11 (2021) 1–19, https://doi.org/10.5696/2156-9614-11.30.210607.

[49] E. Isgren, E. Andersson, An environmental justice perspective on smallholder pesticide use in sub-Saharan Africa, J. Environ. Dev. 30 (2020) 68–97, https://doi.org/10.1177/1070496520974407.

[50] H. Machekano, W. Masamba, B.M. Mvumi, C. Nyamukondiwa, Cabbage or 'pesticide' on the platter? Chemical analysis reveals multiple and excessive residues in African vegetable markets, Int. J. Food Contam. 6 (2019) 1–13, https://doi.org/10.1186/S40550-019-0072-Y/TABLES/4.

[51] A.V.F. Ngowi, T.J. Mbise, A.S.M. Ijani, L. London, O.C. Ajayi, Smallholder vegetable farmers in northern Tanzania: pesticides use practices, perceptions, cost and health effects, Crop Prot. 26 (2007) 1617–1624, https://doi.org/10.1016/J.CROPRO.2007.01.008.

[52] J. Humphrey, Food Safety, Trade, Standards and the Integration of Smallholders Into Value Chains: A Review of the Literature, IFAD, Rome, Italy, 2017, https://doi.org/10.3892/mmr.2017.7929.

[53] S.E. Mshana, C. Sindato, M.I. Matee, L.E.G. Mboera, Antimicrobial use and resistance in agriculture and food production systems in Africa: a systematic review, Antibiot 10 (2021) 976, https://doi.org/10.3390/ANTIBIOTICS10080976.

[54] J.A. Ayukekbong, M. Ntemgwa, A.N. Atabe, The threat of antimicrobial resistance in developing countries: causes and control strategies, Antimicrob. Resist. Infect. Control 6 (2017) 1–8, https://doi.org/10.1186/S13756-017-0208-X/TABLES/2.

[55] B.A. Gemeda, K. Amenu, U. Magnusson, I. Dohoo, G.S. Hallenberg, G. Alemayehu, H. Desta, B. Wieland, Antimicrobial use in extensive smallholder livestock farming systems in Ethiopia: knowledge, attitudes, and practices of livestock keepers, Front. Vet. Sci. 7 (2020) 55, https://doi.org/10.3389/FVETS.2020.00055.

[56] N.B. Alhaji, I.A. Odetokun, A.M. Adamu, A. Hassan, M.K. Lawan, F.O. Fasina, Antimicrobial usage and associated residues and resistance emergence in smallholder beef cattle production systems in Nigeria: a one health challenge, Vet. Res. Commun. 47 (2023) 233–245, https://doi.org/10.1007/s11259-022-09944-1.

[57] A. Chokshi, Z. Sifri, D. Cennimo, H. Horng, Global contributors to antibiotic resistance, J. Global Infect. Dis. 11 (2019) 36, https://doi.org/10.4103/JGID.JGID_110_18.

[58] L. Ampaire, A. Muhindo, P. Orikiriza, J. Mwanga-Amumpaire, L. Bebell, Y. Boum, A review of antimicrobial resistance in East Africa, Afr. J. Lab. Med. 5 (2016) a432, https://doi.org/10.4102/AJLM.V5I1.432.

[59] M.E. Falagas, D.E. Karageorgopoulos, J. Leptidis, I.P. Korbila, MRSA in Africa: filling the global map of antimicrobial resistance, PLoS ONE 8 (2013) e68024, https://doi.org/10.1371/JOURNAL.PONE.0068024.

[60] F. Chidawanyika, P. Mudavanhu, C. Nyamukondiwa, Global climate change as a driver of bottom-up and top-down factors in agricultural landscapes and the fate of host-parasitoid interactions, Front. Ecol. Evol. 7 (2019) 436881, https://doi.org/10.3389/FEVO.2019.00080/BIBTEX.

[61] C. Nyamukondiwa, H. Machekano, F. Chidawanyika, R. Mutamiswa, G. Ma, C.-S. Ma, Geographic dispersion of invasive crop pests: the role of basal, plastic climate stress tolerance and other complementary traits in the tropics, Curr. Opin. Insect Sci. 50 (2022) 100878, https://doi.org/10.1016/J.COIS.2022.100878.

[62] P. Mafongoya, A. Gubba, V. Moodley, D. Chapoto, L. Kisten, M. Phophi, Climate change and rapidly evolving pests and diseases in southern Africa, Nat. Resour. Manag. Policy 53 (2019) 41–57, https://doi.org/10.1007/978-3-030-11857-0_4.

[63] T. Stathers, R. Lamboll, B.M. Mvumi, Postharvest agriculture in changing climates: its importance to African smallholder farmers, Food Secur. 5 (2013) 361–392, https://doi.org/10.1007/S12571-013-0262-Z/METRICS.

[64] D.N. Kalele, W.O. Ogara, C. Oludhe, J.O. Onono, Climate change impacts and relevance of smallholder farmers' response in arid and semi-arid lands in Kenya, Sci. Afr. 12 (2021) e00814, https://doi.org/10.1016/J.SCIAF.2021.E00814.

[65] K.H. Godfrey, P. Kucel, J. Kobusinge, D.N. Olango, L. Nakibuule, W. Nanjego, P. B. Nambozo, S. Olal, W.W. Wagoire, Farmers' knowledge and perception of the use of pesticides in Arabica coffee, *Coffea arabica* agro-ecologies of Uganda, J. Agric. Environ. Sci. 7 (2018) 173–188, https://doi.org/10.15640/JAES.V7N2A17.

[66] N. Lee, Assuring safe pesticide use for commercial crops, including soybean, in sub-Saharan Africa, Afr. J. Food Agric. Nutr. Dev. 19 (2019) 15173–15176, https://doi.org/10.18697/AJFAND.88.SILFARMDOC13.

[67] S.M. Demi, S.R. Sicchia, Agrochemicals use practices and health challenges of smallholder farmers in Ghana, Environ. Health Insights 15 (2021) 1–11, https://doi.org/10.1177/11786302211043033.

[68] ELD Initiative & UNEP, The Economics of Land Degradation in Africa: Benefits of Action Outweigh the Costs. https://www.eld-initiative.org/en/, 2024 (accessed 18 November 2023).

[69] A. Raimi, R. Adeleke, A. Roopnarain, Soil fertility challenges and Biofertiliser as a viable alternative for increasing smallholder farmer crop productivity in sub-Saharan Africa, Cogent. Food Agric. 3 (2017) 1400933, https://doi.org/10.1080/23311932.2017.1400933.

[70] M.A.E. AbdelRahman, An overview of land degradation, desertification and sustainable land management using GIS and remote sensing applications, Rend. Lincei. 34 (2023) 767–808, https://doi.org/10.1007/S12210-023-01155-3/FIGURES/29.

[71] P. Drechsel, D. Kunze, F.P. De Vries, Soil nutrient depletion and population growth in sub-Saharan Africa: a Malthusian nexus? Popul. Environ. 22 (2001) 411–423, https://doi.org/10.1023/A:1006701806772.

[72] Z.P. Stewart, G.M. Pierzynski, B.J. Middendorf, P.V. Vara Prasad, Approaches to improve soil fertility in sub-Saharan Africa, J. Exp. Bot. 71 (2020) 632–641, https://doi.org/10.1093/JXB/ERZ446.

[73] V.O. Nyasembe, X. Cheseto, F. Kaplan, W.A. Foster, P.E. Teal, J.H. Tumlinson, C. Borgemeister, B. Torto, The invasive American weed *Parthenium hysterophorus* can negatively impact malaria control in Africa, PLoS ONE 10 (2015) e0137836, https://doi.org/10.1371/JOURNAL.PONE.0137836.

[74] L.W. Strathie, B.W. Cowie, A.J. McConnachie, F. Chidawanyika, J.N. Musedeli, S. M.C. Sambo, E.X. Magoso, M. Gareeb, A decade of biological control of *Parthenium hysterophorus* L. (Asteraceae) in South Africa reviewed: introduction of insect agents and their status, Afr. Entomol. 29 (2021) 809–836, https://doi.org/10.4001/003.029.0809.

[75] G. Chikowore, R. Mutamiswa, G.F. Sutton, F. Chidawanyika, G.D. Martin, Reduction of grazing capacity in high-elevation rangelands after black locust invasion in South Africa, Rangel. Ecol. Manag. 76 (2021) 109–117, https://doi.org/10.1016/J.RAMA.2021.02.006.

[76] G. Chikowore, G.D. Martin, F. Chidawanyika, An assessment of the invasive alien tree, *Robinia pseudoacacia* canopy traits and its effect on grassland microclimates and subsequent arthropod assemblages, J. Insect Conserv. 25 (2021) 429–439, https://doi.org/10.1007/S10841-021-00311-0/METRICS.

[77] F. Baarsch, J.R. Granadillos, W. Hare, M. Knaus, M. Krapp, M. Schaeffer, H. Lotze-Campen, The impact of climate change on incomes and convergence in Africa, World Dev. 126 (2020) 104699, https://doi.org/10.1016/J.WORLDDEV.2019.104699.

[78] WHO, Africa Faces Rising Climate-Linked Health Emergencies. https://www.afro.who.int/news/africa-faces-rising-climate-linked-health-emergencies, 2024 (accessed 27 April 2024).

[79] C.D. Singano, B.M. Mvumi, T.E. Stathers, H. Machekano, C. Nyamukondiwa, What does global warming mean for stored-grain protection? Options for *Prostephanus truncatus* (horn) control at increased temperatures, J. Stored Prod. Res. 85 (2020) 101532, https://doi.org/10.1016/J.JSPR.2019.101532.

[80] M. Mauerman, C. Ross, E. Ilboudo Nébié, W. Anderson, N. Jensen, P. Chelanga, The long-term impact of multi-season droughts on livestock holdings and pastoralist decision-making in Marsabit, Kenya, J. Arid Environ. 211 (2023) 104928, https://doi.org/10.1016/J.JARIDENV.2022.104928.

[81] A. Otu, E. Effa, C. Meseko, S. Cadmus, C. Ochu, R. Athingo, E. Namisango, D. Ogoina, F. Okonofua, B. Ebenso, Africa needs to prioritize one health approaches that focus on the environment, animal health and human health, Nat. Med. 27 (2021) 943–946, https://doi.org/10.1038/s41591-021-01375-w.

[82] FAO/OIE/WHO, Sharing Responsibilities and Coordinating Global Activities to Address Health Risks at the Animal-Human-Ecosystems Interfaces. A Tripartite Concept Note, WHO, Geneva, 2010.

[83] K.L. Bardosh, J.C. Scoones, D. Grace, G. Kalema-Zikusoka, K.E. Jones, K. de Balogh, D. Waltner-Toews, B. Bett, S.C. Welburn, E. Mumford, V. Dzingirai, Engaging research with policy and action: what are the challenges of responding to zoonotic disease in Africa? Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 372 (2017) 20160172 https://doi.org/10.1098/RSTB.2016.0172.

[84] A.A. Hassan-Kadle, A.M. Osman, A.M. Ibrahim, A.A. Mohamed, C.J.B. de Oliveira, R.F.C. Vieira, One health in Somalia: present status, opportunities, and challenges, One Health 18 (2024) 100666, https://doi.org/10.1016/J.ONEHLT.2023.100666.

[85] P.M. Munyua, M.K. Njenga, E.M. Osoro, C.O. Onyango, A.O. Bitek, A. Mwatondo, M.K. Muturi, N. Musee, G. Bigogo, E. Otiang, F. Ade, Successes and challenges of the one health approach in Kenya over the last decade, BMC Public Health 19 (2019) 1–9, https://doi.org/10.1186/s12889-019-6772-7.

[86] B. Häsler, L. Cornelsen, H. Bennani, J. Rushton, A review of the metrics for one health benefits, Rev. Sci. Tech. 33 (2014) 453–464, https://doi.org/10.20506/RST.33.2.2294.

[87] L. Delesalle, M.L. Sadoine, S. Mediouni, J. Denis-Robichaud, K. Zinszer, C. Zarowsky, C. Aenishaenslin, H. Carabin, How are large-scale one health initiatives targeting infectious diseases and antimicrobial resistance evaluated? A scoping review, One Health 14 (2022) 100380, https://doi.org/10.1016/J.ONEHLT.2022.100380.

[88] D.H. Braam, Zoonoses in the margins: environmental displacement and health outcomes in the Indus Delta, Int. J. Equity Health 21 (2022) 189, https://doi.org/10.1186/S12939-022-01823-0.

[89] M.T. Rahman, M.A. Sobur, M.S. Islam, S. Ievy, M.J. Hossain, M.E. El Zowalaty, A. T. Rahman, H.M. Ashour, Zoonotic diseases: etiology, impact, and control, Microorganism 8 (2020) 1405, https://doi.org/10.3390/MICROORGANISMS8091405.

[90] M.J. Page, J.E. McKenzie, P.M. Bossuyt, I. Boutron, T.C. Hoffmann, C.D. Mulrow, L. Shamseer, J.M. Tetzlaff, E.A. Akl, S.E. Brennan, R. Chou, J. Glanville, J. M. Grimshaw, A. Hróbjartsson, M.M. Lalu, T. Li, E.W. Loder, E. Mayo-Wilson, S. McDonald, L.A. McGuinness, L.A. Stewart, J. Thomas, A.C. Tricco, V.A. Welch, P. Whiting, D. Moher, The PRISMA, Statement: an updated guideline for reporting systematic reviews, BMJ 372 (2021) (2020) 1–11, https://doi.org/10.1136/bmj.n71.

[91] WFPHA, A Systems Framework for Healthy Policy Advancing Global Health Security and Sustainable Well-Being for All, Commonwealth Secretariat, London, UK, 2016.

[92] S. Joubert, What is Health Outcomes Research?. https://graduate.northeastern.edu/resources/what-is-health-outcomes-research/, 2024. (Accessed 15 April 2024).

[93] QGIS Development Team, *QGIS Geographic Information System: Open Source Geospatial Foundation Project* v3.34.3. http://qgis.osgeo.org, 2023.

[94] T. Beedy, O.C. Ajayi, G.W. Sileshi, G. Kundhlande, G. Chiundu, A.J. Simons, Scaling up agroforestry to achieve food security and environmental protection among smallholder farmers in Malawi, Field Actions Sci. Rep. 2013 (2013) 1–6.

[95] M. Fischler, Impact Assessment of Push Pull Technology in Eastern Africa, Icipe Science Press, Nairobi, Kenya, 2010.

[96] K.A. Kayunze, D.M. Kambarage, A. Kiwara, E. Lyamuya, J. Rushton, R. Kock, R. Coker, Practice of one health approaches: bridges and barriers in Tanzania, Onderstepoort J. Vet. Res. 81 (2014) 1–8, https://doi.org/10.4102/OJVR.V81I2.733.

[97] S. Mukankaka, Feasibility of Collaboration Between Water, Sanitation and Hygiene and the Neglected Tropical Disease Control Programmes in Rwanda. https://library.adhl.africa/handle/123456789/12883, 2019. (Accessed 27 April 2024).

[98] A. Nankanja, I. Ndyamuhaki, I. Ssemulondo, Z. Wamema, L. Ceccaroni, L. C. Streichert, A one health social science approach to water security and gender equity in rural Uganda, One Health Cases 2023 (2023) ohcs20230026, https://doi.org/10.1079/ONEHEALTHCASES.2023.0026.

[99] E. Buregyeya, E. Atusingwize, P. Nsamba, C. Nalwadda, J. Osuret, P. Kalibala, R. Nuwamanya, S. Okech, T. Ssekamatte, S. Nitumusiima, T. Wakabi, Lessons from a community based interdisciplinary learning exposure: benefits for both students and communities in Uganda, BMC Med. Educ. 21 (2021) 1–13, https://doi.org/10.1186/S12909-020-02429-2/TABLES/1.

[100] E.A. Mpolya, T. Lembo, K. Lushasi, R. Mancy, E.M. Mbunda, S. Makungu, M. Maziku, L. Sikana, G. Jaswant, S. Townsend, F.X. Meslin, Toward elimination of dog-mediated human rabies: experiences from implementing a large-scale demonstration project in southern Tanzania, Front. Vet. Sci. 4 (2017) 234050, https://doi.org/10.3389/FVETS.2017.00021/BIBTEX.

[101] N.S. Nyokabi, H. Moore, S. Berg, J. Lindahl, L. Phelan, G. Gimechu, A. Mihret, J. L. Wood, Implementing a one health approach to strengthen the management of zoonoses in Ethiopia, One Health 16 (2023) 100521, https://doi.org/10.1016/J.ONEHLT.2023.100521.

[102] A. Aleminew, M. Alemayehu, Soil fertility depletion and its management options under crop production perspectives in Ethiopia: a review, Agric. Rev. 41 (2020) 91–105, https://doi.org/10.18805/AG.R-136.

[103] C. Erika, S.L. Susanna, A. Tonny, S. Karl, F. Klara, Co-created community contracts support biosecurity changes in a region where African swine fever is endemic – part I: The methodology, Prev. Vet. Med. 212 (2023) 105840, https://doi.org/10.1016/J.PREVETMED.2023.105840.

[104] F. Lankester, A. Davis, S. Kinung'hi, J. Yoder, C. Bunga, S. Alkara, I. Mzimbiri, S. Cleaveland, G.H. Palmer, An integrated health delivery platform, targeting soil-transmitted helminths (STH) and canine mediated human rabies, results in cost savings and increased breadth of treatment for STH in remote communities in Tanzania, BMC Public Health 19 (2019) 1398, https://doi.org/10.1186/S12889-019-7737-6.

[105] R.B. Kerr, S. Snapp, M. Chirwa, L. Shumba, R. Msachi, Participatory research on legume diversification with Malawian smallholder farmers for improved human nutrition and soil fertility, Exp. Agric. 43 (2007) 437–453, https://doi.org/10.1017/S0014479707005339.

[106] D.C. Cole, C. Levin, C. Loechl, G. Thiele, F. Grant, A.W. Girard, K. Sindi, J. Low, Planning an integrated agriculture and health program and designing its evaluation: experience from Western Kenya, Eval. Program Plann. 56 (2016) 11–22, https://doi.org/10.1016/J.EVALPROGPLAN.2016.03.001.

[107] E.F. Griffith, J.R. Kipkemoi, A.H. Robbins, T.O. Abuom, J.C. Mariner, T. Kimani, H. Amuguni, A one health framework for integrated service delivery in Turkana County, Kenya, Pastor. Res. Policy Pract. 10 (2020) 7, https://doi.org/10.1186/s13570-020-00161-6.

[108] I. El Berbri, W. Mahir, A. Shaw, M.J. Ducrotoy, Y. Lhor, M. Dehhaoui, A.F. Petavy, A. Dakkak, M. Bouslikhane, F. Boué, O.F. Fihri, Evaluation of integrated control of three dog transmitted zoonoses: rabies, visceral leishmaniasis and cystic echinococcosis, in Morocco, Acta Trop. 212 (2020) 105689, https://doi.org/10.1016/J.ACTATROPICA.2020.105689.

[109] R. Mindekem, M.S. Lechenne, K.S. Naissengar, A. Oussiguéré, B. Kebkiba, D. D. Moto, I.O. Alfaroukh, L.T. Ouedraogo, S. Salifou, J. Zinsstag, Cost description and comparative cost efficiency of post-exposure prophylaxis and canine mass vaccination against rabies in N'Djamena, Chad, Front. Vet. Sci. 4 (2017) 38, https://doi.org/10.3389/FVETS.2017.00038.

[110] N. van Heerden, S.S. Grobbelaar, I. Meyer, E. Vermeulen, Emerging smallholder cattle farming from a one health perspective: a system dynamics model of the highveld region of South Africa, Environ Sci Policy 152 (2024) 103646, https://doi.org/10.1016/J.ENVSCI.2023.103646.

[111] D.H. Braam, A. Tasker, E. Parravani, K. Saville, A fair share? Animal health actors and resources in One Health initiatives: a multisite case study in Ethiopia and Pakistan, CABI One Health 2023 (2023) ohcs202300015, https://doi.org/10.1079/CABIONEHEALTH.2023.0015.

[112] M. Léchenne, A. Traore, J. Hattendorf, V. Kallo, A. Oussiguere, M. Tetchi, R. Moyengar, A.K. Traore, D.D. Moto, R. Ngandolo, B. Bonfoh, Increasing rabies data availability: The example of a one health research project in Chad, Côte d'Ivoire and Mali, Acta Trop. 215 (2021) 105808, https://doi.org/10.1016/J.ACTATROPICA.2020.105808.

[113] G. Alemayehu, E. Gelan, T. Berhe, M. Lemma, R. Doyle, Agroforestry-Livestock Integration for One Welfare: A Report on Community Conversations, ILRI, Nairobi, Kenya, 2021.

[114] S.E. Baum, C. Machalaba, P. Daszak, R.H. Salerno, W.B. Karesh, Evaluating one health: are we demonstrating effectiveness? One Health 3 (2017) 5–10, https://doi.org/10.1016/J.ONEHLT.2016.10.004.

[115] L.C. Falzon, I. Lechner, I. Chantziaras, L. Collineau, A. Courcoul, M.E. Filippitzi, R. Laukkanen-Ninios, C. Peroz, J. Pinto Ferreira, M. Postma, P.G. Prestmo, Quantitative outcomes of a one health approach to study global health challenges, Ecohealth 15 (2018) 209–227, https://doi.org/10.1007/S10393-017-1310-5.

[116] M.A. Barrett, T.A. Bouley, Need for enhanced environmental representation in the implementation of one health, Ecohealth 12 (2015) 212–219, https://doi.org/10.1007/S10393-014-0964-5.

[117] N. Salam, S. Mustafa, A. Hafiz, A.A. Chaudhary, F. Deeba, S. Parveen, Global prevalence and distribution of coinfection of malaria, dengue and chikungunya: a systematic review, BMC Public Health 18 (2018) 1–20, https://doi.org/10.1186/S12889-018-5626-Z/TABLES/3.

[118] N. Athirah Naserrudin, A. Monroe, P. Yaong Pau Lin, S. Baumann, R. Culleton, S. Sato, R. Hod, M.S. Jeffree, K. Ahmed, M.R. Hassan, The One Health approach to addressing zoonotic malaria in rural northern Borneo: challenges and solutions, One Health Cases 2023 (2023) ohcs20230017, https://doi.org/10.1079/ONEHEALTHCASES.2023.0017.

[119] Y. Liu, Z.Q. He, D. Wang, Y.B. Hu, D. Qian, C.Y. Yang, R.M. Zhou, S.H. Li, D.L. Lu, H.W. Zhang, One health approach to improve the malaria elimination programme in Henan Province, Adv. Parasitol. 116 (2022) 153–186, https://doi.org/10.1016/BS.APAR.2022.02.001.

[120] World Bank, Operational Framework for Strengthening Human, Animal and Environmental Public Health Systems at their Interface, World Bank Group, Washington, DC, 2018.

[121] S.R. Rüegg, L.R. Nielsen, S.C. Buttigieg, M. Santa, M. Aragrande, M. Canali, T. Ehlinger, I. Chantziaras, E. Boriani, M. Radeski, M. Bruce, A systems approach to evaluate one health initiatives, Front. Vet. Sci. 5 (2018) 309732, https://doi.org/10.3389/FVETS.2018.00023/BIBTEX.

[122] R. Alders, A. Aongola, B. Bagnol, J. De Bruyn, S. Kimboka, R.A. Kock, M. Li, W. Maulaga, R. Mcconchie, S. Mor, H. Msami, Using a one health approach to promote food and nutrition security in Tanzania and Zambia, GRFDavos Planet@Risk 2 (2015) 188–190.