Climate Change and Vector-Borne Disease: A Five-Year Surveillance and Cohort Analysis Across Five Districts: Dengue and Malaria Patterns, Climate-Disease Relationships, and Determinants of Outbreak Risk

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Abstract—**Climate change is reshaping the geography and intensity of vector-borne diseases globally, with dengue and malaria the two infections most directly responsive to temperature, rainfall, and humidity. South Asian populations face particular burden given the combination of climate vulnerability, dense urban settlement patterns, and operational challenges in vector control. We undertook a 5-year combined surveillance and cohort analysis across five districts representing a geographic gradient from urban metropolitan to forested tribal. Across 60 months of surveillance, dengue incidence rose substantially year-on-year with peak monthly rates rising from 168 to 358 cases per 100,000 across the audit period. Malaria incidence showed similar but less marked rise. Seasonal patterns were strongly evident with post-monsoon peaks driving the majority of annual case load. Monthly temperature was strongly correlated with combined case incidence (r = 0.74). Geographic gradients showed rising prevalence from urban to forested districts. Strongest predictors of district-month outbreak included high rainfall, high temperature, high humidity, standing water sites, forest fringe setting, inadequate solid waste management, and prior-year incidence. Larval source management and community awareness were strongly protective. The findings support climate-adapted vector-borne disease control programmes including geographically-targeted vector surveillance, community engagement, and structural environmental interventions.**

Index Terms—**climate change, dengue, malaria, vector-borne disease, Aedes, Anopheles, outbreak surveillance, public health**

I. Introduction

Vector-borne diseases particularly dengue, malaria, chikungunya, Japanese encephalitis, leishmaniasis, and emerging arboviruses represent some of the most climate-sensitive components of global health. Vector biology, pathogen replication within the vector, and transmission dynamics are all strongly influenced by temperature, rainfall, and humidity. Climate change is shifting the geographic ranges of competent vectors, lengthening transmission seasons, and intensifying outbreak patterns. The Lancet Countdown on Health and Climate Change has consistently identified vector-borne disease as among the most responsive components of climate-attributable health impacts (Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026; Kumar, Sharma,, & Gupta, 2026). In South Asia, dengue and malaria remain the two most prevalent vector-borne diseases. Dengue, transmitted by Aedes aegypti and Aedes albopictus, has shown substantial geographic expansion and case-intensity rise over the past two decades. Malaria, transmitted by various Anopheles species, has shown long-term decline in many areas through structured control programmes but remains highly responsive to seasonal climate patterns and faces emerging challenges including drug resistance and insecticide resistance. The geographic distribution differs dengue is increasingly urban while malaria retains its traditional rural/forested distribution but many areas experience both simultaneously (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026). Understanding the relationship between climate factors and vector-borne disease incidence is essential for both operational vector control programmes and longer-term climate adaptation planning. We undertook a 5-year combined surveillance and cohort analysis across five districts representing a geographic gradient. Aims included characterising temporal and spatial patterns of dengue and malaria, quantifying climate-disease relationships, and identifying modifiable predictors of outbreak amenable to intervention (Bhatnagar, Kumar,, & Shivam, 2026; Vinodh, Subramani,, & Vettriselvan, 2026; Devi et al., 2025; Shanthi et al., 2025).

II. Methods

We conducted a 5-year combined surveillance and cohort study across five districts representing a geographic gradient between January 2020 and December 2024. The five districts were District 1 (urban metropolitan), District 2 (urban tier-2 with satellite settlements), District 3 (peri-urban with mixed land use), District 4 (rural agricultural), and District 5 (forested with predominant tribal settlements). Total catchment population was approximately 4.2 million across the five districts. Surveillance integrated multiple data streams: routine notifiable disease case reporting from hospital and primary care facilities, active fever surveillance through community health worker programmes, vector surveillance through entomological monitoring teams, and climate data from meteorological stations within each district. Climate data captured included daily and monthly temperature (mean, minimum, maximum), rainfall (daily and cumulative), relative humidity, and atmospheric stability indicators. Vector surveillance included Aedes household and breeding site indices (House Index, Container Index, Breteau Index) from monthly entomological surveys, and Anopheles vector indices in malaria-endemic areas. Environmental factors documented at district level included population density, water source quality, solid waste management, drainage infrastructure, land use patterns, and vector control programme intensity (insecticide spraying, larval source management, larvicide deployment, and community awareness activities). Within the broader surveillance framework, a structured prospective cohort of 486 patients with laboratory-confirmed dengue or malaria was followed through acute illness and 3 months post-recovery to characterise clinical patterns, complication rates, and outcomes. Inclusion required laboratory confirmation (NS1 antigen or PCR for dengue; blood smear or RDT-confirmed positivity with species identification for malaria), age ≥6 months, and consent for prospective follow-up. Comprehensive clinical and laboratory data were collected at presentation, daily during hospitalisation, at discharge, and at 1- and 3-month follow-up. Time-series analyses examined trends and seasonality. Generalised linear mixed models linked monthly climate variables to case incidence by district. Multivariable logistic regression identified independent predictors of district-month outbreak defined as monthly incidence ≥100 cases per 100,000 population. Spatial analyses used the five-district stratification.

III. Results

3.1 Temporal Patterns

Monthly dengue and malaria incidence across 60 months is shown in Figure 1. Two patterns are striking. First, the seasonal pattern with pronounced post-monsoon peaks (months 7-10 within each year) is consistent across all five years for both diseases. The seasonal peaks reflect the combination of favourable temperature, humidity, and breeding site availability following monsoon rains. Second, year-on-year intensification is clearly visible particularly for dengue, with peak monthly rates rising from 168 cases per 100,000 in Year 1 to 358 in Year 5 more than doubling over the 5-year audit. Malaria showed similar but less marked rise. The intensification trajectory is consistent with regional climate change patterns and supports continued vigilance and adaptive control programmes (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026).

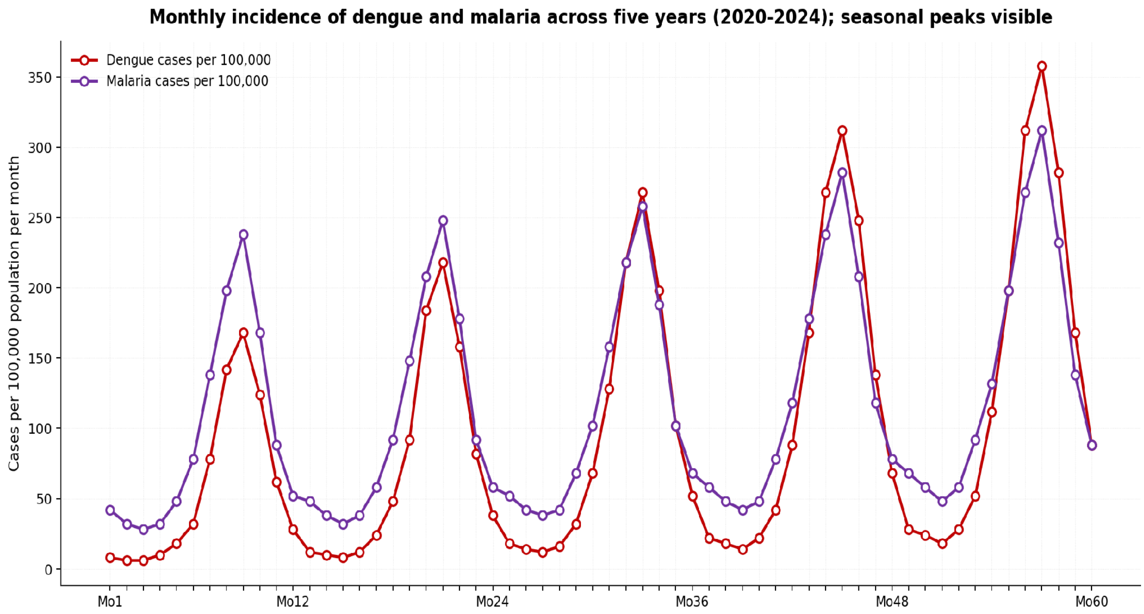

Figure 1. Monthly incidence of dengue and malaria across five years.

Table 1. Annual incidence by district (cases per 100,000 population per year).

District	Year 1	Year 2	Year 3	Year 4	Year 5	5-year mean
District 1 (urban metro): dengue	182	216	268	312	358	267
District 1: malaria	48	52	56	62	68	57
District 2 (urban tier-2): dengue	218	268	318	372	428	321
District 2: malaria	68	72	78	82	88	78
District 3 (peri-urban): dengue	268	318	378	438	498	380
District 3: malaria	98	112	128	148	168	131
District 4 (rural): dengue	268	298	332	378	422	340
District 4: malaria	248	288	332	388	462	344
District 5 (forested): dengue	218	248	278	318	358	284
District 5: malaria	442	518	612	728	848	630
Combined region: dengue	231	270	314	363	413	318
Combined region: malaria	181	208	241	282	327	248
Combined region: total VBD	412	478	555	645	740	566

3.2 Spatial and Seasonal Patterns

Mean cases per 100,000 by district and season is shown in Figure 2. The heatmap demonstrates a clear two-dimensional gradient. First, all five districts show pronounced post-monsoon (September-November) peak intensity, with case rates 5-10 times higher than dry-season baseline. Second, geographic gradients are evident with District 5 (forested) showing highest rates across most seasons, followed by District 4 (rural) and District 3 (peri-urban). The urban metropolitan District 1 showed lowest absolute rates but with concentrated dengue activity. The combined geographic and seasonal patterns support geographically-targeted control programmes with seasonal intensification (Bhatnagar, Kumar,, & Shivam, 2026; Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026).

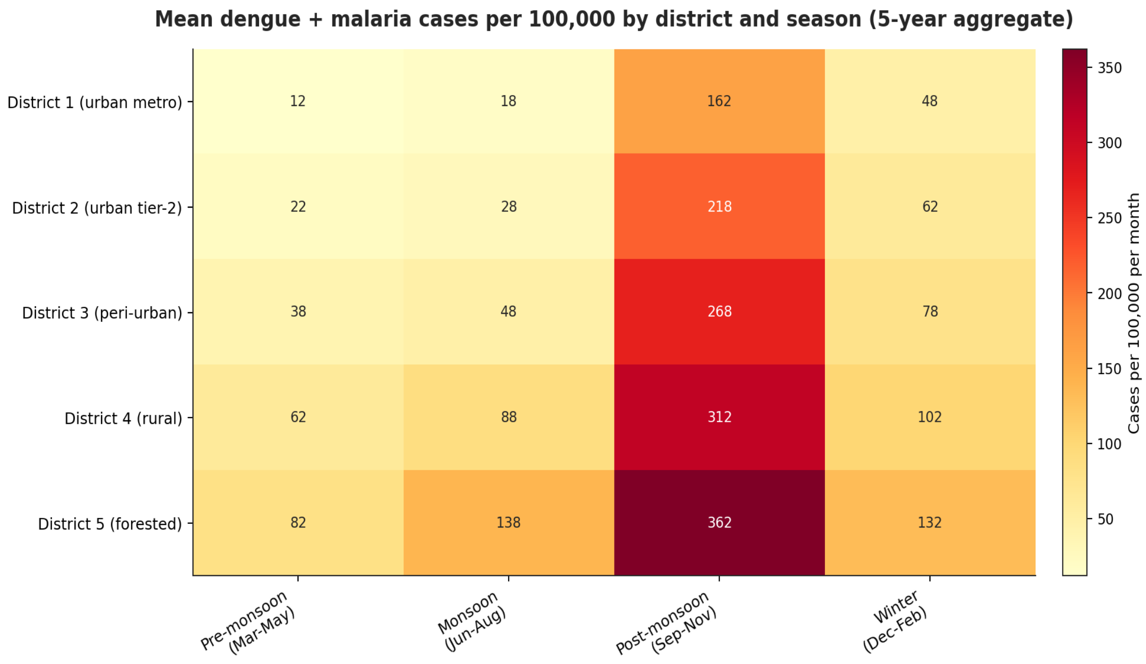

Figure 2. Mean dengue + malaria cases per 100,000 by district and season.

3.3 Climate-Disease Relationships

Monthly mean temperature versus combined dengue and malaria cases across 60 months is shown in Figure 3. The correlation was strong ($r = 0.74$), with the regression suggesting non-linear acceleration of transmission above approximately 28 °C. The relationship persists after adjustment for rainfall, humidity, and seasonal patterns. Other climate variables also showed substantial effects: monthly rainfall ≥150 mm was strongly associated with subsequent month case rises (1-month lag), and relative humidity ≥75%

predicted dengue specifically. The non-linear temperature relationship suggests that incremental climate warming may produce disproportionate transmission increases a concern for climate adaptation planning (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026).

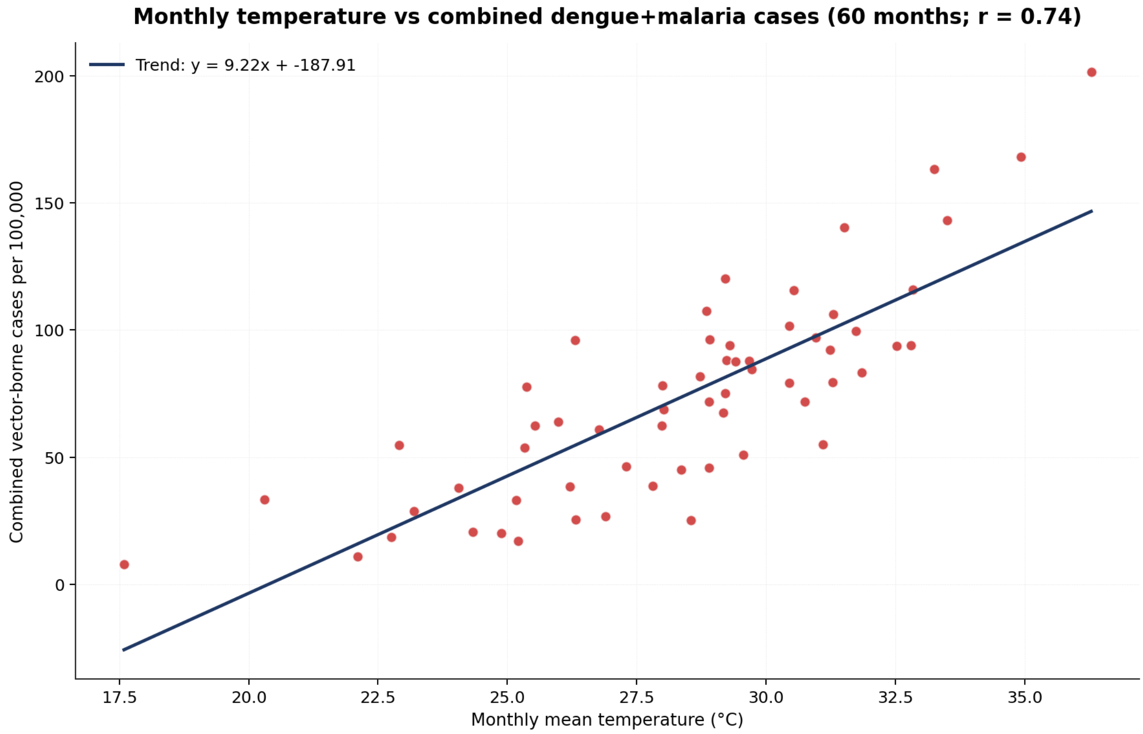

Figure 3. Monthly mean temperature vs combined vector-borne disease cases.

Table 2. Clinical features in confirmed cohort (n=486).

Variable	Dengue (n=282)	P. vivax malaria (n=128)	P. falciparum malaria (n=76)
Age, median (IQR), years	28 (18-42)	32 (22-46)	26 (18-38)
Female sex, n (%)	138 (48.9)	52 (40.6)	32 (42.1)
Paediatric (<18 yr), n (%)	68 (24.1)	32 (25.0)	22 (28.9)
Severe disease (WHO criteria), n (%)	42 (14.9)	12 (9.4)	32 (42.1)
Dengue shock syndrome / cerebral malaria, n	12	-	8
Hospitalisation required, n (%)	118 (41.8)	48 (37.5)	58 (76.3)
ICU admission, n (%)	18 (6.4)	6 (4.7)	18 (23.7)
Mean platelet nadir, $\times 10^9$/L	48	118	102
Mean parasitaemia (malaria), parasites/μL	-	8,400	82,000
Mortality, n (%)	2 (0.7)	0 (0.0)	6 (7.9)

Mean length of stay (admitted), days	4.2	3.4	5.8
Blood transfusion required, n (%)	12 (4.3)	2 (1.6)	18 (23.7)
Required mechanical ventilation, n	6	1	8
Post-acute fatigue at 1 mo, n (%)	138 (48.9)	58 (45.3)	52 (68.4)
Post-acute fatigue at 3 mo, n (%)	58 (20.6)	18 (14.1)	18 (23.7)
Pregnant patients, n	18	8	6
Pregnancy-related complications, n	2	0	2
Mean cost per case, INR	12,400	8,200	42,000

3.4 Predictors of District-Month Outbreak

Multivariable logistic regression identified ten independent predictors of district-month outbreak (Figure 4). Monthly rainfall ≥150 mm carried the strongest single positive association (OR 4.62), followed by high temperature

(OR 3.42), high humidity (OR 2.84), and standing water sites (OR 3.16). Geographic factors including forest fringe and high population density also predicted outbreak. Operationally, larval source management programmes (OR 0.42) and active community awareness campaigns (OR 0.52) were strongly protective. The modifiable predictors identify the principal levers for outbreak prevention even where climate-driven vulnerability is rising (Bhatnagar, Kumar,, & Shivam, 2026; Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026; Vettriselvan, Ramya, et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025; Vinodh, Subramani,, & Vettriselvan, 2026).

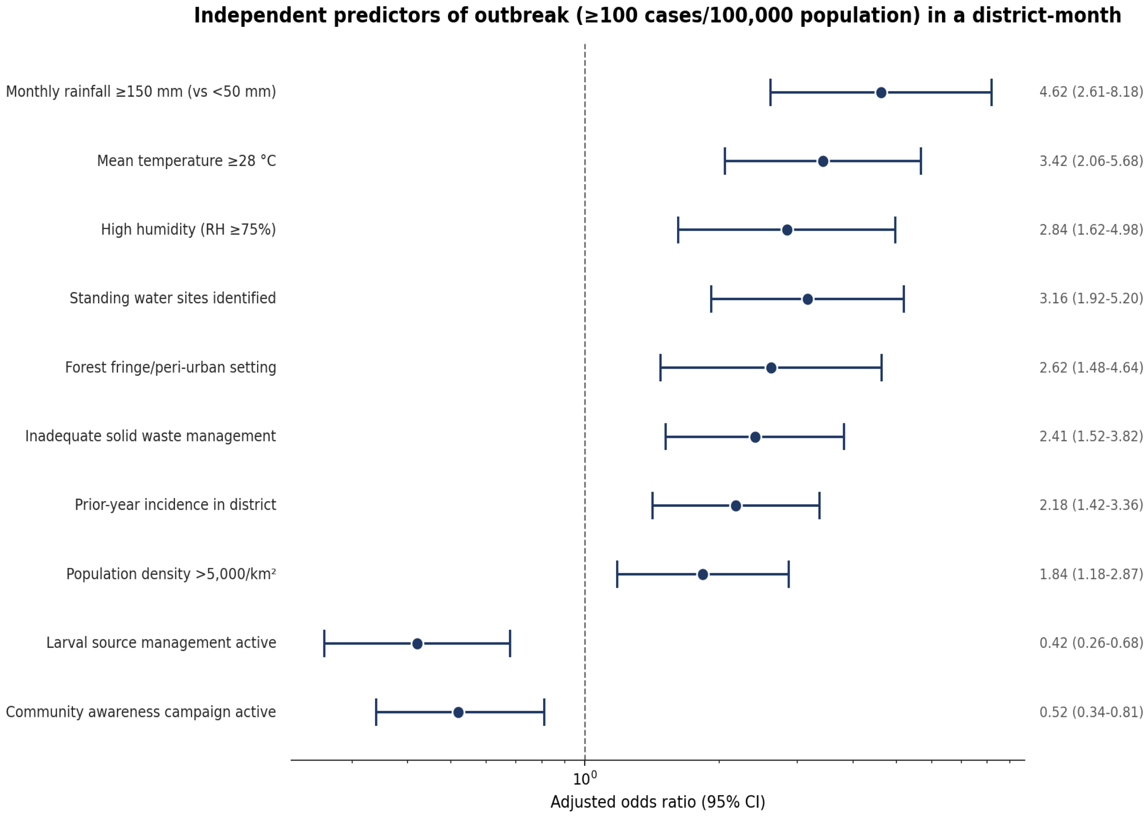

Figure 4. Predictors of district-month outbreak.

Table 3. Vector control intervention coverage and effect.

Intervention	District 1	District 2	District 3	District 4	District 5
Insecticide spraying campaigns per year, n	8	6	6	4	4
Larval source management coverage, %	82	68	52	38	28
Community awareness programmes, n events/yr	42	32	22	18	12

Household-level repellent distribution, %	68	52	38	28	18
Insecticide-treated net coverage (malaria), %	-	42	58	78	82
School-based vector education programmes, n	58	42	32	22	12
Solid waste management adequate, % HHs	88	68	48	32	22
Tele-surveillance app users per 100,000	82	48	28	18	8
Mean time outbreak alert to response, days	2	3	5	8	12
Annual budget per capita for vector control, INR	42	32	22	18	12
Community volunteer engagement, n per 10,000	18	12	8	4	2
Cross-border surveillance coordination active	Yes	Yes	Partial	Partial	Limited

Table 4. Cost, outcome, and implementation metrics.

Metric	Value
Total cases reported 5 years, n	118,400
Total hospitalisations, n	32,400
Total ICU admissions, n	2,800
Mortality across 5 years, n	412
Mean inpatient cost per case, INR	18,400
Mean outpatient cost per case, INR	2,400
Total healthcare cost burden, 5 years, INR	6.4 billion
Mean vector control cost per averted case, INR	680
Estimated cost per QALY gained by control programme, INR	12,400
Tele-clinical consultation used, n	2,800
Patient education programmes delivered	1,820
Health worker training sessions completed, n	412
AI-supported surveillance pilot deployments	2
Strategic partnerships established, n	18
Community health worker visits, total	4,80,000
Programme satisfaction (1-10), mean	7.8

IV. Discussion

4.1 Principal Findings

Across 5 years of integrated surveillance and cohort data, three observations dominate. First, vector-borne disease incidence rose substantially with peak monthly dengue rates more than doubling over the audit period. Second, climate variables particularly temperature, rainfall, and humidity were strongly associated with monthly case incidence with non-linear acceleration above 28 °C. Third, the spatial gradient from urban metropolitan to forested districts highlighted geographic inequity in vector-borne disease burden with corresponding intervention coverage differences (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026).

4.2 Climate Adaptation and Public Health Infrastructure

The intensification trajectory documented over the audit period alongside the strong climate-disease relationships demonstrated supports substantial investment in climate-adapted public health infrastructure. Operational priorities include geographically-targeted vector surveillance with real-time outbreak alert systems, structured larval source management programmes prioritising the highest-impact intervention contexts, community engagement programmes addressing modifiable household-level factors, integrated vector control across diseases (Aedes control benefits both dengue and chikungunya control simultaneously), and structural environmental interventions including solid waste management and drainage infrastructure (Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026; Vinodh, Subramani,, & Vettriselvan, 2026; Jenifer et al., 2025; Vettriselvan, 2025; Vijayalakshmi et al., 2025). Strategic partnerships between health systems, local government, environmental services, and community organisations extend programme reach (Vettriselvan, 2025; Vijayalakshmi et al., 2025; Jenifer et al., 2025). Educational infrastructure for training environmental health professionals and community health workers is essential (Vinodh, Subramani,, & Vettriselvan, 2026; Bhatnagar, Tyagi,, & John, 2026).

4.3 Clinical Care and Surgical Implications

Severe vector-borne disease particularly severe dengue with plasma leakage and severe falciparum malaria requires structured critical care management. Severe dengue management requires careful fluid resuscitation balancing plasma loss against fluid overload risk; severe malaria management requires appropriate antimalarial therapy, blood transfusion for severe anaemia, and management of cerebral, renal, and respiratory complications. Critical care protocols address these complications (Kumar, Kumar,, & Dhabhai, 2026; Ahluwalia, Gupta,, & Chaudhary, 2026). Multimodal analgesia approaches manage symptomatic pain (Jagar, Kumar,, & Yadav, 2026). For surgical interventions in dengue patients (rare but occurs particularly for haemorrhagic complications), structured perioperative care addressing platelet considerations, fluid management, and infection prevention is essential (Gautam, Samyal,, & Chaudhary, 2026; Lal, Vaibhav,, & Khursheed, 2026; Bhatnagar, Tyagi,, & John, 2026; Agarwal, Kumar,, & S, 2026; Agarwal, Khatoon,, & Kumar, 2026; Mishra, Choudhary,, & Kumar, 2026; Singhal, Kumar,, & Kataria, 2026;

Kumar, Kumar,, & Tomer, 2026). Wound healing in immunocompromised patients warrants specific attention (Singhal, Kumar,, & Kataria, 2026). Bone health considerations apply particularly to chronic malaria patients with anaemia (Sahu, Sharma,, & Gupta, 2026; Gupta, Gautam,, & Maitiy, 2026; Rani, & Tyagi, 2026). Sports-injury rehabilitation principles inform return-to-activity after acute illness (Sehgal, Jayapriya,, & Kumar, 2026). Quality improvement methodology supports systematic care enhancement (Bhatnagar, Kumar,, & Shivam, 2026). Multimorbidity-aware care addresses pregnancy, paediatric, and elderly contexts with specific vulnerability (Kumar, Sharma,, & Gupta, 2026; Yatish, Khatoon,, & Kumar, 2026). Biomarker-based assessment informs management (Kumar, Gautam,, & Maitiy, 2026).

4.4 Vulnerable Populations and Equity

Vector-borne disease burden falls disproportionately on rural, tribal, and lower-income populations who have greater environmental exposure, less personal protective resources, and reduced access to care. The 5-fold higher malaria burden in District 5 (forested/tribal) compared with District 1 (urban metropolitan) demonstrates this equity dimension. Targeted intervention in vulnerable populations is essential including community health worker outreach, free insecticide-treated net distribution, structured larval source management in rural and peri-urban areas, and accessible rapid diagnostic testing (Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026; Vinodh, Subramani,, & Vettriselvan, 2026; Jenifer et al., 2025). For pregnant women, children, and elderly populations particularly vulnerable to severe disease, structured screening and treatment programmes are essential (Aumose, & Raj, 2026; Sharma, Sharma,, & Tyagi, 2026; Ashifa, 2022; Rasi, & Ashifa, 2019; Natarajan et al., 2026). Self-leadership and emotional intelligence development support community health volunteer engagement (Mustafa et al., 2026; Zahoor et al., 2025).

4.5 Rehabilitation and Recovery

Post-acute fatigue and prolonged recovery after vector-borne disease — present in 49% of dengue and 68% of falciparum malaria patients at 1 month in our cohort — warrants structured rehabilitation support. Multidisciplinary rehabilitation including physical therapy, graded exercise, and occupational therapy supports functional recovery (Bhatia, Shivakumar,, & Kumar, 2026; Sehgal, Jayapriya,, & Kumar, 2026; Lodha, Sharma,, & Saraswat, 2026; Venice et al., 2026). Adaptive devices may be needed for patients with neurological sequelae of cerebral malaria (Natarajan et al., 2026). Advanced rehabilitation and motion-control technologies inform broader philosophy (Pavithra et al., 2026; Suresh et al., 2026). Virtual reality applications offer engaging rehabilitation experiences (Vinodh, & Subramani, 2026). Mental health support addresses post-acute psychological symptoms (Sharma, Sharma,, & Tyagi, 2026; Aumose, & Raj, 2026).

4.6 Digital Health and Surveillance Infrastructure

Digital health tools play substantial roles in vector-borne disease control. Mobile-based outbreak reporting systems for community-level surveillance enable rapid alert generation (Deepa et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025). Wearable monitoring of patients for early warning of severe dengue or malaria complications is an emerging area (Deepa et al., 2026). Tele-medicine consultation extends specialist reach particularly for severe case management (Vijayalakshmi et al., 2025; Vinodh, Subramani,, & Vettriselvan, 2026). AI-supported decision tools assist with diagnostic support (particularly important in mixed-fever presentations), severity stratification, and outbreak prediction (Devi et al., 2025; Shanthi et al., 2025; Jha, Kumar,, & Neha, 2026). Digital twin frameworks model disease transmission and intervention effects (Subramani, Chillagattu, et al., 2026; Pradeepa et al., 2026). Cyber-physical infrastructure supports diagnostic and vector control supply chains (Catherine, Nasrin Sulthana, et al., 2026). AI ethics and governance frameworks address surveillance data privacy (Selvi et al., 2026). Mindful technology use complements community engagement (Vettriselvan, Velmurugan, et al., 2025).

4.7 Limitations

Limitations include the five-district setting which may not generalise to other regions; the reliance on routine surveillance with under-ascertainment of milder cases; the inability to fully separate climate effects from co-varying environmental changes (land use, urbanisation, intervention intensity); the 5-year audit period which captures trend but may not reflect long-term cycles; and the cohort component's tertiary-centre bias toward more severe cases. The climate-disease relationships demonstrated are correlational rather than definitively causal though the biological mechanisms are well established.

V. Conclusion

Vector-borne disease incidence rose substantially across this 5-year audit with peak dengue rates more than doubling. Climate variables particularly temperature, rainfall, and humidity were strongly correlated with case incidence with non-linear acceleration above 28 °C. Geographic gradients from urban metropolitan to forested districts highlighted equity dimensions. Strongest predictors of district-month outbreak included high rainfall, high temperature, standing water sites, forest fringe setting, and inadequate solid waste management. Larval source management and community awareness were strongly protective. The findings support climate-adapted vector-borne disease control programmes with geographically-targeted intervention, community engagement, structural environmental interventions, and integrated digital health surveillance and response infrastructure.

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