

The Impact of Climate Change on Infectious Disease Patterns

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ABSTRACT

Climate change is becoming an increasingly important component in global public health, notably in the transmission and spread of infectious illnesses. Climatic conditions have a direct impact on the distribution, survival, and behavior of disease vectors like mosquitoes and ticks, facilitating the spread of aquatic diseases. Rising global temperatures, shifting precipitation patterns, and extreme weather events are modifying ecosystems, generating conditions favorable to the spread of vector-borne and waterborne diseases. This study investigates the link between climate change and infectious disease dynamics, focusing on malaria, dengue, Lyme disease, cholera, and leptospirosis. It focuses on how climate parameters such as temperature and rainfall affect pathogen survival, vector ecology, and human vulnerability. This analysis uses case studies to demonstrate how climate change-induced changes in disease transmission patterns could exacerbate global health concerns, particularly in developing countries. It also examines techniques for reducing the impact of climate change on disease transmission, such as surveillance, public health education, and legislative initiatives.

Keywords: Climate change, infectious diseases, vector-borne diseases, waterborne diseases, disease transmission.

INTRODUCTION

Our climate is changing on a global scale, leading to significant implications for public health. Among these, interest is growing in the consequences of changing climate patterns for the spread of infectious diseases. The transmission dynamics of many vector-borne diseases are particularly sensitive to climatic conditions, and over the past decade, a large number of reports have suggested that climate changes will lead to an increase in the transmission of many of these diseases. Similar relationships between climatic conditions and transmission are also thought to exist for several waterborne and foodborne diseases, and a growing number of studies are exploring these interactions. It is now well-accepted that climate acts as a major factor in determining the geographic distribution, seasonal transmission patterns, and prevalence of infectious diseases, and can have a significant influence on the timing and severity of epidemics [1, 2]. The precise mechanisms by which climatic factors influence both pathogens and vector/intermediate hosts, however, are complex and differ for each disease, as do the interactions between these factors and the resultant human health considerations for different epidemic thresholds and infectious disease patterns. However, understanding these patterns is critical to assessing how climate changes might affect the distribution and burden of infectious diseases. This review will investigate the complex relationships between the climate, states of local ecosystems, and the geographic distribution of infectious diseases; examine how the El Niño Southern Oscillation and changes in global climate could impact these relationships and, consequently, outbreaks of infectious diseases; and outline the human health and healthcare implications for global health. Some case examples of infectious diseases with particular relevance to the Asia Pacific region will be incorporated throughout the review. Our climate is changing on a global scale [1, 2].

Climate Change and Its Effects on Disease Vectors

One of the most direct effects of climate change is warming-driven or damp-related changes in the transmission of infectious diseases. The greatest concern is caused by the consequences of the altered activity of vectors of biological agents of dangerous diseases. The significantly increased risk of vector-borne infection in various parts of the world requires constant observation. Climate change also affects environmental conditions leading to the development of waterborne diseases such as bacterial diseases, viruses, and parasitic infestations. This review focuses only on the effect of climate change on the increased transmission of infectious diseases by the above-mentioned mechanisms related to diseases associated with vectors since the outbreaks have the most dangerous effects on the functioning of the population. The most common vectors are insects [3, 4]. Climate change may affect disease biology in several ways, including, for example, an extended or shortened extrinsic period of vectors, the enhanced vectorial capacity of vectors for transmission, changes in the distribution of vectors and even disease agents, and modified demographic, biological or ecological conditions for vectors. The influence can be explained by changes in a limiting ecological, biological, or physiological factor, such as factors that usually influence pathogen growth in a disease agent or a host. Whereas temperature changes primarily affect the development of vectors and disease agents or hosts, humidity or rainfall is concerned primarily with habitats for diseases or vectors. Some characteristics of infectious diseases, such as malaria, schistosomiasis, hookworm infections, leishmaniasis, and dengue fever, are directly related to the prevailing climate, particularly air temperature, precipitation, and relative humidity [5, 6].

Mosquito-Borne Diseases

Mosquito-Borne Diseases Mosquito-transmitted diseases such as malaria are also sensitive to climate. Malaria control efforts depend on changes in temperature, precipitation, and extreme events that have the potential to affect the ecological relationships among the vector, the parasite, and the human host. Malaria transmission is highly dependent on climate, with ambient temperatures influencing the development rate of the Plasmodium parasite within the mosquito and also the speed at which the insect matures. An increase in temperature can lead to an increased rate of parasite development within the mosquito, potentially leading to increased survival of the mosquitoes. Favorable climates are also more likely to occur during droughts, which favor increased mosquito breeding opportunities, in turn increasing the likelihood of transmission to humans. Many epidemics may occur, especially in developed countries, when extreme climate events such as hurricanes, heatwaves, or floods hit previously non-infested areas, with subsequent generations of mosquitoes producing numerous biting adults, resulting in infection rates of up to 80% in a particular community. Interannual oscillations in climate may also result in epidemics, with the wet season following the very dry one providing suitable breeding conditions for both humans and mosquitoes. Urbanization has resulted in climate-dependent epidemics, which are related especially to the spread of the malaria vectors. Additionally, dengue is the world's major viral vector-borne disease, with endemic transmission in at least 125 countries. Transmitted predominantly by *Aedes aegypti*, locally driven transmission is in fact possible in most of the world's population. The warming of the climate has allowed the expansion of the geographic area in which the mosquito can survive, particularly over the past 30 years as dengue reemerges after having been largely contained during the latter half of the 20th century. Changes in environmental variables have a direct impact on multiple *Aedes*-borne infections such as Zika, Chikungunya, and dengue, leading to changes in the vectors' biting rates, extrinsic incubation times, and vectorial capacity, all of which are interlinked in a complex web of interactions between mosquito population parameters, human infection rates, cross-immunities, and the impact of reduction measures [7, 8].

Tick-Borne Diseases

Tick-borne diseases are a major area in infectious diseases affected by changes in climate. Hard ticks are the vectors of a variety of human and animal diseases, which are of significant public health importance. Conditions transmitted via tick species have expanded because of suitable habitats, such as moderate temperature extremes and abundant ground cover. The necessary conditions for the Lyme disease pathogen have expanded due to changes in vegetation type and its use, including housing, in conjunction with a warming climate. The temperature and humidity amplitudes are important for tick reproduction, as their life cycles, which consist of oviposition, hatching of larvae, molting to nymphs, and then to adult ticks, only occur during specific temperature amplitudes. Thus, warmer temperatures would increase the abundance of nymphs and adults [9, 10]. Higher populations of ticks would lead to more exposure of humans and animals to infected ticks, producing more contact with pathogens. An infected tick bite would transfer the pathogen to an incidental host, which can include humans, resulting in a health impact. In the case of a warmer and wetter climate, there might be an environmental cascade where increased vegetation growth might lead to more food for wildlife, and thus native habitats could broaden, thereby

unintentionally leading wildlife to a contaminated area. Anthropogenic factors, such as suburban development and wildlife management strategies, are crucial in shaping the patterns of tick disease transmission in the short and long term, and the prevalence of the disease. Seasonal meteorological events, such as drought and wet excesses, also influence the period and abundance of ticks. Several case studies have been conducted to examine how climate is linked with changing tick-borne disease patterns [11, 9].

Waterborne Diseases

The quality and availability of water are profoundly influenced by climate. High pathogen loads in water are associated with outbreaks of many of the world's most significant waterborne diseases, including cholera, typhoid fever, and leptospirosis. These diseases are closely linked with flooding and other severe weather events, as this is the time when pathogens in water are most accessible. In recent years, an estimated 1.8 billion cases of diarrhea and 3.5 million deaths annually can be traced directly to water or sanitation conditions. Conventional waterborne diseases, such as cholera and typhoid, are also influenced by the distribution of their animal reservoirs, which can change in response to extreme climatic events [12, 13]. Increased rainfall can be linked to outbreaks of leptospirosis. The outbreaks are both a consequence of weather changes and their impact on human damage patterns. The combined impact of violence and physical destruction (and thus increased exposure to *Leptospira*) is particularly evident in low- and middle-income countries, where social safety nets and physical infrastructure are lacking. Waterborne diseases, especially, are linked to flooding and changes to sanitation infrastructure caused by extreme weather events. Ongoing climate-driven changes in temperature and precipitation are likely to further exacerbate the global burden of waterborne diseases. As growth in developing countries continues to struggle, water-related diseases will increase. Costs, population growth, and climate change contribute to this issue. There is a pressing need to address issues of water quality monitoring, modern water treatment, and protection of the human environment. Differences in sanitation practices in developed countries are not the case in developing countries, underlining the importance of monitoring activities and disease surveillance to deal with the threats immediately and effectively. The increase in water-related infectious diseases is expected, and there is a growing body of research that will be addressed [14, 15].

The Influence of Climate Change on Disease Transmission Dynamics

Based on previous discussions, there should be two classes of factors that most shape the dynamics of infectious disease transmission: vectors and environment. Climate change potentially alters both. Vector-borne diseases are subject to the influence of climate in terms of both their biological and ecological traits, all of which interact with the structure of the host and vector communities within which these diseases launch. Importantly, extremes in temperature and/or precipitation from usual can alter standing water characteristics, which could select for different mosquito species, exhibiting different pathogen infection and subsequent transmission dynamics. Additionally, extreme conditions create natural catastrophes that both disperse vertebrate hosts and vectors whose densities become so high that transmission becomes more frequent; cholera is the canonical example here [16, 17]. In addition to extreme weather events, temperature can directly alter another component of transmission dynamics, specifically the duration of the latent period for vector-borne diseases. Most models describing the relationship between complex ecological systems and temperature, however, point out that the effects of temperature and other climate drivers on disease outbreaks are rarely consistent. Ultimately, the different climate influences on transmission are context dependent, but a common prediction is that, in a globally warming world, the seasonal pulse of transmission may be dampened severely in places proximate to an increased climate threshold. In the context of many emerging diseases being those that oscillate, habitat area and increased movements of hosts or vectors may again increase transmission above its natural amount, increasing the overall risk of disease outbreaks. Host populations generally tend to move allopatrically during warm months as part of the increased interaction hypothesis. Especially in diseases exhibiting seasonal effects, there is much evidence that increased human behavior—i.e., increased amounts of or shifts in human recreational activities or food preparation away from urban settings into the disease-mesocyclic disturbed environment. These activities are more likely to bring humans into contact with infective vectors when they happen to be out. Further, the process of global urbanization in many poor, developing countries can increase the interactions of humans and rural vector-borne disease foci due to infested rodent displacement. Public health responses on a global scale, however, remain largely reactive. Analysis of future disease trends, therefore, often looks to current relationships between climate and disease transmission as a starting point. What, then, is the disease-to-climate proxy literature telling us when, at some level correctly done, likely helps us predict future patterns of climate-driven infectious disease

emergence? And what is not yet clear from these analyses as to the current climate drivers of infections? [18, 19].

Case Studies of Climate Change-Driven Infectious Disease Outbreaks

Case studies of disease outbreaks associated with climate change demonstrate how mortality and economic and social disruption can result when climatic conditions prompt infection or transmission dynamics. For example, an extreme El Niño event in the 1990s caused increased malaria incidence up to almost fourfold and nearly 1,000 deaths in two states alone. Following a drought also associated with El Niño, dengue incidence increased 1.5-fold in Brazil and caused nearly 500,000 cases of the hemorrhagic form of dengue fever, leading to reported over 20,000 cases of severe illness and more than 1,700 dengue-related deaths. Localized droughts in West Africa were suggested as the reason for a meningitis outbreak in sub-Saharan Africa that was attributed to 2,500 deaths and more than 100,000 cases of disease. Outbreaks of cholera increase by 3- to 20-fold the long-term summer conditional probabilities of anomalously high rainfall in the Bay of Bengal [20, 21]. Most of these studies point to climate as a potential factor in the emergence of these diseases but are often not substantiated by local health authorities acknowledging or analyzing meteorological variables for their impact on these outbreaks. In either case, they provide examples of climate variability, as well as its predictability and importance in addition to other environmental variables for the development of models to forecast disease outbreaks. Historians have also documented how European outbreaks of plague or other vector-borne diseases could be associated with the climate — particularly wet summers and rainy periods. Some of these hypotheses have been tested with modern data. Despite the general lack of health network reports on climate change–disease studies, more and more climatologists are publishing articles that give brief observations on them or document early attempts at models to forecast such outbreaks. As climate variability will continue to cause infectious disease outbreaks and models must be linked to surveillance and preparedness, researchers also need to document examples to expand the historical record of climate variability–disease associations. Outbreaks may appear as spikes in health surveillance networks' records [22, 23].

Mitigation And Adaptation Strategies for Addressing Climate Change-Related Infectious Diseases

Many mitigation and adaptation strategies have been proposed to reduce the transmission of or protect populations from, infections through climate change. It is generally acknowledged that the most appropriate system of public health responses to climate change-related infectious disease will be integrating approaches to reduce environmental vulnerability with human development and capabilities to reduce socioeconomic vulnerability. Existing surveillance systems may need to be expanded or adapted to accommodate emerging zoonotic hosts and vectors and disease ecologies. Prevention is a key strategy in managing the likely future impacts, and in this regard, several strategies have been proposed including raising community awareness, vaccination programs, and public education programs. A second strategy is the development of surveillance systems that are adaptable to their environmental context [24, 25]. Because of the global nature and human risk of long-distance transmission, control must be based on a broader international cooperative approach. A strong policy framework is required that emphasizes cooperative action, institutional effectiveness, and combining responsibilities across multiple institutions and interest groups. Research is increasing in this area; it is vital to develop strategies to prevent and manage existing and emerging impacts, including research to identify effective responses to this and other infectious disease threats. At the policy level, infectious disease risks need to be incorporated into policy frameworks across regions and sectors, and significant funding is required for further research into the extent and impact of infectious disease to help policymakers plan for future needs. Ongoing community and health worker education is also recommended, but the allocation of national and international resources is the largest barrier to implementation. Public awareness campaigns and health systems need to be built at all levels to prepare for these and other climate change-related health impacts [26, 27].

CONCLUSION

Climate change has a profound impact on the patterns of infectious diseases, particularly vector-borne and waterborne diseases. Changes in temperature, precipitation, and extreme weather events disrupt ecosystems, enhancing conditions favorable for disease vectors and pathogens, and increasing the frequency and intensity of outbreaks. The effects of climate change are especially severe in vulnerable regions, where healthcare infrastructure may struggle to cope with the rising burden of diseases like malaria, dengue, and cholera. Understanding the interaction between climate change and infectious disease dynamics is crucial for developing effective mitigation and adaptation strategies. Global cooperation, enhanced surveillance systems, and community education are key in preventing and

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