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Review article

Climate Change Induces Shifts in Infectious Disease Dynamics: Emerging Global Threats

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ABSTRACT

Climate change and infectious diseases have been topics of interest for professionals such as Environmental Scientists, Ecologists, Public Health professionals, and Social Psychologists. The relationship between climate change and infectious diseases is complex, affecting the environment, social and economic conditions, and human health. It affects pathogens, vectors, transmission routes, and the human population's susceptibility to diseases. Infectious diseases like malaria, dengue fever, cholera, and influenza are sensitive to climate change, and scientists are focusing on better modeling, preemptive warnings, and new technologies like biosurveillance, artificial intelligence, and vaccine development to reduce the consequences of climate change for new and re-emerging diseases. A combination of multi-level and multi-sectoral efforts and a global approach is required to monitor and respond to future outbreaks. This paper will explore effective measures in preventing diseases related to climate change and the existing scientific evidence to prove its impact on infectious diseases.

Keywords: CCHF, Climate changes, Infectious diseases, Vector-Borne Diseases, Waterborne Diseases.

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1. INTRODUCTION

There has been so much attention and so many different views evoked by the proliferation of studies on climate change and health, particularly climate change and infectious diseases [1]. The interplay between climate change and infectious diseases strikes a chord with different professionals, such as Environmental Scientists, Ecologists, Public health professionals, and Social Psychologists [1]. Taking into consideration the psychological consequences on society reported in a previous section, aspects of climate change include addressing its possible causes since the nineties; however, it has been only on a gradual increase in subsequent reports [2]. In meetings conducted in 2007, it was reported that the global average surface temperature has been on the increase since the mid-20th century and hence there are some biological phenomenon that warrants the light of the climate chnges we are facing [3].

It was observed that in this century there shall be extended duration and grouping of more heat waves than what has been observed in the history of the world, rainfall will be erratic, and more climate changes will be on the rise in terms of both frequency and intensity. Nevertheless, in these exact circumstances, the possible consequences of climate change on infectious diseases were rather overlooked. Most of the potential impacts mentioned were more likely to be serious impacts [1]. For instance, the parched soil contains an increased level of intermediate vector leads to a higher incidence of water-borne diseases following rainfall events and an increase in vector moist-borne diseases [1, 3].

There is a definite interrelationship between climate change and transmission dynamics of disease. Climate change affects the environment, alters the social and economic situation, and conse-

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quently changes the state of human health and the spread of infectious diseases [4,5]. It acts on pathogens, vectors, and transmission routes, and also on the human population's susceptibility to the disease. Elements like temperature, rainfall, and humidity lead to the spread of disease-carrying organisms and the threats of the disease to humans and animals [5].

Some infectious diseases, such as malaria, dengue fever, cholera, and influenza, are also sensitive to climate change [1]. To tackle this problem, scientists focus on the necessity of better modeling, preemptive warnings, and other actions [5]. The use of these new technologies, with the addition of biosurveillance, artificial intelligence, and vaccine development, is the most effective approach to lessen the consequences of climate for new and re-emerging infectious diseases. A combination of multi-level and multispectral efforts and a global approach will be required to adequately monitor and respond to future outbreaks.

This paper will consider what measures are efficient in preventing the diseases concerning climate change and what measures are already taken in science to prove climate change's impact on infectious diseases.

2. CLIMATE CHANGE

Climate change is nothing more than earth changes, human-related occurrences that eventually begin to create weather and condition alterations in a certain region. It also poses significant risks to people, animals, and plants, and sustainable development – therefore necessitates cross-border action. According to the United Nations Framework Convention on Climate Change (UNFCCC), climate change is described as changes in variability or average weather conditions caused by human activities that alter the composition of the global atmosphere. Climate forcing considers climate change and is understood through the two ways this can be achieved; with the use of natural factors (eg, volcanic eruptions) or anthropogenic forces directly related to greenhouse gas emissions. Global warming and climate system disruption resulting from the greenhouse effect is an example of a natural process that human activities can amplify or modify. Since climate change creates enormous hazards to environmental health particularly for food systems, water supplies, and biodiversity it becomes essential for public health from an ecological viewpoint [6].

3. INFECTIOUS DISEASES

Infectious diseases are still serious global health problems that involve millions amount of morbidity and mortality. While progress has been made in diagnostics and therapeutic modalities, the persistence of numerous infectious agents such as bacteria and viruses represents continued danger; most acutely these threats concern regions of the developing world [7]. A wide range of pathogens, including viruses, bacteria, fungi, and protozoa cause infectious diseases. Many examples could be given, but specific illustrate-only contagious diseases are tuberculosis, AIDS, and malaria that attach to poor countries. New viruses have emerged in the past couple of decades including SARS, Ebola, Zika and the recent development is COVID-19 which also emphasizes the complexity of public health responses. It is precisely antibiotic resistance that arouses concerns in this context: Pathogens such as methicillin-resistant Staphylococcus aureus (MRSA) represent major problems for therapy. Infectious diseases remain a major killer, accounting for adult deaths in the UK and the US and almost 30% of children's deaths in most developing countries, and up to 40%, if neonatal tetanus is included [8]. Vaccination and improved sanitation have decreased the incidence of both waterborne diseases in developed countries to very low levels. The management of infectious disease has significantly advanced over the last two centuries, however, due to the evolutionary nature of pathogens and their interactions with human populations, public health strategies must continue to develop new methods of prevention and control [7].

4. RELATIONSHIP between CLIMATE CHANGE and INFECTIOUS DISEASES

Climate change plays a critical role in infectious diseases, from their emergence to transmission and distribution [9]. Increased temperatures and changes in precipitation can expand vector habitats, increase fecundity, and shorten the extrinsic incubation period responsible for pathogen transmission, especially for mosquito-borne diseases such as malaria and dengue [7]. For example, climate change-induced changes in water surface temperature and water level are predicted to escalate the transmission of water-borne diseases like cholera [11]. The El Nino Southern Oscillation (ENSO) has been associated with outbreaks of several infectious diseases, such as cholera, cryptosporidiosis, and Hantavirus [12]. For these reasons, Wu et al., (2016) suggested that further rigor in the development and testing of more scientific explanations beyond empirical observations is needed to address many of the challenges associated with spatial-temporal predictions of climate change and associated disease shifts [5]. A focus on developing approaches based on machine learning algorithms for early warning systems could also be an effective avenue where field data are not sufficiently rich or accurate. The convergence of interdisciplinary competencies and greater attention on disease surveillance and pathways must be combined to elucidate the health impacts and develop mitigation strategies as part of a response to climate change [13].

4.1. Direct Effects of Climate Change on Disease Vectors

Climate change greatly affects the spatiotemporal distribution and behavior of disease vectors, particularly arthropods such as mosquitoes and ticks are important in vector-borne disease (VBD) transmission [14]. Aliaga-Samanez and colleagues predicted that climatic change may broaden the territory associated with dengue and yellow fever vectors, especially in West as well as Central Africa and Southeast Asia [15], suggesting the opportunity for re-establishment within Europe. Transmission dynamics are perturbed as increases in temperature, precipitation, and humidity affect reproduction rates by vectors, which along with changes in the survival rates of vectors only makes things worse [16]. Climate exerts an impact on vector-borne diseases by acting directly, getting the mosquito populations up and carrying with it infecting agents that propagate diseases as they do in the case of dengue or yellow fever [17]. The natural interaction of climatic factors and human activities, especially land use transformations, makes accurate predictions concerning VBDs [18]. While the direct effects of climate change on disease vectors are worrisome enough, it is also critical to acknowledge that these impacts are mediated by other mechanisms in addition to public health infrastructure and human behavior that may further blunt or worsen the above impact. Recent studies have shown an increase in infections with hemorrhagic fever viruses, especially the *Crimean-Congo haemorrhagic fever (*CCHF) in Iraq [19]. Coinciding with the extreme climate changes that have occurred in Iraq in recent years, which confirms the role of climate changes in increasing the incidence of this disease through the increased reproduction of the ticks responsible for transmitting the virus (*Hyalomma*), as the increase in temperature and humidity helps to increase the reproduction of this arthropod, especially in areas where the percentage of humidity increases in addition to the heat, and this is found in the southern regions of Iraq.

4.2. Indirect Effects of Climate Change on Disease Transmission

Climate change can indirectly influence disease transmission through human migration, damage to health infrastructure, and potential alterations in the human immune system. Modeling approaches combining climate and disease transmission models are valuable tools for understanding and predicting future disease scenarios under changing environmental conditions [20]. However, considerable uncertainties remain, and further research is needed to quantify the net effects of climate change on infectious disease risks [21]. The indirect effects of climate change on infectious disease transmission are complex and multifaceted. They encompass alterations in vector habitats, changes in human behavior, increased risks for waterborne diseases, and the emergence of new pathogens. Understanding these dynamics is crucial for developing effective public health strategies to mitigate the impact of climate change on infectious disease outbreaks globally [5]. Enhanced surveillance, improved sanitation infrastructure, and targeted public health interventions will be essential in addressing these challenges moving forward.

5. MECHANICAL LINKING CLIMATE CHANGE and INFECTIOUS DISEASES

Climate change significantly influences the transmission dynamics of infectious diseases through various interconnected mechanisms. 1st through the alteration of vector habitats. Climate change affects the habitats suitable for vectors, such as mosquitoes and ticks. For instance, warming temperatures can expand the geographical range of vectors that transmit diseases like malaria, dengue, and CCHF into new areas, including temperate regions that were previously less affected [22]. Climate changes can lengthen the active seasons for these vectors, increasing the duration of transmission periods for vector-borne diseases [22, 23]. 2nd effect on Pathogen Life Cycles, many pathogens have specific temperature ranges that influence their survival and reproduction. Warmer temperatures can accelerate pathogen maturation within vectors, increasing the likelihood of transmission [22, 24]. Climatic conditions also affect pathogen virulence and survival rates outside their hosts. For example, higher temperatures may enhance the survival of pathogens in water, leading to increased risks of waterborne diseases like cholera [23]. 3rd Changes in Human Behavior, climate-induced displacement due to extreme weather events can lead to increased human interactions with vectors and pathogens. Displaced populations often settle in crowded conditions where infectious diseases can spread more easily [23, 24]. Climate changes can alter agricultural practices, affecting food security and nutrition, which in turn influence human susceptibility to infections [24, 25]. 4th Environmental Changes, Climate change disrupts ecosystems, affecting the interactions between hosts, vectors, and pathogens. This disruption can lead to increased host populations or changes in host behavior that facilitate disease transmission [23]. The Changes in precipitation patterns can lead to flooding or droughts, impacting water quality and availability. Contaminated water sources can increase the incidence of waterborne diseases [24, 25]. 5th Cascading Effects, climate change can trigger a series of secondary events, such as changes in land use, urbanization, and global trade that further complicate infectious disease dynamics. These cascading effects may result in large-scale outbreaks that are challenging to control [22].

5.1. Vector-Borne Diseases and Waterborne Diseases

In this study, various ways through which climate change is expected to affect vector-borne and waterborne diseases are discussed below. Temperature increases and changes in rainfall regimes may influence the pathogen life cycle, vector-borne distribution, or disease transmission rates [26]. More vigorous floods associated with extreme wet weather may cause pollution of water resources thus posing a threat to the healthiness of water getting infected by waterborne illness, especially in the developing world [27]. It is now believed that malaria, dengue, and West Nile fever, all vector-borne diseases, are likely to increase both geographical coverage and temporal frequency as a result of climate change [28]. Climate change can influence disease patterns by affecting four key characteristics of host and vector populations: projections of people's affliction rate, the pathogen circulation rate or distribution, population density, and pathogen influx [29]. Therefore, more of the climate change effects require a combination of cross-disciplinary research and ecosystem-based approaches, especially on the relations between climate factors and disease-causing agents, vectors – and hosts [28, 29].

6. CCHF AS CASE STUDY

Climate change significantly impacts the transmission dynamics and outbreaks of CCHF. Temperature Increases Correlation with Incidence of this disease. Studies have shown a positive correlation between rising temperatures and increased CCHF cases. For instance, higher mean temperatures have been linked to greater incidence rates in various regions, including Turkey, Iran, and Iraq. A study in Zahedan, Iran, noted that maximum temperatures with a lag of one month positively correlated with CCHF cases, indicating that warmer conditions may enhance the virus's transmission potential [19,30,31]. Extended Transmission Seasons: Warmer temperatures can prolong the active seasons for ticks, which are the primary vectors for CCHF. This extension increases the window for potential human infections, particularly in areas where ticks were previously less active [32]. Other factors such as humidity and rainfall patterns can influence tick populations and their habitats. Areas experiencing long periods of low rainfall and humidity have been associated with increased CCHF occurrences. Conversely, excessive rainfall can create breeding grounds for ticks but may also disrupt their habitats [33]. Research indicates that the relationship between rainfall and CCHF incidence is non-linear, with specific thresholds affecting tick reproduction and survival rates. For example, certain levels of monthly rainfall may promote tick populations up to a point before becoming detrimental [31].

Climate change alters habitats suitable for *Hyalomma* ticks, which transmit CCHFV. Warmer and drier conditions create ideal environments for tick growth and reproduction, facilitating the spread of CCHF into new regions [31].

The migratory birds also play a role in spreading ticks that carry CCHFV. As climate change affects migratory routes and patterns, it may inadvertently facilitate the movement of infected ticks into new areas [31]. The warmer temperatures may lead to more people spending time outdoors, increasing their exposure to ticks. This is particularly relevant during periods when ticks are most active [30]. Climate change can alter agricultural land use, which may impact tick habitats and the dynamics of livestock management—both critical factors in CCHF transmission.

The increasing incidence of CCHF linked to climate variables underscores the need for enhanced public health surveillance systems to predict outbreaks effectively. Accurate forecasting models that incorporate climatic factors can help target interventions more effectively [30,31]. Public health campaigns should focus on educating communities about the risks associated with climate change and its impact on vector-borne diseases like CCHF. The interplay between climate change and Crimean-Congo Hemorrhagic Fever outbreaks highlights the importance of understanding environmental factors influencing disease transmission. Rising temperatures, altered precipitation patterns, and changes in vector dynamics all contribute to increased risks of CCHF outbreaks. Effective public health responses must incorporate climate data to enhance surveillance, preparedness, and community awareness in affected regions [30,31].

7. MITIGATION and ADAPTATION STRATEGIES

As climate change continues to influence the dynamics of infectious diseases, particularly vector-borne diseases, it is essential to implement effective mitigation and adaptation strategies.

7.1. Mitigation Strategies.

- **Reducing Greenhouse Gas Emissions**: Implementing policies to reduce carbon footprints can help mitigate climate change's impacts. This includes transitioning to renewable energy sources, enhancing energy efficiency, and promoting sustainable transportation practices.
- **Integrating Climate and Health Data**: Incorporating climate data into public health surveillance systems can enhance the ability to predict and respond to infectious disease outbreaks. The Global Framework for Climate Services provides a model for integrating climatic information into health sector activities, allowing for better decision-making.
- **Promoting Research and Funding**: Increasing funding for research on the intersection of climate change and health is crucial. This includes studying the effects of climate variables on disease transmission patterns and developing innovative solutions to combat these challenges.
- **Public Health Campaigns**: Raising awareness about the impacts of climate change on health can encourage communities to adopt preventive measures. Campaigns should focus on educating populations about vector control, hygiene practices, and recognizing symptoms of infectious diseases.
- **Vaccine Development and Distribution:** Investing in research and development of vaccines for climate-sensitive infectious diseases can significantly reduce disease burden. For example, oral cholera vaccines (OCVs) have proven effective in reducing cholera incidence in high-risk areas, demonstrating how vaccination can mitigate climate-related health risks [34].
- **Integrated Surveillance Systems:** Establishing integrated surveillance systems that combine climate data with health data can improve the early detection of disease outbreaks. This approach allows for proactive responses to changing patterns of infectious diseases linked to climate variables [35].

7.2. Adaptation Strategies

- **Public Health Adaptation Planning**: Utilizing frameworks like the CDC's Building Resilience Against Climate Effects (BRACE) program allows health officials to anticipate climate impacts, assess vulnerabilities, project disease burdens, and develop tailored adaptation plans [36, 37]. This includes identifying at-risk populations and implementing targeted interventions.
- **Strengthening Vector Control Measures**: Implementing effective vector control policies is essential for minimizing human contact with disease-carrying vectors. This includes using insecticide-treated nets, environmental management to eliminate breeding sites, and community engagement in vector control efforts [36].
- **Inter-Sectoral Collaboration**: Encouraging collaboration among various sectors of health, agriculture, environment, and urban planning can enhance resilience against infectious diseases. A One Health approach that integrates human, animal, and environmental health is vital for addressing the interconnected challenges posed by climate change [38].
- **Monitoring and Evaluation**: Developing robust monitoring and evaluation programs to assess the effectiveness of adaptation strategies is crucial. Regularly updating these strategies based on new evidence will help ensure their continued relevance as climate conditions evolve [39].
- **Addressing Socioeconomic Vulnerabilities**: Recognizing that socioeconomic factors influence vulnerability to infectious diseases is essential. Addressing issues such as poverty, access to healthcare, and education can enhance community resilience against climate-related health threats [35].

8. CONCLUSION

The intricate relationship between climate change and infectious diseases poses a significant threat to global health. The increasing temperatures and extremes of precipitation, combined with changes in vector dynamics are an influential factor in the outbreak of infectious diseases including malaria, dengue fever, cholera, and CCHF. Climate change affects diseases transmitted by various mechanisms, such as the disturbance of vector habitats, and modifications in pathogen living cycles for human behaviors. Understanding these dynamics is necessary to devise effective public health strategies aimed at reducing the effects of climate change on infectious outbreaks across the planet. To address these challenges, a comprehensive and multifaceted approach is necessitated. These include taking mitigation actions such as cutting greenhouse gas emissions, linking climate-health data, research and investment, public health communication, development and proliferation of immunization in addition to wide-level biosurveillance. Public health adaptation planning includes strengthening vector control, inter-sectorial collaboration, and monitoring and evaluation mechanisms in parallel with addressing socio-economic vulnerabilities.

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Conflict of interest

The authors declare that they have no conflict of interest.

Ethical Approval

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Author contributions

Jenan A. Ghafil: Investigation; Project administration; Resources; Supervision; Validation; Roles/Writing - original draft; and Writing - review & editing.

Zinah Shamil Kamil: Resources; Supervision; Validation; Roles/Writing Writing - review & editing.

9. REFERENCES

[1] Di Napoli C, McGushin A, Romanello M, Ayeb-Karlsson S, Cai W, et al. (2022) Tracking the impacts of climate change on human health via indicators: lessons from the Lancet Countdown. *BMC Public Health* **22**(1):663. doi: 10.1186/s12889-022-13055-6. PMID: 35387618; PMCID: PMC8985369.

[2] Freschi G, Menegatto M, Zamperini A. (2023) How can psychology contribute to climate change governance? A systematic review. *Sustainability* **15**(19):14273.

[3] Stager JC, McNulty S, Beier C, Chiarenzelli J. (2009) Historical patterns and effects of changes in Adirondack climates since the early 20th century. *Adirondack J Environ Stud* **15**(2):14-24.

[4] Mirski T, Bielawska-Drózd A, Bartoszcze M. (2012) Impact of Climate Change on Infectious Diseases. *Pol J Environ Stud* **21**(3):525-532.

[5] Wu X, Lu Y, Zhou S, Chen L, Xu B. (2016) Impact of climate change on human infectious diseases: Empirical evidence and human adaptation. *Environ Int* **86**:14-23. doi: 10.1016/j.envint.2015.09.007. Epub 2015 Oct 18. PMID: 26479830.

[6] Hickmann T, Widerberg O, Lederer M, Pattberg P. (2021) The United Nations Framework Convention on Climate Change Secretariat as an orchestrator in global climate policymaking. *Int Rev Adm Sci 87:* 21-38.doi.org/10.1177/0020852319840425

[7] Bloom DE, Cadarette D. (2019) Infectious Disease Threats in the Twenty-First Century: Strengthening the Global Response. *Front Immunol* **10**:549. doi: 10.3389/fimmu.2019.00549. PMID: 30984169; PMCID: PMC6447676.

[8] Munita JM, Arias CA. (2016) Mechanisms of Antibiotic Resistance. *Microbiol Spectr* **4**(2):10.1128/microbiolspec.VMBF-0016-2015. doi: 10.1128/microbiolspec.VMBF-0016-2015. PMID: 27227291; PMCID: PMC4888801.

[9] Caminade C, McIntyre KM, Jones AE. (2019) Impact of recent and future climate change on vector-borne diseases. Ann N Y Acad Sci **1436**(1):157-173. doi: 10.1111/nyas.13950. Epub 2018 Aug 18. PMID: 30120891; PMCID: PMC6378404.

[10] Liu Z, Zhang Q, Li L, He J, Guo J, et al. (2023) The effect of temperature on dengue virus transmission by Aedes mosquitoes. *Front Cell Infect Microbiol* **13**:1242173. doi: 10.3389/fcimb.2023.1242173.

[11] Nova N, Athni TS, Childs ML, Mandle L, Mordecai EA. (2022) Global Change and Emerging Infectious Diseases. *Annu Rev Resour Economics* **14**:333-354. doi: 10.1146/annurev-resource-111820-024214. Epub 2022 Apr 1. PMID: 38371741; PMCID: PMC10871673.

[12] Hosking R, Smurthwaite K, Hales S, Richardson A, Batikawai S, Lal A. (2023) Climate variability and water-related infectious diseases in Pacific Island Countries and Territories, a systematic review. *PLoS Climate* **2**(10):e0000296.

[13] Van de Vuurst P, Escobar LE. (2023) Climate change and infectious disease: a review of evidence and research trends. *Infect Dis Poverty* **12**(1):51. doi: 10.1186/s40249-023-01102-2. PMID: 37194092; PMCID: PMC10186327.

[14] Manikandan S, Mathivanan A, Bora B, Hemaladkshmi P, Abhisubesh V, Poopathi S. (2023) A review on vector borne disease transmission: Current strategies of mosquito vector control. *Indian J Entomol 85*:503–513. https://doi.org/10.55446/IJE.2022.593

[15] Aliaga-Samanez A, Cobos-Mayo M, Real R, Segura M, Romero D, et al. (2021) Worldwide dynamic biogeography of zoonotic and anthroponotic dengue. *PLoS Negl Trop Dis 15:*e0009496.

[16] Thomson MC, Stanberry LR. (2022) Climate Change and Vectorborne Diseases. *N Engl J Med* **387**(21):1969-1978. doi: 10.1056/NEJMra2200092. PMID: 36416768.

[17] Liu Z, Zhang Q, Li L, He J, Guo J, et al. (2023) The effect of temperature on dengue virus transmission by Aedes mosquitoes. *Front Cell Infect Microbiol* **13**:1242173. doi: 10.3389/fcimb.2023.1242173.

[18] Samuel GH, Pohlenz T, Dong Y, Coskun N, Adelman ZN, et al. (2023) RNA interference is essential to modulating the pathogenesis of mosquito-borne viruses in the yellow fever mosquito Aedes aegypti. *Proc Natl Acad Sci U S A* **120**(11):e2213701120. doi: 10.1073/pnas.2213701120. Epub 2023 Mar 9. PMID: 36893279; PMCID: PMC10089172.

[19] Atwan Z, Alhilfi R, Mousa AK, Rawaf S, Torre JDL, et al. (2023) Alarming update on incidence of Crimean-Congo hemorrhagic fever in Iraq in 2023. *IJID Reg* **10**:75-79. doi: 10.1016/j.ijregi.2023.11.018. PMID: 38173860; PMCID: PMC10762355.

[20] Nova N, Athni TS, Childs ML, Mandle L, Mordecai EA. (2022) Global Change and Emerging Infectious Diseases. *Annu Rev Resour Economics* **14**:333-354. doi: 10.1146/annurev-resource-111820-024214. Epub 2022 Apr 1. PMID: 38371741; PMCID: PMC10871673.

[21] Sterk A, Schijven J, de Nijs T, de Roda Husman AM. (2013) Direct and indirect effects of climate change on the risk of infection by water-transmitted pathogens. *Environ Sci Technol* **47**(22):12648-60. doi: 10.1021/es403549s. Epub 2013 Nov 5. PMID: 24125400.

[22] Semenza JC, Rocklöv J, Ebi KL. (2022) Climate Change and Cascading Risks from Infectious Disease. *Infect Dis Ther* **11**(4):1371-1390. doi: 10.1007/s40121-022-00647-3. Epub 2022 May 19. PMID: 35585385; PMCID: PMC9334478.

[23] Uwishema O, Masunga DS, Naisikye KM, Bhanji FG, Rapheal AJ, et al. (2023) Impacts of environmental and climatic changes on future infectious diseases. *Int J Surg* **109**(2):167-170. doi: 10.1097/JS9.0000000000000160. PMID: 36799840; PMCID: PMC10389506.

[24] Van de Vuurst P, Escobar LE. (2023) Climate change and infectious disease: a review of evidence and research trends. *Infect Dis Poverty* **12**(1):51. doi: 10.1186/s40249-023-01102-2. PMID: 37194092; PMCID: PMC10186327.

[25] Anwar A, Anwar S, Ayub M, Nawaz F, Hyder S, et al. (2019) Climate Change and Infectious Diseases: Evidence from Highly Vulnerable Countries. *Iran J Public Health* **48**(12):2187-2195. PMID: 31993386; PMCID: PMC6974868.

[26] Beermann S, Dobler G, Faber M, Frank C, Habedank B, et al. (2023) Impact of climate change on vector- and rodent-borne infectious diseases. *J Health Monit* **8**(Suppl 3):33-61. doi: 10.25646/11401. PMID: 37342429; PMCID: PMC10278376.

[27] Hunter PR. (2003) Climate change and waterborne and vector-borne disease. *J Appl Microbiol* 94 Suppl:37S-46S. doi: 10.1046/j.1365-2672.94.s1.5.x. PMID: 12675935.

[28] Dave S, Dave P, Pal M. (2015) The impact of climate change on emergence and re-emergence of vector-borne human diseases. *Int J Livest Res* **5**(7):1-10. DOI:10.5455/ijlr.20150729112108.

[29] Mills JN, Gage KL, Khan AS. (2010) Potential influence of climate change on vector-borne and zoonotic diseases: a review and proposed research plan. *Environ Health Perspect* **118**(11):1507-14. doi: 10.1289/ehp.0901389. PMID: 20576580; PMCID: PMC2974686.

[30] Yılmaz S, İba Yilmaz S, Alay H, Koşan Z, Eren Z. (2023) Temporal tendency, seasonality and relationship with climatic factors of Crimean-Congo Hemorrhagic Fever cases (East of Turkey: 2012-2021). *Heliyon* **9**(9):e19593. doi: 10.1016/j.heliyon.2023.e19593. PMID: 37681169; PMCID: PMC10480645.

[31] Nili S, Khanjani N, Jahani Y, Bakhtiari B. (2020) The effect of climate variables on the incidence of Crimean Congo Hemorrhagic Fever (CCHF) in Zahedan, Iran. *BMC Public Health* **20**(1):1893. doi: 10.1186/s12889-020-09989-4. PMID: 33298021; PMCID: PMC7726875.

[32] Hoch T, Breton E, Vatansever Z. (2018) Dynamic Modeling of Crimean Congo Hemorrhagic Fever Virus (CCHFV) Spread to Test Control Strategies. *J Med Entomol* **55**(5):1124-1132. doi: 10.1093/jme/tjy035. PMID: 29618023.

[33] Messina JP, Pigott DM, Golding N, Duda KA, Brownstein JS, et al. (2015) The global distribution of Crimean-Congo hemorrhagic fever. *Trans R Soc Trop Med Hyg* **109**(8):503-13. doi: 10.1093/trstmh/trv050. Epub 2015 Jul 4. PMID: 26142451; PMCID: PMC4501401.

[34] Kim CL, Agampodi S, Marks F, Kim JH, Excler JL. (2023) Mitigating the effects of climate change on human health with vaccines and vaccinations. *Front Public Health* **11**:1252910. doi: 10.3389/fpubh.2023.1252910. PMID: 37900033; PMCID: PMC10602790.

[35] Hess J, Boodram LG, Paz S, Stewart Ibarra AM, Wasserheit JN, Lowe R. (2020) Strengthening the global response to climate change and

infectious disease threats. *BMJ* **371**:m3081. doi: 10.1136/bmj.m3081. PMID: 33106244; PMCID: PMC7594144.

[36] **Semenza JC, Paz S** (2021). Climate change and infectious disease in Europe: Impact, projection and adaptation. *Lancet Reg Health Eur* **9**:100230. doi: 10.1016/j.lanepe.2021.100230. Epub 2021 Oct 7. PMID: 34664039; PMCID: PMC8513157.

[37] **Austin SE, Ford JD, Berrang-Ford L, Biesbroek R, Ross NA.** (2018) Enabling local public health adaptation to climate change. *Soc Sci Med* **220**:236-244. doi: 10.1016/j.socscimed.2018.11.002. Epub 2018 Nov 9. PMID: 30472516.

[38] **Grobusch LC, Grobusch MP.** (2022) A hot topic at the environment-health nexus: investigating the impact of climate change on infectious diseases. *Int J Infect Dis* **116**:7-9. doi: 10.1016/j.ijid.2021.12.350. Epub 2021 Dec 29. PMID: 34973415; PMCID: PMC8716146.

[39] **Ebi KL, Lindgren E, Suk JE, Semenza JC.** (2013) Adaptation to the infectious disease impacts of climate change. *Climatic Change* **118**:355–365 (2013). https://doi.org/10.1007/s10584-012-0648-5.

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