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Climate Change and Emerging Infectious Diseases: A Biomedical Perspective

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Abstract:
Climate change is converting ecosystems into deserts while other plant and animal species are pushed to the brink of extinction. Among this, the rising and re-emerging of infectious diseases is quite alarming. The disease-carrying vectors, like mosquitoes and ticks, spread to new locations because of increased temperatures, changing rainfall patterns, humidity, and land usage, which all affect the distribution and lifecycle of vectors, pathogens, and hosts. This review investigates the various ways by which climate change can cause infectious diseases to emerge. These include vector-borne, zoonotic, waterborne, and foodborne diseases. The study looks at how human migration, urban drifting, and socio-political events impact disease transmission. It also looks at how the latest biomedical tools, like genomics, AI, and real-time surveillance, can improve disease preparedness. In the end, the countries of the world, power players, and nations as a whole, also need to set global policies to treat infectious diseases from climate change.

INTRODUCTION

Climate change is no longer a distant threat; it is a current and accelerating force reshaping our planet's ecosystems, with profound consequences for human health (Iqbal, 2021; 2023a; Iqbal and Ashraf, 2023). One of the major concerns is its influence on the geography of infectious disease transmission. The rise in global temperatures, changing rainfall patterns, the melting of ice caps, and the increasing number of extreme weather events will alter the geographical and temporal distribution of pathogens, vectors, and reservoirs (Watts *et al.,* 2018). As ecosystems destabilize, humans also destabilize the microorganisms with which we share our lives and environment.

In the past, disease has emerged from environmental, social, and biological changes. The Black Death in the 14th century, the influenza pandemic in 1918, and the HIV/AIDS crisis in the 20th century originated in complex interactions between human populations and changing ecological contexts. Climate change in the 21st century is a new and powerful environmental stressor that can disrupt these balance points further and spur pathogen emergence faster. According to the Intergovernmental Panel on Climate Change (IPCC), climatic changes from human activity will increase the risk of spillover of zoonoses and facilitate the spread of diseases, including vector-borne, food-borne, and water-borne diseases (IPCC, 2022).

Diseases like malaria and cholera are sensitive to climate. So are Chikungunya, Dengue, and Zika, which are spread by mosquitoes. Warmer temperatures can shorten incubation periods within the vectors, increase reproductive rates, and expand vector space into areas previously considered uninhabitable (Ryan *et al.,* 2019). At the same time, rising sea levels and changing rainfall patterns disrupt water sanitation infrastructure, which is associated with outbreaks of diarrhea and waterborne diseases in low-resource settings (Levy *et al.,* 2016).

In addition, climate change impacts ecosystems indirectly; deforestation, urbanization, and forced migration also cause effects. Increased contact between humans and wildlife due to these pressures is a major driver of zoonotic disease emergence (Jones *et al.,* 2008). The COVID-19 pandemic has made us realize how fragile the relationship is between ecosystems and human disease. Scientists have warned that environmental destruction due to climate change could result in future pandemics (Iqbal, 2020; Carlson *et al.,* 2022).

Despite these increasing threats, public health infrastructure across the world is still prepared inadequately. The distribution of surveillance systems, vaccine distribution networks, and healthcare access is unequal, leaving many vulnerable populations exposed to outbreaks worsened by climate change (Iqbal, 2024). Through an assessment of biological mechanisms, historical data on disease outbreaks, predictive modelling, and future mitigation options, this review article discusses links between climate change and emerging infectious diseases. It is necessary to apply science and teamwork for the prediction, prevention, and treatment of diseases witnessed in our warming world.

Mechanisms of climate-driven disease emergence

The complex interaction of environmental, biological, and socio-economic mechanisms increases infectious diseases due to climate change. Climate factors like temperature, humidity, and precipitation affect disease vectors, pathogens, and hosts, their transmission and intensity, both directly and indirectly, and also extreme weather events (Ashraf and Iqbal, 2022).

The development of places occupied by vectors is probably the most studied mechanics. This explains how infectious pathogens can spread to colder climates. As temperatures worldwide increase, it has become possible for mosquitoes, ticks, and other pathogens to survive, develop, and breed in regions that were previously unreachable. According to Ryan et al. (2019), warming is allowing the *Aedes aegypti* mosquito, a major vector of dengue, chikungunya, and Zika viruses, to expand into more temperate regions. The regions where the diseases propagated by *Aedes* mosquitoes occur are expected to experience an expansion of almost a billion people by 2080 on the basis of a rise in emissions (Carlson *et al.,* 2022).

The black-legged tick *Ixodes scapularis*, which spreads Lyme disease, has penetrated further in North America due to milder winters and longer summers supporting its life cycle (Ogden *et al.,* 2014). Warmer temperatures increase the ability of mosquitoes to transmit pathogens to humans. The time it takes for the pathogen to develop inside the mosquito (as opposed to the human host's body) shortens as temperature increases. Warmer and moist environments can help develop the dengue virus in the mosquito populations. The shift in climate alters how pathogens work with hosts (Ikhlak *et al.,* 2016; Zaynab *et al.,* 2019). As habitats disappear and thermometers rise, encounters with wildlife increase, as do the risks of their contagious diseases. Diseases that move from the animal community to humans are called zoonotic diseases (Ali *et al.,* 2017; Iqbal *et al.,* 2019). Warming and destruction of habitat are making things worse. As developments are expanding, forests are disappearing, and droughts are increasing. The animals start moving to other places in search of a new habitat. In doing so, they come in contact with human settlements. Consequently, this increases the risk of new spillover events (Jones *et al.,* 2008; Carlson *et al.,* 2022).

The habitat damage and climate-induced pressures are forcing bats, the reservoir of numerous viruses including Ebola and coronaviruses, to search for new shelters. These species are often migratory and roost in human-altered landscapes. Thus, it makes them more likely to transmit their viruses to other species. According to this hypothesis, the loss of biodiversity and climate stress increases zoonotic risks (Plowright *et al.,* 2017). Climate change is causing more frequent and severe floods, hurricanes, and droughts, not to mention. Events such as flooding disrupt the water and sanitation infrastructure. In addition, they facilitate the transmission of waterborne pathogens such as *Vibrio cholerae*, *Cryptosporidium*, and *Giardia*. Coastal floods can cause epidemics, like cholera, when flooding displaces individuals or floods waters (Pascual *et al.,* 2002).

Rural-urban migration caused by climate change results in slum expansion, leading to increased susceptibility to infectious and vector-borne diseases (Muhammad *et al.,* 2015). The increase in leptospirosis and dengue in densely populated urban areas can be attributed to extreme weather events, as observed by Confalonieri et al. (2007). The ocean temperature and saltiness change with time because of El Niño, Southern Oscillation (ENSO), and other patterns and ocean-atmospheric conditions that affect marine disease dynamics. During an El Niño event, typically warmer sea-surface temperatures favour plankton growth in coastal Bangladesh. This plankton is a host for *V. cholerae,* which has an increased incidence of cholera there (Lipp *et al.,* 2002). The Increase in Diseases in East Africa Associated with Changes in Rainfall and Mosquito Breeding Conditions, due to ENSO cycles (Anyamba *et al.,* 2006).

Here's a less common, but growing, mechanism: the thawing of Arctic permafrost. During this process, dormant pathogens could awaken, including viruses and bacteria that have long since died off. In 2016, an anthrax outbreak occurred in Siberia. According to Revich and Podolnaya (2011), the permafrost thaw was responsible for this outbreak. Though rare, these instances demonstrate the negative effects climate change can have on diseases.

Ultimately, the large-scale movements of people into diverse disease environments occur as a result of droughts, floods, and resource scarcity. Migrants may be vulnerable to local endemic pathogens due to poor immunity and lack of access to health care. Migrants sometimes take disease with them to areas that were not previously affected. As a result of climate change, more outbreaks worldwide are likely to occur, like the COVID-19 virus (Iqbal, 2022).

Vector-borne diseases and climate sensitivity

Vector-borne diseases are well-known climate-sensitive infectious diseases (Abdel Aziz *et al.,* 2017; Abdulaziz *et al.,* 2019; Valcárcel and Olmeda, 2019). These diseases are transmitted by arthropods, which are mosquitoes, ticks, and sandflies. Diseases such as dengue, chikungunya, Zika, and West Nile virus are transmitted through mosquitoes, and the transmission of these diseases at the regional and global levels is closely related to prevailing environmental conditions, particularly temperature, rainfall, and humidity, which exert an influence on vector biology, pathogen capabilities, and human-mosquito interactions. Temperature determines the life cycle of vectors and their ability to transmit pathogens. According to Mordecai et al. (2019), the mosquito has an immature stage that is an egg. If the temperature rises, it impacts the older states. Furthermore, mosquitoes can bite more frequently. Additionally, external incubation periods decrease. For instance, the best temperature for *Aedes aegypti* to transmit dengue virus is at 29°C, while too cold or too hot will result in less efficiency (Liu-Helmersson *et al.,* 2014).

As temperatures continue to rise everywhere, regions that were previously too cold to support vectors are becoming more and more suitable. For example, viruses like dengue, chikungunya, and Zika, which were limited to tropical/subtropical regions, are now seen in temperate regions like southern Europe and North America (Ebi and Nealon, 2016). Dengue that is locally transmitted has occurred in Florida, Texas, and even New York (Kraemer *et al.,* 2015). Climate change has acted as a key enabling factor. Malaria epidemics have been shown to depend on unusual weather, such as unexpected rainfall and warmer temperatures. Most of these variations are attributed to climate variability (Pascual *et al.,* 2006; Caminade *et al.,* 2014).

As the climate warms, vectors are moving steadily into higher altitudes and latitudes. Warming trends have allowed Anopheles mosquitoes to establish populations in the East African highlands, which has led to outbreaks in already affected areas, where previously very low temperatures inhibited their spread (Siraj *et al.,* 2014). Like this, in the European Alps and Andean highlands, ticks bearing tick-borne encephalitis and Lyme disease have extended their range upwards (Danielová *et al.,* 2008; Randolph and Rogers, 2010). This elevation change can affect groups that do not have prior immunity against the diseases or sufficient monitoring infrastructure, making them more susceptible. Health systems not ready for diseases believed to be exotic or endemic face a challenge from such epidemiological transitions.

Malaria is one of the most studied climate-related vector-borne diseases out there. Global warming may alter malaria transmission zones. Increased suitability is expected in some areas, while in others it may decline when temperatures become too hot for mosquitoes to survive or the malaria parasite to develop (Caminade *et al.,* 2014; Dilshad *et al.,* 2016). There are highlands in Africa that may not be high; first and foremost, docile warming may result in a huge increase in cases due to the naive immunity of the people (Siraj *et al.,* 2014).

The cycles of El Niño – Southern Oscillation (ENSO) have been linked to sub-Saharan Africa malaria epidemics. The conditions for mosquito breeding and pathogen development are exacerbated by increased rainfall and temperature during El Niño years (Thomson *et al.,* 2006). Climate change is causing vector-borne diseases to appear or come back in places where they didn't happen before. For example:

• Chikungunya and Zika viruses used to be limited to Africa and Asia. However, outbreaks have occurred in the Americas and Europe. (Musso and Gubler, 2016)

• West Nile virus was first detected in the U.S. in 1999, although experts believe that it was introduced here a long time earlier. When temperatures warm, Culex mosquitoes become highly efficient transmitters of West Nile virus.

Paull et al. (2017) stated that West Nile virus has now become endemic in the U.S.

• Due to the warming and desertification of the Mediterranean basin and Middle East, Leishmaniasis, which is transmitted by sandflies, is now expanding in these regions (Ready, 2010).

Waterborne and foodborne infections

Climate change can significantly affect water- and food-borne infectious diseases, primarily by altering the environment that modifies the survival, growth, and transmission of disease-causing microbes. The changes are a public health threat in places where there isn't the infrastructure, sanitation, clean water, or safe food to cope with them. The emergence, spread, and seasonality of enteric infections are all influenced by rising temperatures, increased rainfall, flooding, and droughts (Levy *et al.,* 2016; Urooj *et al.,* 2018; Ashraf *et al.,* 2019; Fatima *et al.,* 2021; Echevarría, 2022).

Water and food systems may become more conducive to the reproduction of bacteria, viruses, and protozoa when the ambient temperature rises. According to Baker-Austin et al. (2017), *Vibrio cholerae* and other pathogens like *Salmonella* spp., *Escherichia coli,* and *Campylobacter jejuni* favour warm conditions. This results in outbreaks during heatwaves and the warmer seasons. For example, Vibrio species, including *V. cholerae*, are very sensitive to sea surface temperature, and outbreaks are strongly correlated with ocean warming in coastal areas (Vezzulli *et al.,* 2016). Beach sands are directly contaminated by human garbage, which acts as a nutrient for fungal development (Echevarría, 2019a,b).

Research indicates that the warming of sea surface temperatures in the Baltic Sea and North Atlantic has resulted in increased *Vibrio* habitat suitability. This has caused infections to occur in northern Europe, where these previously unrecorded cases were not known to happen. Like the above, in the USA, cases of Salmonella outbreaks are rising due to the increase in summer temperatures. Improperly storing or transporting food allows bacteria to multiply quickly (Soon *et al.* 2020). Climate change characteristics, such as increased floods and rainfall, can overwhelm sewage systems, contaminating drinking water sources with faeces and promoting the emergence of diarrheal illnesses (Hunter, 2003; Fatima *et al.,* 2021).

Global warming of surface waters, coupled with nutrient runoff, encourages the growth of harmful algal blooms (HABs). These flowering plants pose dangers to aquatic environments as well as biotoxins which spoil seafood for food, causing paralytic shellfish poisoning, diarrheic shellfish poisoning among others (Wells *et al.,* 2015; Ashraf and Iqbal, 2021). As oceans become warmer, the geographic range and seasonality of harmful algal blooms are expanding, putting new coastal populations at risk (Glibert *et al.,* 2014). Higher sea levels contaminate freshwater sources in coastal areas, say microbes, raising the risk of Vibrio infections that prefer brackish waters (Vezzulli *et al.,* 2016). Microbial ecology changes in food production systems due to salinity changes can compromise safety and quality in aquaculture and irrigation-based agriculture (Levy *et al.,* 2016). Overall, diseases related to water and food respond greatly to temperature, rainfall, pollution, and other changing elements of the climate. Due to climate change, the chance of such illnesses will most likely increase. It will happen particularly in vulnerable communities with less infrastructure or surveillance. To avoid future problems, we need integrated climate and health monitoring, climate-resilient water infrastructure, and climate-smart food safety policies (Iqbal, 2023b).

Zoonoses and habitat disruption

Climate change is responsible for spreading diseases that jumped from animals to human beings as it alters the ecosystem, wildlife location, and human–animal interaction. Animals and humans are increasingly coming into contact with diseases because their homes are getting smaller, and wildlife reserves are getting smaller. This is being observed mainly because of climatic events like drought, fire, and changing vegetation. The emergence of high-impact infectious diseases like Ebola, Nipah virus, and possibly SARS-CoV-2 is due to this process (Jones *et al.,* 2008; Carlson *et al.,* 2021).

Spillover from a reservoir into man or another intermediate can lead to disease outbreaks, including pandemics. These steps start with a pathogen that already circulates in the reservoir host, zoonotic spillover, followed by the host infection, and then host-to-host transmission. Zoonotic spillover will not lead to a pandemic or epidemic unless the pathogen can transmit back to humans or continue to be transmitted between humans. Environmental changes (e.g., habitat fragmentation, loss of biodiversity, different environment) may increase the occurrence of these spillover events through changes that occur in the behaviour of the reservoir host and the increased contact points between species (Plowright *et al.,* 2017).

As forests and wildlands become farmland or cities, biodiversity drops. Usually, the survivors are adaptable, generalist species like rodents and bats. These animals are overrepresented as carriers of zoonotic pathogens due to their high reproduction rate, high population density, and proximity to people (Han *et al.,* 2016). Warming temperatures and varying precipitation patterns are pushing wildlife species to shift their geographical ranges into new communities. This reassignment increases the risk of cross-species transmission when formerly isolated species come into contact (Carlson *et al.,* 2021).

A landmark modeling study found that by 2070, climate-driven range shifts could cause over 15000 new viral cross-species transmission events among mammals. These would mainly occur in tropical Africa and Southeast Asia, both already hotspots for emerging infectious diseases (Carlson *et al.,* 2022). These spillover events may plant the seeds for new zoonoses, which may have epidemic or pandemic potential. Due to climate-induced food insecurity, agricultural intensification is resulting in large-scale commercial livestock farming replacing areas previously inhabited by wild animals. Since the animals live so close together, it makes it easier for a pathogen to jump from a wild animal to a domestic animal to a person. According to Daszak et al. (2000), domestic animals may enhance or enable pathogens to make the jump to humans.

Case Studies of Climate-Linked Spillover

• Outbreaks of the Ebola virus have been linked to forest encroachment and bush meat hunting. In West Africa, the change in rainfall and vegetation has altered bat foraging behavior, probably increasing contact with humans (Pigott *et al.,* 2014).

• Due to climate change, ticks and host species are spreading. This is raising the risk for Lyme disease, which was previously only present in some temperate regions. When predator populations go down and habitats fragment, then mice, deer, and other species become the reservoir hosts (Levi *et al.,* 2012).

• Though the origin of SARS-CoV-2 is still unclear, it is believed that a spillover has occurred due to wildlife trade or interaction in disturbed habitats where humans and reservoir species (like bats) interact more often (Zhou *et al.,* 2020; Andersen *et al.,* 2020).

Zoonotic spillover is seen as a climate-sensitive process due to habitat loss, species range shifts, and biodiversity loss. One Health approach helps human, animal, and environmental health experts to devise strategies to predict and prevent future pandemics as per the interactions. To prevent emerging diseases in humans, we must enhance monitoring of humans and animals, work on wildlife trade, conserve wildlife, and improve climate change.

Urbanization, migration, and disease spread

Rural-urban migration and forced human migration due to climate change and related factors could be responsible for infectious disease emergence and spread. Displaced people and forced migrants have been known to be impacted by climate change as a threat multiplier. Natural disasters like earthquakes, cyclones, droughts, floods, or landslides displace tens of millions of people annually, many of whom are related to climate (IDMC, 2023). Such displacements raise the risk of outbreaks in originating and destination areas. Refugee camps and makeshift shelters are often overcrowded, unsanitary, and lack access to adequate clean water and medical services, all of which create conditions perfect for outbreaks of disease from cholera to measles to COVID-19 (Toole and Waldman, 1997; Bellizzi *et al.,* 2020).

Floods and cyclones in South Asia, for example, have resulted in mass displacements, which have been associated with increased incidences of diarrheal diseases, leprosy, and mosquito-borne illnesses (Watts *et al.,* 2015). Likewise, desertification and drought in the Sahel have caused internal and cross-border migrations, putting additional pressure on already overstretched urban health systems with limited infrastructure (Caminade *et al.,* 2014).

Diseases grow in cities like megacities in low-income and middle-income countries that quickly evolve their composition. Overcrowding, poor housing, limited access to health services, and waste management result in the transfer of airborne organisms, for example, tuberculosis and influenza (Alirol *et al.,* 2011; Ahsan *et al.,* 2020). Besides that, the high temperature caused by urban heat islands and water storage practices in cities may aid the proliferation of dengue, Zika, and chikungunya virus vectors (like *Aedes aegypti*) (Ryan *et al.,* 2019). As towns expand into peri-urban and rural territory, closer contact occurs between people, wildlife, and domestic animals, increasing the risk of zoonotic spillover. This has been observed in a number of outbreaks, including during the 2002–2003 SARS epidemic associated with wet markets and the wildlife trade in rapidly urbanizing areas of southern China (Wang *et al.,* 2006).

Modern transport systems allow the rapid global spread of pathogens. Urban migrations across the world are propagated by hubs and megacities that act as "nodes" in the global disease network, which offer the conditions for pathogens to emerge and which enable diseases to be transported quickly across continents (Tatem *et al.,* 2006). As worldwide travel spiked, so did the possibility of encounters. The COVID-19 epidemic spread due to intensive urban connectedness (Bogoch *et al.,* 2020).

In addition, climate-related migration can also disrupt disease surveillance and control programs. Mobile populations are frequently excluded from immunization campaigns and routine health services. Consequently, this creates blind spots within public health systems, allowing the reemergence or introduction of diseases such as polio and measles in previously controlled regions (Reiner *et al.,* 2020).

It is important to connect climate adaptation with public health planning to tackle these challenges. Cities need to invest in infrastructure, early warning, disease surveillance, and accessible health care. The design of cities should be environmentally sustainable and reduce health hazards. Furthermore, health programs need to include mobile and migrant populations to ensure that disease prevention and control efforts are equitable (Myers *et al.,* 2017).

Biomedical tools and surveillance innovations

The interaction of climate-sensitive infectious diseases with technology in public health has resulted in new strategies for early warning, real-time monitoring, and quick and efficient response to outbreaks. Outbreaks may take time to be detected, but climate-related diseases may not be used by conventional disease surveillance assembles. In this sense, climate-informed surveillance brings together weather, ecosystem, and health information to forecast and track disease trends. For example, the use of remote technologies and GIS allows scientists to see environmental changes (such as vegetation, standing water, or land-use patterns) when the emergence of vector diseases such as malaria and dengue (Beck-Johnson *et al.,* 2017; Semenza and Suk, 2018).

The European Centre for Disease Prevention and Control (ECDC) aids in disease risk modeling adapted to climate for West Nile virus and tick-borne encephalitis, which allows public health agencies to conduct targeted vector control before the occurrence of an outbreak (Semenza *et al.,* 2019). NASA's Earth Observation System has also been able to assist in global disease monitoring by identifying hotspots of environmental change and correlating these changes with vector expansion (Anyamba *et al.,* 2014).

The detection and characterization of emerging pathogens have been revolutionized by next-generation sequencing (NGS) and genomic surveillance tools. These technologies enable us to track the evolution of microbes and their resistance in real time. One example is the rapid sequencing of SARS-CoV-2, which helped scientists identify variants of concern, identify transmission dynamics, and guide vaccine development (Fontanet *et al.,* 2021). Moreover, novel viruses can be discovered from animal reservoirs and environmental specimens even prior to the outbreak. It is particularly critical in biodiverse regions facing deforestation and urbanization, which are the areas with the highest probability of zoonotic spillover (Carroll *et al.,* 2018).

Artificial intelligence (AI) has improved climate-sensitive disease forecasting. Predictive models based on climate, vector, and case data have been used successfully to predict outbreaks of dengue, chikungunya, and Zika in Latin America and Southeast Asia (Racloz *et al.,* 2012; Johansson *et al.,* 2019). Moreover, the detection of physiological signals of infection is being studied using mobile apps and wearables for community and health care biosurveillance (Topol, 2019).

Innovations in vaccines and diagnostics play an important role in reducing infections. A warming climate is expanding the range of diseases like dengue and yellow fever into new regions. In order to tackle this issue, new and improved vaccines are being designed with greater speed and scalability than ever before, especially mRNA-based platforms (e.g., Zika, COVID-19) (Pardi *et al.,* 2018; Krammer, 2020). Rapid point-of-care diagnostic tests, which are sensitive and can be deployed in the field, are important in situations involving climate-sensitive outbreaks. Recent developments in CRISPR-based diagnostics for SHERLOCK and DETECTR enable intensive testing for viral pathogens in low-resource settings, thus enhancing response times for emerging epidemic zones (Gootenberg *et al.,* 2017).

Increasingly, global data sharing initiatives are being put into action due to the cross-border nature of infectious disease threats. Websites like GISAID (for genetic data), WHO's Epidemic Intelligence from Open Sources (EIOS), as well as One Health-type strategies, make it easy to bring together human, animal, and environmental data. These collective actions are very useful to predict and manage diseases made worse by climate change (Atlas *et al.,* 2020).

Technological tools by themselves, however, are not enough, as governance, ethics, and access are important too. Aid countries that don't have the means (low- and middle-income countries (LMICs)) to develop their own surveillance technologies and biomedical production capacity, as these countries are a serious risk to global health security (Moon *et al.,* 2015).

Ethical considerations and equity in climate health

Climate change and health are not just science or politics - they are a serious ethical issue. The most vulnerable communities have contributed the least to global greenhouse gas emissions, yet they disproportionately experience the impacts of climate change. We must ask whose health is at risk as climate-sensitive diseases rise, and what equity and justice exist between those countries that contribute and those that are affected. Ethical frameworks help inform the policies, research, and interventions we develop in ways that uphold human rights, limit harm, and distribute the benefits fairly.

Climate justice acknowledges that people who are most impacted by climate change generally do the least to cause it. The health risks posed by extreme weather events, vector-borne diseases, malnutrition, and lack of water (Hickel *et al.,* 2022) threaten low-income groups, Indigenous people, the elderly, children, the disabled, and people in weak states (WHO, 2023). Poor people often live in the most fragile settings; this means they often lack infrastructure or health care. As a result, they face immunity problems when diseases flare up or there are natural disasters.

Distributive justice ethics requires that climate change adaptation efforts should target the vulnerable groups. Programs aimed at ensuring equity could be increasing healthcare access in climate-vulnerable regions, investment in early warning systems for disadvantaged groups, or ensuring that climate health financing flows to the poorest countries (Boyd *et al.,* 2021). For example, the impact of the drought on food insecurity in the Horn of Africa is putting women and children at risk of malnutrition and disease (UNICEF, 2023).

Indigenous peoples are stewards of biodiverse ecosystems; however, they suffer heightened exposure to climate change and infectious diseases due to a legacy of colonialism, alienation from land, and systemic neglect (Cunsolo *et al.,* 2020). Ethical global health must protect Indigenous sovereignty, support culturally appropriate health care, and incorporate traditional ecological knowledge into climate adaptation strategies. For example, melting permafrost and changing animal migration patterns threaten food security and cultural practices in Arctic regions; meanwhile, the emergence of zoonotic diseases such as Anthrax and Hantavirus is facilitated (Hueffer *et al.,* 2020). Involving Aboriginal people in decision-making processes, especially in projects that influence their lives, is crucial for more effective and equitable public health responses.

Rich countries that pollute the most must admit their historical wrongs and help the Global South adapt to climate change and get ready for health shocks. Technology transfer, capacity building, and fair access to diagnostics, vaccines, and therapeutics for emerging diseases make ethical climate action (Byskov *et al.,* 2022). Climate change poses a long-term threat, and future generations of people will experience the health effects of climate change. Today's choices must not interfere with the ability of future generations to lead healthy and dignified lives. The increasing instances of respiratory diseases because of air pollution, rising susceptibility to water-borne diseases, and mental health issues among youth due to climate change (for instance, eco-anxiety) only underline the need for maintaining public health infrastructure for the future (Crimmins *et al.,* 2021).

The right to health is mentioned in international regulations and law, for example, the Universal Declaration of Human Rights and the International Covenant on Economic, Social, and Cultural Rights. Due to climate change, the environmental factors of health, including clean air, safe drinking water, adequate food, and secure shelter, are threatened, and therefore, this right is threatened (UN Human Rights Council, 2021). Tackling such problems is more than just a public policy. It is also a moral issue.

Biomedical studies on climate-related diseases must also follow ethical standards. These are things like informed consent, community engagement, and benefit-sharing, particularly in vulnerable populations. Health research undertaken in the name of ethics should not be exploitative but should build local capacity and autonomy. Also, the design of health technologies (e.g., mobile diagnostics, surveillance tools, telehealth platforms) must consider digital equity. If we do not deal with issues, such as internet access, health literacy, and cultural appropriateness, then innovations may widen rather than narrow disparities (Ebi *et al.,* 2021).

CONCLUSION

Growing evidence indicates that climate change drives the emergence of infectious diseases. Thus, we need urgent, integrated, and ethical action from global scientists, health professionals, and policymakers. Planetary systems are destabilizing due to human-made greenhouse gas emissions. The ecological niches that maintain pathogens, vectors, and animal hosts are shifting, providing new opportunities for the emergence and spread of disease.

The recent pandemic of COVID-19 showed us how the world is still not ready for large zoonotic outbreaks and how quickly our health, economic, and social systems collapse due to a new pathogen. As climate change speeds up these threats, the health sector must change just as fast, by creating strong surveillance systems, rolling out new biomedical tools, and strengthening public health infrastructure in high- and low-income regions. The diseases that are driven by the climate are not just a scientific problem. It is also a societal problem. One that tests the ability of the international community to work together with compassion and foresight.

We must come together with planetary stewardship, scientific integrity, and health equity moving forward. If we act quickly and have everyone on board, the link between climate and health can be useful. Rather than giving rise to harm, it can lead to societies that are fairer and more resilient.

CONFLICT OF INTEREST

The author hereby declares no conflict of interest.

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