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Review Article

The Impact of Climate Change on Vector-Borne Diseases (VBDs): Indian and Global Perspectives

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A B S T R A C T

Climate change is significantly altering the transmission dynamics and geographic distribution of vector-borne diseases (VBDs), including malaria, dengue, chikungunya, and others. Rising temperatures, erratic rainfall, and extreme weather events influenced by global warming and phenomena such as El Niño are transforming vector habitats, shortening pathogen incubation periods, and intensifying disease risk. This review synthesises current evidence on climate-sensitive VBDs, with a dual focus on global patterns and the Indian context. A transition to climate-informed surveillance systems and predictive modelling tools is critical for early outbreak detection. Multisectoral coordination and climate-resilient public health strategies are essential to mitigate the growing burden of VBDs under changing environmental conditions. This review underscores the need for adaptive planning, innovative technologies, and integrated health policies to strengthen preparedness and resilience.

Keywords: Climate, Ector-Borne Diseases, Malaria, Dengue, Transmission, India, Health, Environmental Factors

Introduction

Climate change has emerged as a defining global challenge of the 21st century, significantly altering ecological and public health landscapes. Global surface temperatures have risen markedly, with a clear warming trend observed between 1906 and 2005.[1] The Intergovernmental Panel on Climate Change (IPCC) projects that the global average surface temperature is likely to reach or exceed 1.5°C above pre-industrial levels within the next two decades.[2] Such warming is associated with increased frequency and severity of extreme weather events, intensified precipitation patterns, glacier retreat, and accelerating sea-level rise.[3,4] These environmental changes have profound implications for public health, contributing to approximately 150,000 deaths annually through mechanisms such as undernutrition, heat-related illnesses, and the expanded spread of infectious diseases.[5]

One of the most pressing health threats linked to climate change is the rising incidence and distribution of vector-borne diseases (VBDs). Arthropod vectors, such as mosquitoes and ticks, are ectothermic organisms whose survival, reproduction, and competence as disease vectors are strongly influenced by climatic conditions, particularly temperature and humidity.[6] Numerous studies have highlighted the potential geographic expansion of vector species under changing climatic scenarios, demonstrating their adaptability to new ecological niches and the evolution of traits favouring wider dispersal and transmission efficiency.[7–10] Consequently, the burden of VBDs has increased globally, with diseases such as malaria, dengue, Zika, chikungunya, West Nile virus, Ross River virus, Japanese encephalitis, Lyme disease, and tick-borne encephalitis affecting vast populations.[11]

Currently, over 80% of the global population is at risk of one or more VBDs, which collectively account for about 17% of all infectious diseases worldwide.[1] The World Health Organization (WHO) reports over one billion infections and more than one million deaths from VBDs annually[1], though some estimates place annual VBD-related deaths at over 700,000.[12] Notably, the global suitability for arboviral disease transmission has expanded significantly, with 86% of countries (218 out of 250) now offering favourable conditions for transmission, underscoring the escalating risk posed by these climate-sensitive diseases.[13]

Among VBDs, malaria and dengue are particularly prominent and are heavily influenced by environmental and climatic shifts. Climatic phenomena such as El Niño further exacerbate vector proliferation and disease transmission by altering rainfall patterns and temperature norms.[14] In regions like India-characterised by diverse ecosystems, rapid urbanisation, development, and population growth along with global warming and climate changes—the risk is especially acute. The dynamic interplay of socio-environmental factors and climate change necessitates a coordinated public health response.

This review consolidates recent literature and global initiatives to examine the link between climate change and the epidemiology of VBDs. It places a special focus on India, evaluating the integration of surveillance systems and proposing strategies for climate-resilient health interventions in light of growing environmental volatility.

Methods

This review adopts a structured, literature-based approach to synthesise current evidence on the influence of climate change on vector-borne diseases (VBDs), with an emphasis on both global dynamics and the Indian context. Peer-reviewed journal articles, official reports, and grey literature were systematically identified and selected through targeted searches of academic databases (e.g., PubMed, Scopus, Google Scholar) and institutional repositories. Key sources included scientific publications, policy briefs, and technical reports from leading agencies such as the World Health Organization (WHO), the Intergovernmental Panel on Climate Change (IPCC), the United Nations Environment Programme (UNEP), and the National Centre for Vector Borne Disease Control (NCVBDC). Only English-language literature published between 2000 and 2024 was considered.

The selected materials were critically reviewed and analysed to extract insights across the following thematic domains:

- Climatic determinants of vector-borne diseases (temperature, rainfall, humidity)
- Complex ecological and epidemiological interactions driven by climate change
- Climate-sensitive health outcomes and transmission patterns
- Global and national policy frameworks addressing VBDs in the context of climate change
- Climate adaptation strategies for surveillance, control, and outbreak preparedness
- Innovation and system resilience in public health responses
- Knowledge gaps and future research priorities

By triangulating scientific evidence with global and regional policy responses, this review aims to propose actionable, climate-resilient public health strategies for the effective management of VBDs in the face of an evolving climate crisis.

Review and Discussion

Climatic Determinants of Vector-Borne Disease Transmission

Vector-borne disease transmission is strongly influenced by climatic factors, particularly temperature, precipitation, and humidity, which directly affect vector biology, pathogen development, and transmission dynamics. These factors modulate mosquito survival, biting frequency, breeding patterns, and the extrinsic incubation period (EIP - the time required for a pathogen to develop within the vector before transmission to humans becomes possible).

Temperature and Vector Ecology

Temperature plays a pivotal role in determining vector competence and pathogen development rates. Mordecai et al.[15] found that the optimal temperature for P*lasmodium falciparum* transmission by *Anopheles* mosquitoes is approximately 25°C, rather than the previously assumed 30°C, suggesting a narrower thermal range for efficient malaria transmission. Warmer temperatures have also been shown to accelerate the EIP and increase vector survival, enhancing the potential for disease spread.

Paaijmans et al.[16] emphasised the non-linear impact of fluctuating temperatures on malaria transmission in Southeast Asia, demonstrating that both high and low extremes can suppress vector competence, while intermediate, fluctuating temperatures may enhance transmission potential. In East Africa, rising temperatures have facilitated malaria transmission in previously cooler highland regions such as Kenya and Ethiopia, where increasing altitude-related warming has been associated with emerging transmission zones.[17]

In India, similar trends have emerged. *Anopheles culicifacies*, traditionally confined to central lowlands, is now present in high-altitude states like Himachal Pradesh and

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Arunachal Pradesh.[18] The recent detection of *Anopheles culicifacies* in high-altitude states such as Himachal Pradesh and Arunachal Pradesh is linked to climate change-induced shifts in temperature, rainfall, and humidity patterns. Rising mean temperatures, longer frost-free periods, and altered precipitation patterns have created thermal and ecological conditions conducive to vector survival, breeding, and parasite development. Coupled with human-driven land-use changes such as deforestation and rice cultivation, these factors have removed previous ecological barriers, enabling the species to establish and transmit malaria in areas once considered unsuitable.

Concurrently, the urbanisation-driven expansion of *Anopheles stephensi*, an efficient urban malaria vector, has contributed to the growing burden of urban malaria. This species thrives in city-specific microclimates and man-made habitats, showing high adaptability to thermal stress.[19] Urban heat islands (UHIs) exacerbate this situation by sustaining warm microclimates conducive to mosquito activity year-round.

The spread of arboviral diseases such as dengue has been strongly influenced by climate change and urbanisation. In particular, *Aedes aegypti*, the primary vector of dengue, has shown ecological flexibility in adapting to domestic and peri-urban habitats with poor sanitation and irregular water supply.[20,21] Rising temperatures support faster vector development and prolonged biting activity, while indoor microhabitats created by heat mitigation strategies (e.g., closing windows, use of coolers) unintentionally support vector survival. The urban heat island effect, combined with climate-induced changes in temperature and humidity, has expanded the seasonal window and intensity of dengue outbreaks.

Aedes albopictus, once a rural and feral species breeding in natural sites like tree holes and bamboo stumps, has adapted to urban environments by exploiting artificial containers such as tyres, plastic containers, buckets, and water storage tanks. Increased human mobility and urban expansion have facilitated its spread, while its ability to tolerate a range of climatic conditions and utilise man-made habitats has enabled it to thrive in densely populated areas. This shift from natural to artificial breeding sites has expanded its role as an important urban vector of arboviral diseases. Kumari et al.[22] reported its establishment in urban localities of Delhi, contributing to sustained dengue transmission along with *Aedes aegypti*. Rising temperatures shorten the EIP of the dengue virus within *Aedes mosquitoes* and increase biting rates, contributing to the higher transmission efficiency observed in India during and after the monsoon season.[18,23]

The study by Watts et al.[24] demonstrated that the EIP for the dengue virus in *Aedes aegypti* mosquitoes decreased from 12 days at 30°C to as few as 7 days at 32–35°C. This reduction in EIP at higher temperatures significantly increases the likelihood of transmission during warmer months, as more mosquitoes become infectious within their lifespan. Additionally, the study by Rohani et al.[25] supports this finding by indicating that the EIP shortens as temperatures rise above 26°C. In summary, both studies provide robust evidence that even modest increases in temperature can significantly reduce the EIP of the dengue virus in *Aedes aegypti* mosquitoes, thereby amplifying the risk of dengue outbreaks.

These interlinked factors-climate variability, vector adaptability, indoor microclimates, and urbanisation-underline the complexity of dengue transmission and call for integrated, climate-informed urban health strategies.

Impact of Rainfall and Humidity on Vector-Borne Diseases

Rainfall significantly influences mosquito population dynamics by creating stagnant water habitats that serve as ideal breeding grounds for larvae. Moderate rainfall typically supports mosquito proliferation, while excessive rainfall or flooding may temporarily wash away immature stages. However, these disruptions are often followed by a rapid resurgence of mosquito populations as standing water accumulates in new habitats post-flooding.

For instance, in Mozambique, the 2000 floods were associated with a major malaria outbreak.[26] Similarly, Pakistan experienced a sharp rise in malaria cases following the extensive flooding during the 2022 monsoon season, which created favourable conditions for mosquito breeding.[27] In 2023, Bangladesh recorded its deadliest dengue epidemic, with over 321,000 cases, partially attributed to unusually intense rainfall that increased Aedes mosquito breeding sites.[28]

In India, heavy monsoons and subsequent flooding have also been linked to increased vector-borne disease transmission. The 2020 Assam floods generated extensive stagnant water bodies, facilitating malaria transmission while hampering access to healthcare and vector control services.[29] Likewise, the 2018 Kerala floods contributed to a significant rise in malaria and other VBDs, as widespread waterlogging promoted mosquito breeding.[30]

Japanese encephalitis (JE) has shown a strong association with monsoon-driven flooding in endemic states such as Uttar Pradesh. A 30-year study by Kumari and Joshi.[31] demonstrated that persistent waterlogging in the Terai region, caused by monsoon rains and extensive rice cultivation, supported elevated vector densities and virus circulation. Notably, JE seasonality has shifted over time. Before 1988, outbreaks peaked between August and November, but by the 2000s, the peak had shifted earlier to

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June–December, correlating with changes in monsoon patterns [31]. These examples underscore the urgency of integrating vector surveillance with climate-sensitive health systems to mitigate climate-amplified VBD risks.

Humidity and Vector Survival

High humidity enhances adult mosquito survival and increases the likelihood of disease transmission by extending the life span of vectors and accelerating pathogen development within them. For instance, elevated humidity supports longer survival of *Anopheles* mosquitoes and enhances *Plasmodium* development, thereby lengthening the malaria transmission window.[26,32,33]

In India, the combined effect of high humidity and monsoon rains contributes to increased breeding and survival of vectors of dengue, chikungunya, malaria, and Japanese encephalitis. These climatic factors not only influence breeding patterns but also shape disease seasonality. A study in Delhi reported by Kumari et al.[21] found that dengue incidence closely followed monsoon trends, with cases peaking during the post-monsoon period in October–November when both rainfall and humidity were high during the post monsoon season.

Drought Conditions and Malaria Risk

Contrary to conventional associations between vector-borne diseases and heavy rainfall, drought conditions in India - particularly in arid and semi-arid states such as Rajasthan, Gujarat, and parts of Karnataka - can also elevate malaria, dengue, chikungunya, and Zika risk. Prolonged dry spells and water scarcity compel households and communities to store water in tanks, containers, and open vessels. These unmanaged and often uncovered water storage systems create ideal breeding sites for *Anopheles stephensi*, a highly adaptable urban malaria vector known to thrive in artificial habitats. Additionally, such domestic water storage practices promote heavy breeding of *Aedes aegypti*, the primary vector for dengue and other arboviruses.[34] Epidemiological studies have reported a resurgence of malaria and transmission and outbreaks of dengue, chikungunya and Zika in urban slums and drought-affected rural areas, where water storage practices are prevalent and poorly managed.[35,36] This trend is of growing concern amid increasing climate variability and the rising frequency of extreme weather events, including prolonged droughts.

The World Health Organization has acknowledged this climate–vector interaction and emphasised the need to integrate vector control strategies with climate-resilient water management. Such integration is crucial to mitigate malaria outbreaks driven by environmental stressors like drought and water insecurity.[27,37]

Global Initiatives and Policy Frameworks to Combat and Mitigate Vector-Borne Diseases: Strategic Responses Amid Climate Change

Vector-borne diseases (VBDs), including malaria, dengue, Zika, chikungunya, and yellow fever, have intensified with climate change. Rising temperatures, altered rainfall patterns, and extreme weather events have expanded vector habitats and shifted transmission dynamics. These changes necessitate coordinated action at global, regional, and national levels.

Global Policy Frameworks

The World Health Organization (WHO) has strengthened efforts against VBDs in response to climate-related changes. The *Global Vector Control Response 2017–2030* (GVCR) promotes integrated vector management (IVM), capacity building, and multisectoral coordination.[38] The *Global Arbovirus Initiative* (GLAI), launched in 2022, targets emerging and re-emerging Aedes-borne diseases by emphasising surveillance and the outbreak response.[39] In 2023, WHO classified dengue as a Grade 3 global emergency due to outbreak scale and international spread risk.[40] Subsequently, a Global Dengue Surveillance System was established in 2024, collecting monthly data from 162 countries.

The United Nations Development Programme (UNDP) recognises VBDs as both health and development challenges and supports climate-informed health planning by integrating early warning systems and adaptation measures into national policies.[40] Similarly, the United Nations Environment Programme (UNEP) advocates ecosystem-based approaches such as wetland restoration and water management to reduce mosquito breeding sites.[42]

Climate Adaptation Strategies for Vector-Borne Disease Control and Surveillance

WHO supports climate-resilient health systems through training in climate-sensitive vector control, ensuring availability of diagnostics and supplies, and maintaining service delivery during climate shocks.[43,41,44] These measures align with Health National Adaptation Plans (HNAPs) under the UNFCCC, supported by funding mechanisms such as the Green Climate Fund.[45] Together, these approaches enhance health system resilience to climate-driven VBD threats.

Predictive modelling utilising climate and rainfall data is crucial for outbreak forecasting, supported by tools like the Early Warning, Alert and Response System (EWARS).[46,47] The European Centre for Disease Prevention and Control (ECDC) employs climate-based models to monitor vector expansion in Europe, particularly the northward spread of *Aedes albopictus*, linked to rising temperatures and precipitation shifts. New outbreaks of dengue, West Nile virus, and Lyme disease in previously unaffected areas have been documented.[47]

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In flood-prone regions, WHO recommends infrastructure improvements, including drainage and urban design, to reduce stagnant water and vector breeding.[44] Urban adaptation measures such as zoning laws, green buffer zones, and land-use policies protect vulnerable populations, especially in densely populated low-income areas.[42,49]

Innovation and Resilience

Beyond conventional methods, WHO promotes innovations including *Wolbachia*-infected mosquitoes, gene drive technologies, and novel vaccines (e.g., Dengvaxia, R21/Matrix-M) to combat insecticide resistance and ecological changes.[40,50] UNDP and the Green Climate Fund (GCF) support projects in sub-Saharan Africa to enhance climate-resilient health infrastructure, cold chain systems, and workforce training in climate-sensitive vector control.[51]

Knowledge Gaps and Future Research Directions

Closing knowledge gaps is essential to mitigate climate change impacts on VBDs. High-resolution, India-specific models integrating epidemiological, entomological, and climatic data are needed. Genomic surveillance of vectors and pathogens combined with climate variables can elucidate emerging transmission and adaptation patterns.[52] Linking vector ecology with real-time meteorological data will improve early warning systems. Interdisciplinary collaboration among climate scientists, public health experts, entomologists, and data scientists is critical to develop predictive and climate-resilient control strategies tailored to dynamic environments.

Conclusion

Rainfall, temperature, and humidity are foundational environmental drivers governing mosquito ecology and the transmission dynamics of vector-borne diseases (VBDs) such as malaria, dengue, chikungunya, and Japanese encephalitis (JE). Climate change fundamentally alters these determinants by shifting precipitation patterns, raising ambient temperatures, and increasing humidity levels, thereby expanding the geographical range, seasonality, and intensity of these diseases. Urbanisation, unplanned development, poor water storage practices, and extreme weather events further compound this risk. These shifts have already resulted in outbreaks in previously unaffected areas, such as the first reported indigenous transmission of JE in urban Delhi, underscoring the urgency of climate-informed public health planning.

In this evolving landscape, disease surveillance systems must transition from traditional reactive models to integrated, climate-smart approaches. Embedding meteorological and environmental data into real-time epidemiological platforms—such as India's Integrated Health Information Platform (IHIP), the Integrated Disease Surveillance Programme (IDSP), and WHO's Early Warning, Alert and Response System (EWARS)—is essential for early outbreak detection and timely implementation of control measures. Strengthening early warning systems, enhancing urban planning with climate-resilient designs, and deploying targeted vector control interventions will be critical to mitigating the growing burden of climate-sensitive VBDs.

The escalating threat demands a paradigm shift in global health systems, driven by cross-sector collaboration, innovative technologies, and community engagement. As VBD risks rise globally, integrating environmental intelligence into health systems is no longer optional but essential. Climate-smart surveillance and adaptive planning must become the new standard.

Health risks posed by climate change, particularly vector-borne diseases, require a multipronged approach. Coordinated efforts involving global agencies such as WHO, UNEP, UNDP, and the Green Climate Fund (GCF), alongside regional bodies like the European Centre for Disease Prevention and Control (ECDC), and national and local institutions, provide a strategic pathway forward. Tools such as EpiClim, which combine climate forecasting with disease modelling, hold promise for enhancing outbreak preparedness and response capacity.

For India, with its ecological diversity and strong technical infrastructure, there is an opportunity to take leadership by integrating climate adaptation into vector-borne disease programmes. Urban agglomerations, especially vulnerable regions, must urgently adopt integrated public health policies addressing the compounding effects of unplanned urbanisation, poor water storage practices, and climate variability. Investments in climate-resilient health infrastructure, predictive analytics, and inclusive capacity building—from local health workers to research institutions—are central to this transformation.

In conclusion, addressing the rising burden of climate-sensitive VBDs requires a proactive, multisectoral response. Integrating environmental intelligence into disease surveillance, strengthening public health infrastructure, and aligning national strategies with global frameworks will be key to building adaptive and resilient systems capable of protecting public health amid accelerating climate change.

Way Forward

To effectively address the growing challenge of climate-sensitive vector-borne diseases, India and other endemic countries must adopt a climate-smart, multisectoral approach that is proactive and adaptive. This requires institutional transformation across surveillance, research, policy, and community engagement. Key strategic directions include:

- **Integrate Climate Data into Surveillance Systems:** Embed meteorological and climate data (temperature, rainfall, humidity) into real-time disease monitoring platforms such as IDSP, IHIP, and WHO's EWARS to enhance early warning and timely response. Institutionalise One Health collaboration frameworks for integrated surveillance and control of zoonotic and vector-borne diseases.

- **Scale Predictive Analytics and Modelling Tools:** Utilise advanced tools like EpiClim and GIS-based predictive models to anticipate outbreak risks and guide interventions at local and national levels.
- **Strengthen Early Warning and Response Systems:** Establish robust systems combining climatic, entomological, and epidemiological indicators to trigger timely, evidence-based public health actions.
- **Promote Climate-Resilient Urban Planning:** Redesign urban environments to minimise vector breeding sites by improving drainage, waste management, water storage, and housing infrastructure, particularly in informal settlements.
- **Foster Innovation through Public–Private Partnerships:** Encourage collaboration between academia, startups, public agencies, and private enterprises to develop and scale novel diagnostics, vector control technologies, and digital health tools adapted to diverse ecological settings.
- **Build Community Engagement and Equity into Programmes:** Empower communities through health education, behaviour change communication, and participatory vector control strategies, ensuring marginalised populations are included in climate adaptation efforts.
- **Align with National and Global Frameworks:** Harmonise national strategies under the National Centre for Vector Borne Disease Control (NCVBDC) with international commitments such as WHO's Global Vector Control Response (GVCR), Sustainable Development Goals (SDGs), and UNFCCC Health National Adaptation Plans to build sustainable and resilient health systems.
- **Invest in Capacity Building and Research:** Strengthen competencies of health professionals, entomologists, meteorologists, and data scientists to operate within integrated ecosystems. Continuous operational research and innovation should inform programmatic and policy decisions.

India's ecological diversity, scientific expertise, and institutional frameworks position it to lead regional and global efforts in mitigating climate-driven VBD threats. By embedding resilience, inclusiveness, and innovation into vector control strategies, the country can transition from reactive containment to proactive prevention—shaping a future where public health systems anticipate, absorb, and adapt to climate challenges.

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