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Ecosystem and Climate Interactions in Vector-borne Disease Emergence

Dharanikota Lalithambica Devi[1], Jaya Jeevitha SRM[2], Gedela Venkata Hima Sameera[2], Arshi Zeba[1], Jatin Kumar Singh[1*]

Abstract: -

Climate change is increasingly recognized as a significant driver of vector-borne diseases, altering the patterns of disease transmission across the globe. Rising temperatures, shifting rainfall patterns, increased humidity, and extreme weather events have created favorable conditions for vectors such as mosquitoes, ticks, and sand-flies to thrive and expand into new regions. These environmental changes influence vector behavior, breeding cycles, and the survival of disease-causing pathogens, leading to the emergence or re-emergence of diseases like malaria, dengue, Zika, and Lyme disease in areas previously unaffected. The dynamic relationship between climate and vector-borne diseases presents growing challenges for public health systems, particularly in vulnerable and resource-limited regions. Effective surveillance, adaptive vector control strategies, and climate-resilient health infrastructure are essential to mitigate the risks. This paper explores the complex interplay between climate change and vectorborne diseases, highlighting the urgent need for integrated approaches in global health and environmental policy.

Keywords: Climate change, Vectorborne diseases, Disease transmission, Mosquito-borne illnesses, Public health.

Introduction:

Global climate change presents a significant risk of causing widespread social disruption, displacement of populations, economic instability, and degradation of ecosystems. In addition to these challenges, human health may also be adversely affected due to increased variability and long-term changes in weather patterns, including shifts in temperature, rainfall, storm intensity, flooding, droughts, and rising sea levels (Lipp *et al.*, 2002). Climate variability is expected to have

Dharanikota Lalithambica Devi[1], Jaya Jeevitha SRM[2], Gedela Venkata Hima Sameera[2], Arshi Zeba[1], Jatin Kumar Singh[1*]

[1] PhD student, Department of Entomology, GBPUAT, Pantnagar, Uttarakhand

[2] PhD student, Department of Plant Pathology, GBPUAT, Pantnagar, Uttarakhand

a particularly strong influence on vectorborne diseases. This is largely because the insects and arthropods that transmit these diseases are ectothermic (cold-blooded), making their development, reproduction, behavior, and population growth highly sensitive to changes in temperature. Temperature fluctuations can also influence the growth of pathogens inside these vectors and, when combined with humidity levels, impact their survival and ability to transmit disease. Additionally, precipitation patterns directly affect the availability of breeding habitats for mosquitoes and other vectors with aquatic larval stages. In the case of zoonotic vectorborne diseases—those involving animal hosts—climate can influence the geographic distribution and population size of these hosts, thereby affecting disease transmission dynamics. This article aims to explore how climate conditions influence the spread and transmission of vectorborne diseases and to identify key knowledge gaps. It evaluates how current research on climate variability contributes to our understanding of how long-term climate change may alter the complex relationships between vectors, hosts, and pathogens. Furthermore, it examines how human behavior, land use practices, and demographic trends may interact with climate to shape the true burden of vectorborne diseases. Finally, the article proposes adaptive strategies to mitigate the future impact of climate change on human exposure to these diseases (Watson *et al.*, 2005).

The article is structured into three key sections, each focusing on how climate variability influences diseases spread by mosquitoes, other flying arthropods, and ticks and fleas. This organization reflects the unique characteristics of each vector group, including differences in their movement patterns, host-seeking behaviour, ability to travel long distances, and reliance on specific hosts or habitats for survival. For instance, some mosquito species are highly mobile, capable of flying across several kilometers, or being unintentionally transported over vast distances via planes, ships, or other modes of travel. Their distribution often depends more on the availability of favorable breeding sites and environmental conditions than on a limited set of host species or habitats. In contrast, other arthropod vectors like sand flies and triatomine bugs, while capable of flight, usually remain within closer range of their breeding and host habitats. Their presence is often restricted to areas that support both suitable conditions for breeding and shelter for their hosts (Randolph, 2004)..

Ticks and fleas, lacking wings, have limited mobility and typically depend on their animal hosts for movement across locations. Many of these vectors spend substantial time in nests or burrows, lying in wait for their hosts to return. Those that seek hosts in more open environments, such as grassy areas or forest floors, may face challenges from extreme weather conditions, such as high temperatures or low humidity, and may be forced to search for hosts only during brief periods when the climate is more favorable. Although vectors like ticks, fleas, and some flying insects generally have restricted mobility compared to mosquitoes, they can still be carried over long distances through human activities—for example, via transported animals, luggage, or goods. This means that even species with limited natural dispersal abilities, along with the pathogens they carry, may be introduced into new regions. If these regions become environmentally suitable due to climate change, there's a potential for these vectors to establish local transmission cycles. However, successful establishment doesn't depend solely on vector movement; it also requires favorable ecological conditions and human-related factors.

Mosquito-Borne Diseases and Climate Change

Climate change influences the transmission of mosquito-borne diseases like malaria, though its impact must be considered alongside evolving social, economic, and healthcare conditions. Improved interventions—such as insecticide-treated nets, indoor spraying, better diagnostics, and access to treatment—have significantly reduced malaria in many areas. However, factors like urbanization, land use changes, population displacement, and drug/insecticide resistance continue to shape disease patterns. Climatic factors, especially **temperature and rainfall**, directly affect mosquito and parasite development. For example, *Plasmodium falciparum* requires temperatures between 16°C–33°C for transmission, while *P. vivax* can develop at slightly lower temperatures. Rising temperatures may expand or restrict malaria zones depending on the region(Van Lieshout, 2004). Rainfall impacts mosquito breeding by creating or reducing larval habitats. In Africa, for instance, *Anopheles gambiae* populations decline during droughts, reducing malaria transmission. However, decreased transmission can also increase future outbreak risks due to growing non-immune populations. Events like the 1997 El Niño in Indonesia led to severe malaria epidemics due to altered vector breeding habitats. Additionally, humidity—linked to rainfall—affects mosquito survival, which is essential for malaria parasites to mature and become infectious.

Tickborne and Flea-Borne Diseases

Ticks pose a significant public health risk by transmitting a variety of pathogens—including bacteria, viruses, and parasites—to humans. Notable tick-borne diseases include Lyme borreliosis, tularemia, tick-borne relapsing fever, human granulocytic anaplasmosis, human monocytic ehrlichiosis, Rocky Mountain spotted fever, tick-borne encephalitis (TBE), and babesiosis. In Europe, the incidence of TBE and Lyme borreliosis has risen, with cases emerging at higher elevations and latitudes. However, it's unclear whether these shifts are due to climate change or alterations in land use and human movement patterns.

The life cycles of ticks and the dynamics of the diseases they carry are influenced by several factors:

1. **Geographic Distribution**: Human exposure to tick-borne pathogens is confined to areas where both the vector ticks and the pathogens are established.
2. **Seasonal Activity**: The timing and frequency of tick-borne diseases correspond with the seasonal activity patterns of vector ticks.
3. **Disease Incidence**: The prevalence of tick-borne diseases depends on tick abundance, infection rates within tick populations, and the frequency of human-tick interactions. (Lindgren & Gustafson, 2001).

Ticks are limited to regions where climatic conditions support their life cycles. Changes in temperature and precipitation may shift their geographic range and alter the seasonal risk periods, impacting disease transmission dynamics. For instance, climate change has been implicated in the expansion of tick habitats into higher latitudes and elevations in Europe, potentially increasing the occurrence of tick-borne diseases. Additionally, climate change has influenced the transmission of various vector-borne diseases in Europe, presenting significant public health challenges. Theories suggest that higher proliferation rates, extended transmission seasons, ecological balance changes, and climate-induced migration of vectors and hosts contribute to this trend. In summary, while climate change is a contributing factor, the distribution and incidence of tick-borne diseases are also shaped by complex interactions involving land use changes, human behaviour, and ecological dynamics.

Fleas are primarily recognized for transmitting *Yersinia pestis*, the bacterium responsible for plague, which has led to significant human fatalities, notably during the Black Death in the Middle Ages. Historical evidence suggests that climatic factors have played a role in the emergence and spread of major plague pandemics:

- **Justinian's Plague (6th century):** This pandemic coincided with the Late Antique Little Ice Age, a period marked by cooler and drier conditions. Such climatic stressors may have influenced the outbreak by affecting food availability, rodent populations, and human migration patterns, thereby increasing susceptibility to disease.

- **Black Death (14th century):** Prior to this devastating pandemic, Europe experienced significant climate anomalies, including the Medieval Warm Period followed by the Little Ice Age. These shifts led to agricultural failures and famine, conditions that could have facilitated the spread of plague by weakening human populations and altering ecosystems.
- **Modern Pandemic (19th century):** Originating in southwestern China, this pandemic's early years were characterized by wetter and warmer conditions. Such environmental changes may have influenced rodent and flea populations, thereby affecting the dynamics of plague transmission. In the Indian subcontinent, recurrent plague outbreaks between 1896 and the 1920s were closely linked to seasonal climatic variations. Epidemic intensity often decreased during peak monsoon rainfall and escalated during drier, warmer periods. Notably, cases declined when temperatures exceeded approximately 27°C (81°F), suggesting that higher temperatures may suppress plague transmission.

Temperature also appears to influence the geographic distribution of *Y. pestis*. A significant majority of human plague cases have occurred in regions with mean annual temperatures above 13°C (55°F), with large outbreaks predominantly in areas where annual temperatures range from 24° to 27°C (75° to 81°F). In summary, climatic factors such as temperature and precipitation have historically influenced the emergence, spread, and intensity of plague pandemics by affecting the habitats and behaviours of rodent hosts and flea vectors, as well as human societal conditions (Cavanaugh & Williams, 1981).

Diseases Transmitted by Other Flying Arthropods

Climate change significantly influences the transmission dynamics and distribution of vector-borne diseases such as onchocerciasis (river blindness) and Chagas disease by altering environmental conditions that affect their insect vectors.

Onchocerciasis (River Blindness):

Onchocerciasis is caused by the parasitic worm *Onchocerca volvulus*, transmitted through the bites of black flies (*Simulium* species). In Venezuela, factors like geological substrates, landscape types, and vegetation significantly impact transmission intensity, with specific black fly species associated with particular environments. Climate change can modify these landscapes and vegetation patterns, potentially altering black fly habitats and affecting disease transmission. For instance, changes in river heights and flow rates due to altered precipitation patterns can create or eliminate black fly breeding sites, thereby influencing their population dynamics and the risk of onchocerciasis transmission (Botto *et al*, 2005).

Chagas Disease:

Chagas disease, or American trypanosomiasis, is caused by the parasite *Trypanosoma cruzi*, primarily transmitted by triatomine bugs. The distribution of these vectors is closely linked to climatic factors such as temperature, humidity, and vegetation types. In Mexico, climate variables, along with rainfall, have been utilized to develop transmission risk maps predicting house infestations by *Triatoma dimidiata* and infection rates with *T. cruzi*. Severe weather events, like hurricanes, can disrupt local ecosystems and host populations, leading to increased domiciliary infestation by triatomine bugs and elevating Chagas disease transmission risk. For example, after Hurricane Isidore, there was a notable rise in *T. dimidiata* infestations in Mexican homes, likely due to the death of wild animals that typically serve as hosts for these vectors. In Brazil, certain native triatomine species, such as *Triatoma brasiliensis*, inhabit natural environments but can invade human dwellings following environmental disturbances. Severe climatic events may trigger significant increases in the domiciliary colonization by these vectors, thereby heightening the risk of Chagas disease transmission.

In contrast, African trypanosomiasis (sleeping sickness) does not exhibit a clear link to climate change or interannual variability. Its transmission is more closely associated with factors like cattle movements, human population shifts, deforestation, and drug resistance. In summary, climate change can profoundly impact the distribution and behavior of disease vectors, thereby influencing the transmission patterns of diseases like onchocerciasis and Chagas disease. Understanding these relationships is crucial for developing effective public health strategies to mitigate the impacts of climate change on vector-borne diseases.

Conclusion

Climate change significantly influences the dynamics of vector-borne diseases by altering the habitats and behaviors of disease-carrying organisms. Rising global temperatures and shifting precipitation patterns have expanded the geographical range and extended the active seasons of vectors such as mosquitoes and ticks, leading to increased transmission of diseases like malaria, dengue fever, Lyme disease, and West Nile virus. These climatic changes not only affect the vectors but also impact the pathogens and reservoir hosts, thereby complicating disease control efforts. Addressing these challenges requires integrated strategies that combine climate mitigation, enhanced surveillance, and robust public health interventions to manage and reduce the burden of vector-borne diseases in a changing climate.

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