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Chapter-12

# Eco-Health Dynamics: Climate Change, Sustainable Development and the Emergence of Infectious Challenges

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**Keywords: Climate change, sustainable development, vector-borne disease, environmental policies.**

**Abstract:**

This comprehensive review explores the intricate relationships between climate change, sustainable development and emerging infectious diseases (EIDs). Changes in climate parameters, such as rising temperatures and altered precipitation patterns pose profound ecological, environmental and socio-economic threats. The review delves into emerging threats such as vector-borne diseases, the resurgence of dormant pathogens due to melting ice layers and the complex global health challenge of antimicrobial resistance. It emphasizes the importance of integrating EID risk into sustainable development planning through a multisectoral approach. The review underscores the pivotal role of Sustainable Development Goals (SDGs), particularly Goals 2 and 15, in mitigating EID risks, emphasizing the delicate balance required to simultaneously enhance agricultural productivity and conserve terrestrial ecosystems. Mitigation and adaptation tactics required for responding to climate change necessitate effective international policies, particularly in key sectors like agriculture, industry, forestry, transport and land use. Associations between climate change and infectious diseases suggest collaborative efforts among researchers, policymakers and nations to achieve a balanced and sustainable future. Effective mitigation, calibrated with the UN's 2030 Agenda for Sustainable Development, lowers the risks of new infectious diseases and ensures the well-being of both ecosystems and societies on a global scale.

## Introduction:

Climate change is recognized as a multifaceted global challenge that affects various aspects of ecological, environmental, socio-political and socio-economic domains (Adger et al., 2005). It is generally characterized by elevated temperatures worldwide (Battisti and Naylor, 2009). However, the comprehensive, longstanding changes in temperature, pressure, humidity and precipitation patterns define the nature of climate change. Notable international and domestic effects of the changed climate include irregular weather patterns, the retreat of global ice sheets, and the corresponding rise in sea levels (Lipczynska-Kochany., 2018; Michel et al., 2021).

The 21$^{st}$ century is witnessing profound global transformations, such as rapid population growth, shifts in dietary patterns and an increase in energy demands (Tilman and Clark., 2014).

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These changes have sparked extensive debates and serious scientific inquiry. Concurrently, the United Nations' 2030 Agenda for Sustainable Development, designed to address environmental and social challenges, inadvertently introduces a heightened risk of infectious disease outbreaks (Di Marco et al., 2020; Mukherjee et al., 2022). The complex connection between observed and anticipated global climatic changes and the increasing prevalence of infectious diseases, such as the impactful case of COVID-19, must be explored with detailed scientific investigations (Basak et al., 2021; Basak & Sanyal., 2022; Sen et al., 2021; Kaur et al., 2023). The severity of this issue is further compounded by the enhancement of climate-related challenges through the consumption of fossil fuels. Determining the root causes of disease emergence demands a comprehensive approach harmonized with the Sustainable Development Goals (SDGs). The direct link between environmental change and the risk of emerging infectious diseases necessitates an action plan aimed at achieving various goals of Sustainable Development for healthy lives and promoting well-being (Di Marco et al., 2020; Saha et al., 2022a; Saha et al., 2022b). Goals 2 and 15 focus on agricultural productivity and the conservation of terrestrial ecosystems and have a direct influence on the risks of Emerging Infectious Diseases (EIDs) (Di Marco et al., 2020). Surprisingly, 70% of EIDs and nearly all recent pandemics find their origins in animals (Morse et al., 2012). This underscores the intricate interplay between wildlife, domestic animals, and humans shaped by diverse factors, including human population density, wildlife diversity, deforestation, agricultural expansion, livestock intensification and wildlife trade (Jones et al., 2008; Allen et al., 2017; Ghosh et al., 2023). Societal instability, particularly in conflict-affected regions, emerges as an additional driver amplifying EIDs (Stoett et al., 2016). Conflict influences human migration, and transmission risk and disrupts disease control efforts by affecting healthcare systems (Stoett et al., 2016). Goal 16 of the UN 2030 Agenda promotes effective institutions and the end of violence and acknowledges disease as a threat to societal security (Di Marco et al., 2020).

In light of the ongoing challenges outlined in the UN 2030 Agenda (Di Marco et al., 2020), this review underscores the profound impact of climate change on infectious diseases, emphasizing how climate patterns contribute to the emergence of pandemics. In this context, Sustainable Development Goals (SDGs), especially Goals 2 and 15, become very important. It is crucial to find the right balance between the progress of sustainable development and the emergence of new infectious diseases. Collective efforts to achieve the goals of the UN's 2030 Agenda (Di Marco et al., 2020) and to prevent the inception of new diseases are essential to ensure a safe and healthy future for human beings in the coming decades.

## Unravelling Climate Change, Ecological Shifts and Disease Dynamics:

The close interrelationship between climate change and infectious diseases begins with profound ecological transformations induced by human activities; particularly noteworthy are deforestation and the alarming loss of biodiversity (Ryan et al., 2019; Bartlow et al., 2019). These activities affect the distribution, survival and transmission of pathogens, their animal reservoirs, and vectors (Mansour., 2013). Such environmental changes can potentially lead to higher rates of premature mortality (Di Marco et al., 2020). Various environmental modifications have profound implications for the prevalence and distribution of diseases by creating habitat conditions conducive to the transmission of specific illnesses (Ryan et al., 2019). The construction of canals, dams and irrigation pathways can give rise to diseases such as schistosomiasis, malaria, helminthiases and river blindness (Abbass et al., 2022). The alteration of landscapes through agro-strengthening practices like crop pesticides may intensify the incidence of malaria and Venezuelan hemorrhagic fever driven by increased rodent abundance and contact (Abbass et al., 2022). Suburbanization marked by deprived hygiene and water pollution in municipal areas can foster diseases like cholera and dengue, the latter finding breeding sites in water-gathering rubbish (Abbass et al., 2022). Deforestation and new tenancy contribute to the spread of malaria, Oropouche fever and visceral leishmaniasis through the creation of breeding sites, altered trajectories and the migration of vulnerable populations (Abbass et al., 2022). In agricultural settings, Lyme disease may proliferate due to the presence of tick hosts and heightened outdoor exposure (Abbass et al., 2022). Furthermore, ocean heating leads to red tide poisoning characterized by toxic algal blooms (Abbass et al., 2022). The 1998 Nipah virus outbreak in Malaysia resulted from increased pig farming near tropical forests where fruit bats, the virus reservoir, reside (Di Marco et al., 2020). Similarly, the origins of SARS and Ebola viruses are linked to bats either through hunting or greater human development (Di Marco et al., 2020). In each case, environmental modifications play a pivotal role in shaping the dynamics of disease transmission, highlighting the acquaintance between human activities and public health outcomes. To prevent such outbreaks, social and economic development aligning with a spectrum of societal issues outlined in the SDGs is crucial.

## Rising Temperatures as Expanding Threats: Impact on Vector-Borne Diseases:

Before the industrial revolution, natural sources such as volcanoes, forest fires and seismic activities were considered the primary culprits for the emission of greenhouse gases (GHGs) (Murshed et al., 2020; Hussain et al., 2020; Murshed, 2022). However, contemporary anthropogenic activities linked to industrialization, urbanization and intensive agriculture are now recognized as the main drivers of climate change. Human actions, notably the substantial increase in the use of fossil fuels, widespread use of fuel-based mechanization, agricultural residue burning, deforestation and transportation activities (Huang et al., 2016), significantly influence global warming by releasing large quantities of heat-trapping GHGs (Balsalobre-Lorente et al., 2022; Mallick et al., 2022; Ishikawa-Ishiwata and Furuya, 2022). Additionally, industrial and agricultural processes release pollutants such as black carbon particles or soot, contributing to warming by absorbing incoming solar radiation (USGCRP, 2009). Moreover, human activities such as unsustainable land management and land use extend their impact on the climate of specific regions (IPCC, 2020). These types of illegal practices not only carry negative economic consequences but also amplify the climate crisis across various spatial scales. Alterations in land use, like the conversion of forests and peatlands into agricultural areas, release carbon stored in biomass and soil, contributing to 10 to 15 percent of total $CO_2$ emissions (FAO, 2011). This transformation and degradation affect roughly 39 to 50 percent of the world's land area, undergoing deterioration due to human activities (Vitousek et al., 1997).

Deforestation, elevated by factors such as agricultural expansion, infrastructure development, urbanization and industrialization, has notably increased atmospheric $CO_2$ levels (Adnan et al., 2011) and affects the exchange of water and energy (IPCC, 2020). The repercussions of changes in forest cover resonate globally and regionally, leading to unpredictable rainfall patterns, lengthy dry periods and the rise of wildfires, contributing to exacerbated pollution (Strasser et al., 2014; Saha & Sarkar, 2022; Deb et al., 2022). Frequent deforestation-induced droughts in vulnerable areas such as the Amazon and other tropical regions need special consideration (Gash et al., 1996). These alterations pose serious threats to plant species, wildlife and ecosystems with potential consequences for the spread of diseases.

Numerous studies illustrate the significant association between massive-scale species dynamics and various aforementioned climatic alterations (Abraham and Chain, 1988; Manes et al., 2021; Ghosh., 2022). The pace and magnitude of climate change alter compatible habitat ranges for entities and influence their ecosystems in diverse ways, including variations in species abundance, range shifts, alterations in activity timing and microhabitat use (Bates et al., 2014). In the face of climate change, local species must either accept, adapt, migrate, or confront the risk of extinction (Berg et al., 2010). Species that exhibit superior adaptive capacities have a higher likelihood of surviving in new ecosystems or a reduced ability to endure in their existing habitats (Bates et al., 2014).

Unlike traditionally confined to specific geographical regions, vector-borne diseases have undergone significant alterations in distribution patterns due to climate change. Diseases like Malaria, Leishmaniasis, Filariasis, Japanese Encephalitis and Dengue Fever have extended their ranges to higher altitudes once deemed inhospitable (Dhimal et al., 2015). Nepal, nestled in the Himalayan mountains, exemplifies this phenomenon with the emergence of major vector-borne diseases at high altitudes (Dhimal et al., 2015).

The proliferation of mosquito-borne diseases also occurs through mechanisms such as the invasion of vector species to new areas. For instance, the chikungunya virus, typically transmitted by *Aedes albopictus*, emerged in Europe with native European mosquito species like *Aedes geniculatus* potentially replacing *Aedes albopictus* in disease transmission (Ng et al., 2019; Prudhomme et al., 2019).

Tick habitats have extended to higher elevations and northern regions in Canada and Europe due to global warming, leading to the emergence of more than 11 bacterial tick-borne pathogens affecting humans (Tokarevich et al., 2011; Porretta et al., 2013). This expansion has resulted in the spread of tick-borne diseases like Anaplasmosis, Babesiosis, Powassan viruses, *Rickettsia helvetica*, *Neoehrlichia mikurensis* and *Borrelia miyamotoi* diseases (Kawahara et al., 2004; Jado et al., 2007; Bouchard et al., 2019). The northward expansion of *Ixodes ricinus* ticks, vectors of *Borrelia burgdorferi*, has been well-documented in Europe and Eurasia, reaching countries like the UK, Germany, Sweden and Russia (Jaenson et al., 2012; Cull et al., 2018). Ticks serve as vectors for numerous serious zoonotic viruses as well (El-Sayed &Kamel, 2020).

The spread of diseases is linked to the geographical expansion of ticks into new areas (Kazimírová et al., 2017). The viruses transmitted by ticks include Phlebovirus, Bourbon virus, Powassan virus, Tick-Borne Encephalitis viruses, Crimean-Congo Hemorrhagic Fever Virus (CCHFV), and Alkhurma Hemorrhagic Fever Virus (Mansfield et al., 2009). In Europe, the expansion of ticks is associated with the emergence of Tick-Borne Encephalitis (TBE) and Lyme disease (El-Sayed & Kamel, 2020). The prevalence of TBE and Lyme diseases has increased due to global warming and the northward migration of tick vectors (Lindgren, 2000; Randolph, 2004). Warmer winters since the mid-1980s in Scandinavia have led to a steady increase in TBE cases (El-Sayed & Kamel, 2020).

Factors contributing to the rise of tick-borne diseases include climatic changes (Andreassen et al., 2012; Lindgren & Gustafson, 2001). The Louping Ill virus, part of the TBE complex, has also been recently detected in Europe and the UK (Gilbert, 2016). Another emerging zoonotic tick-borne viral disease in Europe is Congo Haemorrhagic Fever (CCHF) (El-Sayed & Kamel, 2020). This virus poses a significant public health threat due to its high fatality rate in humans (Papa et al., 2015). The warmer climate allows ticks to invade new areas, contributing to the virus's endemicity in Africa, the Middle East, the Balkan Peninsula, Eastern and Southern Europe and Asia (Baylis, 2017). Ticks are also responsible for the emergence of Piroplasmorida, including *Babesia* spp. and *Theileria* spp. (El-Sayed & Kamel., 2020). Babesiosis, a major tick-borne protozoan disease in cattle, poses a global animal health problem with substantial economic losses (El-Sayed & Kamel., 2020). The increasing prevalence of babesiosis is exacerbated by the geographic expansion of ticks driven by global warming (Beugnet & Chalvet-Monfray., 2013).

Additionally, global warming not only influences the geographical distribution of vectors but also intermediate hosts, encompassing invertebrate hosts such as insects, rodents and migratory birds. For instance, the zoonotic bacterial pathogen *Chlamydia* sp. is transported by birds and annually infects 92 million people, as reported by the World Health Organization (WHO) (El-Sayed & Kamel., 2020). The transmission of this zoonotic pathogen is closely tied to bird movement and migration, which are in turn impacted by changes in climate and ecology (Geisler., 2012).

Furthermore, climate change, such as the global temperature rise, directly affects the transmission dynamics of diseases such as Malaria, African Trypanosomiasis, Yellow Fever, Plague and Dengue fever (Hickmann et al., 2015; Saha et al., 2023). Malaria is a prime example of the consequences of temperature changes. A modest global temperature rise of 2 to 3°C expands the proportion of the population at risk by 3 to 5% and exposes millions more individuals to the threat of infection (Shuman., 2010). Temperature shifts also influence the reproduction rates and extrinsic incubation periods of pathogens. For instance, the extrinsic incubation period for *Plasmodium falciparum*, the Malaria parasite, decreases from 26 days at 20°C to 13 days at 25°C, indicating the potential for a more rapid spread of the disease (Bunyavanich et al., 2003). *Plasmodium vivax* and *Plasmodium falciparum*, the parasites responsible for Malaria, are highly sensitive to environmental temperatures (El-Sayed & Kamel, 2020). Climate change directly influences the life cycle, survival and reproduction of pathogens, thereby affecting the ecology of diseases like the Japanese Encephalitis virus (JEV) (Tian et al., 2015; Mellor & Leake., 2020).

## Unveiling Ancient Threats: Melting Ice Layers and the Resurgence of Dormant Pathogens:

The often underestimated threat of global warming lies in the melting of ice layers that have existed for thousands of years (El-Sayed & Kamel., 2020). The loss of land-based ice from glaciers and ice sheets through melting and thermal expansion of the ocean surface is expected to further elevate global mean sea levels (Gregory et al., 2001; Hansen et al., 2016). Rising sea levels will be responsible for ocean acidification, changes in rainfall patterns exacerbating droughts and worsening the overall impact of climate change (Allen et al., 2010). Rising sea levels not only pose threats to cities and river deltas but also reactivate frozen biological materials stored in the frozen soil (El-Sayed & Kamel., 2020). Melting ice reveals hidden biological materials beyond the potential discovery of ancient animal carcasses like mammoths. In 2012, for example, the Virola virus was detected in a 300-year-old frozen mummy in Siberia (Biagini et al., 2012).

The consequences of melting ice extend to the revival of ancient bacteria. In 2005, NASA scientists successfully revived bacteria that had been frozen in Alaska for 32,000 years, while 8-million-year-old bacteria were isolated from ice samples in Antarctica (Bidle et al., 2007). Viable bacteria have also been found in ice samples dating back 25,000 years and in Dominican amber, estimated to be 20-40 million years old (Katayama et al., 2007; Greenblatt et al., 1999).

The real-world impact of melting ice became noticeable in 2016 when a 12-year-old child died and 20 people were hospitalized in Siberia as a result of anthrax infections (El-Sayed & Kamel, 2020). The spores responsible for anthrax, caused by the bacterium *Bacillus anthracis*, were concealed for over 75 years under frozen soil until released as the ice melted (El-Sayed & Kamel, 2020). These spores, known for their resilience, can persist in a dormant form for a hundred years and can be transported by floods or insects such as tabanid fly (El-Sayed & Kamel, 2020). There is a conceivable risk that the smallpox virus could be stored frozen in human bodies buried in the frozen soil of Siberia where a significant smallpox epidemic occurred in 1890 (Antonenko et al., 2013; Walsh et al., 2018).

## Antimicrobial Resistance: A Complex Global Health Challenge and Its Implications for Human Health and Economies:

Antimicrobial resistance (AMR) stands as a burgeoning and intricate global health challenge, generating substantial concern among health professionals worldwide (Garner et al., 2019). This phenomenon possesses the critical potential to undo much of the progress achieved in the field of health so far (Gosling & Arnell, 2016). The production of a vast quantity of antibiotics by numerous pharmaceutical industries globally is met with a gradual development of resistance among pathogenic microorganisms (UNEP, 2017).

Notably, AMR is not confined to a specific region or country; it is flourishing on every continent, propelling humanity toward a post-antibiotic era where currently susceptible pathogens may once again lead to endemics and pandemics after developing resistance (WHO, 2018). The escalating cases of drug resistance have made common illnesses such as pneumonia, post-surgical infections, HIV/AIDS, tuberculosis and malaria increasingly difficult and costly to treat effectively (WHO, 2018). The impact of climate change-induced global warming on the spread of antibiotic-resistant strains adds economic burden necessitating the development of new and costlier antibiotics (Abbass et al., 2022).

The exchange of antibiotic-resistance genes in wastewater, particularly in conventional urban treatment plants, serves as a hotspot for bacterial strains to share genetic material through horizontal gene transfer (Abbass et al., 2022). Although the extent of risks associated with antibiotic resistance in wastewater is complex, environmental scientists and engineers express particular concerns about the potential implications of resistance genes on human health (Ashbolt, 2015). In the worst-case scenario, antibiotic-resistant genes may find their way into the environment through irrigation water for crops and public water supplies, thus integrating into food chains and food webs (Pruden et al., 2013; Wu et al., 2019). This issue has been reported in various countries where wastewater is commonly used for irrigation, highlighting the multifaceted challenges posed by AMR (Hendriksen et al., 2019).

Furthermore, floods have the potential to facilitate the spread of antibiotic-resistant microorganisms into the environment (Carignan et al., 2019). This concern is particularly relevant due to the extensive use of antibiotics in agriculture and the presence of antibiotic-resistant microorganisms in both solid and liquid waste by-products (Wang et al., 2014). The risk lies in the possibility of these resistant microorganisms being dispersed during flooding, leading to the direct transfer of resistance genes to human pathogens.

## Changes in precipitation patterns and the Escalation of Emerging Infectious Diseases (EIDs):

The Intergovernmental Panel on Climate Change (IPCC) projects a temperature increase of 1.5°C during this century (IPCC, 2018). Numerous studies suggest that this temperature rise could amplify hurricanes characterized by increased rainfall and stronger winds, leading to lasting consequences for sea temperatures and phenomena such as El Niño Southern

Oscillations (ENSO) in the Southern Pacific (Cann et al., 2013). Recent studies underscore the potential impact of climate change on the intensification and frequency of El Niño/La Niña events (Cai et al., 2014).

Historically, El Niño has brought heavy rainfall to the Horn of Africa, linked to Rift Valley Fever (RVF) outbreaks—a severe disease transmitted by mosquitoes affecting both cattle and humans (Linthicum et al., 1999). Extreme weather events contribute to the resurgence of waterborne diseases such as Cholera. Cholera, sensitive to temperature, becomes more virulent in warm conditions, spreading through contaminated water, swimming pools and shellfish consumption (Schets et al., 2006). The implications of global warming on Cholera and Vibrio-associated diseases extend to non-traditional regions, such as Northern Europe, posing a real and concerning prospect where increased disease prevalence has been observed (Andersson & Ekdahl, 2006; Semenza et al., 2012).

Climatic conditions, such as elevated humidity, temperature, and increased rainfall, can contribute to the proliferation of non-infectious diseases, favoring the growth of fungi and the dissemination of diseases associated with mycotoxins. During warm summers, multiple factors converge to increase the incidence of food poisoning. This includes heightened bacterial survival, prolonged outdoor activities where people consume food and beverages, and a rise in the population and activity of insects and rodents (El-Sayed et al., 2008; Milazzo et al., 2017; Park et al., 2018; Touchon et al., 2009).

## Conclusion:

In conclusion, addressing the complex nexus of climate change, sustainable development, and emerging infectious diseases (EIDs) demands a robust and interconnected approach centered on effective mitigation strategies. The urgency of this matter is underscored by the far-reaching consequences of climate change, which not only impact ecological and environmental systems but also pose significant risks to global health.

Mitigating the risks of EIDs necessitates a careful balancing act, particularly in the pursuit of Sustainable Development Goals (SDGs), with a key focus on Goals 2 (Zero Hunger) and 15 (Life on Land). To meet growing food demand, the expansion of cropland must be approached sustainably to minimize the risk of emerging infectious diseases (EID). Environmental policies that advocate sustainable land-use planning, reduced deforestation, and heightened biodiversity protection not only contribute to SDGs but also act as crucial mitigators by minimizing wildlife contact and reducing the risk of disease transmission.

Societal disruptions and conflicts emerge as critical factors that amplify the risk of EIDs. Recognizing the detrimental impact of armed conflicts on healthcare infrastructure and stability is paramount. Mitigating EID risk and achieving SDGs are contingent on avoiding societal disruptions, especially armed conflicts. Conflict can severely damage infrastructure and stability, as seen during the West Africa Ebola epidemic. Violence against healthcare workers, treatment centers, and critical infrastructure decreases the effectiveness of containment measures. Local and international socio-economic and political instability is also liable for disease spread, even for infectious agents on the brink of eradication. For instance, the spread of wild poliovirus from Pakistan into Syria in 2013 and 2014 was linked to low vaccination levels due to years of conflict in both countries (Mbaeyi et al., 2017). Unmanageable epidemics can contribute to the breakdown of societal functions, exacerbating violence, sexual exploitation, educational disruption, food insecurity, and corruption. Therefore, mitigation efforts should aim to reduce local and international socio-economic and political instability, thereby preventing disease spread and contributing to overall societal well-being.

Unintended consequences, such as the elevated risk of disease transmission resulting from certain conservation measures or the rapid expansion of livestock production, must be carefully considered. For instance, expanding livestock production rapidly in developing countries can improve protein intake but poses a risk of spreading diseases due to increased contact between wildlife, livestock, and humans, leading to production losses. Prioritizing monogastric species over ruminants may reduce greenhouse gas emissions but raises the potential for the emergence of pandemic influenza. Implementing conservation measures, like establishing wildlife corridors, may heighten the risk of disease transmission among different populations. Unfortunately, the restoration of degraded natural habitats through reforestation in the northeastern United States has various benefits but contributes to an elevated risk of Lyme disease among people.

Effective international policies, particularly in key sectors like agriculture, industry, forestry, transport, and land use, are crucial for addressing the interconnected challenges of climate change and infectious diseases. The holistic approach advocated aligns efforts with the UN's 2030 Agenda for Sustainable Development, emphasizing the imperative of mitigating the impacts of climate change on disease emergence while fostering sustainable development for a healthier and resilient global future. Therefore, mitigation strategies should involve prioritizing monogastric species over ruminants, implementing conservation measures with caution, and recognizing the potential impacts on biodiversity, disease emergence, and societal well-being.

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