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Impact of Climate Variability on Dengue Transmission in West Bengal: Rainfall, Temperature Effects, and Implications for Early Warning Systems

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Abstract— *Dengue fever, a mosquito-borne viral disease, poses a significant public health challenge in tropical and subtropical regions, with its transmission dynamics intimately linked to climate variability. This review article examines the impact of climate factors, particularly rainfall and temperature, on dengue transmission in West Bengal, India, and explores the potential for developing effective early warning systems (EWS). Drawing on a comprehensive analysis of epidemiological data and climatic records from the region, we highlight how seasonal monsoon patterns and temperature fluctuations influence Aedes mosquito populations and dengue incidence. The study underscores the urgency of integrating climate data into public health strategies to mitigate future outbreaks amid climate change. By synthesizing existing literature and presenting comparative data from multiple studies, we provide insights into the complex interactions between environmental variables and disease dynamics, offering recommendations for policy and practice to enhance preparedness in West Bengal and similar endemic areas.*

***Keywords*— Dengue, Climate variability, West Bengal, Rainfall, Temperature, Early warning systems**

Introduction

Dengue fever, caused by the dengue virus (DENV) and primarily transmitted by *Aedes aegypti* and *Aedes albopictus* mosquitoes, has emerged as one of the most rapidly expanding vector-borne diseases globally, with an estimated 390 million infections annually and approximately 96 million manifesting clinically [1]. In India, the burden is particularly acute, accounting for a substantial proportion of global cases, driven by a confluence of rapid urbanisation, population density, and climatic conditions that favour vector proliferation [2]. West Bengal, situated in eastern India and characterised by a tropical monsoon climate, exemplifies this vulnerability. The state's diverse topography, from the humid Gangetic plains to coastal regions, combined with dense urban centres like Kolkata, creates ideal breeding habitats for dengue vectors. Over the past two decades, dengue incidence in West Bengal has shown marked increases, with outbreaks often occurring during the post-monsoon period, underscoring the critical role of climate variability in disease transmission [3].

A detailed literature review reveals that climate factors, especially rainfall and temperature, exert profound influences on dengue epidemiology through multiple pathways. Rainfall creates breeding sites by filling artificial containers and natural depressions, while temperature modulates mosquito development rates, survival, and the extrinsic incubation period (EIP) of the virus within the vector [4]. Globally, systematic reviews have consistently demonstrated positive associations between these variables and dengue incidence, with lags ranging from weeks to months depending on local ecology [5]. For instance, Naish et al. (2014) synthesised quantitative modelling studies and concluded that dengue transmission is highly sensitive to climatic conditions, with temperature thresholds around 25–30°C optimising vectorial capacity [5]. In Asia, similar patterns emerge, where monsoon-driven rainfall not only augments vector abundance but also extends the transmission season, often amplifying case numbers by creating prolonged periods of high humidity that sustain adult mosquito longevity [6].

Within India, national-level analyses highlight the lag effects of climatic variables with remarkable precision. Kakarla et al. (2019) analyzed dengue burden across multiple states and found that the highest relative risk (RR) occurred at mean temperatures of 30°C with a 0–3 week lag, while rainfall peaks at 60 mm with a 12-week lag doubled transmission risk in some regions; these patterns were particularly pronounced in eastern states sharing ecological similarities with West Bengal [7]. These findings align with broader trends observed in southern and eastern India, where unplanned urbanisation exacerbates the creation of peri-domestic breeding sites during rainy seasons, transforming moderate precipitation events into significant transmission amplifiers [8]. In West Bengal specifically, localised studies provide granular insights into these dynamics. Poddar et al. (2016) examined weather effects in Kolkata and reported strong positive correlations between monthly rainfall ($r = 0.573$, $p < 0.001$), number of rainy days ($r = 0.624$, $p < 0.001$), and dengue cases, with July rainfall triggering peaks in October; relative humidity emerged as an even stronger predictor ($r = 0.636$, $p < 0.001$), illustrating how post-monsoon moisture retention sustains vector populations long after peak rains subside [9]. Similarly, Bal and Sodoudi (2020) developed predictive models for Kolkata using climate factors and identified autocorrelations and partial correlations linking temperature and rainfall to dengue occurrences, emphasising the utility of zero-inflated Poisson regression for forecasting and revealing that minimum temperatures of 24–26°C combined with lagged rainfall best explained case surges [10].

Comparative data from neighbouring regions and national syntheses further contextualise West Bengal's situation while highlighting regional heterogeneities. Mutheneni et al. (2017) analysed national trends from 2001–2015 and documented positive correlations between annual rainfall and dengue cases in monsoon-influenced states, with eastern regions like West Bengal showing stronger dependence on temperature anomalies due to the state's consistently high baseline humidity [2]. Biswas et al. (2014) investigated a rural outbreak in the Purba Medinipur district in 2012, revealing how localised water-storage practices interacted with monsoon rains to drive transmission in non-urban settings [11]. Majhi et al. (2020) documented dynamics of outbreaks in Gangetic West Bengal, noting 15 outbreaks in 2012 and a peak of 7,573 cases in 2016 concentrated in districts like North 24 Parganas, where climate signals interacted with population density and mobility [3]. These studies collectively illustrate a shifting epidemiological landscape: dengue, once predominantly urban, is now encroaching into rural and peri-urban areas of West Bengal, where poor drainage and water storage practices amplify climate-driven risks [3, 11].

Critically, while temperature accelerates mosquito metabolism and shortens EIP (typically 8–12 days at optimal 26–30°C), excessive heat above 35°C can reduce vector survival, introducing nonlinear thresholds that complicate predictions and demand sophisticated modelling beyond linear regressions [4, 12]. Rainfall exhibits dual effects: moderate levels promote breeding, but heavy downpours may flush larvae, as observed in some Indian monsoon studies where cumulative precipitation exceeding 150 mm occasionally suppressed short-term vector indices before rebounding [13]. In West Bengal's context, where annual rainfall averages 1,600–2,000 mm concentrated in June–September, these dynamics create a post-monsoon surge in cases, often extending into November due to lingering humidity and residual water bodies [3, 9]. Literature also highlights socioeconomic modifiers: high population density in Kolkata (over 24,000/km²) and inadequate vector control amplify climate signals, while rural incursions post-2010 reflect changing land-use patterns that interact with climatic drivers [14].

Despite robust evidence, gaps persist. Many studies rely on aggregated state-level data, overlooking district-specific heterogeneities in West Bengal (e.g., higher burdens in North 24 Parganas and Kolkata versus drier western districts like Purulia) [3, 15]. Moreover, few integrate multiple serotypes or co-circulate with other arboviruses, which may alter transmission efficiency under varying climates, as serotypic shifts observed in West Bengal have coincided with climatic optima [16]. Climate change projections exacerbate concerns: rising temperatures and altered monsoon intensity could expand the range of suitable transmission windows, potentially increasing cases in endemic zones such as the Gangetic plains [17]. This review synthesises these insights, focusing on West Bengal while drawing comparative lessons from national and regional data up to 2021, to advocate for climate-informed EWS. By critically evaluating epidemiological and climatological evidence, including detailed lag analyses and vector distribution models, we aim to bridge gaps in understanding and inform adaptive public health strategies in a warming world, emphasising the need for interdisciplinary approaches that account for both biophysical and anthropogenic factors.

Climate Drivers of Dengue Transmission: Global and Regional Perspectives

The interplay between climate variability and dengue transmission operates through intricate ecological and physiological mechanisms that extend beyond simple correlations. Globally, temperature governs key vector life-history traits: egg hatching, larval development, adult longevity, and viral replication within mosquitoes, with each stage exhibiting distinct thermal optima that create windows of heightened transmission risk [4]. Optimal ranges (26–30°C) maximise the basic reproduction number (R_0) for DENV, while deviations, whether cooler winters delaying development or extreme summer heat reducing survival, introduce thresholds that challenge simplistic forecasting [18]. Rainfall influences breeding site availability, with cumulative precipitation over weeks creating stagnant water pools essential for *Aedes* oviposition; however, the effect is modulated by intensity, as excessive rains can disrupt larval habitats through flushing, a phenomenon documented in tropical monsoons [19]. Relative humidity above 60% further enhances mosquito survival and host-seeking behaviour, acting synergistically with temperature to prolong the transmission season [20].

In South and Southeast Asia, these drivers manifest distinctly due to monsoon climates. Reviews of quantitative models indicate that a substantial portion of inter-annual dengue variability in tropical settings is attributable to climate, with lags of 1–4 months common and often longer in humid eastern regions due to persistent waterlogging [5, 21]. For India, Mutheneni et al. (2017) analysed national trends from 2001–2015 and found positive correlations between annual rainfall and dengue cases in states like Punjab, Haryana, and Gujarat, though eastern regions showed stronger temperature dependence, with minimum temperatures emerging as a key limiter in cooler months [2]. Critically, these associations are not uniform; urban heat islands in megacities like Kolkata can elevate local temperatures by 2–4°C, decoupling them from regional averages and intensifying transmission while masking broader cooling effects in rural areas [22].

Specific to West Bengal: Rainfall and Temperature Effects

West Bengal's tropical humid climate (mean annual temperature 26–29°C, rainfall 1,500–2,000 mm) renders it highly susceptible, with detailed district-level data revealing nuanced patterns. Post-monsoon humidity sustains vector populations long after peak rains, explaining October–November case surges that account for a large share of annual incidence in some analyses [9, 10]. Bal and Sodoudi (2020) reported that dengue in Kolkata peaks when minimum temperatures hover at 24–26°C and rainfall lags by 2–3 months, with zero-inflated models capturing excess zeros in dry periods effectively [10]. Poddar et al. (2016) noted negative correlations with extreme maximum temperatures (>35°C), suggesting that heat stress limits adult mosquitoes, while rainy days ($r = 0.624$) outperformed total rainfall volume in predictive power due to sustained breeding-site creation [9].

District-level variations are pronounced. Coastal and Gangetic areas experience prolonged wet seasons, fostering *A. albopictus* (outdoor breeder) alongside *A. aegypti* (domestic), with North 24 Parganas consistently recording high outbreak counts [3, 11]. Majhi et al. (2020) documented that outbreaks peaked in 2012 and 2016, with cases concentrated in urban-peri-urban interfaces where climate signals interact with population mobility [3].

Table 1. Comparative Lag Effects of Rainfall and Temperature on Dengue Incidence in Selected Indian Studies (Published ≤2021)

Study	Location	Rainfall Association/Lag	Temperature Association/Lag	Key Findings/Correlation	Reference
Poddar et al. (2016)	Kolkata, West Bengal	Positive ($r=0.573$, $p<0.001$); July peak triggers October cases	Positive with min/mean temp; negative with max temp (>35°C)	Rainfall and rainy days strongest predictors; humidity $r=0.636$	[9]

		(0–3 months lag); rainy days r=0.624			
Kakarla et al. (2019)	Multi-state India (incl. eastern regions)	Highest RR at 60 mm (12-week lag); positive monsoon association	Highest RR at 30°C (0–3 weeks); min temp 26°C (2 weeks)	Transmission risk >2-fold with temp rise above 24°C	[7]
Bal & Sodoudi (2020)	Kolkata, West Bengal	Positive correlation with lagged monthly totals (2–3 months)	Positive with mean/min temp (24–26°C optimal); autocorrelations noted	Zero-inflated Poisson model predicts cases using climate lags; humidity synergy	[10]
Mutheneni et al. (2017)	National India	Positive annual correlation in monsoon states	Positive in warmer zones; seasonal thresholds	Climate explains seasonal patterns; urbanisation is a critical modifier in the east	[2]
Majhi et al. (2020)	Gangetic West Bengal	Post-monsoon surges linked to monsoon rainfall (1–3 months)	Peaks with sustained 25–30°C	15 outbreaks in 2012; 7573 cases in 2016 in North 24 Parganas	[3]

Note: Lags reflect the time between the climate peak and the case incidence. Data synthesised from epidemiological records up to 2019; nonlinear effects highlighted.

This table illustrates consistency in lagged positive effects yet highlights context-specific nuances e.g., West Bengal's shorter lags (2–3 months) due to perennial humidity versus arid states demanding region-tailored thresholds.

Vector Ecology in the Context of Climate Variability

Aedes species in West Bengal thrive under specific climatic envelopes, with *A. aegypti* preferring indoor sites with stable temperatures and *A. albopictus* exploiting outdoor containers post-rain [22]. Studies show rainfall increases Stegomyia indices (e.g., Breteau Index) by 20–50% in monsoon months, while temperature accelerates larval development from 10–14 days at 25°C to 6–8 days at 30°C [4, 23]. Critical analysis reveals that warming trends may favour *the expansion of A. albopictus into rural West Bengal, as it tolerates a wider temperature range* and exhibits greater exophily, complicating traditional indoor-focused control [24]. Chatterjee et al. (2015) characterised breeding habitats around Kolkata, noting that physicochemical factors such as pH and conductivity interact with rainfall to enhance larval survival in artificial containers [25].

Table 2. Entomological Indices and Climate Correlations in West Bengal Studies (≤2021)

Study/Year	Site	Breteau Index (BI) Correlation	Container Index (CI) with Rainfall	Temp Threshold for High Vector Density	Reference
Poddar et al. (2016) / surveillance	Kolkata & surroundings	Positive with lagged rainfall (r~0.6–0.7)	CI spikes post-monsoon (>20%)	26–32°C optimal; min >20°C sustains	[9]
Chatterjee et al. (2015)	Kolkata peri-urban	BI is elevated in humid post-monsoon	Indoor CI stable; outdoor spikes with rain	24–30°C for larval viability	[25]
Majhi et al. (2020)	Gangetic WB districts	1–3 month lag for peak BI in high-rain districts	Rural CI tied to water storage + rain	Sustained 25–28°C with humidity >70%	[3]
Biswas et al. (2014)	Rural Purba Medinipur	Outbreak linked to monsoon water accumulation	High CI in domestic containers post-rain	Ambient monsoon temperatures	[11]

These data underscore the need for targeted surveillance beyond urban foci, incorporating climate-driven shifts in vector behaviour.

Epidemiological Trends in West Bengal

Dengue cases in West Bengal have risen from sporadic outbreaks prior to 2010 to annual epidemics, with 2012 recording the highest number of outbreaks (15) and 2016 a peak of over 7,500 cases, disproportionately affecting North 24 Parganas and Kolkata [3, 11]. Serotype shifts interact with climate, as warmer conditions may enhance viremia and transmission efficiency [16]. Rural incursions, noted in the 2012 Purba Medinipur outbreak, challenge traditional urban-centric control, with climate variability exacerbating spread through expanded breeding opportunities in flood-prone areas [11].

Implications for Early Warning Systems

Integrating climate data into EWS could provide 1–3 month lead times, enabling proactive vector control, public alerts, and resource allocation [10, 26]. Models such as those by Bal and Sodoudi (2020) demonstrate feasibility with readily available meteorological inputs [10]. Challenges include data integration across departments and accounting for non-climatic factors (e.g., mobility, immunity, serotype dynamics) [27]. Region-specific thresholds for West Bengal, e.g., >150 mm weekly rain or sustained 28°C, offer actionable triggers, with potential for improved accuracy through refined statistical approaches [7, 21].

Challenges and Future Directions

Limitations include underreporting, gaps in serotype surveillance, and model uncertainties across varying climate scenarios, compounded by socioeconomic confounders such as urbanisation [17, 28]. Future research should prioritise longitudinal vector-virus-climate studies and community-based EWS pilots in West Bengal to address these gaps, building on pre-2022 evidence.

CONCLUSION

The intricate relationship between climate variability and dengue transmission in West Bengal reveals a pressing public health imperative shaped by both immediate environmental drivers and long-term climatic shifts. Throughout this review, rainfall and temperature have emerged not as isolated variables but as interconnected forces that dictate mosquito breeding success, viral replication efficiency, and ultimately human exposure risks. From the monsoon-fed breeding surges in Kolkata's urban sprawl, where July rains correlate strongly with October peaks, to the lagged post-rainfall surges in rural districts like North 24 Parganas and Purba Medinipur, the evidence consistently points to a system where moderate, sustained precipitation combined with temperatures in the 26–30°C range creates optimal conditions for *Aedes* proliferation and DENV transmission. Comparative analyses across national and state-level studies underscore that West Bengal's patterns mirror broader Indian trends yet exhibit unique regional nuances, shorter lags in humid eastern zones (often 2–3 months), dual vector dominance with *A. albopictus* gaining ground, and increasing rural encroachment that demand tailored responses rather than one-size-fits-all strategies imported from drier western states.

Critically, these dynamics are not static. Projections of rising temperatures and altered monsoon intensity suggest expanded transmission windows that could elevate dengue incidence in the coming decades, disproportionately affecting vulnerable populations in densely settled, low-lying Gangetic and coastal areas prone to waterlogging. Yet, the literature also illuminates clear pathways for resilience: predictive models incorporating lagged climate signals have demonstrated skilful forecasting potential, offering 2–3 month lead times that far exceed current reactive approaches reliant on case reporting alone. Early warning systems, when grounded in real-time meteorological data, entomological surveillance, and epidemiological intelligence, hold transformative promise for West Bengal. By alerting authorities to impending high-risk periods defined by cumulative rainfall thresholds, sustained minimum temperatures above 24°C, or humidity synergies, such systems could enable preemptive larval source reduction campaigns, intensified community education on water storage practices, and targeted insecticide deployment, potentially averting thousands of cases annually while reducing healthcare system strain during peak seasons.

However, realising this potential requires overcoming systemic barriers that extend beyond technical modelling. Fragmented data sharing between health, meteorological, and urban planning agencies, coupled with resource constraints in rural health infrastructure, currently hampers integration and scalability. Moreover, socioeconomic factors, such as poverty, unplanned urbanisation, inadequate waste management, and limited public awareness, amplify climate signals, transforming environmental risks into full-blown epidemics that disproportionately burden marginalised communities. A holistic EWS must therefore transcend purely climatic inputs to incorporate vulnerability mapping, serotype monitoring, behavioural interventions, and equity-focused resource allocation. Policymakers in West Bengal have a unique opportunity to pioneer such integrated frameworks, leveraging existing national programs under the National Vector Borne Disease Control Programme while fostering inter-sectoral collaboration with bodies like the India Meteorological Department and local municipalities.

Ultimately, addressing dengue in West Bengal amid climate variability is not merely a technical challenge but a call to reimagine public health governance in an era of environmental uncertainty. The comparative tables and analytical syntheses presented here affirm that while climate sets the stage through biophysical mechanisms, human agency, through proactive surveillance, sustainable urban planning, equitable resource allocation, and community empowerment, determines the outcome. Investing in climate-resilient EWS today will yield dividends in reduced morbidity, lower healthcare burdens, strengthened community resilience, and more efficient use of limited public health resources tomorrow. As West Bengal navigates its dual burdens of endemicity and environmental change, the path forward lies in evidence-based adaptation that prioritises prevention over reaction, ensuring that future generations inherit not only a warmer planet but also the tools, systems, and knowledge to thrive upon it. Only through sustained, multidisciplinary commitment spanning researchers, policymakers, healthcare workers, and communities can the state transform climate threats into opportunities for innovative, equitable health security that serves as a model for other endemic regions facing similar challenges.

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