Journal of Zoonotic Diseases
https://jzd.tabrizu.ac.ir/
Published by the University of Tabriz
Online ISSN: 2717-2910

Interconnected risks: Exploring the nexus of zoonosis and climate change

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Article type:
Review article

Keywords:
Zoonosis
Climate change
Human activity
Ecology

Article history:
Received:
May 14, 2024
Revised:
June 4, 2024
Accepted:
June 5, 2024
Available online:
June 18, 2024

Abstract

Climate change is the twenty-first century's most significant threat to human health. Human activity has led to a gradual increase in greenhouse gas concentrations, resulting in global warming and other related hazards. Climate change is significantly impacting ecosystems and biodiversity, leading to a potential increase in zoonotic diseases. Zoonoses are infectious diseases that are transmitted among animals and humans. Vector-borne, foodborne, and waterborne diseases are major infectious diseases associated with climate change. Changes in temperature and precipitation patterns influence the survival, reproduction, and activity of disease-carrying vectors like mosquitoes, ticks, and sandflies. Variations in climate can affect the spread of diseases such as malaria, leishmaniasis, and rodent-borne illnesses like leptospirosis, bartonellosis, plague, and hantavirus infections. Climate change can also impact waterborne illnesses by altering water quality and increasing the risk of contamination during natural disasters. Additionally, higher temperatures and increased humidity can cause transmission of airborne zoonotic diseases, such as aspergillosis, tuberculosis, and influenza. The evolving climate may also contribute to the development of resistance in disease-causing microorganisms, making treatment more challenging. Human behavior influenced by climate change, such as changes in agricultural practices and land use, can indirectly affect disease transmission by altering vector habitats and human-animal interactions. Overall, the complex interplay between climate change, ecological factors, and human behavior underscores the need for comprehensive strategies to mitigate the risks posed by zoonotic diseases and protect public health.

Introduction

More and more research indicates that new infections and possible epidemics may originate from interactions at the animal-human interface. An infectious disease that spreads from vertebrate animals to humans, either directly or indirectly, is known as zoonosis (1). More than 200 varieties of zoonoses are recognized. Most emerging infectious diseases are zoonotic, accounting for 60% to 70% of reported cases (2). Humans can contract zoonotic

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https://doi.org/10.22034/jzd.2024.18076
https://jzd.tabrizu.ac.ir/article_18076.html
Cite this article: Basiri S. Interconnected risks: Exploring the nexus of zoonosis and climate change. Journal of Zoonotic Diseases, 2024, 8 (3): 515-523

disease either directly or indirectly through a vector or fomites. Farm animals, domesticated animals, and wildlife can transmit zoonotic disease. Survival of the pathogens and their reservoirs in continually changing environments, human population specifications (demographic, immunity, etc.), and environmental changes all influence the incidence of zoonosis infections (3). The frequency and distribution of zoonotic illnesses are influenced by how sensitive they are to climate.

Climate change, causes, and impacts

The most significant threat to human health in the twenty-first century is the climate crisis. Emissions of greenhouse gases including carbon dioxide, methane, and nitrous oxide are the primary driver of climate change (4). Since the onset of the Industrial Revolution, human activities have led to a steady rise in greenhouse gas levels in the atmosphere. This has caused the atmosphere to absorb more solar radiation in the form of thermal infrared radiation, increasing Earth's average global temperature. As a result, sea levels may rise, oceans and ice sheets may diminish in size, the frequency of extreme weather events may increase, food and crop failures may escalate, and biodiversity and the health of the ecosystems that sustain life on Earth may decline (5).

Fossil fuels remain the primary source of greenhouse gas emissions. It's important to note that about a third of global anthropogenic greenhouse gas emissions come from food systems (6). Furthermore, emissions from animal-based foods globally are double those from plant-based foods (7).

Given that human activity is a major contributor to global climate change, significant and sustained behavioral changes are required to mitigate its effects. These behavioral changes include switching to electric vehicles and reducing flying and driving, changing one's diet to include fewer animal products and less food waste, energy-efficient renovations, and reliance on renewable energy sources (8).

Global warming, stratospheric ozone depletion, distress in aquatic and terrestrial ecosystems, loss of biodiversity, changes in the freshwater supply, land deficiency and loss of river deltas and coastal cities, urbanization, desertification, population immigration, and limited food production are among the numerous health risks associated with climate change that the World Health Organization has identified (9).

Between 1850 and 1900, the average global temperature rose by around 1.1 °C due to greenhouse emissions, and for the following 20 years, it is predicted to reach or exceed 1.5 °C of warming (10). Many species may lose their habitat due to this trend, increasing the risk of heat-related illnesses and human fatalities.

Droughts, floods, and storms are becoming more frequent and sever due to changes in precipitation patterns caused by climate change. Global warming may lead to increased surface aridity, thus increasing the power and period of droughts. However, the water-holding capacity of air increases by about 7% per 1 °C rise in temperature, which means increasing the water vapor in the atmosphere. Hence, storms produce more intense precipitation events. Due to warming, more precipitation occurs as rain instead of snow, and snow melts earlier. Early spring has higher runoff and a chance of floods, whereas summertime sees a higher risk of drought, particularly over continental areas. This could lead to severe damage to infrastructure, water supplies, and agriculture, while also raising the risk of food insecurity and water scarcity (11, 12).

Since many plant and animal species struggle to adapt to rapid climate changes, ecosystems and habitats are changing, causing loss of biodiversity and the extinction of numerous species. This can weaken ecosystems' resistance to additional external shocks and have cascade consequences on food chains and ecosystems.

Since the seas absorb a significant amount of carbon dioxide, the rise in atmospheric carbon dioxide is also contributing to ocean acidification. Sea surface temperature increases, ocean acidification, modifications to wind and current patterns, and the possibility of influencing fish distribution patterns will all cause significant changes to the physical and biological composition of the oceans. This may have a negative influence on shellfish populations, fisheries, and coastal communities reliant on the ocean for their economy. All of these developments may affect the global increase in hunger and malnutrition (13).

The Middle East's temperature is expected to rise by up to 2 °C over the next 15 to 20 years and by more than 4 °C by the end of the century, according to IPCC predictions. In addition, there has been a 20% decrease in precipitation (14). Iran will endure a more severe reduction in precipitation of 35% and an increase in mean temperatures of 2.6 °C over the next few decades than the rest of the Middle East (15). However, Iran ranks first in the Middle East and seventh worldwide for climate responsibility, with total greenhouse gas (GHG) emissions nearing 616,741 million tons of CO_2 (16).

The relationship between climate change and zoonosis

In general, there is a complicated and multifaceted interaction between zoonotic diseases and climate change. Human behavior and ecological factors significantly impact the transmission and spread of these diseases. A comprehensive strategy that takes into account the ecological, social, and environmental elements that influence the genesis and spread of zoonotic diseases is needed to address these interrelated problems. Figure 1 summarizes the effects of climate change on zoonoses.

The relationship between climate change and zoonosis: ecological implications

Ecosystem and biodiversity changes brought about by climate change may have an impact on the occurrence and spread of zoonotic illnesses. Vector-borne diseases, foodborne diseases, and waterborne diseases are the major infectious diseases related to climate change (17). The life cycles of mosquitoes, ticks, and sandflies are dependent on ambient temperature due to their ectothermic life cycles.

Climate change impacts various aspects of vector-borne zoonotic diseases, such as the survival and reproduction rates of vectors, the intensity and temporal pattern of activity, development rates, and disease transmission within these vectors (18, 19). This impact is significant as over 17 percent of infectious illnesses are transmitted through vectors (20).

Tick seasonality and regional distribution may be impacted by variations in precipitation and temperature. In addition, it can quicken the tick's life cycle, egg production, density, and dispersion—all of which have a significant role in the increased prevalence and dissemination of diseases carried by ticks, like Crimean-Congo hemorrhagic fever. Tick growth phases are influenced by soil moisture and composition, which also has an impact on the survival and spread of infections like Bacillus anthracis spores (21).

Mosquitoes are the best-known disease vector, and their life cycle is closely tied with environmental conditions (20). They can transmit some viruses, protozoa, and also the filariae. Variations in the pattern of transmission of this zoonosis are caused by changes in the environment and global warming. Long-term mosquito proliferation seems to be sustained by factors like temperature rise, heightened likelihood of overwintering, and altered precipitation patterns (20).

Malaria is the most serious disease that mosquitoes transmit. More than 35 countries were granted the status of being malaria-free. Although Iran is thought to be at the phase of eliminating malaria, it is more difficult to keep the sickness case rate at zero. The most well-known factors influencing malaria incidence and vectors are changes in temperature and precipitation patterns. The low level of immunity in the population combined with the increased number of vectors is expected to cause an increase in the incidence of sickness. If the areas at risk for transmission are not identified and suitable vector control measures are not implemented in the at-risk areas, malaria will continue to be a health issue in these regions (21, 22).

One of the seven most significant tropical illnesses, leishmaniasis, is spread globally and is carried by sandflies (24). An increased risk of illness has been associated with increased sandfly activity and the proliferation of leishmania parasites at high temperatures (25). Given that certain regions of the world, like Iran, are more conducive to the co-occurrence of vectors and reservoirs due to climate change, it was anticipated that an increase in the frequency of the disease would follow (26).

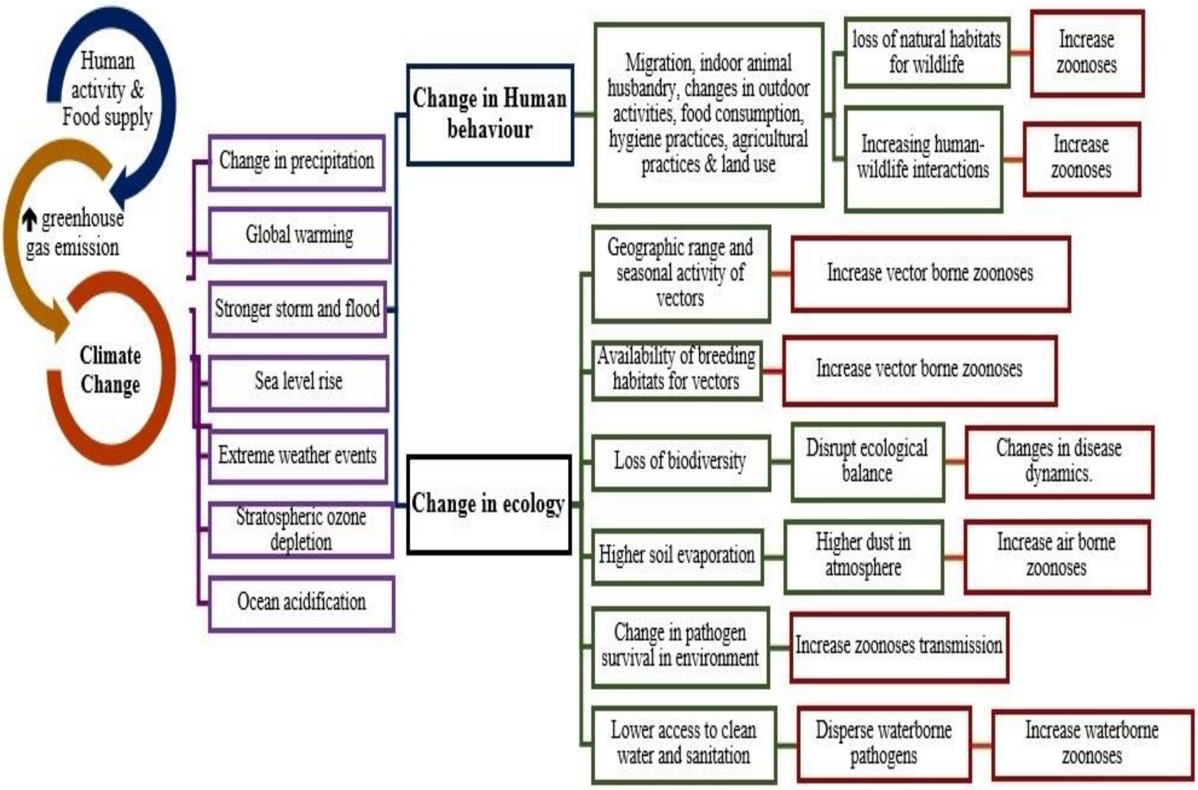

Fig 1. The effects of climate change on zoonotic diseases.

Numerous species, including rats, have population dynamics that are significantly impacted by anthropogenic disturbances and climate change. Rodents make up the biggest order of extant mammals, accounting for over 42% of all mammalian species worldwide. Rodents are found almost everywhere in the world. Iran is home to 79 species out of the 2,277 recognized species of rodents (27). According to Meerburg et al. (2009), humans can contract rodent-borne illnesses either directly—by being bitten or by breathing in the germs in the excrement of the mice—or indirectly—by consuming food and water that has been tainted by the urine or feces of the rodents (28).

Anticipated rainfall and warmer winters may promote rat survivability, potentially leading to more rodent disease reservoirs in some areas. Severe weather conditions, including heavy rain and flooding, can make it more likely for people to come into contact with rodents, their fleas, and their potentially contagious urine and excrement (29).

Leptospirosis, bartonellosis, plague, and Hantavirus infections are among these diseases.

Humans can contract waterborne illnesses mostly through drinking, food processing, and recreational use of contaminated water. Campylobacter, Vibrio, E. coli O157:H7, Cryptosporidium, and Leptospira are significant waterborne zoonotic diseases that have been described over the past few decades (30). Climate change may increase the risk of water-borne infections due to fluctuations in the quality of water sources and an increase in the frequency of natural disasters that could contaminate water supplies (31). The incidence of cryptosporidiosis and giardiasis during wet weather increased significantly (32). There might be significant regional and national differences in the association between climate variables and waterborne illnesses; in poorer countries, especially those in Southeast Asia, the relationship is strongest (31). Rising sea levels, shifting precipitation patterns, and changing seawater salinity all have an impact on a number of variables, including surface water temperature and the ability of bacteria and viruses to reproduce, survive, and sustain themselves in water, all of which have an effect on human health (31). The prevalence of *V. cholerae* increases with increased temperatures. Rise in sea level leads to increased saltwater intrusion into inland areas, raising levels of marine and estuarine bacteria, including *V. cholerae* (33). Floods and severe rains have the potential to disperse waterborne pathogens, particularly viruses. Heavy rainfall can also result in overflowing sewage treatment plants, animal dung, and manure, all of which increase the danger of water-borne zoonosis epidemics (33). The increase in global temperature will also enhance the emergence of freshwater snails in free areas, which will enable the expansion of snail-mediated trematodes (34).

Both increased relative humidity brought on by heavy rainfall and global warming may be directly associated with a rise in the prevalence of foodborne illnesses. These factors may also boost the survival of infections in the environment and increase their presence in food. The global burden of food-borne illness may be impacted by variables such as altitude, climate change, extreme weather events, moisture, oscillations, particle matter, rainfall, salinity, temperature, vegetation, and wind (35). Different foodborne bacteria are affected differently by variations in temperature and relative humidity. Foodborne bacterial pathogens, such as *C. jejuni*, Salmonella spp., Vibrio spp. (36, Europe), and pathogenic E. coli (37, South Korea) were found to be most affected by changes in air temperature and precipitation. For each degree increase in weekly temperature above 5 ◦C, the risk of salmonellosis was increased by 5–10% in the EU member countries (38). Bacteria that cause gastroenteritis, such as Escherichia coli, can survive longer in contaminated food at higher temperatures (39). A potential 1°C increase in temperature is linked to increases in bacillary dysentery of up to 12- 16% (40; China) and campylobacteriosis of up to 5% (41; England). Cropland flooding patterns may shift as a result of climate change, which could introduce viruses into the food chain if raw produce from impacted areas is consumed.

Human health is significantly affected by airborne zoonotic diseases such as aspergillosis, tuberculosis, and influenza virus infections. A pandemic could potentially be caused by recently identified diseases such as the MERS coronavirus, Coxiella, and Francisella if they could spread effectively from person to person.

Warmer, drier summers lead to increased soil evaporation and dust release. Wind is a crucial means of dispersing bacterial, fungal, and spore particles in soil dust to distant areas (42). Warm, humid weather may increase the likelihood of airborne zoonosis spreading. Apart from the direct consequences of climate change, seasonal variations in population patterns, including indoor crowding, also have an impact on the spread of airborne zoonosis. Elevated humidity levels and the disruption of soil that has been colonized by excavation or comparable tasks can encourage the discharge of spores and escalate the likelihood of disease dissemination (43). Temperature variations brought on by climate change have increased the prevalence of infections in places that were previously free of some diseases. A few instances of this are zoonotic viruses. Previously limited to hot areas, many disorders are now seen in high altitudes and subtropical climates (44). According to Chen et al. (45), there was a significant increase in the concentration of the H1N1 influenza virus on days with Dust Storms as compared to regular days. Apart from the increased geographic dispersion of zoonotic diseases, climate change has also compelled vectors to evolve adaptation strategies. This has led to the diseases' increased resistance to traditional treatments because of their enhanced survival strategies and resilience, which promotes the spread of infection even more. In certain situations, alterations in the environment could contribute to microorganisms' resistance, including viruses and bacteria, making treatment more challenging (46).

The relation between climate change and zoonosis: human behavior

Climate change can indirectly affect zoonotic disease transmission by changing human behavior in a number of ways. Changes in temperature and precipitation patterns, for instance, might affect strategies for managing water resources, agricultural methods, land use, and the number of people who relocate to cities during a drought. These alterations may also have an effect on disease-carrying vectors' habitats and those of animals (47). Human sociodemographics may be impacted by climate change, which may also increase the migration of humans and domestic animals from arid, hot places to new areas with more hospitable climates. Due to human activity, natural ecosystems have drastically decreased and deteriorated in recent decades. 75% of terrestrial surface, 65% of oceans, and 85% of wetland regions have seen considerable alteration or loss due to human activation (48). El-Sayed and Awad (2018) reported that these changes are accompanied by alterations in the traditional geographic distribution of wild animals, insects, and rodents, as well as their global population (49). Small rodents are more resistant to human disturbances owing to their large populations, high reproductive rates, high dispersal rate, and small body size. Moderate human disturbance could benefit rodent species by providing promising situations to cause population increases, but over-disturbance by human activities may converse its helpful effects on rodents (50).

To combat heat stress, indoor animal husbandry is being used more frequently, which could increase the risk of zoonotic infections spreading from animal to animal. On the other hand, a longer growing season might encourage more outdoor dining, increasing the risk of transmitting environmental pathogens. Pathogen susceptibility may be impacted by the emergence of (or demand for) new livestock breeds that are less sensitive to heat stress, and shifts in livestock patterns may present opportunities for diseases to cross-pollinate between species. Indirect effects of higher temperatures on behavior patterns include increased water intake and careless hygiene, which may facilitate the spread of diarrhea (51). It also makes people more likely to swim. It might be connected to swimmers with open wounds having a higher risk of contracting certain water-borne zoonoses, like *Vibrio cholera* and *Schistosoma* (52).

Conclusions

In conclusion, the intricate connection between zoonotic diseases and climate change underscores the urgent need for a comprehensive approach to address the interconnected challenges posed by these phenomena. The ecological implications of climate change, such as alterations in vector-borne diseases and changes in biodiversity, play a substantial role in the emergence and spread of zoonotic illnesses. Human behavior, influenced by shifting climate patterns, also impacts disease transmission dynamics. As climate change continues to accelerate, the incidence and distribution of zoonotic diseases are likely to be further affected, necessitating proactive measures to mitigate risks to human health. A holistic strategy that considers environmental, social, and health factors is essential to effectively combat the complex interplay between climate change and zoonosis.

Acknowledgments
Not applicable.

Ethical approval
Not applicable.

Conflict of Interests
There is no conflict of interest.

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