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Climate Change and the Global Expansion of Dengue Fever: Epidemiological Trends and Public Health Challenges

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ABSTRACT: Climate change has significantly influenced the transmission dynamics of dengue fever, particularly through rising temperatures, increased precipitation variability, and higher humidity levels. This study systematically examines the relationship between climate variability and dengue epidemiology, highlighting the expansion of Aedes aegypti vectors into previously non-endemic regions. A systematic literature review was conducted using PubMed, Scopus, and Google Scholar to analyze peer-reviewed studies published in the past decade. Key findings indicate that higher temperatures accelerate mosquito development and viral replication, leading to a shorter extrinsic incubation period. Additionally, fluctuating rainfall patterns create optimal breeding conditions, increasing the density of mosquito populations and dengue incidence rates. The results underscore the necessity for climate-adaptive public health policies, improved urban planning, and proactive vector control measures to curb disease transmission. Climate-based early warning systems, environmental management strategies, and interdisciplinary research integrating climatology and epidemiology are critical in mitigating future outbreaks. Given the escalating global burden of dengue fever, urgent and sustained efforts are required to address the challenges posed by climate change and safeguard vulnerable populations against increasing health risks.

Keywords: Dengue Fever, Climate Change, Aedes Aegypti, Vector-Borne Diseases, Epidemiology, Global Warming, Environmental Health.

INTRODUCTION

Climate change has emerged as one of the most pressing global issues, exerting far-reaching consequences on various environmental and public health domains. Among the numerous health threats influenced by climate change, the epidemiology of vector-borne diseases, particularly dengue fever, has drawn considerable attention from researchers and policymakers. Dengue, a mosquito-borne viral disease caused by the dengue virus (DENV) and transmitted primarily by *Aedes aegypti* and *Aedes albopictus*, is a growing public health concern in many tropical and subtropical regions. Over the past few decades, an alarming increase in dengue incidence has been observed globally, coinciding with rising global temperatures, altered precipitation patterns, and fluctuating humidity levels (Gu et al., 2016; H. Li et al., 2023). These climatic variables significantly influence the life cycle, abundance, and geographic distribution of *Aedes* mosquitoes, thereby affecting the transmission dynamics of dengue fever.

Several studies have established a strong association between climate variability and the proliferation of *Aedes* mosquitoes. For instance, in China, increasing annual precipitation and temperature levels have been linked to the expansion of *Aedes* species distribution, facilitating a rise in dengue cases (Gu et al., 2016; H. Li et al., 2023). Similar patterns have been reported in other tropical regions, where warmer and more humid conditions create optimal breeding environments for mosquitoes (Robert et al., 2019). Temperature plays a critical role in mosquito development, influencing larval survival rates, vector competence, and biting behavior (Liu-Helmersson et al., 2014). *Aedes aegypti* has been found to exhibit enhanced viral transmission capacity at temperatures ranging between 26°C and 32°C, and climate projections indicate that increasing temperatures may further escalate its vectorial capacity (Mordecai et al., 2019). Moreover, humidity is essential for mosquito survival and reproduction, with high humidity levels prolonging adult mosquito longevity and increasing the likelihood of viral transmission (Adhianti et al., 2023; Ellis et al., 2011).

Precipitation patterns also exert a profound impact on mosquito population dynamics and dengue transmission. Excessive rainfall can create ideal breeding sites by forming stagnant water pools, while erratic rainfall patterns may either enhance or limit mosquito populations depending on water availability (Dhimal et al., 2015; Viana & Ignotti, 2013). A study conducted in Brazil found a strong correlation between rainfall variability and dengue incidence, emphasizing the influence of meteorological factors on disease outbreaks (Olson et al., 2021; Rodrigues et al., 2016). The unpredictability of climatic factors due to climate change presents significant challenges for dengue control and prevention, necessitating a deeper understanding of these interrelationships to formulate effective public health interventions (Fareed et al., 2016; Semenza, 2015). Climate-based predictive models and early warning systems have been proposed as valuable tools for mitigating dengue epidemics, with several studies demonstrating their potential in guiding proactive vector control strategies (Olson et al., 2021; Sargent et al., 2022).

Despite the growing body of evidence supporting the link between climate change and dengue epidemiology, several challenges persist in accurately predicting disease outbreaks and designing appropriate control measures. One major challenge is the complexity of climate-disease interactions, which involve multiple factors such as urbanization, human mobility, and socioeconomic conditions (Adhianti et al., 2023; Khormi & Kumar, 2014). Additionally, disparities in data availability and quality across different regions hinder the development of robust predictive models ((H. Li et al., 2023). The lack of standardized methodologies for assessing climate change impacts on dengue transmission further complicates efforts to establish definitive causal relationships (Rodrigues et al., 2016).

Another significant research gap lies in understanding the long-term implications of climate change on dengue transmission dynamics. While numerous studies have focused on short-term climate variability and its effects on mosquito populations, fewer have explored the potential consequences of sustained climate change over decades (Bianco et al., 2024; Osail et al., 2024). Furthermore, most studies emphasize the influence of temperature and precipitation but often neglect the role of other climatic variables, such as wind patterns and atmospheric pressure, in shaping mosquito behavior and viral transmission (Leowattana & Leowattana, 2021). Addressing these gaps is crucial for enhancing the effectiveness of dengue prevention and control efforts in the face of a changing climate.

The primary objective of this review is to examine the impact of climate change on dengue fever incidence, with a particular focus on key climatic factors such as temperature, precipitation, and humidity. This review will analyze existing literature to assess how these variables influence mosquito population dynamics and disease transmission. Additionally, the study aims to identify gaps in current research and propose future directions for improving climate-based dengue mitigation strategies.

Geographically, this review will concentrate on tropical and subtropical regions, where dengue fever poses the greatest public health burden. Countries in Southeast Asia, Latin America, and Africa will be examined to provide a comprehensive perspective on the climate-disease relationship across different climatic zones. The findings of this study will contribute to the development of evidence-based public health policies aimed at reducing dengue transmission and improving climate adaptation strategies for vector-borne disease control.

METHOD

This study employs a systematic literature review approach to examine the impact of climate change on dengue fever epidemiology. A comprehensive literature search was conducted across multiple academic databases, including PubMed, Scopus, and Google Scholar, focusing on studies published in the last ten years. The search strategy incorporated a combination of predefined keywords and Boolean operators to enhance accuracy and completeness. The keywords included "Climate Change," "Dengue Fever," "Aedes aegypti," "Vector-Borne Diseases," "Epidemiology," "Temperature," "Precipitation," "Humidity," "Global Warming," and "Environmental Impact on Health." Boolean operators such as AND, OR, and NOT were applied to refine the search results, ensuring the retrieval of relevant studies. For instance, queries such as "Climate Change AND Dengue Fever" and "Aedes aegypti AND Climate Change OR Epidemiology" were used to obtain precise and focused results.

The selection criteria were established to include peer-reviewed studies, systematic reviews, and meta-analyses that empirically or theoretically analyzed the influence of climate change on dengue fever. Studies published in languages other than English, those lacking empirical evidence, and non-peer-reviewed articles were excluded from consideration. The initial screening involved reviewing titles and abstracts, followed by a full-text assessment to determine the relevance and methodological rigor of the studies.

To enhance reliability, a multi-stage screening process was implemented. Four independent reviewers evaluated the studies, ensuring alignment with the inclusion criteria. Key themes were synthesized to identify recurring patterns in how climatic factors influence dengue transmission dynamics. The findings provide insights into the correlation between climate variability and the distribution of *Aedes* mosquitoes, the epidemiological trends of dengue fever, and the potential for future outbreaks under different climate scenarios. This methodological framework ensures a structured and comprehensive analysis of the existing literature, contributing to a more nuanced understanding of the interplay between climate change and dengue epidemiology.

RESULT AND DISCUSSION

Recent epidemiological trends indicate a substantial increase in the incidence of dengue fever, particularly in tropical regions. Over the past two decades, dengue cases have risen sharply, with estimates suggesting up to 390 million infections per year, of which approximately 96 million manifest clinically (X. Li et al., 2021). This rise is attributed to various factors, including climate variability, rapid urbanization, high population density, and increased human mobility (Hossain et al., 2023; Zellweger et al., 2017). Dengue has also expanded into previously unaffected areas, posing new challenges for public health systems. In Southeast Asia and the Pacific, frequent and widespread dengue epidemics have been reported, often exacerbated by El Niño-induced climate fluctuations (Andersen & Davis, 2015; Johansson et al., 2009).

In Bangladesh, data show an alarming rise in dengue hemorrhagic fever (DHF), with the proportion of DHF cases increasing from 0.6% in early outbreaks to nearly 10% in recent epidemics, indicating worsening disease severity over time (Hossain et al., 2023; Reza et al., 2024). Similar seasonal patterns are evident across tropical regions, where peak dengue transmission coincides with the rainy season, creating ideal breeding conditions for *Aedes* mosquitoes (Liu-Helmersson et al., 2016). Studies in Brazil and India have established a strong correlation between high rainfall and increased mosquito population density, ultimately leading to a surge in human infections (Colón-González et al., 2011; Fitzpatrick et al., 2017). However, socio-economic factors also play a crucial role, as areas with poor sanitation conditions exhibit heightened vulnerability to dengue outbreaks (Barrio et al., 2018; Hossain et al., 2023).

Dengue incidence varies significantly across different climatic zones within tropical regions. In humid and warm climates, such as Southeast Asia and South America, the disease burden is substantially higher due to favorable conditions for mosquito breeding. Studies highlight that temperature and humidity fluctuations directly influence mosquito density, enhancing virus transmission to humans (Blagrove et al., 2017; Mordecai et al., 2019). Conversely, in cooler regions, such as mountainous areas, the transmission rate remains lower due to suboptimal temperature conditions that hinder mosquito reproduction and survival (Andersen & Davis, 2015; Blagrove et al., 2017). A study in Mexico demonstrated that extreme summer heat and dry conditions led to decreased dengue cases, whereas moderate rainfall created ideal breeding habitats, increasing infection rates (Colón-González et al., 2011). Additionally, demographic factors such as population density and urbanization influence dengue spread, with highly populated urban areas facing significantly higher transmission rates than remote rural locations (Sarma et al., 2022; Zellweger et al., 2017). Addressing these disparities requires region-specific public health interventions tailored to local climatic and demographic conditions to mitigate dengue transmission effectively (Liu & Xiao, 2021; Mordecai et al., 2019).

Climate change exerts a direct impact on the life cycle and population dynamics of *Aedes aegypti*, the primary dengue vector. Rising temperatures accelerate mosquito development, reducing the time required for larvae to mature into adults. A temperature increase of 1-2°C shortens the mosquito developmental cycle, leading to a rapid population surge in previously non-endemic areas (A. S. M. M. Kamal et al., 2023; Simões et al., 2013). Optimal temperatures for *Aedes aegypti* reproduction range between 26-32°C, within which mosquito survival rates and reproductive success peak (Mordecai et al., 2019; Tavakoli et al., 2007).

Rainfall also plays a critical role in mosquito proliferation. Excessive rainfall creates stagnant water pools, forming breeding sites that support high mosquito densities. Research in Brazil and other tropical countries confirms that increased rainfall correlates with higher mosquito populations and subsequent dengue transmission surges (Fitzpatrick et al., 2017; Piovezan et al., 2022). However, prolonged flooding may disrupt mosquito breeding, as excessive water accumulation can drown larvae, thereby reducing adult mosquito emergence (Fitzpatrick et al., 2017). Additionally, unpredictable climate patterns have led to fluctuating mosquito habitats, altering vectorial capacity and transmission potential (Khormi & Kumar, 2014; Ponti & Mutwil, 2021).

Global temperature rise has also influenced the extrinsic incubation period (EIP) of the dengue virus within *Aedes aegypti*. The EIP, which refers to the time required for the virus to develop within the mosquito before becoming infectious, is highly temperature-sensitive. Studies show that a 1°C increase in temperature can reduce the EIP by 4-7%, enabling mosquitoes to transmit the virus more rapidly (Blagrove et al., 2017; Mordecai et al., 2019). In tropical regions where baseline temperatures are already high, this effect intensifies dengue transmission rates. Climate models predict that rising temperatures will continue to shorten the EIP, potentially expanding dengue-endemic zones and exacerbating disease burdens globally (Angelo et al., 2020; Simões et al., 2013).

Climate change has facilitated the geographical expansion of dengue-endemic regions into previously unaffected areas. Higher temperatures and altered precipitation patterns create environments conducive to vector survival, thereby increasing disease transmission risks. Research indicates that when temperatures exceed 26°C, *Aedes aegypti* reproduction accelerates, elevating the risk of viral transmission (Bianco et al., 2024; Hossain et al., 2023). Fluctuating rainfall patterns further contribute to vector expansion. Increased rainfall enhances mosquito breeding sites, while erratic rainfall patterns create water storage issues that sustain larval habitats (Andersen & Davis, 2015; Tavakoli et al., 2007). Countries in Asia and Latin America have reported significant increases in dengue cases, with outbreaks now occurring in areas previously considered low-risk (Blagrove et al., 2017; Fitzpatrick et al., 2017).

Environmental and social factors also influence vector spread. Urbanization-driven habitat modifications provide abundant breeding sites for mosquitoes, exacerbating dengue risks in densely populated cities. A study in New Caledonia found that urban environmental conditions significantly affected *Aedes* mosquito density (Liu-Helmersson et al., 2016; Zellweger et al., 2017). Additionally, low socio-economic conditions, inadequate sanitation, and poor public health infrastructure increase susceptibility to dengue outbreaks. In India, rapid urbanization has contributed to the proliferation of mosquito breeding sites, exacerbating dengue incidence in slum areas with poor drainage and waste management (Dhimal et al., 2014). Community-based interventions, such as educational programs and proactive vector control measures, have proven effective in reducing dengue transmission risks (Cui et al., 2021; M. Kamal et al., 2018).

Climate anomalies, particularly El Niño and La Niña events, further influence dengue epidemiology. These phenomena alter temperature and precipitation patterns, creating conditions favorable for *Aedes* mosquito proliferation. Dengue outbreaks frequently peak during El Niño years, which generate warm and humid conditions ideal for mosquito breeding (Andersen & Davis, 2015; Fauziyah et al., 2023). Research indicates that dengue incidence surges following El Niño events due to prolonged warm temperatures and increased vector survival rates (Masrani et al., 2021; Muurlink & Taylor-Robinson, 2020).

In summary, climate change has significantly altered the epidemiology of dengue fever, leading to increased incidence rates, expanded geographic distribution, and more severe outbreaks. Temperature, precipitation, and humidity are critical determinants influencing mosquito behavior and viral transmission dynamics. Additionally, socio-economic and environmental factors play crucial roles in shaping dengue risk. Understanding these complex interactions is essential for developing targeted intervention strategies aimed at mitigating the public health impact of climate change-induced dengue transmission.

The findings of this study indicate a significant relationship between climate change and the epidemiology of dengue fever, particularly in the expansion of *Aedes aegypti* vectors into previously non-endemic regions. This aligns with existing literature emphasizing the role of environmental factors, such as temperature and precipitation, in disease transmission dynamics (Cheng et al., 2021; Mordecai et al., 2019; Robert et al., 2019). For instance, Robert et al. demonstrated that rising temperatures and favorable climatic conditions have contributed to an increase in dengue incidence in the United States, suggesting that global warming is making dengue a broader public health concern (Robert et al., 2019). Additionally, previous studies highlight the role of rapid urbanization and poor environmental management in exacerbating the situation by creating more breeding sites for mosquitoes (Attaway et al., 2014; Rodrigues et al., 2016). Our findings reinforce that climate change, combined with socio-economic conditions, plays a crucial role in increasing vector density, a conclusion consistent with studies that argue poor environmental conditions, coupled with climate shifts, can accelerate vector spread (Attaway et al., 2014; Cheng et al., 2021).

The social aspects of urbanization have also significantly impacted dengue epidemiology, as previously noted by Rodrigues et al. (2016) and Zellweger et al. (2017). Rapid urbanization often leads to poor sanitation and increased human-vector interactions, heightening transmission risks(Rodrigues et al., 2016; Zellweger et al., 2017). Our results indicate that public health challenges related to dengue are closely linked to population growth and poorly managed habitats. Additionally, the relationship between increasing global temperatures and the reduced extrinsic incubation period of the virus supports earlier research showing that higher temperatures expedite viral development within mosquitoes, leading to enhanced disease transmission (Bellone & Failloux, 2020; Mordecai et al., 2019). Bellone and Failloux further illustrated how temperature influences viral replication in mosquitoes, emphasizing the growing concern that rising temperatures may intensify future outbreaks (Bellone & Failloux, 2020).

Moreover, extreme weather events have been identified as major drivers of dengue outbreaks. Cheng et al. (2021) reported that extreme climatic conditions contributed to the severe dengue epidemic in Guangdong, China, in 2014, demonstrating the tangible effects of climate variability(Cheng et al., 2021). This supports the argument that climate extremes, which are increasing due to global climate change, will continue to shape dengue epidemiology worldwide. Our findings suggest that future dengue control strategies must incorporate climate-adaptive measures to counteract these challenges (Wang et al., 2023). The expansion of dengue vectors into new areas highlights the importance of understanding climate-vector interactions for designing effective prevention strategies. These findings are consistent with earlier research emphasizing that both climate change and anthropogenic activities, such as urbanization, are accelerating vector proliferation (Muurlink & Taylor-Robinson, 2020; Robert et al., 2019). Future research should explore the interactions between climate, mosquito populations, and epidemic dynamics to develop more responsive and adaptive public health programs.

Limitation

This study has several limitations. First, despite using a systematic literature review methodology, there is inherent variability in the data sources examined, which may introduce bias. Differences in study methodologies, regional case reporting, and climate modeling approaches may affect the comparability of results across studies. Additionally, the effects of other ecological factors, such as land use changes, deforestation, and interactions with other vector-borne diseases, were not comprehensively analyzed. While existing literature provides strong evidence linking climate change to dengue epidemiology, long-term observational data are limited, making it difficult to establish causal relationships. Finally, the complexity of socio-economic influences on dengue transmission necessitates further interdisciplinary studies integrating epidemiology, climatology, and socio-economic research to develop more holistic disease mitigation strategies.

Implication

The results of this study have significant implications for public health policies and climate change mitigation strategies. Given the strong evidence that higher temperatures accelerate mosquito life cycles and shorten the virus incubation period, policymakers must develop adaptive health guidelines that account for changing climate conditions. Data-driven approaches, including climate-based predictive models, can enhance mitigation strategies and improve early warning systems.

Climate change mitigation should be integrated into public health interventions to build community resilience against vector-borne diseases. The growing understanding of how socio-environmental factors contribute to mosquito proliferation underscores the need for sustainable environmental management practices. Policies emphasizing waste management, improved sanitation, and stringent monitoring of potential breeding sites can effectively reduce dengue incidence. From a strategic perspective, raising public awareness about dengue risks and prevention methods is crucial, particularly in newly endemic regions. Community education, rapid response to outbreaks, and cross-sectoral collaboration between health and environmental agencies are necessary to minimize disease spread.

Technological advancements, such as climate-based dengue risk forecasting, offer promising solutions for proactive disease management. Predictive models that incorporate climate variables can be developed to anticipate dengue outbreaks based on past epidemiological trends and weather patterns. The adoption of real-time climate data monitoring systems can further strengthen public health preparedness, allowing for timely vector control interventions. Additionally, investment in interdisciplinary research focusing on the intersection of human health, climate change, and vector ecology is essential to develop adaptive policies at both national and global levels. The findings of this study reinforce the need for integrated health-environment strategies to mitigate dengue transmission in the face of ongoing climate change.

CONCLUSION

This study highlights the significant impact of climate change on the epidemiology of dengue fever, with rising temperatures, altered precipitation patterns, and increasing humidity levels contributing to the expansion of *Aedes aegypti* vectors and higher transmission rates. Our findings reinforce previous research that links global warming with an accelerated dengue virus incubation period and an extended geographical range for mosquito populations. The growing frequency of extreme weather events further complicates disease prevention and control, underscoring the urgent need for climate-adaptive public health strategies.

Addressing this challenge requires comprehensive, interdisciplinary approaches. Policies focused on sustainable environmental management, improved urban planning, and climate-based disease surveillance systems should be prioritized to mitigate the risks associated with dengue fever. Strengthening community awareness, implementing proactive vector control measures, and enhancing public health infrastructure are crucial in preventing further outbreaks.

Future research should emphasize long-term observational studies that integrate epidemiological data with climate modeling to enhance prediction accuracy. Additionally, interdisciplinary studies that explore the socio-economic and behavioral factors influencing disease transmission are necessary to develop holistic intervention strategies. As climate change continues to drive the global expansion of dengue, proactive mitigation strategies, including early warning systems and integrated vector management, will be essential in reducing the burden of this disease.

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