One Health Outlook

REVIEW

The role of climatic changes in the emergence and re-emergence of infectious diseases: bibliometric analysis and literature-supported studies on zoonoses

Walter Leal Filho[1,2], Gustavo J. Nagy[3], Gouvidé Jean Gbaguidi[1,4*], Shlomit Paz[5], Maria Alzira Pimenta Dinis[6,7], Johannes M. Luetz[8,9,10] and Ayyoob Sharifi[11]

Abstract
Climate change (CC) is increasingly recognised as a critical driver in the emergence and re-emergence of infectious diseases. The relationship between CC and infectious diseases is complex and multifaceted, encompassing changes in temperature, precipitation patterns, and extreme weather events. This study describes the role of CC in the emergence and re-emergence of infectious diseases, emphasising zoonoses. It used a mixed methodology, including an initial literature contextualisation and a bibliometric analysis, to identify key thematic research areas related to CC and zoonotic diseases and show their connections. The research relied on the Scopus database for the identification of relevant source literature and focused the search query on publications in English. VOSviewer was used to discover clear thematic clusters that illustrate what research areas have been addressed in the literature and how they are interlinked. In addition, the research selected and analysed twelve literature-supported studies to investigate the relevance of the zoonoses involved in infectious disease emergence and re-emergence linked to CC impacts. Many pathogens and their vectors, such as mosquitoes, ticks, and rodents, are sensitive to temperature and moisture. CC can expand or shift the geographical distribution of these vectors, bringing diseases to new areas. Warmer temperatures may allow mosquitoes that transmit diseases like malaria and dengue fever to survive and reproduce in regions that were previously too cold. Also, extreme events such as floods, droughts, and hurricanes can lead to immediate increases in waterborne and vector-borne diseases (VBD) by facilitating the spread of pathogens. There is a need to better understand the connections between CC and zoonoses. To address the challenges posed by zoonoses linked to CC, international organizations like the WHO should coordinate a global response to provide clear guidance. Governments must integrate CC and zoonoses into national health policies, ensuring that health frameworks address these interconnected risks. Funding should be allocated for research on the root causes of CC and for strengthening defenses, particularly in developing countries with fragile health systems. Additionally, enhanced communication, education, and training for healthcare professionals about the links between CC and zoonoses are essential for raising awareness and promoting proactive measures.

*Correspondence:
Gouvidé Jean Gbaguidi
gouvidejeang@gmail.com
Full list of author information is available at the end of the article

Keywords Climate Change (CC), Zoonoses, Literature analysis, Case studies, Strategies

Climate change in the emergence and re-emergence of infectious diseases

The current climate crisis significantly impacts all systems of our planet, including human and animal health [25]. One of the main impacts of climate change (CC) on public health is the influence on zoonotic diseases that are transmitted from vertebral animals to humans by parasites, viruses, and bacteria [25], and in particular on vector-borne diseases (VBD) transmission since a warmer climate and changing rainfall patterns may create more hospitable environments for climate-sensitive vectors such as mosquitoes, sand-flies, and ticks [40]. Such diseases are, for example, malaria, dengue, and West Nile fever (transmitted by mosquitos), leishmaniasis (transmitted by sand flies), and Lyme disease (transmitted by ticks). Although the impacts of climate are complicated by nonlinear feedbacks inherent in the dynamics of many infections and variable among different vector/pathogen combinations, climate is well known as a major environmental driver influencing the epidemiology and transmission of zoonotic diseases from shorter (seasonal, annual) to longer (decadal) time scales [41, 42]. There are also signs that the autochthonous spread of some infectious diseases may be facilitated by climatic changes increasing ecological suitability (the availability of niches suitable for vectors and pathogens) and vectorial capacity (the ability of the vector to transmit the disease) in multiple settings [16]. CC can disrupt the delicate balance between hosts and pathogens. Temperature and rainfall patterns change can impact animals' life cycles, reproduction, and migration patterns, influencing their interactions with disease-causing agents [29, 37, 13]. Ambient temperature plays an important role in viral replication rates and pathogen transmission by affecting the length of extrinsic incubation, the seasonal phenology of vector host populations and the geographical variations in human case incidence [40]. Such disruptions can lead to increased transmission rates and the emergence of new infectious diseases, such as the spread of malaria in West Africa. Transmission of malaria was linked to changes in temperature, rainfall patterns, humidity, and changes in land use [5, 13, 26]. Indeed, tropical species spread towards the poles, and species are established in higher elevations due to rising temperatures. These processes include spreading disease vectors to new, including non-endemic, areas due to improved (warmer) habitat suitability [6].

CC exacerbates environmental degradation, including deforestation, habitat loss, and land-use changes [30]. These factors drive animals and humans closer together, creating opportunities for zoonotic spillover. When wildlife populations come into contact with human settlements due to the shrinkage of natural habitats, this proximity can facilitate the spread of infectious pathogens such as coronavirus disease (COVID-19), severe acute respiratory syndrome (SARS), Ebola, and Lassa diseases that can arise when humans invade previously unaffected ecosystems [27]. Notably, CC disproportionately affects vulnerable populations, amplifying their susceptibility to infectious diseases; disadvantaged communities, particularly those in low-income countries, may lack access to adequate healthcare, clean water, and sanitation infrastructure, making them more susceptible to infection [9]. Those in refugee camps are at very high risk of outbreaks due to high population density, poor sanitation, and inadequate access to health and social services [42]. In regions where CC impacts agriculture and food security, malnutrition weakens immune systems, increasing the risk of disease transmission [19]. In synthesis, zoonotic infectious diseases significantly affect vast systems beyond public health, including human security, wildlife trade, and tourism [23, 46, 49].

Set against this background, the current study departs from the following research question: **To what extent does climate change contribute to the emergence of zoonoses?** Consistent with this research question, the study aims to review how climatic changes influence the emergence and re-emergence of infectious diseases based on focused literature research and a bibliometric analysis from zoonoses. This study is structured as follows. Further to this introduction, Sect. "Methods" details the methods used, Sect. "Bibliometric analysis methods" presents and analyses the results, and Sect. "Literature-supported studies approach" presents some conclusions, drawing together the main lessons from the study. It also highlights specific measures that can be implemented to encourage action in addressing a globally significant issue.

Methods

The current study used a mixed methodology, including an initial literature contextualisation and a bibliometric analysis, to identify key thematic research areas related to CC and zoonotic diseases and show their links. A set of tables was compiled, containing a list of literature with studies on zoonotic diseases and the links between CC and some of the zoonoses, including their incidences, allowing the connection between both topics to be better perceived. The current study sourced data from the Scopus database with the intention of focusing the search query on publications in English. The choice for Scopus was informed by the fact that this database provides a wide range of peer-reviewed studies and caters for prompt retrieval of the essential details of each publication. Based on the information collected on the topic under study, we selected twelve literature-supported studies that help illustrate the relevance of the zoonoses involved in infectious disease emergence and re-emergence linked to CC impacts.

Figure 1 illustrates the methodology used in this study.

Bibliometric analysis methods

Most definitions of bibliometrics are considered to be too broad [4, 33]. introduced the bibliometric concept and much has been written about it since then. It mainly deals with the links between the volume (number of scientific publications and citations) of scientific data on a specific topic and the statistics around it [33] became the first one to coin a definition of bibliometrics ("the application of mathematical and statistical methods to books and other media of communication"; p. 348), a vague concept that evolved considerably in the days since, including via work of [11], who defined bibliometrics as "the search for systematic patterns in comprehensive bodies of literature" (p. 40). A bibliometric analysis is in fact a method that helps map the research landscape and highlight key thematic areas of research fields. It allows the analysis of large volumes of academic research that may be challenging to address using other literature review methods such as systematic reviews and meta-analyses. Among different bibliometric analysis techniques, we used the term co-occurrence analysis offered by VOSviewer, a widely used bibliometric analysis software [53]. Various tools, such as CiteSpace and SciMAT, have been used in the literature [52, 53]. We used VOSviewer because its term co-occurrence analysis outputs are user-friendly and readily interpretable. The outputs provide clear thematic clusters that help to understand what research areas have been addressed in the literature and how they are interlinked. The data for analysis in VOSviewer was obtained from Scopus, a database indexing academic research, which has a broader coverage of peer-reviewed scholarly research than other sources. We used the following broad-based search string to retrieve relevant publications for inclusion in the study:

("Climate change*" or "climatic change*" or "global warming*") AND (zoono *)

Searching for titles, abstracts, and keywords for publications indexed in Scopus on March 3, 2024, found 1495 articles. After excluding articles not written in English and removing documents not explicitly focused on CC and zoonotics, 1340 articles remained in the database. We downloaded the bibliographic data of these articles and used it for term co-occurrence analysis. Before the final term co-occurrence analysis, we also developed a thesaurus file. We added it to the software to ensure that synonymous terms were not counted separately (e.g., climate change and climatic change). The co-occurrence analysis resulted in a graph network of nodes and links, where nodes represent key terms and links, showing how they are interlinked. The node size is proportional to the frequency of terms, and the width of the links is proportional to the degree of strength of connections between terms. Terms closely linked to each other form research clusters shown in unique colours, which we discuss in the results section.

Literature-supported studies approach

The authors selected a set of twelve literature-supported studies using three main criteria. The first was the relevance of the studies. The second was the need to cater for a wide geographical distribution. The third criterion was covering various challenges and concerns to complement the bibliometrics. Whereas many other studies could have been used, the chosen ones fit well with the purpose and scope of this study.

Results and discussion

Bibliometrics

Figure 2 shows the results of the bibliometric analysis. We identified four major thematic clusters in distinct colours (**green**, **red**, **blue**, and **yellow**). The **green** cluster focuses on human activities, population growth, and urbanisation. The **red** cluster focuses on nonhuman factors and epidemiology. The **blue** and **yellow** clusters are mainly related to environmental risk factors and infection

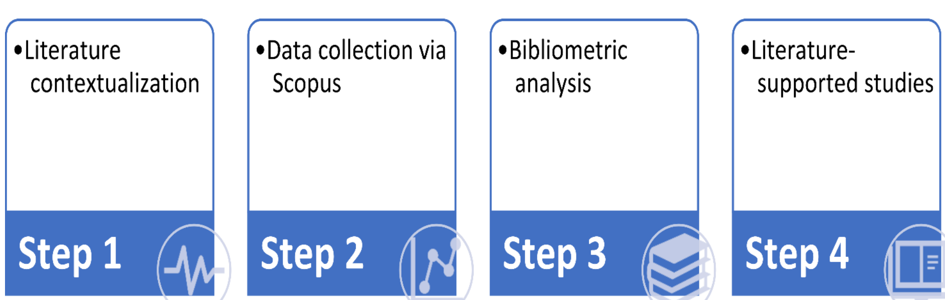

Fig. 1 Methodological steps followed in the study (source: authors)

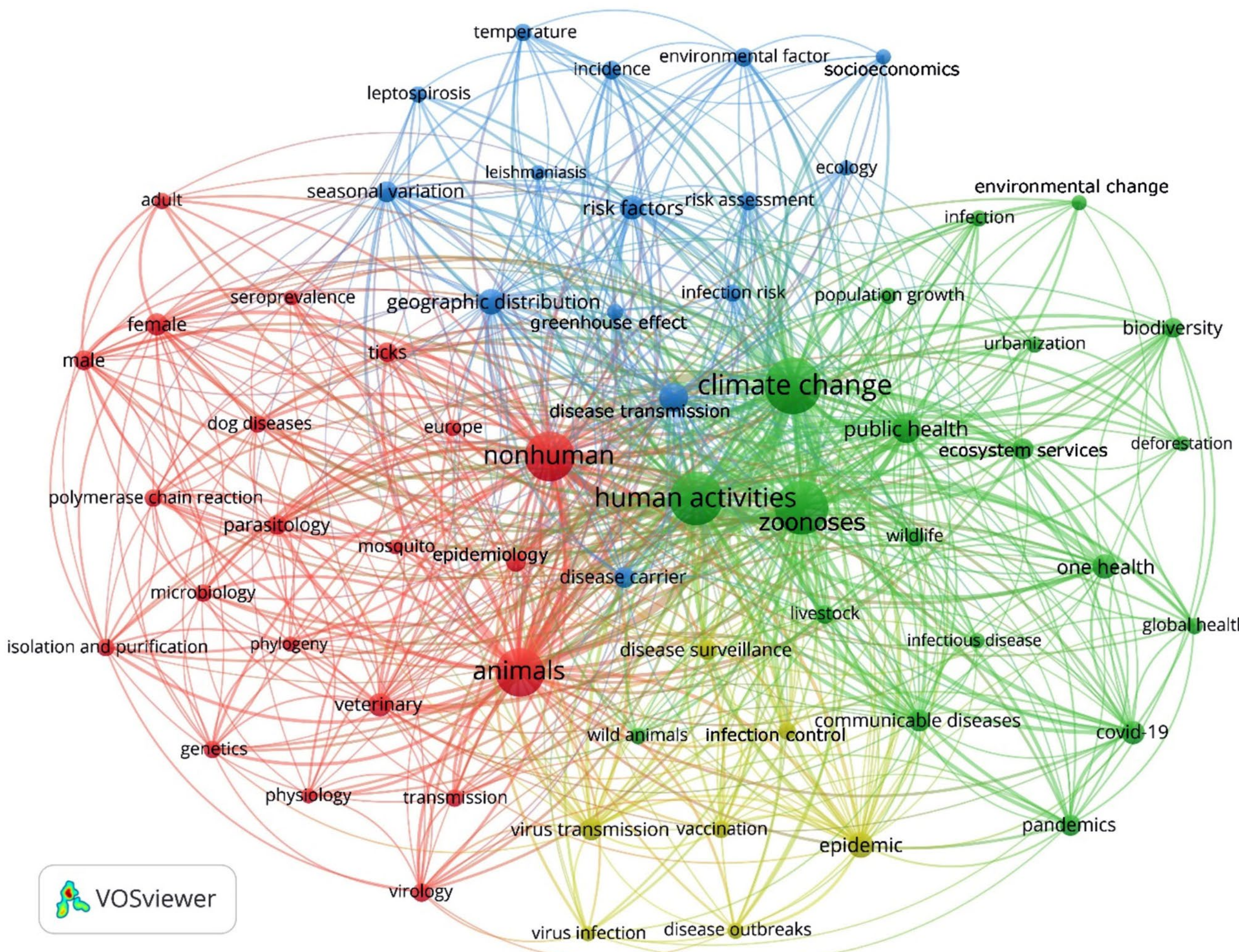

Fig. 2 The output of the bibliometric analysis

control. The four clusters are closely interlinked, indicating that factors that determine the impacts of CC on the emergence and spread of zoonotic diseases interact with each other [31]. Each of these clusters is briefly explained in the remainder of this section.

The **green cluster** is dominant, as indicated by frequently co-occurring terms such as 'climate change', 'human activities', 'zoonoses', and 'public health'. These are highly central terms in the network and strongly connected to terms in other networks. The strong connections between these terms show that issues related to the impact of CC and human activities on the emergence and spread of zoonotic diseases are widely explored in the literature [31]. Terms such as urbanisation and population growth are central in the green cluster. Rapid population growth and urbanisation are widely recognised as key drivers of CC [28]. Unregulated urbanisation and sprawl have resulted in deforestation and increased encroachment on natural ecosystems [35], which supports increased exposure to vectors and wildlife hosts of zoonotic diseases, resulting in the emergence of infectious diseases. Urbanisation and CC significantly impact the emergence and spread of zoonotic diseases [20]. Urbanisation disrupts natural habitats, bringing wild animals that host zoonotic pathogens closer to human populations, thus increasing the likelihood of spillover events and disease transmission [18, 20]. Further, deforestation and converting natural land for agricultural purposes may also increase the risk of disease transmission as livestock exposure to pathogens can amplify the transmission of infection to humans. In addition, urbanisation often leads to crowded living conditions, inadequate sanitation, and limited access to healthcare; these factors can exacerbate the spread of diseases. CC further complicates the situation by altering the distribution and abundance of disease vectors and hosts (e.g., CC has the potential to increase the geographic distribution and abundance of mosquitoes that transmit malaria) as well as the timing and intensity of disease outbreaks [18, 43]. Zoonotic diseases such as Dengue, Chikungunya, Ebola, Leptospirosis, Helminthiases, Lyme disease, and Zika thrive under these conditions, posing significant threats to public health, particularly among vulnerable populations [18, 35]. Addressing these complex challenges requires a holistic, interdisciplinary approach that considers ecological, social, and economic factors to prevent and control zoonotic disease spread effectively. Adopting a One Health perspective that considers the links between human, animal, and environmental health is crucial for preventing and controlling zoonotic diseases [18, 35].

The **red cluster** includes various influential terms from multiple fields of knowledge related to nonhuman factors. CC impacts the movement, distribution, behaviour, and number of nonhuman elements involved in the spread of zoonotic diseases [35]. For instance, ticks carry Lyme disease, babesiosis, and anaplasmosis, and their movements are influenced by temperature and humidity. Rising temperatures are causing ticks to spread into new areas, increasing the likelihood of disease transmission to humans and domestic animals like dogs. Dogs can be sources of zoonotic diseases such as leishmaniasis and Leptospirosis, which may be affected by climate-related conditions like flooding or urbanisation. Understanding how CC affects these factors is essential for predicting and preventing future outbreaks that could affect human and animal health [35]. The same cluster also identifies other key terms related to nonhuman factors. These issues are well-documented in the literature and can have a considerable cumulative impact on zoonotic disease propensity as they interact with each other and the influence of CC. Various scientific fields are thus interlinked to human health via CC, including veterinary science, genetics, microbiology, and phylogeny [56, 57]. Veterinary science is connected to CC through the changing distribution and prevalence of infectious diseases in animals, changing habitats and food sources for wildlife, and changes in the health and productivity of livestock, among others (Bezerra-Santos et al., 2023). Likewise, research on genetics plays a vital role in informing human understanding of the evolving genetic makeup of pathogens and their hosts. Genetics is linked to CC through changing environmental conditions and species' associated evolving adaptation capacity and resilience. Areas of research interest include genomic sequencing of zoonotic pathogens, predicting potential mutations, and tracking disease transmission [55]. Relatedly, research on phylogenetics investigates the evolutionary relationships between different species and their genetic divergence over time. Literature in this area identifies the origins and transmission dynamics of zoonotic diseases, including how climate-induced changes in ecosystems may impact the phylogenetic relationships of pathogens and their hosts [14, 58]. The literature also notes microbiology interacting with CC and influencing the evolution of microorganisms, including zoonotic pathogens. Microorganisms are crucial in mediating greenhouse gas emissions through sequestration and influencing the overall balance of atmospheric gases [59]. Significantly, CC and other human environmental changes may produce shifts in microbial communities, which may have cascading effects on ecosystems, agricultural productivity, and human health [60]. This cluster thus identifies a range of interrelated nonhuman factors that interact with CC and may have a considerable cumulative impact on human health through evolving zoonotic disease propensity. Therefore, climate science is raised as an essential interdisciplinary undertaking for understanding interlinked environmental and nonhuman factors that influence the distribution and prevalence of zoonotic diseases [14, 56, 57].

The **blue** cluster focuses on environmental factors that pose a risk. Changes in climate and seasonal patterns can impact these factors, potentially increasing the likelihood of zoonotic diseases spreading. For instance, CC can potentially modify the habitats and behaviours of disease-carrying vectors and reservoirs like sandflies and rodents, leading to an expansion in their population size and geographical range [14]. Seasonal variations can also impact the population and behaviour of these species and people's exposure to them [24]. Two examples of zoonotic diseases influenced by CC and seasonal variations are leishmaniasis and Leptospirosis. Protozoan parasites carried by sandflies cause leishmaniasis, and their prevalence and distribution are influenced by temperature, rainfall, humidity, and vegetation [8, 43]. Leptospirosis is brought about by bacteria spread by rodents or polluted water, and its frequency and seriousness are affected by flooding, urban development, and land utilisation [35]. Thus, it is crucial to monitor and predict the impact of CC and seasonal variations on these environmental risk factors to prevent and manage zoonotic diseases.

Finally, there is a small **yellow** cluster focused on disease surveillance, infection control, and vaccination, which are essential strategies for preventing and managing these illnesses while safeguarding human and animal well-being. Surveillance involves gathering, analysing, and sharing data on the occurrence and distribution of zoonotic diseases to identify outbreaks, risk factors, and intervention effectiveness [39, 44]. Infection control complements surveillance by reducing disease transmission through isolation, quarantine, disinfection measures, personal protective equipment use, and biosecurity practices [39, 44]. Additionally, vaccination is crucial for building immunity against zoonotic diseases to protect both humans and animals while minimising pathogen reservoirs [32]. Integrated implementation of these strategies also necessitates a comprehensive approach that aligns efforts in areas of human, animal, and environmental health [39].

Figure 3 schematises the interrelated factors contributing to evolving zoonotic disease propensity framed by a One Health perspective, which the quadripartite World Health Organization (WHO)- World Organisation for Animal Health (WOAH)- Food and Agriculture Organization (FAO)- United Nations Environment Programme (UNEP) defines as an integrated, unifying approach that aims to sustainably balance and optimise the health of people, animals, and ecosystems. It recognises that the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and interdependent. The approach mobilises multiple sectors, disciplines and communities at varying levels of society to work together to foster well-being and tackle threats to health and ecosystems while addressing the collective need for clean water, energy and air, safe and nutritious food, taking action on CC, and contributing to sustainable development [48].

Literature-supported studies

CC has increasingly been linked to the emergence of zoonoses [25], with studies indicating that CC alters pathogen distribution [22]. As zoonotic infections are expected to rise [2, 5], there is an urgent need for effective monitoring systems [51]. A few years before the onset of the COVID-19 pandemic, UNEP warned that the global spread of zoonotic diseases could pose a significant health risk. Environmental changes and ecological disturbances—such as agricultural intensification and encroachments into forests—are often associated with the emergence of zoonoses. These linkages can be opportunistic, as hosts are frequently stressed by environmental, social, or economic factors. CC has accelerated the spread of zoonotic diseases worldwide [61].

12 illustrative studies, presented in Table 1, were reviewed, highlighting the connections between zoonoses and CC, as well as their contributions to the rise in infectious diseases. Monitoring the evolution of zoonoses linked to increasing zoonotic infections and new pathogens due to rising global temperatures is crucial for helping healthcare providers recognize and address these threats. For instance [22], used data from Finland's National Infectious Disease Register to showcase comprehensive reporting of all laboratory-confirmed infections. Additionally [17], examined 46 studies from Europe, North America, Asia, and Africa regarding ticks

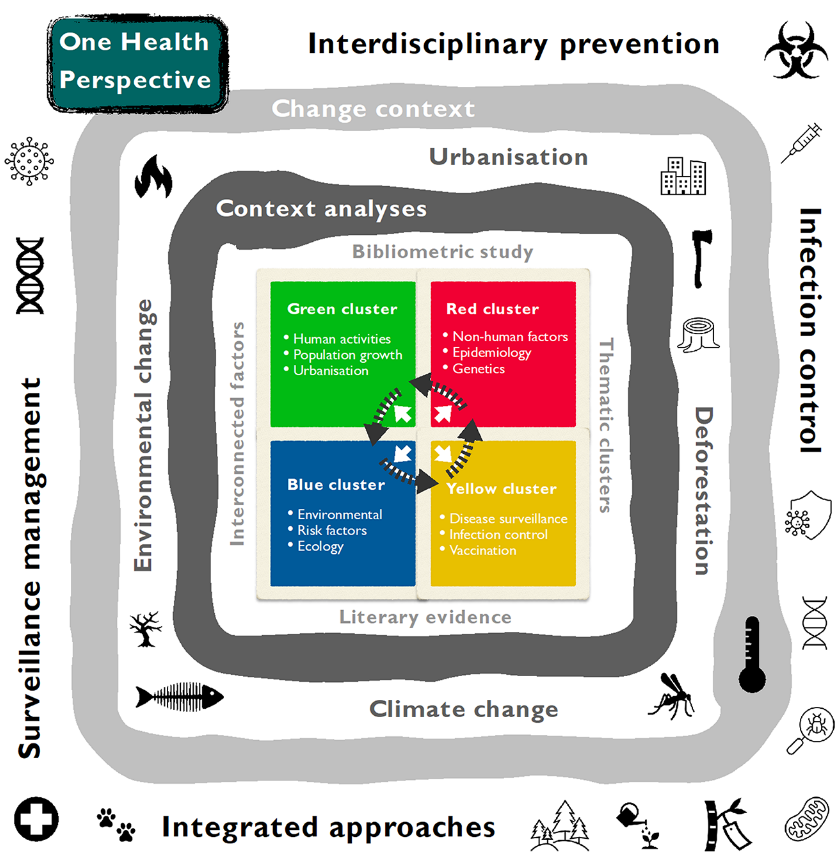

Fig. 3 Schematic representation of interrelated factors contributing to evolving zoonotic disease propensity framed by a One Health perspective. (source: authors)

Table 1 Literature-supported studies on zoonoses connected to climate change worldwide

Study	Zoonose pathogen /disease and scope	Incidence and Evidence	Reference(s)
1	*Borrelia burgdorferi* Puumala virus *Francisella tularensis* Tick-borne encephalitis (TBE) (*Nationwide Children*, *Finland*)	11.2 per 100,000 person-years (increasing trend and expansion 1996–2019) 6.4 per 100,000 person-years (stable) 2.5 per 100,000 person-years (cyclic change) 0.4 per 100,000 person-years (increasing trend and expansion 1996–2019)	[22]
2	*Borrelia burgdorferi* (*46 countries in 4 continents: Europe*, *North America*, *Asia*, *and Africa*) Review	Lyme disease caused by *Borrelia burgdorferi* is expected to increase by about 20% in the next 1 or 2 decades in the USA alone (increasing distribution of tick-associated *Borrelia burgdorferi*)	[17]
3	Zoonotic cutaneous leishmaniasis (ZCL) caused by Phlebotomine sand flies (*Iran*)	17–47 cases per 100,000 population (1983–2012) and 15.8 cases per 100,000 population (2019) (increasing distribution in the central, southern and eastern parts of Iran)	[7]
4	Zoonotic Babesia, vectored by *Ixodes* ticks (*Global*) Review	Increasing incidence of babesiosis over time, mainly in the USA	[50]
5	Ticks transmit multiple bacterial, parasitic, and viral diseases (*Latin America*) Review	Tick-borne diseases have been significantly increasing and extending to new territories.	[34]
6	Zoonotic multi-host, multi parasite system (*West Africa*)	Increasing evidence of hybridisations and introgressions between co-infecting parasite species is becoming more common.	[3]
7	Arthropods and rodents transmitting zoonotic diseases (*China*)	Incidence rates related to the density of rodents reveal potential. Increase in the incidence of climate-sensitive diseases.	[15]
8	H5N1 and H7N9 subtypes of influenza A transmitting zoonotic influenza (*Vietnam*)	Climatic variables being associated with seasonal variation in the incidence of avian influenza outbreaks in the North.	[12]
9	Lassa fever	100,000–300,000 infections per annum, with circa 5,000 deaths	[62]
10	Leptospirosis	Roughly 1 million annual cases	[63]
11	Brucella spp., causing Brucellosis (*Kenya*, *Yemen*, *Syria*, *Greece*, *Eritrea*)	An evidence-based conservative estimate of the annual global incidence is 2.1 million, significantly higher than was previously assumed. 47.26 per 100,000 inhabitants in Syria (2017), 42.96 per 100,000 inhabitants in Greece (2015) and 21.82 per 100,000 inhabitants in Eritrea (2017).	[64, 65]
12	Rabies (*worldwide*)	Globally, 59,000 people are predicted to die each year from Rabies caused by dogs, resulting in a loss of 3.7 million DALYs. The central portion of deaths (59.6%) are reported in Asia and the African continent (36.4%).	[66]

collected from various sources. Their research highlights the expanding range of Borrelia burgdorferi, likely due to accelerated tick population growth in response to CC and tick dispersal via migratory birds. The study emphasizes that understanding transmission channels is essential to mitigating CC's impact on tick life cycles. Similarly [7], aimed to predict CC scenarios in Iran by analyzing the ecological niches for vectors and reservoirs of zoonotic cutaneous leishmaniasis (ZCL). Their predictive climate adequacy maps indicate that the risk of infection will increase in central, southern, and eastern Iran, underscoring the importance of monitoring this critical disease, which is present in 18 out of 31 provinces. More than 80% of cases of cutaneous leishmaniasis in Iran are caused by Phlebotomine sand flies, encompassing around 50 species. Leishmaniasis is on the rise in many countries, particularly in Iran, driven by CC and shifts in lifestyle patterns [1]. According to [50], zoonotic *Babesia*—a significant threat to blood supplies in the United States of America (USA)— is vectored by *Ixodes* ticks, particularly *Ixodes scapularis*, which also transmits pathogens responsible for Lyme disease and other illnesses. Their scoping review revealed a lack of predictive models assessing the impact of CC on *Babesia* species, highlighting the need for increased scientific investment in this area. The authors noted that most incidence cases were reported in the USA, possibly due to the underrepresentation of non-English or non-French articles. The studies reviewed indicate that the frequency of tick-borne diseases has risen and expanded into new territories, driven by land use patterns and CC [25, 34]. However, specific regions, such as Latin America, lack sufficient studies on these topics, even though pathogens reported in other areas have not yet been adequately addressed there. This gap is compounded by a lack of expertise and funding to confront the scientific and financial challenges related to these studies [34].

Regarding zoonotic hybrid systems, Table 2 summarises some aspects highlighted concerning CC emergence and the role played by zoonoses in a set of selected studies in different regions of the world.

Table 2 Highlights in specific literature-supported studies on zoonoses and climate change emergence

Study	Literature-supported Studies	Challenges	Concerns	References
1	Epidemiology of Zoonotic Infections in Finland	Recognise zoonotic infections in practice.	Zoonosis linking to hospitalisation and mortality.	[22]
2	Borrelia burgdorferi emergence ticls worldwide	Compiling tick species responsible for transmitting the zoonotic vector across the globe.	Monitoring overwhelming effects on human and animal health and well-being.	[17]
3	Iran zoonotic cutaneous leishmaniasis (ZCL)	Prioritising areas where the vector and reservoir(s) of ZCL have yet to be reported.	Refines and updated future dissemination models.	[7]
4	Zoonotic *Babesia* global evidence	Knowledge gaps will be used to inform future health policy and decision-making.	Required epidemiology and surveillance work, tracking the possible spread of *Babesia* into previously unaffected areas, as predictive models investigating the impact of CC on *Babesia* species.	[50]
5	Epidemiology of zoonotic tick-borne diseases in Latin America	Molecular and epidemiological studies in specific parts of the world.	Scientific and financial restrictions to further studies investigating tick-borne diseases.	[34]
6	Zoonotic hybrid schistosomiasis in west Africa	Expanding and adapting existing mathematical model frameworks for schistosome transmission to zoonotic hybrid systems.	Exploring model frameworks to use molecular and epidemiological data.	[3]
7	China's Capacity to Manage Emerging and Re-emerging Zoonotic Diseases	Increasing changes hamper China's capacity to manage zoonotic diseases in movement, urbanisation, and climate.	Optimising successful disease control and prevention practices.	[15]
8	Economic factors influencing zoonotic diseases dynamics	The importance of anthropogenic factors is to be fully considered.	Focus on the economic factors in the transmission of zoonotic diseases.	[12]

The examples discussed in both Tables 1 and 2 (focusing on the challenges and concerns identified in literature-supported studies 1–8 from Table 1) illustrate the necessity of investing in existing mathematical frameworks to adapt to zoonotic hybrid systems. These frameworks aim to tackle the challenges posed by the complex, dynamic interactions within multihost, multiparasite systems. For instance, studies of the *Schistosoma* spp. haematobium group in West Africa reveal how climate and habitat changes have increased opportunities for hybridization and the emergence of more virulent strains [3], further impacting both the environment and human health [15]. examined zoonotic diseases transmitted by arthropods and rodents, which remain significant public health concerns in China, where infectious diseases continue to be a major issue. They predict that climate-sensitive diseases will resurge, driven by globalization, urbanization, and a warming climate, underscoring the need for health professionals to be prepared to identify emerging and re-emerging trends. Climate factors are associated with the temporal dynamics of zoonotic influenza viruses transmitted from domestic animals to humans. Using a stochastic compartmental model [12], emphasized the role of economic factors in influencing the changing trends of avian influenza outbreaks in Vietnam, concluding that anthropogenic factors must be considered when assessing disease epidemiology to enhance surveillance and control interventions. In the context of Lassa Fever, predictions suggest that increasing precipitation and agricultural development across western Africa may extend suitable habitats for reservoir hosts. Similarly, anticipated changes in seasonal precipitation may affect reservoir host population cycles and seasonal variations in human risk. On another note, evidence indicates that Leptospirosis—one of the leading zoonotic causes of pulmonary hemorrhage worldwide—has seen increases in morbidity and mortality, predominantly in impoverished rural and urban communities that are highly susceptible to rodent-contaminated environments [35].

The connections between CC and infectious diseases, particularly zoonoses, are evident. The complex interplay of ecological disruptions, altered host-pathogen interactions, environmental degradation, and changing transmission dynamics underscores the need for comprehensive strategies to address these challenges [38]. Mitigating CC, protecting biodiversity, improving healthcare infrastructure, and promoting sustainable practices are essential for reducing the emergence and re-emergence of infectious diseases in the face of a changing climate [9, 10, 16, 38, 45]. By acknowledging and addressing these connections, we can better protect both human and animal health in a world affected by CC.

Conclusions

This review study explores the complex relationship between CC and zoonotic diseases, revealing relevant trends. As the planet warms, conditions generally become more favorable for the spread of diseases that originate in animals and are transmitted to humans. This connection underscores the role of CC in the emergence of zoonoses, which is the central research question addressed by this study. It also highlights the urgent need to tackle CC as both an environmental issue and a critical public health concern, for several important reasons. Firstly, CC accelerates the emergence and spread of zoonotic diseases by altering ecosystems and affecting the behavior of vectors, hosts, and pathogens. Variations in temperature, precipitation patterns, and the frequency of extreme weather events disrupt natural habitats, leading to shifts in biodiversity and causing species to migrate to new regions. These movements increase interactions between wildlife, domestic animals, and humans, thereby heightening the risk of zoonotic transmission. For instance, the spread of mosquito-borne diseases like Zika and West Nile virus has been directly linked to changing climatic conditions, with warmer temperatures and altered rainfall patterns providing ideal breeding environments for disease vectors such as mosquitoes. Secondly, the effects of CC on human health are multifaceted, impacting not only physical health but also placing significant strain on public health systems, economies, and social structures. Rising temperatures can exacerbate the incidence of heat-related illnesses, while altered disease dynamics force health systems to adapt to new challenges, often overwhelming resources in affected regions. Economic disruptions from reduced agricultural productivity and increased healthcare costs further compound these challenges, creating a ripple effect that threatens societal stability. Thirdly, vulnerable populations, particularly in low-income countries, are disproportionately at risk. These populations often have the least capacity to adapt to the environmental changes brought on by CC and lack the infrastructure needed to effectively respond to zoonotic outbreaks. Limited access to healthcare, inadequate public health resources, and dependence on climate-sensitive livelihoods make these communities especially susceptible to both the direct and indirect impacts of climate-related zoonotic diseases.

A comprehensive approach is essential to mitigate these risks and safeguard global health. This approach should include enhancing surveillance and monitoring of zoonotic diseases, investing in research to better understand the complex relationship between CC and disease transmission, and implementing policies to reduce greenhouse gas emissions and limit global warming. Additionally, strategies aimed at preserving biodiversity and protecting natural habitats can help decrease the likelihood of zoonotic spillover events. Furthermore, public health measures must be integrated with climate adaptation efforts to ensure communities are resilient to the effects of both CC and zoonotic diseases. This includes strengthening health infrastructure, developing early warning systems for disease outbreaks, and promoting global cooperation to share knowledge, resources, and best practices.

This study has limitations. First, the bibliometric analysis was conducted to identify key thematic research areas related to CC and zoonotic diseases and to highlight their connections. However, the search strings used focused primarily on direct links between CC and zoonoses, without considering the broader socio-economic factors that may also influence these relationships. This narrowed scope could limit the understanding of how socio-economic variables, such as poverty, urbanization, and access to healthcare, contribute to the dynamics between CC and zoonotic disease spread. Another limitation is that only twelve illustrative studies from the literature were selected to demonstrate how CC influences the emergence and re-emergence of zoonotic diseases, contributing to the increase in infectious diseases. While these studies provide valuable insights, the small sample size may not fully capture the diversity of research in this rapidly evolving field, potentially omitting other critical findings.

Despite these limitations, this study makes a valuable contribution to the growing body of literature on CC and zoonotic diseases. It underscores the pressing need to address the intersection of these two factors, which pose an increasingly significant threat to global public health. By reiterating the importance of understanding the complex dynamics at play, the study calls attention to the clear and present danger that CC and zoonotic diseases together present to human health worldwide, and highlights the urgency of integrated approaches in research and polic.

Based on the research conducted in this study, several recommendations emerge that could guide the development of measures to prevent or minimize the emergence and re-emergence of zoonoses in the context of CC:

i. **An immediate and coordinated response** to the escalating challenges posed by zoonoses linked to CC should be initiated by international organizations, such as the World Health Organization (WHO), to provide clear guidance on the necessary actions at the global level. Such coordination is vital to ensuring a unified global strategy that can effectively address the rising threat of zoonotic diseases exacerbated by CC.
ii. **The integration of climate change and zoonoses** into national health policies and climate policies is crucial. Governments must recognize the interconnectedness of these issues and ensure that their health frameworks account for the growing risks posed by climate-related zoonotic diseases. This could involve creating policies that promote surveillance, preparedness, and public health responses that consider the climate-disease nexus.
iii. **Specific funding allocations** should be made for research addressing the root causes of CC and for initiatives that strengthen our defenses against

the health threats it intensifies. In particular, attention must be given to the needs of developing countries, where health systems are often fragile and ill-equipped to handle the additional pressures of climate-related zoonoses. Adequate financial support is critical for improving resilience in these regions, enabling better preparedness and response mechanisms.

iv. **Increased emphasis on communication, education, and training** regarding CC and zoonoses is essential, especially for healthcare professionals. Raising awareness of the connections between CC and the emergence of zoonotic diseases will not only help prepare medical personnel for the challenges ahead but also draw broader public attention to the issue. Educational programs and training initiatives can foster a deeper understanding of how climate shifts contribute to the spread of these diseases, encouraging more proactive measures at both local and global levels.

By recognizing the deep interconnections between the health of our planet, ecosystems, CC, and human societies, we can pave the way toward a more sustainable future. This holistic understanding enables us to take proactive measures that not only address the immediate threats of zoonotic diseases and environmental degradation but also promote the long-term well-being of both current and future generations. Protecting the integrity of natural ecosystems, mitigating CC, and strengthening global health systems are all crucial steps toward ensuring a resilient and healthy planet for al.

Abbreviations

CC	Climate change
COVID-19	Coronavirus disease
FAO	Food and Agriculture Organization
SARS	Severe acute respiratory syndrome
TBE	Tick-borne encephalitis
UNEP	United Nations Environment Programme
USA	United States of America
VBD	Vector-borne diseases
WHO	World Health Organization
WOAH	World Organisation for Animal Health
ZCL	Zoonotic cutaneous leishmaniasis

Acknowledgements
Not Applicable.

Author contributions
All the authors have contributed to this work and agree to appear in this article. WL implemented the study, validated the data and methods, and drafted and reviewed the manuscript. GN collected the data on the study supporting the literature review, wrote the manuscript, and processed the data on the literature-based case studies. GJG collected the data and wrote the manuscript. SP and AD collected the data for the bibliometric analysis, wrote the manuscript, and processed the data for the bibliometric analysis. JL contributed to the bibliometric analysis, wrote the manuscript, and produced conceptual Fig. 3. AS contributed to the bibliometric analysis.

Funding
This study did not receive any external funding.

Data availability
The data will be available on reasonable request from the HAW Hamburg University of Applied Sciences, Faculty of Life Sciences, Hamburg, Germany. Please contact the corresponding author.

Declarations

Ethics approval and consent to participate
This study did not need any ethics approval and consent to participate.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]International Climate Change Information and Research Programme, International Expert Centre for Climate Change and Health, Research and Transfer Centre "Climate Change and Sustainable Development", Hamburg University of Applied Sciences, Ulmenliet 20, 21033 Hamburg, Germany
[2]Department of Natural Sciences, Manchester Metropolitan University, Chester Street, Manchester M1 5GD, UK
[3]Instituto de Ecología y Ciencias Ambientales (IECA), Facultad de Ciencias, Universidad de la República (UdelaR), Iguá 4225, Montevideo 11440, Uruguay
[4]West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), Faculty of Human and Social Sciences, Department of Geography, Togo, University of Lomé, Lomé, Togo
[5]School of Environmental Sciences, Climate and Environmental Sustainability Center, University of Haifa, Haifa 3103301, Israel
[6]Fernando Pessoa Research, Innovation and Development Institute (FP-I3ID), University Fernando Pessoa (UFP), Praça 9 de Abril 349, Porto 4249-004, Portugal
[7]Marine and Environmental Sciences Centre (MARE), University of Coimbra, Edifício do Patronato, Rua da Matemática, 49, Coimbra 3004-517, Portugal
[8]Graduate Research School, Alphacrucis University College, Brisbane, QLD 4102, Australia
[9]School of Law and Society, University of the Sunshine Coast, Maroochydore, QLD 4556, Australia
[10]School of Social Sciences, University of New South Wales, Sydney, NSW 2052, Australia
[11]The IDEC Institute & Network for Education and Research on Peace and Sustainability (NERPS), Hiroshima University, 1-5-1 Kagamiyama, Higashi Hiroshima City, Hiroshima 739-8529, Japan

Received: 28 May 2024 / Accepted: 18 November 2024
Published online: 25 February 2025

References

1. Askari A, Sharifi I, Aflatoonian MR, Babaei Z, Almani PGN, Mohammadi MA, Alizadeh H, Hemati S, Bamorovat M. Aug). A newly emerged focus of zoonotic cutaneous leishmaniasis in South-western Iran. Microb Pathog. 2018;121:363–8. https://doi.org/10.1016/j.micpath.2018.04.053.
2. Bartlow AW, Manore C, Xu C, Kaufeld KA, Valle D, Ziemann S, Fairchild A, G., Fair JM. Forecasting zoonotic infectious disease response to Climate Change: Mosquito vectors and a changing environment. Vet Sci. May 2019;6(2). https://doi.org/10.3390/vetsci6020040. *6*.
3. Borlase A, Webster JP, Rudge JW. Opportunities and challenges for modelling epidemiological and evolutionary dynamics in a multi-host, multi parasite system: zoonotic hybrid schistosomiasis in West Africa. Evol Appl. 2018, Apr;11(4):501–15. https://doi.org/10.1111/eva.12529.
4. Broadus RN. Toward a definition of bibliometrics. Scientometrics. 1987;12(5–6):373–9. https://doi.org/10.1007/bf02016680.

5. Caminade C, McIntyre KM, Jones AE. Impact of recent and future climate change on vector-borne diseases. Ann N Y Acad Sci. 2019, Jan;1436(1):157–73. https://doi.org/10.1111/nyas.13950.
6. Carlson CJ, Bannon E, Mendenhall E, Newfield T, Bansal S. Rapid range shifts in African Anopheles mosquitoes over the last century. Biol Lett. 2023;19(2):20220365.
7. Charrahy Z, Yaghoobi-Ershadi MR, Shirzadi MR, Akhavan AA, Rassi Y, Hosseini SZ, Webb NJ, Haque U, Bozorg Omid F, Hanafi-Bojd AA. Climate change affects the vulnerability to zoonotic cutaneous leishmaniasis in Iran. Transbound Emerg Dis. 2021. https://doi.org/10.1111/tbed.14115.
8. Chaves LF, Pascual M. Climate cycles and forecasts of cutaneous leishmaniasis, a Nonstationary Vector-Borne Disease. PLoS Med. 2006;3(8):e295. https://doi.org/10.1371/journal.pmed.0030295.
9. Cissé G, McLeman R, Adams H, Aldunce P, Bowen K, Campbell-Lendrum D, Clayton S, Ebi KL, Hess J, Huang C, Liu Q, McGregor G, Semenza J, Tirado MC. Health, Wellbeing, and the changing structure of communities. In: Roberts DC, Tignor M, Poloczanska ES, Mintenbeck K, Alegría A, Craig M, Langsdorf S, Löschke S, Möller V, Okem A, Rama B, editors. Climate Change 2022: impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner. Cambridge, UK and New York, NY, USA: Cambridge University Press; 2022. pp. 1041–170. https://doi.org/10.1017/9781009325844.009.
10. Cook PA, Howarth M, Wheater CP. Biodiversity and Health in the Face of Climate Change: implications for Public Health. In: Marselle M, Stadler J, Korn H, Irvine K, Bonn A, editors. Biodiversity and Health in the Face of Climate Change. Cham: Springer; 2019. https://doi.org/10.1007/978-3-030-02318-8_11.
11. De Glas F. Fiction and Bibliometrics: Analysing a Publishing House's Stocklist. Libri. 1986;36(1). https://doi.org/10.1515/libr.1986.36.1.40.
12. Delabouglise A, Choisy M, Phan TD, Antoine-Moussiaux N, Peyre M, Vu TD, Pfeiffer DU, Fournie G. Jul 19). Economic factors influencing zoonotic disease dynamics: demand for poultry meat and seasonal transmission of avian influenza in Vietnam. Sci Rep. 2017;7:5905. https://doi.org/10.1038/s41598-017-06244-6.
13. Diouf I, Fonseca BR, Caminade C, Thiaw WM, Deme A, Morse AP, Ndione JA, Gaye AT, Diaw A, Ndiaye MKN. Climate variability and malaria over West Africa. Am J Trop Med Hyg. 2020;102(5):1037–47. https://doi.org/10.4269/AJTMH.19-0062.
14. González C, Wang O, Strutz SE, González-Salazar C, Sánchez-Cordero V, Sarkar S. Climate Change and Risk of Leishmaniasis in North America: predictions from Ecological Niche Models of Vector and Reservoir species. PLoS Negl Trop Dis. 2010;4(1):e585. https://doi.org/10.1371/journal.pntd.0000585.
15. Hansen A, Xiang J, Liu Q, Tong MX, Sun Y, Liu X, Chen K, Cameron S, Hanson-Easey S, Han GS, Weinstein P, Williams C, Bi P. Experts' Perceptions on China's Capacity to Manage Emerging and Re-emerging Zoonotic Diseases in an Era of Climate Change. Zoonoses Public Health. 2017, Nov;64(7):527–36. https://doi.org/10.1111/zph.12335.
16. Hess J, Boodram LL, Paz S, Ibarra AM, Wasserheit JN, Lowe R. (2020). Strengthening the global response to climate change and infectious disease threats. BMJ 2020;371.
17. Hussain S, Hussain A, Aziz U, Song B, Zeb J, George D, Li J, Sparagano O. Dec). The role of Ticks in the emergence of Borrelia burgdorferi as a Zoonotic Pathogen and its Vector Control: A global systemic review. Microorganisms. 2021;9(12). https://doi.org/10.3390/microorganisms9122412. Article 2412.
18. Jeremy H, Laura-Lee GB, Shlomit P, Anna MSI, Judith NW, Rachel L. Strengthening the global response to climate change and infectious disease threats. BMJ. 2020;371:m3081. https://doi.org/10.1136/bmj.m3081.
19. Johnson, R. C., Segla, H., Dougnon, T. V., Boni, G., Bankole, H. S., Houssou, C.,& Boko, M. (2014). Situation of Water, Hygiene and Sanitation in a Peri-Urban Area in Benin, West Africa: The Case of Sèmè-Podji. Journal of Environmental Protection, 05(12), 1277–1283. https://doi.org/10.4236/jep.2014.512121
20. Kolimenakis A, Heinz S, Wilson ML, Winkler V, Yakob L, Michaelakis A, Papachristos D, Richardson C, Horstick O. The role of urbanisation in the spread of Aedes mosquitoes and the diseases they transmit—A systematic review. PLoS Negl Trop Dis. 2021;15(9):e0009631. https://doi.org/10.1371/journal.pntd.0009631.
21. Krefis AC, Schwarz NG, Krüger A, Fobil J, Nkrumah B, Acquah S, Loag W, Sarpong N, Adu-Sarkodie Y, Ranft U, May J. Modeling the relationship between precipitation and malaria incidence in children from a holoendemic area in Ghana. Am J Trop Med Hyg. 2011;84(2):285–91. https://doi.org/10.4269/ajtmh.2011.10-0381.
22. Kuitunen I, Renko M. Apr). Changes in the epidemiology of Zoonotic Infections in Children A Nationwide Register Study in Finland. Pediatr Infect Disease J. 2022;41(4):E113–9. https://doi.org/10.1097/inf.0000000000003440.
23. Lancet. (2020). Zoonoses: beyond the human–animal–environment interface. Editorial V 396. https://www.thelancet.com/action/showPdf?pii=S0140-6736%2820%2931486-0
24. Lau CL, Smythe LD, Craig SB, Weinstein P. Climate change, flooding, urbanisation and leptospirosis: fuelling the fire? Trans R Soc Trop Med Hyg. 2010;104(10):631–8. https://doi.org/10.1016/j.trstmh.2010.07.002.
25. Leal Filho W, Ternova L, Parasnis SA, Kovaleva M, Nagy GJ. Jan 14). Climate Change and zoonoses: a review of concepts, definitions, and Bibliometrics. Int J Environ Res Public Health. 2022;19(2). https://doi.org/10.3390/ijerph19020893.
26. Leal Filho W, May M, May J, Nagy GJ. Climate change and malaria: some recent trends of malaria incidence rates and average annual temperature in selected sub-saharan African countries from 2000 to 2018. Malar J. 2023a;22:248. https://doi.org/10.1186/s12936-023-04682-4.
27. Leal Filho W, Vidal GG, Pimenta Dinis MA, editors. Climate Change and Health hazards. Springer, Cham: Addressing Hazards to Human and Environmental Health from a Changing Climate; 2023b.
28. Lwasa S, Seto KC, Bai X, Blanco H, Gurney KR, Kilkiş S, Lucon O, Murakami J, Pan J, Sharifi A, Yamagata Y. (2022). Urban systems and other settlements. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, editors]. Cambridge University Press, Cambridge, UK and New York, NY, USA. https://doi.org/10.1017/9781009157926.010
29. Magombedze G, Ferguson NM, Ghani AC. A trade-off between dry season survival longevity and wet season high net reproduction can explain the persistence of Anopheles mosquitoes. Parasites Vectors. 2018;11(1). https://doi.org/10.1186/s13071-018-3158-0.
30. Matsumoto-Takahashi ELA, Iwagami M, Oyoshi K, Sasaki Y, Hongvanthong B, Kano S. Deforestation inhibits malaria transmission in Lao PDR: a spatial epidemiology using Earth observation satellites. Trop Med Health. 2023;51(1). https://doi.org/10.1186/s41182-023-00554-4.
31. Mills JN, Gage KL, Khan AS. Potential influence of Climate Change on Vector-Borne and Zoonotic diseases: a review and proposed Research Plan. Environ Health Perspect. 2010;118(11):1507–14. https://doi.org/10.1289/ehp.0901389.
32. Paul-Pierre P. Emerging diseases, zoonoses and vaccines to control them. Vaccine. 2009;27(46):6435–8. https://doi.org/10.1016/j.vaccine.2009.06.021.
33. Pritchard A. Statistical bibliography or bibliometrics? J Doc. 1969;25:348–9.
34. Rodriguez-Morales AJ, Bonilla-Aldana DK, Idarraga-Bedoya SE, Garcia-Bustos JJ, Cardona-Ospina JA. (2018, 2018). Epidemiology of zoonotic tick-borne diseases in Latin America: Are we just seeing the tip of the iceberg? *F1000Research, 7*, 1988–1988. https://doi.org/10.12688/f1000research.17649.1
35. Rory G, Lydia HVF, David WR, Kate EJ. Ecosystem perspectives are needed to manage zoonotic risks in a changing climate. BMJ. 2020;371:m3389. https://doi.org/10.1136/bmj.m3389.
36. Rupasinghe R, Chomel BB, Martínez-López B. (2022). Climate change and zoonoses: A review of the current status, knowledge gaps, and future trends. In *Acta Tropica* (Vol. 226). Elsevier B.V. https://doi.org/10.1016/j.actatropica.2021.106225
37. Segun OE, Shohaimi S, Nallapan M, Lamidi-Sarumoh AA, Salari N. Statistical modelling of the effects of weather factors on malaria occurrence in Abuja, Nigeria. Int J Environ Res Public Health. 2020;17(10). https://doi.org/10.3390/ijerph17103474.
38. Semenza JC, Paz S. Climate change and infectious disease in Europe: impact, projection and adaptation. Lancet Reg Health Eur Doi. 2021. https://doi.org/10.1016/j.lanepe.2021.100230.
39. Sharan M, Vijay D, Yadav JP, Bedi JS, Dhaka P. 2023/01/01/). Surveillance and response strategies for zoonotic diseases: a comprehensive review. Sci One Health. 2023;2:100050. https://doi.org/10.1016/j.soh.2023.100050.
40. Paz S. (2015). Climate change impacts on West Nile virus transmission in a global context. Philosophical Transactions of the Royal Society B: Biological Sciences, 370(1665), p.20130561.
41. Paz S. Effects of climate change on vector-borne diseases: an updated focus on West Nile virus in humans. Emerg Top Life Sci. 2019;3(2):143–52.
42. Paz S. (2024). Climate change: A driver of increasing vector-borne disease transmission in non-endemic areas. PloS Medicine, In press.

43. Thomas MB. Epidemics on the move: climate change and infectious disease. PLoS Biol. 2020;18(11):e3001013. https://doi.org/10.1371/journal.pbio.3001013.
44. Wang C-X, Xiu L-S, Hu Q-Q, Lee T-C, Liu J, Shi L, Zhou X-N, Guo X-K, Hou L, Yin K. 2023/12/01/). Advancing early warning and surveillance for zoonotic diseases under climate change: interdisciplinary systematic perspectives. Adv Clim Change Res. 2023;14(6):814–26. https://doi.org/10.1016/j.accre.2023.11.014.
45. WHO. (2021). New WHO-IUCN Expert Working Group on Biodiversity, Climate, One Health and Nature-based Solutions. https://www.who.int/news/item/30-03-2021-who-iucn-expert-working-group-biodiversity
46. WHO. (2022). One Health is critical to addressing zoonotic public health threats and environmental issues.
47. https://www.who.int/news/item/21-03-2022-one-health-is-critical-to-addressing-zoonotic-public-health-threats-and-environmental-issues
48. WOAH. (2021). OHHLEP. Tripartite and UNEP Support OHHLEP's Definition of One Health. World Organisation for Animal Health. www.woah.org/en/tripartite-and-unep-support-ohhleps-definition-of-one-health/
49. WWF. (2024). Reducing zoonotic disease risk from wildlife trade. https://www.worldwildlife.org/initiatives/reducing-zoonotic-disease-risk-from-wildlife-trade
50. Young KM, Corrin T, Wilhelm B, Uhland C, Greig J, Mascarenhas M, Waddell LA. Dec 30). Zoonotic babesia: a scoping review of the global evidence. PLoS ONE. 2019;14(12). https://doi.org/10.1371/journal.pone.0226781. Article e0226781.
51. Zinsstag J, Schelling E, Crump L, Whittaker M, Tanner M, Stephen C. (2021). One Health: the theory and practice of integrated health approaches. https://doi.org/10.1079/9781789242577.0000
52. Qian L, Zeng X, Ding Yand PL. Mapping the knowledge of ecosystem service-based ecological risk assessment: scientometric analysis in CiteSpace, VOSviewer, and SciMAT. Front Environ Sci. 2023;11:1326425. https://doi.org/10.3389/fenvs.2023.1326425.
53. Van Eck NJ, Waltman L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics. 2010;84(2):523–538. https://doi.org/10.1007/s11192-009-0146-3. Epub 2009 Dec 31. PMID: 20585380 PMCID: PMC2883932 DOI: 10.1007/s11192-009-0146-3.
54. Bezerra-Santos MA, Dantas-Torres F, Benelli G, Otranto D. (2022). Emerging parasites and vectors in a rapidly changing world: from ecology to management. Acta Trop. 2023;238:106746. https://doi.org/10.1016/j.actatropica.2022.106746. Epub 2022 Nov 17. PMID: 36403676.
55. Mohapatra S, Menon NG. (2022). Factors responsible for the emergence of novel viruses: An emphasis on SARS-CoV-2. Curr Opin Environ Sci Health. 2022;27:100358. https://doi.org/10.1016/j.coesh.2022.100358. Epub 2022 Mar 28. PMID: 35369608; PMCID: PMC8958772.
56. Kolsky MR, Grossman E, Levy Y, Klang E. Human health and climate change–an evolving discourse: a bibliometric citation analysis of top-cited articles within health sciences databases. J Clim Change Health. 2023;14:100272. (15 pages).
57. Shaheen MNF. (2022). The concept of one health applied to the problem of zoonotic diseases. Rev Med Virol. 2022;32(4):e2326. https://doi.org/10.1002/rmv.2326
58. Hernández-Cabanyero C, Amaro C. (2020). Phylogeny and life cycle of the zoonotic pathogen Vibrio vulnificus. Environ Microbiol. 2020;22(10):4133–4148. https://doi.org/10.1111/1462-2920.15137. Epub 2020 Jul 22. PMID: 32567215.
59. Dutta H, Dutta A. (2016).The microbial aspect of climate change. Energ. Ecol. Environ. 1, 209–232 (2016). https://doi.org/10.1007/s40974-016-0034-7
60. Morand S, Lajaunie C. Biodiversity and COVID-19: a report and a long road ahead to avoid another pandemic. One Earth. 2021;4(7):920–3. https://doi.org/10.1016/j.oneear.2021.06.007.
61. UNEP Frontiers. ReportT: emerging issues of environmental concern. Chapter 2. Zoonoses: Blurred Lines of Emergent Disease and Ecosystem Health - UNEP frontiers 2016. Report: Emerging Issues of Environmental Concern; 2016.
62. Kenmoe S, Tchatchouang S, Ebogo-Belobo JT, Ka'e AC, Mahamat G, Guiamdjo Simo RE, et al. Systematic review and meta-analysis of the epidemiology of Lassa virus in humans, rodents and other mammals in sub-saharan Africa. PLoS Negl Trop Dis. 2020;2020(14):e0008589. https://doi.org/10.1371/journal.pntd.0008589.
63. Costa F, Hagan JE, Calcagno J, Kane M, Torgerson P, Martinez-Silveira MS. (2015). Global morbidity and mortality of leptospirosis: A systematic review. PLoS Negl Trop Dis. 2015;9(9):e0003898. https://doi.org/10.1371/journal.pntd.0003898
64. Laine CG, Johnson VE, Scott H, Arenas-Gamboa AM. Global Estimate of Human brucellosis incidence. Emerg Infect Dis. 2023;29(9):1789–97. https://doi.org/10.3201/eid2909.230052.
65. Wang XH, Jiang H. (2020). Global prevalence of human brucellosis. Zhonghua Liu Xing Bing Xue Za Zhi. 2020;41(10):1717–1722. Chinese. https://doi.org/10.3760/cma.j.cn112338-20191022-00751. PMID: 33297632.
66. WHO. Rabies. World Health Organization. text=Globally%20there%20are%20an%20estimated%2059%20000%20deaths,documented%20case%20numbers%20often%20differ%20from%20the%20estimate; 2024. https://www.who.int/news-room/fact-sheets/detail/rabies#:~.

Publisher's note