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The effects of climate change on zoonotic disease risks in Ghana: reviewing the state of knowledge from a One Health perspective

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Abstract

Climate change and zoonoses are significant causes of morbidity and mortality worldwide. Globally, they share several anthropogenic drivers, including deforestation, urbanization, and agricultural land conversion, yet studies of the effects of climate change on zoonotic disease emergence and spread are limited. We conducted a literature review on the implications of climate change and zoonotic and vector-borne diseases in Ghana through 2022. The review was followed by a multi-sectoral workshop with expert representatives from across the human, animal (wildlife and livestock), and environment sectors to validate and expand on the findings. There is very little existing research on climate change and emerging disease risks to humans, livestock, and wildlife in Ghana. Of the studies found, most focused on the potential impacts of climate change on vector-borne diseases, such as malaria. No research was found on its impact on wildlife- or livestock-associated diseases, and little was found on mechanisms of disease risk. To better understand the effects of climate change on zoonoses and their associated drivers that can inform appropriate risk management strategies in Ghana, additional investment in climate-health research is needed. Improvements in surveillance and early warning systems for climate-sensitive diseases, ecological data to predict shifts in animal hosts and vectors, and transhumance are necessary to inform disease risk reduction and climate mitigation strategies. Ghana´s National Climate Change Committee and One Health platform are primed to support the integration of climate and disease considerations into national planning and policies and advance One Health in practice.

Introduction

Globally, climate change is and will continue to drive temperatures higher and increase the frequency and intensity of extreme events, including heavy precipitation, flooding, and drought. Weather hazards such as droughts, floods, and cyclones are forecasted to occur more frequently and forcefully, causing insecure living conditions, resource shortages, and forced migration of both humans and animals [1].

These effects are influencing the geographic range, survival, and reproduction of pathogens and hosts and making overall conditions more favorable for disease transmission in many regions [2]. Deforestation, agricultural intensification, natural resource extraction, and human mobility-many of which are also driving the climate crisis- can push wildlife, livestock, and humans into new or greater contact and increase the risk of zoonotic disease transmission [3-5]. As a result, novel diseases are emerging in new locations, transmission seasons are lengthening or shifting altogether, and the frequency and size of zoonotic disease outbreaks are increasing [6]. Migration due to climate change can also increase interactions between animals and humans [7]. Globally, climate change has increased the severity of diseases from wildlife, outbreak frequency, and emergence of novel vectors and their diseases into new areas [1].

As a “hotspot” for emerging infectious diseases [8], Ghana faces dual threats of climate change and zoonotic disease risk. The country contributes relatively little to climate change, yet several climate shocks threaten the country, including rising temperatures, less predictable rainfall [9,10], drought [9], and flooding [11], and are anticipated to influence the distribution and patterns of infectious diseases in other regions and likely Ghana [2]. Ghana has a list of national priority zoonotic diseases, including anthrax, rabies, zoonotic avian influenza, zoonotic tuberculosis, viral hemorrhagic fevers, and

trypanosomiasis [12], while other viral zoonoses of national importance have been identified [13]. Several national priority diseases (i.e. Lassa virus, rabies, anthrax, yellow fever) have potential climate links [14,15] that require a One Health approach to anticipate, mitigate, and adapt to changing disease and climate risks. This is further complicated by Ghana´s three climate zones, which likely means that any climate effects and impacts on zoonotic disease risk will be varied and potentially complex.

The objective of this study was to review the state of knowledge on the implications of climate change on zoonotic disease threats in Ghana. We aimed to ground-truth findings in the literature and identify relevant disease interfaces and strategies in place that address climate change and disease threats. Building on Ghana´s existing efforts to combat climate change and emerging infectious diseases, we conclude with recommendations for research and policy action to prevent, reduce, and respond to climate-sensitive disease threats.

Methods

Study design: we searched the peer-reviewed literature using online databases, including Web of Science Core, BIOSIS Previews, PubMed, and CAB Direct. Gray literature searches were also conducted using the University of Ghana document repository, which includes students´ theses and dissertations; the World Health Organization webpage; the Food and Agriculture Organization of the United Nations document repository; the World Organization for Animal Health database; Google Scholar; and the Government of Ghana disease reports. The keywords used in the search included combinations of: “Climate change”, “zoonoses”, “zoonotic”, “pathogens”, “diseases”, and “Ghana” with the Boolean operators “OR” and “AND”. Literature extending from the earliest date for each database through 2022 was included. Additional publications found while writing this paper during 2023-2024 have also been included. The titles and abstracts were screened for relevance to climate change effects on zoonotic diseases in Ghana. Publications were excluded if they did not satisfy the search criteria or were opinion papers without original or cited reports of climate change and infectious disease studies. Reference lists from publications were also used to find relevant sources. Information extracted from each source included climate change´s impact on diseases and transhumance in Ghana. Where Ghana-specific evidence is more limited, we introduce regional and global evidence to explore potential impacts of climate change on zoonotic disease risks.

Following the literature review, a workshop was organized to document existing efforts and inform priorities for multi-sectoral research and collaboration, with a focus on the connections between changing environmental conditions and disease emergence and spread, relevant interfaces such as transhumance and migration, surveillance and data needs for early warning and risk mitigation, and barriers and opportunities for operationalizing One Health. This approach provided an opportunity to review the scientific state of knowledge and relevant national plans and frameworks; validate, refine, and expand the scope; and consider operational aspects in the context of climate change and emerging infectious diseases, as well as One Health approaches more broadly. Workshop themes and guiding discussion questions are in Table 1.

Setting: a workshop (in-person in Accra, Ghana, and virtual) was organized in March 2022. It brought together experts from across the animal-human-environment interface to examine the state of knowledge on climate-sensitive zoonotic disease risk in Ghana and identify priorities for strengthening One Health systems to prevent and prepare for disease threats.

Participants: all participants were one-health stakeholders. They were selected from government ministries and departments/agencies-

National Disaster Management Organization, Environmental Protection Agency, Ghana Health Services, Public Health Dept and Surveillance Dept, Ghana Health Services, Neglected Tropical Disease Unit, Veterinary Services Department, Forestry Commission, Wildlife Division. Universities and research institutions - School of Veterinary Medicine of University of Ghana (UG), Vector Borne Research Unit, UG, Geography Department, UG, School of Public Health, UG, Animal Biology and Conservation Science Department, UG, Marine and Fisheries Dept, UG, Kumasi Centre for Collaborative Research in Tropical Medicine, Kwame Nkrumah University of Science and Technology (KNUST), Animal Research Institute of Council for Scientific and Industrial Research (CSIR), Ghana Atomic Energy, Commission. International one-health partners included -United Nations Environment Programme, World Health Organization, Food and Agriculture Organization of the United Nations. The private sector was represented by private veterinarians. The workshop was held on 22nd March 2022

Variables: the study focused on climate change´s impact on zoonotic disease risk in Ghana. Variables examined included climate-sensitive zoonotic diseases, patterns of disease emergence, transmission pathways, and environmental factors affecting disease spread. Additional variables explored included the influence of transhumance, migration, and land-use changes on disease dynamics.

Data sources: data were extracted from published literature, government reports, and institutional repositories. Climate change´s impact on zoonotic diseases was analyzed based on available epidemiological, ecological, and climatic data from reviewed studies.

Bias:we addressed possible bias that may arise by including a diverse range of sources, such as peer-reviewed studies, government documents, and international agency reports. A systematic approach to literature search and inclusion in our review was followed to minimize selection bias.

Study size: the study analyzed 35 publications meeting the inclusion criteria.

Quantitative variables: from our work, the quantitative variables measured included the number of relevant publications, disease incidence, and prevalence data. We also measured climate-related environmental changes data impacting the possible spread of diseases.

Statistical methods: we conducted a descriptive analysis to summarize trends in climate change impacts on zoonotic disease risks.

Results

Participants: in all we had 40 participants in total who were present at the workshop. Workshop participants and their affiliations are presented in Table 2.

Descriptive data: the research based on climate change and zoonotic disease risk in Ghana is limited. From the search of articles published up to March 2022, thirty-five (35) publications were included in the review. Eleven (11) of these articles reported on climate change only, nineteen (19) reported on both climate change and diseases. The remaining five (5) were general articles on global climate change issues. Most studies focused on the potential impacts of climate change on vector-borne diseases. No research was found on its impact on wildlife - or livestock-associated diseases, and little was found on the mechanisms of disease risk.

Impacts of climate change on infectious diseases: most studies relating climate and vector-borne diseases were focused on malaria [16-18]. Accounting for projected population growth, over 58 million people could be at risk of malaria in Ghana by 2070 under both low and high greenhouse gas emission scenarios [19]. Short-term increases brought on by flooding and rising temperatures are more likely to occur in coastal urban areas, especially where temporary populations lack access to sanitary facilities and

clean water [20]. Pathogen transmission dynamics vary across Ghana´s four agro-ecological zones, particularly with respect to variations in temperature and rainfall [16,21]. In some cases, water storage, more so than rainfall, may be a key driver of transmission. According to a study conducted in Northern Ghana, the dry season had greater Aedes mosquito larvae populations and human-vector contact rates than the rainy season [22]. The authors attribute this to water storage practices that promote *Aedes* breeding. At the same time, rising temperatures may reduce suitable areas for certain vectors and thus, the abundance [23].

We couldn't find any data about how climate change affects the risk of zoonotic diseases in livestock or wildlife. In Ghana, several viral pathogens associated with emerging infectious diseases have been detected in wildlife reservoirs, including potentially zoonotic Achimota virus 1 and 2 [24] and *Henipa virus* infections in fruit bats (*Eidolon helvum*) [25], which have led to spillover and human infection in other countries. Seasonality was linked to viral prevalence in a 2022 study of a possibly zoonotic bat coronavirus in Ghana, with higher detection during the rainy season when the population's proportion of vulnerable juveniles was higher [26]. Previous research from other low- and lower-middle-income nations has documented the impact of climate change on the distribution and prevalence of livestock diseases through a number of mechanisms, including making livestock more susceptible to disease by decreasing their resistance to infections, despite the paucity of evidence in Ghana [27]. Climate change-related changes in temperature and precipitation can also affect the ability of pathogens and vectors of cattle diseases, such as ticks, midges, and mosquitoes, to survive, reproduce, and disseminate [27]. Key epidemiological parameters, such as infection rates and disease dispersion patterns inside vectors, are significantly influenced by temperature [28].

In addition to being found in Ghana, Lassa fever is thought to be prevalent in nearby Nigeria, Guinea, Liberia, and Sierra Leone; local transmission of the disease was documented in 2015 [13]. Higher temperatures and more rainfall are expected to expand the range of the rodent reservoir, *Mastomys natalensis* [14]. As this rat species is typically found near agricultural and residential areas (compared to forest areas), impacts on crop yields related to climate change (as well as other factors) could either be a limiting or supporting factor for *M. natalensis* abundance [29].

Impacts of climate changes on drivers of infectious disease risk: we found limited documentation on how climate change is affecting the mechanisms that drive or amplify infectious disease risk in Ghana. This includes drivers of increased interaction between wildlife and livestock, such as transhumance, human migration, and encroachment in protected areas, and migration of wild birds. Effects of such climate change observed in the West African subregion have led to the intensification of transhumance. Data from the University of Ghana´s Department of Geography shows that desertification is extending rapidly from the Sahara to the sub-Saharan region and limiting access to water sources such as Lake Chad, which in turn has increased transhumance and migration activities in Ghana. This can introduce conflict between farmers and pastoralists when animals intrude on farms and protected areas in search of food and water. Transhumance is likely to intensify with climate change and reinforces links between climate, health, and security [30]. Seasonal pressures force farmers to migrate from Northern Ghana southward, influenced by the seasons, to agricultural-rich areas for farming [31]. Farming practices can lead people to encroach on wildlife habitats, including into protected areas, pushing humans, livestock, and wildlife into contact, with the potential for animal-human or wildlife-livestock pathogen transmission. Evidence is lacking on the risks of climate-intensified

transhumance in Ghana in relation to infectious disease risk.

Wetlands, the habitat for breeding and feeding sites for most waterfowl, are the most threatened of all ecosystems, and one of the habitats likely to be most adversely affected by climate change [1]. Migratory waterbirds are vulnerable to climate change because they are dependent on a network of dispersed sites for migration. Climate change, alongside other major changes to wetland habitat in many countries, increases the potential for mixing of wild birds and domestic poultry (and potentially other species), which can increase opportunities for the development and transmission of highly pathogenic avian influenza viruses [32]. Migratory birds may also carry ectoparasites, such as ticks and lice, some of which in turn carry microorganisms, including those of concern to animal and human health [33]. Though Ghana has many wetlands and is home to waterfowl, we found no research on the precise risks regarding wild bird-mediated disease introduction.

Climate change may be influencing farming system selection in Ghana towards livestock and away from more environmentally sensitive crops [34]. Intensification of livestock farming, such as via piggeries, may create conditions to amplify viral circulation and increase ease of transmission to humans from emerging diseases such as the Nipah virus [35]. Several outbreaks of African swine fever virus (ASFV) in Ghana [36] raise concerns of potential wildlife-livestock virus transmission through direct contact or tick-mediated transmission between warthogs, other suids, and domestic pigs, though research on ASFV circulation in wildlife is sparse in Ghana. Other research has shown evidence of filoviruses (Ebola virus and Taï Forest virus) exposure in pigs sampled from the Greater Accra, Upper West, and Upper East Regions [37].

Concurrent land-use change, habitat degradation (including commercial surface mining and galamsey), and over-exploitation taking place in Ghana can also affect the resilience of ecosystems in the face of climate shocks [38]. In Ghana, galamsey, or small-scale mining, is common and degrades formerly fruitful agricultural areas [39]. Existing wildlife, especially endangered species like elephants in the Ahafo region, has been displaced as a result. As a result, invading species like rodents-which are significant carriers of zoonoses like Lassa fever-have proliferated. There have been reports of livestock in these areas suffering from cyanide and mercury poisoning, as well as water pollution [40].

Climate change can increase interaction between wildlife and livestock where environmental pressures reduce access to resources, including water and grazing resources, which can result in more opportunities for pathogen exchange. These resource constraints, often exacerbated by changes in temperature, rainfall patterns, and other environmental factors, are likely leading to wildlife habitat fragmentation, loss, as well as species decline and extinction, yet little information can be found in Ghana. Additionally, human behavior can influence zoonotic disease transmission through encroachment into wildlife areas and hunting, civil conflict, and poor sanitation, which can negatively impact the health of wild animals, including through new or changing interactions. Wildlife health, including diseases affecting wild animals and their populations, is understudied in Ghana.

Existing climate and environmental strategies: Ghana's government has long been an active and successful participant in international climate negotiations and is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC). As a result, Ghana's national climate change initiatives have been centered on the international climate regime since the middle of 1990. In 2001, Ghana submitted its first national communication and greenhouse gas emissions inventory to the UNFCCC [41]. In addition to implementing strategies that support adaptation, Ghana is a signatory to the Paris Agreement to also achieve climate targets using the nationally

determined contributions, which include reducing emissions by 15-45% by 2030 [**42**].

In 2012, Ghana released a National Climate Change Adaptation Strategy. The strategy was highly multi-sectoral, with health being a major focus. Noting some deficits in healthcare systems to tackle existing disease burden, the strategy called for increased and upgraded healthcare facilities and equipment to increase access and withstand flooding and other disasters, enhanced sanitation infrastructure to reduce water-borne infections, and improved awareness by healthcare professionals to cope with climate change-related health problems. However, the National Action Plan on Antimicrobial Resistance (AMR) for 2017-2021, while ambitious in its call for a One Health approach and the inclusion of the environment sector, did not specifically take into consideration the role of climate change on future AMR risks and impacts.

The Ministry of Environment, Science, Technology, and Innovation (MESTI) is in charge of Ghana's National Climate Change Committee (NCCC). Ghana's Fourth National Communication to the UNFCCC was released in 2021. Food security, climate-proof infrastructure, energy security, sustainable forest management, and urban waste management are just a few of the sustainable land use practices that Ghana has made a priority. The energy, industrial, garbage, and forest sectors are the main targets of mitigation [43]. When it comes to finding cross-sector synergies in its climate efforts, Ghana has taken the lead. Notably, Ghana presented a resolution on the Animal Welfare - Environment - Sustainable Development Nexus at the 26thConference of the Parties to the UNFCCC (often known as the UN climate conference, or COP26). The call to action to "protect animals, protect their habitats, and meet their animal welfare requirements, in the context of halting biodiversity loss, restoring ecosystems, mitigating climate change, preventing pollution, reducing the risk of new emerging infectious zoonotic disease, moving to sustainable and agroecological food systems, and achieving sustainable development" was mentioned in this resolution, which was eventually approved by the UN Environment Assembly.

Policies designed to increase resilience to climate change may also have an impact on disease dynamics, even though climate change can directly affect the emergence and spread of infectious diseases. The Ghanaian government's commercial agriculture program, which aims to feed the country's growing population, may unintentionally raise the danger of several diseases due to climate change. Waterborne parasites and mosquitoes may have more breeding grounds because of irrigation dams. For instance, after dams and irrigation canals were built, Rift Valley disease outbreaks happened in various nations on the continent [44].

The Government of Ghana´s current efforts to expand valley lowland rice and commercial rice farming, though laudable for its food security objectives, may risk infectious diseases spreading between wild birds and poultry farms, if mitigation strategies are not included in planning around current conditions and projections for conditions under climate change. The possibility of influenza virus overflow from wild birds to domestic birds and pigs, as well as its subsequent evolution and amplification in domestic animals and transmission to people (and maybe back into wild animals), can be influenced by both intensive and extensive farming practices. According to reports from Thailand and Europe, free-grazing duck farming in wetland areas, along with rice paddies, brings wild and domestic waterfowl closer together [45,46], facilitating the spread of disease in both directions.

Discussion

Key results: overall, there is very little existing research on the effect of climate change on livestock health and emerging disease risks to humans and wildlife in Ghana. Outbreaks of avian

influenza and yellow fever in the country reinforce the need for a multi-disciplinary approach in the face of climate change. These associations, which have been seen in other regions, are important to consider in land planning, particularly for areas where livestock-wildlife contact could increase as a result of livestock and crop production system growth, shifting species ranges and habitat, and wildlife food-seeking behaviors during drought and other stress periods.

The literature review and workshop identified actions that can be taken for preventing and responding to climate-sensitive infectious disease threats in Ghana. First, data on the effects of climate on animal disease distribution should be gathered to initiate and target mitigation measures as relevant. For example, the daily monitoring of wildlife trade products carried out in the Kumasi market by the Wildlife Division was noted. This information was recognized as valuable for having a baseline understanding of the scale and scope of the trade that can enable monitoring and detection of trends in light of climate and other changing conditions (including species ranges and food acquisition practices, for example). Multi-sectoral integration of monitoring and surveillance systems is not currently conducted at scales necessary to establish adequate baselines and early warning systems for climate-sensitive diseases. For example, the detection of Marburg outbreaks in the country in 2022 raised questions about the circulation of the Marburg virus in Ghana, including how climate or other environment-related changes may potentially be playing a role in disease dynamics. There are also opportunities to engage local communities and leverage indigenous knowledge in disease surveillance and on the drivers of human-wildlife interactions to emphasize risk reduction, including through initiatives such as Nature for Health, for which Ghana is a partner country. Collaboration with indigenous peoples and local communities to generate a qualitative understanding of where and why people interact with wildlife, including economic and cultural incentives, is essential for implementing context-specific public awareness and community sensitization campaigns to reduce zoonotic spillover risks.

A targeted climate-health-adaptation research agenda can support the identification and analysis of trends and associations between diseases and weather, and develop indicators to improve health sector capacity to respond, as well as add or expand zoonotic risk to the existing surveillance system. The development of health early warning systems is needed, specifically for heat waves and flooding. Data from early warning systems may also inform climate and ecological models to better predict shifts in animal hosts and vectors that contribute to zoonotic disease outbreaks.

Second, the capacity for and enforcement of animal quarantine and screening along borders and wildlife corridors is limited in Ghana. Insufficient screening activities at the borders can result in the introduction of animal and zoonotic diseases. Limited resources have hampered effective work at the quarantine stations of Ghana´s borders, impacting the entry of diseases into Ghana, including the increased meningitis cases in the northern regions of Ghana. Often, animals are only screened physically, rather than tested for transboundary diseases of concern. Establishing and enforcing buffer zones between wildlife and human settlements, and enforcing quarantine systems as well as using biodiversity areas, can also aid in preventing and detecting zoonoses such as Ebola, Lassa fever, rabies, and others.

Third, environmental and health risk assessments should be integrated into the process of land use decision-making. In the case of mining, while assessments have been conducted, they may not necessarily be transparent or rigorous in their inclusion of emerging disease risks. Additionally, infectious disease considerations could be integrated into future national planning processes in the environment, human health, animal health, agriculture, and disaster management sectors. For

example, as Ghana looks to nationalize the global One Health Joint Plan of Action (2022-2026) [47] and Global Action Plan on Biodiversity and Health under the UN Convention on Biological Diversity and broader targets under the Kunming-Montreal Global Biodiversity Framework, there is an opportunity to integrate evidence on the linkages between climate change, biodiversity, and zoonotic diseases into national programs and strengthen collaboration among One Health sectors. These assessments and plans can seek to mitigate and adapt to direct impacts (e.g. from climate-sensitive diseases) and indirect effects (e.g., healthcare infrastructure vulnerable to flooding, changes in behavior, and mitigation from nutrition and water security needs) of climate change. Bridging between the (NCCC) and Ghana´s One Health platform, operationalized through routine information exchange, participation in technical working groups, and other mechanisms for routine coordination, can help promote a One Health lens to reduce disease risks and enhance biodiversity conservation.

Global evidence indicates that many of the drivers of climate change also contribute to zoonotic disease emergence and spread. Deforestation is a significant contributor to climate change as it releases carbon dioxide stored by trees into the atmosphere and decreases the abundance of trees that absorb carbon. The act of deforestation (e.g., for cocoa plantation in Ghana) [48] can put humans and wildlife in close contact and increase disease risk. Actions such as urbanization and agricultural land conversion also act as co-drivers of climate change and zoonotic disease risk; however, additional research is needed in Ghana to understand their linkages at the local and national levels. As Ghana implements interventions to reduce the risk of zoonoses and fight climate change, it will be important to balance the economic incentives (e.g. from cocoa farming and mining) to ensure local communities and Regional and Municipal Coordination Councils are proactively enabling zoonotic risk reduction measures.

The limited research on climate change and zoonoses in Ghana indicates a need for global advocacy and increased investment in low and lower-middle-income countries at the nexus of climate change, zoonotic disease, and sustainable development. Leading up to the 2025 United Nations Climate Change Conference (COP 30) in Brazil, and future international and regional climate and health security initiatives, there is an opportunity to catalyze and amplify research and advocate voices from countries disproportionately affected by climate change and zoonotic and vector-borne diseases, like Ghana.

Limitations: we conducted a comprehensive literature review and had widespread sectoral participation at the workshop. However, there may have been more localized knowledge not captured from stakeholders in other regions of Ghana. In the future, we recommend additional workshops in other regions of Ghana to uncover regional literature and capture expert opinion from more stakeholders. In addition, as pathogen circulation and disease transmission mechanisms are studied more in Ghana, these could serve as the basis for climate-disease projections that may shed greater light on specific dynamics, potentially some of which were not considered or reflected in our review.

Conclusion

Given the global importance and increasingly devastating effects of climate change and zoonotic and vector-borne diseases, it is essential to take stock of the existing evidence and identify areas for future research, investment, and action. This review outlines the state of knowledge in Ghana and proposes specific entry points to mainstream climate change, zoonoses, and One Health principles into existing interventions and national plans. Research in the Ghanaian context will inform disease risk reduction and climate mitigation strategies and advance One Health in practice to preserve the health of Ghanaian

people, animals, ecosystems, and the environment.

Competing interests

The authors declare no competing interests.

Authors' contributions

Richard Dery Suu-Ire, Catherine Machalaba, and William Bamberger Karesh conceptualised the work, designed the methodology, and provided supervision. Richard Dery Suu-Ire, Catherine Machalaba, William Bamberger Karesh, Gilbert Gyebi, and Sarah Baum conducted the investigation. Richard Dery Suu-Ire, Gilbert Gyebi, Sarah Baum, and Catherine Machalaba conducted project administration. Catherine Machalaba and William Bamberger Karesh led funding acquisition. Richard Dery Suu-Ire wrote the original draft. All authors wrote, reviewed, edited the manuscript, and approved the final version of this manuscript.

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Tables

Table 1: workshop themes and guiding questions from the group activities and open forum discussion

Table 2: participants who attended the workshop on operationalising One Health through the lens of climate change and emerging disease risk, 24th March 2022, University of Ghana

References

1. Intergovernmental Panel on Climate Change. Climate change 2022: impacts, adaptation and vulnerability. 2022.
2. Rupasinghe R, Chomel BB, Mart??nez-L??pez B. Climate change and zoonoses: A review of the current status, knowledge gaps, and future trends. Acta tropica. 2022 Feb 1;226: 106225. **PubMed**| **Google Scholar**
3. Morand S, Lajaunie C. Outbreaks of vector-borne and zoonotic diseases are associated with changes in forest cover and oil palm expansion at global scale. Frontiers in veterinary science. 2021 Mar 24;8: 661063. **PubMed**| **Google Scholar**
4. Jones BA, Grace D, Kock R, Alonso S, Rushton J, Said MY *et al*. Zoonosis emergence linked to agricultural intensification and environmental change. Proceedings of the national academy of sciences. 2013 May 21;110(21): 8399-404. **PubMed**| **Google Scholar**
5. Karesh WB, Dobson A, Lloyd-Smith JO, Lubroth J, Dixon MA, Bennett M, Aldrich S, Harrington T, Formenty P, Loh EH, Machalaba CC. Ecology of zoonoses: natural and unnatural histories. The Lancet. 2012 Dec 1;380(9857): 1936-45. **PubMed**| **Google Scholar**

6. Jones KE, Patel NG, Levy MA, Storeygard A, Balk D, Gittleman JL, Daszak P. Global trends in emerging infectious diseases. Nature. 2008 Feb;451(7181): 990-3. **PubMed**| **Google Scholar**
7. Abrahms B, Carter NH, Clark-Wolf TJ, Gaynor KM, Johansson E, McInturff A, Nisi AC, Rafiq K, West L. Climate change as a global amplifier of human??wildlife conflict. Nature Climate Change. 2023 Mar;13(3): 224-34. **Google Scholar**
8. Allen T, Murray KA, Zambrana-Torrelio C, Morse SS, Rondinini C, Di Marco M *et al*. Global hotspots and correlates of emerging zoonotic diseases. Nature communications. 2017 Oct 24;8(1): 1124. **PubMed**| **Google Scholar**
9. Müller-Kuckelberg K. Climate change and its impact on the livelihood of farmers and agricultural workers in Ghana. Preliminary research results General agricultural workers´ union of GTUC friedrich ebert stiftung (Fes). 2012: 1-47. **Google Scholar**
10. Asante FA, Amuakwa-Mensah F. Climate change and variability in Ghana: Stocktaking. Climate. 2014;3(1): 78-101. **Google Scholar**
11. World Bank Group. Climate Risk Profile: Ghana. 2021.
12. Centers for Disease Control and Prevention. One Health Zoonotic Disease Prioritization for Multisectoral Engagement in Ghana. CDC. 2018.
13. Suu-Ire RD, Obodai E, Bonney JK, Bel-Nono SO, Ampofo W, Kelly TR. Viral zoonoses of national importance in Ghana: advancements and opportunities for enhancing capacities for early detection and response. Journal of tropical medicine. 2021;2021(1): 8938530. **PubMed**| **Google Scholar**
14. Klitting R, Kafetzopoulou LE, Thiery W, Dudas G, Gryseels S, Kotamarthi A, Vrancken B, Gangavarapu K, Momoh M, Sandi JD, Goba A. Predicting the evolution of the Lassa virus endemic area and population at risk over the next decades. Nature communications. 2022 Sep 27;13(1): 5596. **PubMed**| **Google Scholar**
15. Judson SD, Kenu E, Fuller T, Asiedu-Bekoe F, Biritwum-Nyarko A, Schroeder LF *et al*. Yellow fever in Ghana: Predicting emergence and ecology from historical outbreaks. PLOS Global Public Health. 2024 Oct 21;4(10): e0003337. **PubMed**| **Google Scholar**
16. Asare EO, Amekudzi LK. Assessing climate driven malaria variability in Ghana using a regional scale dynamical model. Climate. 2017 Mar 5;5(1): 20. **Google Scholar**
17. Akpalu W, Codjoe SN. Economic analysis of climate variability impact on malaria prevalence: The case of Ghana. Sustainability. 2013 Oct 17;5(10): 4362-78. **Google Scholar**
18. Klutse NA, Aboagye-Antwi F, Owusu K, Ntiamoa-Baidu Y. Assessment of patterns of climate variables and malaria cases in two ecological zones of Ghana. Open Journal of Ecology. 2014 Sep 15;4(12): 764-75. **Google Scholar**
19. World Health Organization. **Climate and Health Country Profile - 2015**. Ghana; 2015. Accessed January 30, 2025.
20. Global Risk Modelling Alliance. Gap Analysis Report: Contribution to the Global Shield against Climate Risks & Global Risk Modelling Alliance In-Country Process in Ghana. 2017. Accessed January 30, 2025
21. Oheneba-Dornyo TV, Amuzu S, Maccagnan A, Taylor T. Estimating the impact of temperature and rainfall on malaria incidence in Ghana from 2012 to 2017. Environmental Modeling & Assessment. 2022 Jun;27(3): 473-89. **Google Scholar**

22. Appawu M, Dadzie S, Abdul H, Asmah H, Boakye D, Wilson M *et al*. Surveillance of viral haemorrhagic fevers in ghana: entomological assessment of the risk of transmission in the northern regions. Ghana Med J. 2006;40(4): 137-41. **PubMed**| **Google Scholar**
23. Giesen C, Roche J, Redondo-Bravo L, Ruiz-Huerta C, Gomez-Barroso D, Benito A *et al*. The impact of climate change on mosquito-borne diseases in Africa. Pathog Glob Health. 2020;114(6): 287-301. **PubMed**| **Google Scholar**
24. Baker KS, Todd S, Marsh GA, Crameri G, Barr J, Kamins AO *et al*. Novel, potentially zoonotic paramyxoviruses from the African straw-colored fruit bat Eidolon helvum. J Virol. 2013;87(3): 1348-58. **PubMed**| **Google Scholar**
25. Hayman DTS, Suu-Ire R, Breed AC, McEachern JA, Wang L, Wood JLN *et al*. Evidence of Henipavirus Infection in West African Fruit Bats. PLoS One. 2008 Jul 23;3(7): e2739. **PubMed**| **Google Scholar**
26. Suu-Ire R, Obodai E, Bel-Nono SO, Ampofo WK, Mazet JA, Goldstein T *et al*. Surveillance for potentially zoonotic viruses in rodent and bat populations and behavioral risk in an agricultural settlement in Ghana. One health outlook. 2022 Mar 8;4(1): 6. **PubMed**| **Google Scholar**
27. Thornton PK, van de Steeg J, Notenbaert A, Herrero M. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. Agricultural systems. 2009 Jul 1;101(3): 113-27. **Google Scholar**
28. Kimaro E, Chibinga O. Potential impact of climate change on livestock production and health in East Africa: A review Potential impact of climate change on livestock production and health in East Africa: A review. 2020.
29. Gibb R, Moses LM, Redding DW, Jones KE. Understanding the cryptic nature of Lassa fever in West Africa. Pathog Glob Health. 2017;111(6): 276-88. **PubMed**| **Google Scholar**
30. Alidou SM. Cross-border transhumance corridors in West Africa. CapEx in supporting pastoral development. 2016;8. **Google Scholar**
31. Wiafe ED, Arku FS. Victims' Perspectives of Lowe's Monkeys'(Cercopithecus campbelli lowei) crop raiding events in Ghana: A case of Boabeng-Fiema Monkey Sanctuary. Journal of Biodiversity and Environmental Sciences. 2012;2(2): 1-8. **Google Scholar**
32. Gilbert M, Slingenbergh J, Xiao X. Climate change and avian influenza. Revue scientifique et technique (International Office of Epizootics). 2008 Aug;27(2): 459. **PubMed**| **Google Scholar**
33. Hoffman T, Olsen B, Lundkvist ??. The biological and ecological features of northbound migratory birds, ticks, and tick-borne microorganisms in the African??Western Palearctic. Microorganisms. 2023 Jan 7;11(1): 158. **PubMed**| **Google Scholar**
34. Etwire PM. The impact of climate change on farming system selection in Ghana. Agricultural Systems. 2020 Mar 1;179: 102773. **PubMed**| **Google Scholar**
35. Epstein JH, Field HE, Luby S, Pulliam JR, Daszak P. Nipah virus: impact, origins, and causes of emergence. Current infectious disease reports. 2006 Feb;8(1): 59-65. **PubMed**| **Google Scholar**
36. Spinard E, Rai A, Osei-Bonsu J, O'Donnell V, Ababio PT, Tawiah-Yingar D, Arthur D, Baah D, Ramirez-Medina E, Espinoza N, Valladares A. The 2022 outbreaks of African swine fever virus demonstrate the first report of genotype II in Ghana. Viruses. 2023 Aug 11;15(8): 1722. **PubMed**| **Google Scholar**

37. Ogawa H, Ohya K, Ayizanga R, Miyamoto H, Shigeno A, Yamada M, Takashima Y, Inoue-Murayama M, Takada A, Kayang BB. Detection of anti-ebolavirus antibodies in Ghanaian pigs. Journal of Veterinary Medical Science. 2022;84(11): 1491-4. **PubMed**| **Google Scholar**
38. Convention on Biological Diversity. Ghana Country Profiles. 2022.
39. Heymann DL, Rodier G. SARS: lessons from a new disease. Learning from SARS: Preparing for the next disease outbreak. 2004 Apr 26: 234-45. **Google Scholar**
40. Ofori SA, Dwomoh J, Yeboah EO, Aggrey ML, Nti S, Philip A, Asante C. A ecological study of galamsey activities in Ghana and their physiological toxicity. Asian Journal of Toxicology, Environmental, and Occupational Health. 2024 Jul 31;2(1): 40-57. **Google Scholar**
41. Nelson N. Climate change mitigation measures in Ghana. Advances in Environmental Sciences. 2018;10(2): 97-105. **Google Scholar**
42. UNDP. How Ghana is Strengthening its Climate Plan. UNDP. 2020.
43. MESTI. Ghana: Updated Nationally Determined Contribution under the Paris Agreement (2020 - 2030). MESTI. 2021. **Google Scholar**
44. Pepin M, Bouloy M, Bird BH, Kemp A, Paweska J. Rift Valley fever virus(Bunyaviridae: Phlebovirus): an update on pathogenesis, molecular epidemiology, vectors, diagnostics and prevention. Vet Res. 2010;41(6): 61. **PubMed**| **Google Scholar**
45. Artois M, Bicout D, Doctrinal D, Fouchier R, Gavier-Widen D, Globig A *et al*. Outbreaks of highly pathogenic avian influenza in Europe: the risks associated with wild birds. Rev Sci Tech. 2009;28(1): 69-92. **PubMed**| **Google Scholar**
46. Gilbert M, Xiao X, Chaitaweesub P, Kalpravidh W, Premashthira S, Boles S *et al*. Avian influenza, domestic ducks and rice agriculture in Thailand. Agriculture, ecosystems & environment. 2007 Mar 1;119(3-4): 409-15. **PubMed**| **Google Scholar**
47. FAO U, WHO, and WOAH. One Health Joint Plan of Action (2022-2026). Working together for the health of humans, animals, plants and the environment. Rome: 2022. **Google Scholar**
48. Kalischek N, Lang N, Renier C, Daudt RC, Addoah T, Thompson W *et al*. Cocoa plantations are associated with deforestation in Côte d´Ivoire and Ghana. Nature Food. 2023;4(5): 384-93. **PubMed**| **Google Scholar**

Table 1: workshop themes and guiding questions from the group activities and open forum discussion	
Themes	**Guiding Questions**
Climate change and interfaces where zoonotic disease risk occurs	Do the findings of the literature review align with your assessment of the climate-related research gaps under each theme?
Impacts and effects of transhumance and migration	What are the near-, medium-, and long-term research and implementation priorities?
Surveillance and data needs	What are the key coordination needs for early warning and risk reduction?
	Are there specific stakeholder groups or occupations that are most vulnerable to risk and impact?

Table 2: participants who attended the workshop on operationalising One Health through the lens of climate change and emerging disease risk, 24th March 2022, University of Ghana	
Organisation	**Number of participants**
School of Veterinary Medicine, University of Ghana	5
Vector Borne Research Unit, University of Ghana	2
Geography Department, University of Ghana	2
School of Public Health, University of Ghana	2
Animal Biology and Conservation Science Department, University of Ghana	2
Marine and Fisheries Dept, University of Ghana	2
Noguchi Memorial Institute for Medical Research	1
Naval Medical Research Unit, Noguchi Memorial Institute for Medical Research	1
Kumasi Centre for Collaborative Research in Tropical Medicine, Kwame Nkrumah University of Science and Technology	1
Ghana Atomic Energy Commission	1
Animal Research Institute, Council for Scientific and Industrial Research	2
National Disaster Management Organisation	1
Environmental Protection Agency	2
Ghana Health Services, Public Health Department, and Surveillance Department	2
Ghana Health Services, Neglected Tropical Disease Unit	1
Veterinary Services Department	3
Forestry Commission	1
Forestry Commission, Wildlife Division	1
United Nations Environment Programme	1
World Health Organisation	1
Food and Agriculture Organisation of the United Nations	1
Young Professionals	5