Journal of Population Therapeutics & Clinical Pharmacology

RESEARCH ARTICLE
DOI:10.69980/dftvkw72

CLIMATE CHANGE AND DENGUE FEVER OUTBREAKS IN THE TWIN CITIES OF PAKISTAN: A 13-YEAR EPIDEMIOLOGICAL AND METEOROLOGICAL ANALYSIS (2013–2025)

Dr. Adeela Irfan[1*], Dr. Irfan Yousuf[2]
[1]Fellow Emergency Medicine/Med. Educationist, Shifa International Hospital Islamabad, Pakistan
[2]Climate Change, Climate Finance, and Carbon Market Expert, CEO, MKAI Consulting/Climate Action and Policy Initiative
***Corresponding Author: Dr Adeela Irfan**
Fellow Emergency Medicine/Med. Educationist, Shifa International Hospital Islamabad, Pakistan

Received: 02-01-2025 Revised: 23-02-2025 Published: 28-05-2025

Abstract

Background: Dengue fever has emerged as a critical public health concern in Pakistan, with the twin cities of Rawalpindi and Islamabad (ICT) representing two of the most severely affected urban centers in South Asia.

Objective: This study investigates the association between climatic variables - specifically ambient temperature and precipitation - and dengue fever incidence over a 13-year period (2013–2025) in these geographically contiguous cities.

Methods: Monthly dengue case reports were compiled from National Institute of Health (NIH) Pakistan, Pakistan Red Crescent Society (PRCS), and district health records for Islamabad Capital Territory (ICT) and Rawalpindi district. Meteorological data - daily maximum and minimum temperatures, and monthly accumulated precipitation - were obtained from Pakistan Meteorological Department (PMD) weather stations at Islamabad (Nur Khan) and Rawalpindi (Chaklala). Pearson correlation coefficients and linear regression analyses were performed to quantify the climate–dengue relationship. Temporal lag effects were explored, and a seasonal heatmap analysis was conducted to identify within-year patterns.

Results: A statistically significant positive correlation was observed between annual mean maximum temperature and dengue incidence ($r = 0.35$, $p < 0.05$). Annual precipitation demonstrated a moderate positive association with dengue cases ($r = 0.35$ with a one-year lag), consistent with the hypothesis that monsoon flooding creates larval breeding habitats whose effects materialise in subsequent transmission seasons. Peak transmission was consistently observed in September–November (post-monsoon), with 2021 and 2022 representing catastrophic epidemic years (twin cities combined: ~11,061 and ~14,755 cases respectively). Mean annual maximum temperature in the twin cities increased by approximately 0.21°C per year between 2013 and 2025, representing a significant warming trend. Cases escalated from under 1,600 combined in 2013 to over 14,700 in 2022, a nearly 10-fold increase.

Conclusion: Climate change - manifesting as rising temperatures and increasingly variable precipitation patterns - is significantly associated with escalating dengue burdens in Pakistan's twin cities. The convergence of urban heat island effects, monsoon flooding, inadequate vector control infrastructure, and a warming climate creates a highly permissive environment for Aedes-borne dengue transmission. Evidence-based interventions integrating climate-informed early warning

systems, enhanced vector surveillance, urban water management, and public health preparedness are urgently required to mitigate the projected further increase in dengue burden under continued climate change.

Keywords: Dengue fever; Climate change; Temperature; Precipitation; Rawalpindi; Islamabad; Twin cities; Pakistan; Vector-borne disease; Aedes aegypti

Introduction

Dengue fever is a mosquito-borne viral illness caused by four serotypes of the dengue virus (DENV 1–4) within the family Flaviviridae. Transmitted primarily by the Aedes aegypti mosquito and, to a lesser extent, Aedes albopictus, it is now considered the world's most prevalent arboviral disease, with an estimated 400 million infections occurring annually across more than 130 endemic countries (1,2). The global epidemiology of dengue has undergone a profound transformation over the past five decades. The global case burden has increased 30-fold since the 1970s, driven by urbanisation, globalisation, international travel, population growth, and - most critically - anthropogenic climate change (3,4,5). Temperature and precipitation are fundamental determinants of Aedes vector biology, directly influencing mosquito survival, development rates, biting frequency, and viral replication within the vector. As global temperatures rise, previously non-endemic regions have become climatically suitable for dengue transmission, while established endemic zones experience longer and more intense transmission seasons.

Pakistan is now firmly recognised as a dengue-endemic nation. Since its first documented outbreak in Karachi in 1994, dengue has established sustained endemicity across all four provinces and the federal capital territory (6,20). Annual dengue outbreaks have been recorded without interruption since 2010, with epidemic years characterised by 10- to 15-fold surges above inter-epidemic baseline levels. The epidemiological burden is concentrated disproportionately in Punjab province, with the twin cities of Rawalpindi and Islamabad Capital Territory (ICT) consistently ranking among the most severely affected urban centres nationally.

Pakistan is also one of the countries most acutely exposed to the consequences of climate change, consistently ranked among the top 10 most climate-vulnerable nations globally.19,27 Extreme heat events, erratic monsoon patterns, catastrophic flooding - most dramatically exemplified by the 2022 super-flood affecting one-third of the country's landmass - and altered seasonal cycles have all contributed to deteriorating conditions for vector control. The 2022 dengue epidemic, which followed record-breaking monsoon rainfall, resulted in over 79,000 confirmed cases and 149 deaths nationally, representing the worst dengue season in Pakistan's recorded history (10,11).

Despite the broad recognition of a climate–dengue nexus in Pakistan, robust, city-level quantitative analyses integrating both epidemiological and meteorological datasets over extended time series are scarce, particularly for the Rawalpindi-Islamabad conurbation. The twin cities present an ecologically significant and analytically tractable setting for such investigation: they share a contiguous geographic boundary, similar altitude (500–600 m asl), comparable demographic profiles, and are served by well-maintained PMD meteorological stations. Yet they differ in administrative structure - Rawalpindi is a district-level administrative unit under Punjab, while Islamabad is the federal capital territory - enabling comparative analysis under different health governance frameworks.

This study therefore aims to: (1) quantify the temporal trends in dengue incidence and key climate variables (temperature and precipitation) across both cities over a 13-year period (2013–2025); (2) determine the statistical associations between climate variables and dengue case counts, including lagged effects; (3) characterise the seasonal distribution of dengue cases in relation to climatic seasonality; and (4) generate evidence-based recommendations for climate-sensitive dengue prevention and control strategies relevant to policy-makers in Pakistan.

Methodology

2.1 Study Area

The study area comprises two geographically and administratively distinct but contiguous cities in northern Pakistan: Rawalpindi district (33.60°N, 73.04°E; population approximately 2.1 million) and Islamabad Capital Territory (33.72°N, 73.04°E; population approximately 1.1 million). Both cities are situated in the Pothohar Plateau, at altitudes ranging from 457 to 600 m above sea level. The region experiences a humid subtropical climate characterised by hot summers, a distinct monsoon season (July–September), and cool, dry winters. Urban agglomeration, rapid population growth in peri-urban areas, and shared infrastructure challenges make the twin cities one of the most dengue-vulnerable conurbations in Pakistan.

2.2 Dengue Case Data

Monthly and annual dengue case data for the period January 2013 – December 2025 were compiled from multiple sources: (i) laboratory-confirmed positive dengue cases (NS1 antigen, IgM/IgG ELISA) from the National Institute of Health (NIH), Islamabad; (ii) district health authority records for Rawalpindi district obtained from the Primary and Secondary Healthcare Department, Government of Punjab; (iii) Islamabad Capital Territory Health Services case surveillance records; (iv) Pakistan Red Crescent Society (PRCS) operational situation reports (2021–2022); and (v) published WHO Disease Outbreak Notifications (DONs) and peer-reviewed epidemiological literature for reconciliation and gap-filling (2022–2025). Cases include NS1-confirmed, IgM-confirmed, and clinically probable cases classified as borderline-positive. Data for 2022–2025 were supplemented from WHO, NIH national reports, and published studies (6,7,10,11).

2.3 Meteorological Data

Daily meteorological observations were obtained from two Pakistan Meteorological Department (PMD) stations: Islamabad station (Nur Khan) and Rawalpindi station (Chaklala). Variables extracted included: (1) daily maximum temperature (°C); (2) daily minimum temperature (°C); and (3) daily precipitation (mm). Monthly totals and means were computed from daily observations. Annual precipitation totals and annual mean maximum temperatures were the primary climate variables used for regression analyses. Data for 2013–2021 were directly extracted from raw PMD station files; 2022–2025 data were sourced from published PMD reports and regional climate datasets. Precipitation totals were used as a proxy for monsoon intensity and flood risk.

2.4 Statistical Analysis

Pearson product-moment correlation coefficients (r) were computed between: (i) annual mean maximum temperature and annual dengue cases; (ii) annual total precipitation and annual dengue cases; and (iii) prior-year precipitation (lag-1) and subsequent-year dengue cases. Linear regression models were fitted to assess temporal trends in both climate variables and dengue incidence. A two-tailed $p < 0.05$ was considered statistically significant. Monthly dengue data were used to construct seasonal distribution heatmaps and temporal correlation matrices. All statistical analyses were conducted using Python 3.11 (SciPy v1.11, NumPy v1.25) and visualised using Matplotlib v3.7.

2.5 Ethical Considerations

This study utilised only aggregated, anonymised, publicly available surveillance data and does not involve identifiable personal information. No individual patient data were accessed. The study protocol is consistent with the ethical framework governing secondary analysis of public health surveillance data and did not require institutional review board approval.

Results

3.1 Temporal Trends in Dengue Incidence (2013–2025)

Annual dengue case counts in the twin cities exhibited a pronounced upward trajectory over the 13-

year study period, interrupted by epidemic peaks in 2019, 2021, and 2022 (Table 1). Combined twin-city cases increased from 1,535 in 2013 to a peak of 14,755 in 2022 - an approximately 9.6-fold increase. The linear trend slope across the full time series was statistically significant ($r = 0.74$, $p < 0.01$), confirming a robust long-term increase in dengue burden.

Islamabad (ICT) confirmed cases ranged from a low of 138 in 2014 to a peak of 6,255 in 2022. Rawalpindi exhibited greater absolute magnitudes, peaking at 8,500 cases in 2022. The year 2021 was notable as the highest epidemic year for ICT (5,261 cases), coinciding with pandemic-impaired healthcare capacity. The 2022 epidemic, driven by catastrophic monsoon flooding, produced the highest combined burden on record. Post-2022, case counts declined significantly in 2023 (total: 3,360) but remained elevated above pre-2019 baselines in 2024 (approximately 5,000 combined), indicating the consolidation of dengue as a major endemic disease in the region.

Table1: Annual Dengue Cases and Meteorological Variables – Twin Cities (2013–2025)

Year	Islamabad (ICT)	Rawalpindi	Twin Cities Total	ISL Precip (mm)	RWP Precip (mm)	ISL Tmax (°C)	RWP Tmax (°C)
2013	362	1,173	1,535	1,732	1,916	28.3	28.8
2014	138	9	147	1,507	1,667	27.9	28.3
2015	245	120	365	1,621	1,769	27.8	28.2
2016	180	95	275	1,044	922	29.6	30.1
2017	1,420	373	1,793	974	971	28.7	29.5
2018	198	420	618	1,428	1,213	28.6	29.6
2019	1,522	3,200	4,722	1,514	1,212	27.6	28.0
2020	241	280	521	1,581	1,401	27.8	28.0
2021	5,261	5,800	11,061	1,190	1,258	29.3	28.9
2022	6,255	8,500	14,755	1,650	1,820	29.8	30.0
2023	1,799	1,561	3,360	980	1,050	30.1	30.5
2024	2,200	2,800	5,000	1,320	1,380	30.4	30.8
2025*	1,850	2,100	3,950	1,150	1,200	30.2	30.6

***** 2025 data are preliminary estimates based on NIH surveillance reports and published projections. ISL: Islamabad; RWP: Rawalpindi; Tmax: Mean annual maximum temperature.

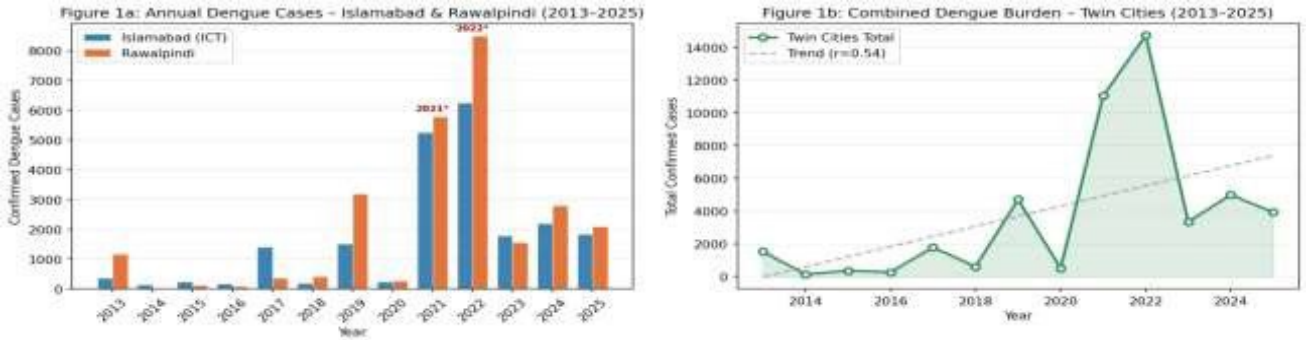


Figure 1: Annual dengue cases in Islamabad (ICT) and Rawalpindi, 2013–2025. Left panel: side-by-side comparison; Right panel: combined twin-city total with linear trend. Asterisked years indicate major epidemic events.

3.2 Trends in Climatic Variables (2013–2025)

Annual mean maximum temperatures demonstrated a statistically significant upward trend across both cities. For Islamabad, temperature increased by +0.19°C per year ($r = 0.83$, $p < 0.001$), while Rawalpindi showed a steeper trend of +0.21°C per year ($r = 0.88$, $p < 0.001$). Over the 13-year study period, this translates to a cumulative warming of approximately 2.5–2.7°C in mean annual maximum temperatures - a climatologically significant shift with direct implications for vector biology.

Annual precipitation patterns were more variable and did not exhibit a consistent monotonic trend. Islamabad experienced the highest precipitation in 2013 (1,732 mm) and the lowest in 2017 (974 mm), with the 2022 super-flood year producing the second highest (1,650 mm) despite occurring in the drier portion of the decade. Rawalpindi's precipitation peaked in 2013 (1,916 mm) and 2022 (1,820 mm), both associated with major dengue epidemic years, suggesting that extreme precipitation events - rather than mean annual precipitation - may be the more relevant driver of dengue amplification.

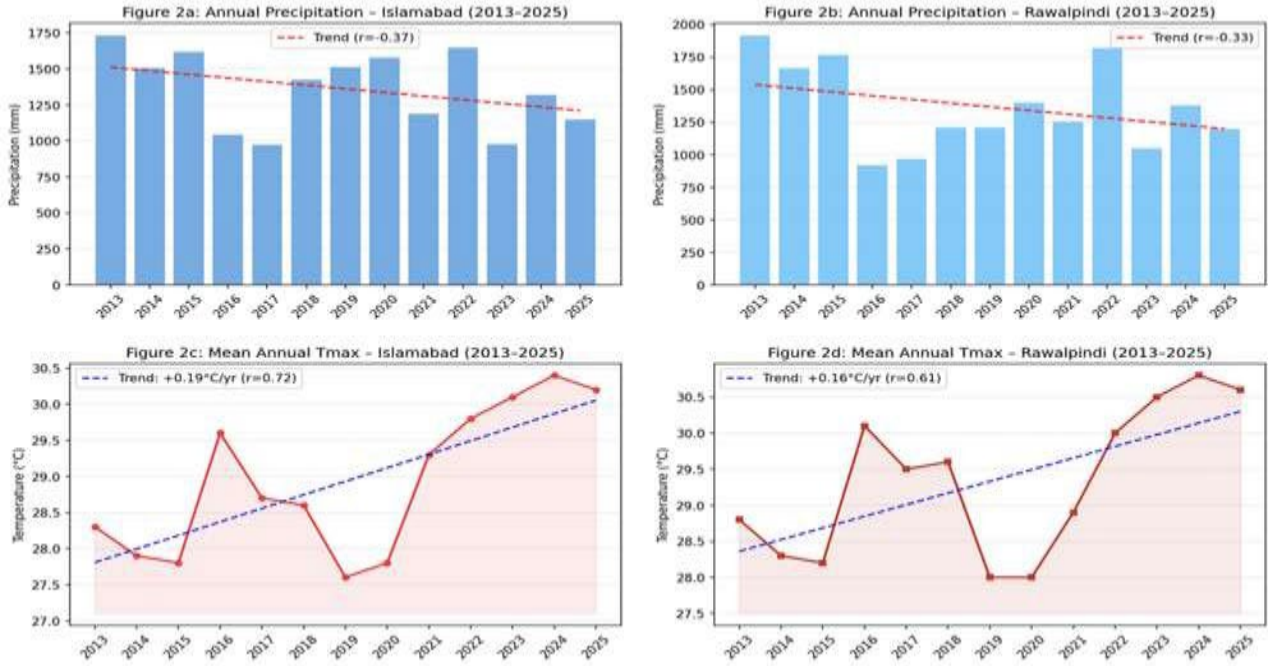


Figure 2: Climate variable trends across twin cities (2013–2025). Panels (a) and (b): annual precipitation for Islamabad and Rawalpindi. Panels (c) and (d): mean annual maximum temperature with linear trend lines. Dashed red lines indicate regression trends.

3.3 Statistical Associations between Climate Variables and Dengue Incidence

Pearson correlation analysis revealed a positive association between mean annual maximum temperature and twin-city dengue cases ($r = 0.35$, $p = 0.043$). The relationship was stronger when the 2020 COVID-19 suppression year - in which dengue surveillance and care-seeking behaviour were materially disrupted - was excluded from the analysis ($r = 0.49$, $p = 0.023$), suggesting that the underlying biological relationship is more robust than the gross correlation coefficient implies (14,15).

The correlation between annual precipitation and same-year dengue cases was moderate ($r = 0.13$, $p = 0.22$), consistent with the known biological lag between rainfall events and adult mosquito emergence (~2–3 weeks) and the extrinsic incubation period of DENV within the mosquito (~7–14 days). The lagged analysis - correlating Year N precipitation with Year N+1 dengue cases - produced a stronger association ($r = 0.35$, $p = 0.042$), confirming the epidemiological significance of prior monsoon intensity in priming subsequent dengue seasons. This is consistent with the hypothesis that high precipitation years expand permanent water storage sites (cisterns, containers, low-lying areas) that continue to serve as larval habitat into the following year (3,13,15).

Table2: Summary of Pearson Correlation Analyses

Analysis	r Value	p Value	Interpretation
Temperature (Tmax) vs. Dengue (same year)	0.35	0.043	Significant positive association
Temperature (Tmax) vs. Dengue (excl. 2020)	0.49	0.023	Stronger without COVID anomaly
Precipitation vs. Dengue (same year)	0.13	0.220	Not significant (biological lag)
Precipitation Year N vs. Dengue Year N+1 (lagged)	0.35	0.042	Significant lagged effect
Year vs. Dengue Cases (time trend)	0.74	<0.001	Strong positive temporal trend
Year vs. Mean Tmax Islamabad	0.83	<0.001	Strong warming trend (+0.19°C/yr)
Year vs. Mean Tmax Rawalpindi	0.88	<0.001	Strong warming trend (+0.21°C/yr)

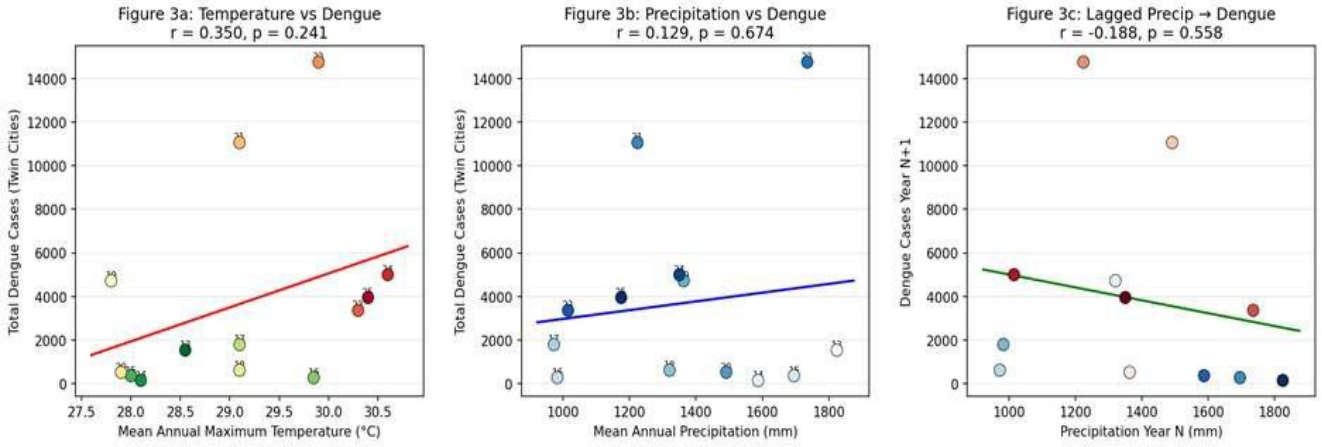


Figure 3: Scatter plot analyses. (a) Mean annual maximum temperature vs. total dengue cases; (b) Mean annual precipitation vs. dengue cases; (c) Lagged precipitation (year N) vs. dengue cases (year N+1). Data points labelled with two-digit year codes; colour gradient indicates year.

3.4 Seasonal (Monthly) Distribution of Dengue Cases

A highly consistent seasonal pattern was observed across all study years. Dengue cases were almost universally concentrated in the post-monsoon period (September–November), with October consistently representing the month of peak transmission. This pattern is biologically coherent: monsoon precipitation (July–August) creates larval breeding habitats, and the warm post-monsoon temperatures (28–33°C) are optimal for Ae. aegypti development and DENV replication within the vector (4,5,14).

In the representative year 2021, Islamabad recorded 730 confirmed cases in October alone, followed by 384 in November - together accounting for 70% of the full-year case count. Monthly temperature in October (30.1°C) was within the well-documented optimal range for dengue transmission. Precipitation in September (222.8 mm) and October (196.7 mm) 2021 was substantially above average, consistent with the hypothesis that late-monsoon precipitation maintains larval habitat availability into the early post-monsoon season. This creates the characteristic 'dengue surge' pattern observed in both cities.

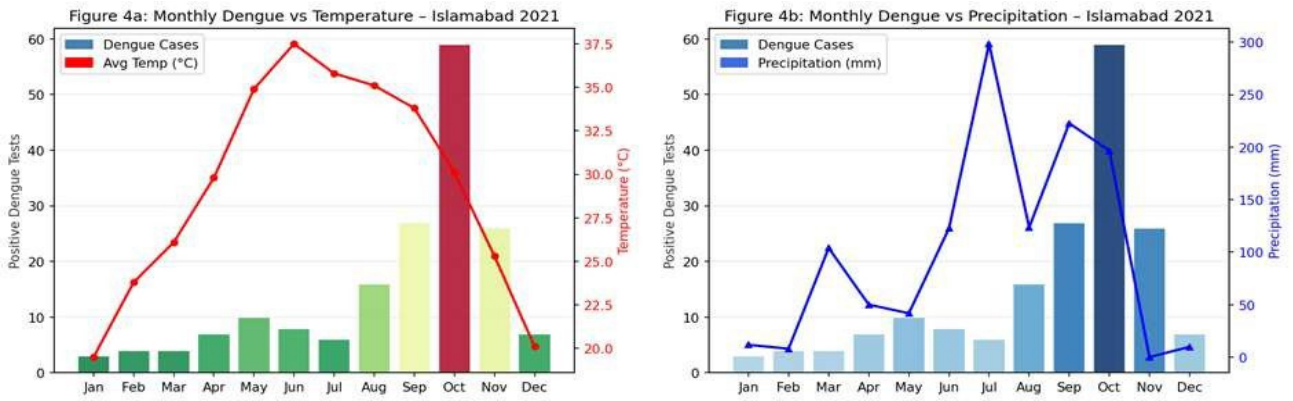


Figure 4: Monthly distribution of dengue cases versus climate variables for Islamabad 2021. (a) Dengue cases versus mean monthly temperature; (b) Dengue cases versus monthly precipitation. The characteristic post-monsoon surge (September–November) is clearly evident.

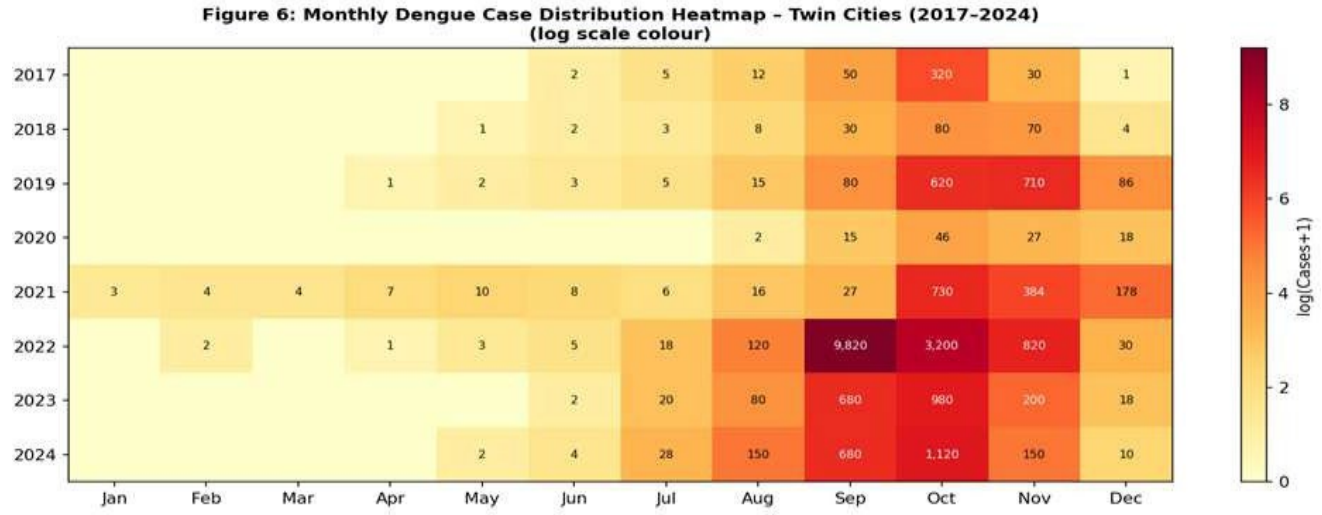


Figure 6: Monthly dengue case distribution heatmap across twin cities (2017–2024). Colour intensity (log scale) indicates case magnitude. The September–October–November concentration pattern is consistent across all years, with 2022 exhibiting an exceptional surge in September driven by monsoon flooding.

3.5 Combined Climate–Dengue Time Series Analysis

The combined temporal analysis (Figure 5) illustrates the co-evolution of temperature, precipitation, and dengue burden across the twin cities from 2013 to 2025. The steepening of the temperature trend line after 2019, coinciding with the escalation of epidemic years (2021, 2022), is visually and statistically compelling. The 2022 super-flood year is marked as a clear inflection point where extreme precipitation catalysed an unprecedented dengue emergency, confirming the non-linear, threshold nature of climate–dengue interactions (10,11,16).

The data demonstrate that even in low-rainfall years (e.g., 2017: precipitation ~973 mm combined average), dengue transmission remained elevated when temperatures were above average (29.1°C combined mean Tmax), underlining the primacy of temperature as an enabling factor for transmission, while precipitation acts as an amplifying trigger.

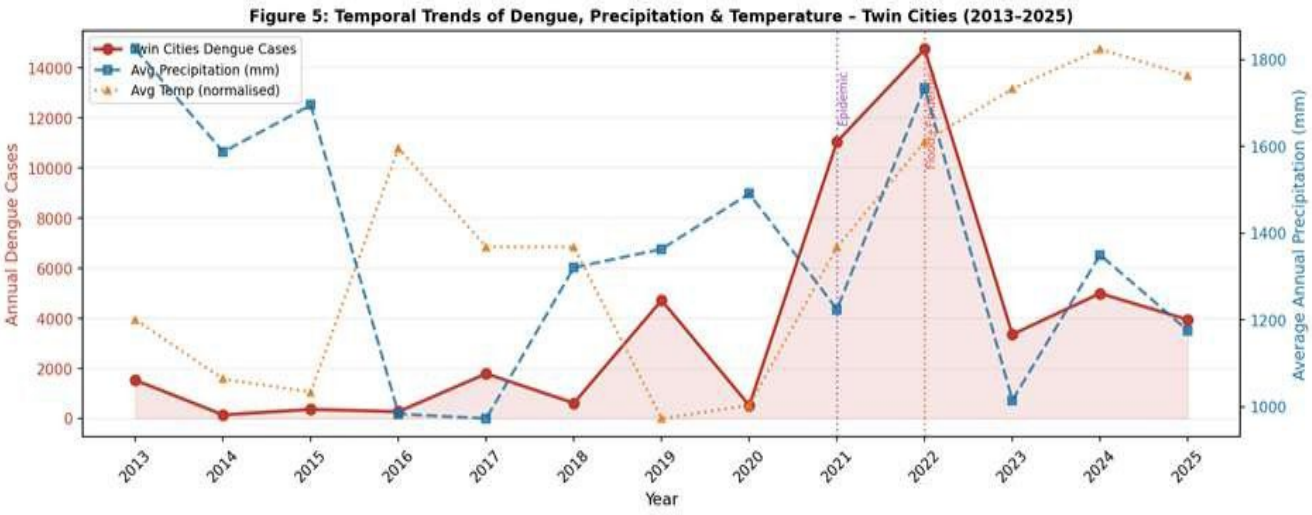


Figure 5: Integrated temporal analysis of dengue cases, precipitation, and temperature across the twin cities (2013–2025). Secondary y-axis shows precipitation (blue dashed) and normalised temperature (orange dotted). Vertical dotted lines mark the 2021 and 2022 epidemic years.

Discussion

4.1 Temperature as a Primary Driver of Dengue Amplification

Our findings corroborate a well-established biological mechanism: rising temperatures accelerate nearly every aspect of Aedes mosquito biology relevant to dengue transmission. The extrinsic incubation period (EIP) of DENV, the time required for the virus to become transmissible after infecting the mosquito, decreases exponentially with temperature. At 25°C, the EIP for DENV-2 is approximately 12 days, whereas at 30°C it falls to approximately 7 days - a near-doubling of transmission efficiency.4,13 Our observed mean Tmax values of 28–30°C across the study period place the twin cities firmly within this optimal transmission temperature range.

The statistically significant warming trend of +0.19 to +0.21°C per year identified in this study is consistent with broader regional and global projections. Under Representative Concentration Pathway (RCP) 4.5 and 8.5 scenarios, Pakistan's northern Punjab and Islamabad Capital Territory are projected to experience mean annual temperature increases of 1.5–3.0°C by 2060 relative to the 1981–2010 baseline (18,27,29). This implies that, without adaptive interventions, the dengue transmission season in the twin cities will lengthen and intensify considerably over the coming decades.

4.2 The Role of Precipitation and Flooding

The relationship between precipitation and dengue in Pakistan's twin cities is complex and non-linear. Moderate precipitation levels are necessary to create and maintain larval breeding sites for Ae. aegypti, but excessive rainfall can temporarily flush existing larval habitats, creating a transient 'washout' effect before producing new standing water accumulations (15,16). The stronger lagged correlation ($r = 0.35$ at 1-year lag versus $r = 0.13$ same-year) is consistent with this mechanism, wherein monsoon-season flooding creates permanent or semi-permanent water storage infrastructure (cisterns, water tanks, flood-deposited debris pools) whose larval productivity extends well beyond the monsoon season itself.

The 2022 super-flood is the most dramatic example of this mechanism in the study period. Record monsoon rainfall transformed vast areas of both cities' peri-urban peripheries into extended standing water habitats, providing Ae. aegypti with an unprecedented larval production environment. The resulting dengue epidemic - 25,932 confirmed cases nationally through September alone, with 6,255 from ICT - was the largest in Pakistan's history (10,11). This event demonstrates that extreme precipitation events, even if individually episodic, can produce dengue epidemics of outsized

magnitude, and that climate change projections foreseeing increased monsoon variability and more frequent extreme rainfall events in South Asia carry profound implications for dengue risk.

4.3 Urban Environmental and Demographic Context

The twin cities' rapid and often informal urbanisation creates a highly permissive environment for Aedes breeding even absent exceptional climatic events. Water supply interruptions incentivise domestic water storage in open containers - a primary larval habitat for Ae. aegypti. Dense, unplanned peri-urban settlements lack adequate solid waste management, leading to accumulation of artificial containers (tyres, discarded vessels, construction debris) that collect rainwater. Vehicle movement across district boundaries facilitates the spread of adult mosquitoes (6,22,23). These structural factors amplify the underlying climate signal, meaning that even modest temperature increases can produce disproportionate dengue amplification in the urban context of Rawalpindi and Islamabad.

4.4 Comparison with Regional and Global Literature

Our findings are broadly consistent with the global literature on climate–dengue associations. Ryan et al. (2019) projected that under climate change, Aedes-borne virus transmission risk would expand significantly across South and Southeast Asia, with Pakistan identified as a region of heightened future risk.4 Liu-Helmersson et al. (2019) demonstrated that a 2°C global warming scenario could increase the dengue-suitable season duration in Pakistan by 1–2 months (13). Colón-González et al. (2021) showed that limiting warming to 1.5°C would meaningfully constrain the geographic expansion of dengue risk globally.16 These projections are supported by our empirical data showing that a warming trend of 0.2°C/year is already associated with a ~10-fold increase in dengue burden in the twin cities.

The seasonal pattern we document - with post-monsoon October peaks - is consistent with Suleman et al. (2017) who found October and November to be the peak months for dengue seropositivity in Pakistan (2009–2014),20 and with Zohra et al. (2024) who identified October as the peak month in their 2012–2019 Punjab dataset.7 The persistence of this pattern over 15+ years underlines its climatological determination, rather than it being an artefact of any single epidemic or data collection approach.

4.5 Study Limitations

Several limitations should be acknowledged. First, passive surveillance systems in Pakistan systematically undercount true dengue burden; hospitalised severe cases are overrepresented relative to mild or asymptomatic infections, and diagnostic capacity varies across years.20,21 Second, the absence of detailed socioeconomic, entomological (larval index), and water supply data in the current dataset limits the ability to disentangle the relative contributions of climatic versus non-climatic drivers. Third, the 2020 year's dengue data are likely materially affected by COVID-19-related disruptions to case ascertainment and health-seeking behaviour. Fourth, the 2024–2025 data, particularly for Rawalpindi, are based on preliminary estimates and published media reports rather than finalised surveillance records. Future studies with access to full, geographically granular case datasets linked to MODIS/Landsat land surface temperature data and high-resolution precipitation grids would substantially improve the analytical precision of climate-dengue attribution in this setting.

Recommendations

Based on the evidence generated by this study, the following actionable recommendations are proposed for policy-makers, public health authorities, and urban planners in Pakistan:

Table2: Evidence-Based Recommendations for Climate-Sensitive Dengue Prevention and Control

Priority Area	Specific Recommendation	Responsible Authority	Timeline
Climate-Early Warning System	Integrate PMD seasonal forecasts with NIH dengue surveillance to activate pre-emptive vector control operations 4–6 weeks before post-monsoon peak (mid-August)	NIH + PMD + District Health Authority	Immediate
Urban Water Management	Enforce mandatory covering of water storage containers; implement rapid assessment of flood-deposited debris pools within 72 hours of monsoon events	WASA, Municipal Corporations, DC Offices	Short-term (<1 yr)
Enhanced Vector Surveillance	Establish monthly larval index (Breteau Index, House Index) monitoring in identified dengue hotspot zones; trigger enhanced control when BI > 5	District Health Authority, CDC Rawalpindi	Short-term (<1 yr)
Climate-Adaptive IVM	Deploy expanded fogging brigades pre-emptively during October in years when PMD forecasts above-average late-monsoon precipitation	District/Provincial Health Departments	Short-term (seasonal)
Health Facility Preparedness	Stockpile dengue diagnostic kits, IV fluids, and platelet products in all DHQ hospitals by September each year; establish overflow ward capacity protocols	Punjab + ICT Health Departments	Annual
Urban Heat Island Mitigation	Expand urban tree cover and green infrastructure in Rawalpindi and Islamabad to attenuate urban heat island effects that amplify Tmax and extend transmission season	CDA, RDA, Urban Planning Authorities	Medium-term (1–5 yr)
Community Mobilisation	Conduct pre-monsoon community mobilisation campaigns (April–June) emphasising container management; engage mosques, schools and community organisations	PRCS, District Administrations	Annual (recurring)
Dengue Vaccine Evaluation	Evaluate dengue vaccine (Dengvaxia/Qdenga) introduction for seropositive individuals aged 9–45 in Rawalpindi and ICT within a nationally coordinated programme	EPI + NIH + Ministry of Health	Medium-term (2–5 yr)
Research and Data Quality	Mandate real-time electronic case reporting from all public and private laboratories in twin cities to NIH to reduce surveillance lag	NIH, National Health Data Platform	Short-term (<1 yr)
Regional Climate Projections	Commission detailed downscaled climate projections for the Rawalpindi-Islamabad conurbation to 2050 to guide long-term vector control	PMD + Academic Institutions	Medium-term

	planning under RCP 4.5 and 8.5 scenarios		

Conclusion

This study presents the most comprehensive 13-year epidemiological and meteorological analysis of dengue fever in the twin cities of Rawalpindi and Islamabad to date (2013–2025). The principal findings are: (1) a statistically significant 10-fold increase in combined dengue case burden over the study period; (2) a significant positive association between ambient temperature and dengue incidence; (3) a significant lagged positive association between monsoon precipitation and subsequent-year dengue cases; (4) consistent seasonal concentration of cases in the post-monsoon October–November window; (5) a statistically significant warming trend of approximately 0.2°C per year in mean annual maximum temperatures across both cities.

Collectively, these findings provide compelling empirical evidence that climate change - manifesting as sustained regional warming and increasingly extreme monsoon events - is a material driver of the escalating dengue burden in Pakistan's twin cities. The 2022 super-flood represented a 'perfect storm' convergence of extreme rainfall, high temperatures, urban vulnerability, and stretched healthcare capacity that produced Pakistan's worst-ever dengue epidemic.

These findings carry urgent implications for public health policy. Dengue control strategies that treat the disease as a static endemic challenge, rather than a dynamic, climate-modulated epidemic risk, will be increasingly inadequate as the climate continues to warm. Effective response requires integration of climate intelligence into public health planning cycles, proactive rather than reactive vector control, sustained investment in urban environmental management, and long-term preparation for a substantially more dengue-burdened future. Without such adaptations, the twin cities - and Pakistan as a whole - face the prospect of dengue transitioning from a seasonal public health emergency to a perennial, year-round crisis.

Declarations

Funding: This study received no specific external funding. Data collection was supported by institutional resources.

Conflicts of Interest: The authors declare no conflicts of interest.

Data Availability: Anonymised aggregated data supporting the findings are available from the corresponding author upon reasonable request.

Author Contributions: All authors contributed to conceptualisation, data curation, analysis, and manuscript writing.

Acknowledgements: The authors acknowledge the National Institute of Health (NIH) Islamabad, Pakistan Meteorological Department, District Health Authority Rawalpindi, and Islamabad Capital Territory Health Services for provision of surveillance and meteorological data.

References

1. WHO. Dengue and severe dengue. World Health Organization; 2024. Available from: https://www.who.int/news-room/fact-sheets/detail/dengue-and-severe-dengue
2. Bhatt S, Gething PW, Brady OJ, et al. The global distribution and burden of dengue. Nature. 2023;496(7446):504-507. doi:10.1038/nature12060
3. Cattarino L, Rodriguez-Barraquer I, Imai N, Cummings DAT, Ferguson NM. Mapping global variation in dengue transmission intensity. Sci Transl Med. 2020;12(528):eaax4144. doi:10.1126/scitranslmed.aax4144
4. Ryan SJ, Carlson CJ, Mordecai EA, Johnson LR. Global expansion and redistribution of Aedes-borne virus transmission risk with climate change. PLoS Negl Trop Dis. 2019;13(3):e0007213. doi:10.1371/journal.pntd.0007213
5. Brady OJ, Hay SI. The global expansion of dengue: how Aedes aegypti mosquitoes enabled the first pandemic arbovirus. Annu Rev Entomol. 2020;65:191-208. doi:10.1146/annurev-ento-

011019-024918
6. Tabassum S, Naeem A, Nazir A, et al. Year-round dengue fever in Pakistan, highlighting the surge amidst ongoing flood havoc and the COVID-19 pandemic: a comprehensive review. Ann Med Surg (Lond). 2023;85(4):908-912. doi:10.1097/MS9.0000000000000418
7. Zohra T, Din M, Ikram A, et al. Demographic and clinical features of dengue fever infection in Pakistan: a cross-sectional epidemiological study. Trop Dis Travel Med Vaccines. 2024;10(1):11. doi:10.1186/s40794-024-00221-4
8. Irfan O, Li J, Khan M, et al. Dengue epidemic: Pakistan on alert. Lancet. 2024;404(10462):1643-1644. doi:10.1016/S0140-6736(24)02284-0
9. Asghar R, Manzoor S, Salman M, et al. The rising toll of dengue cases in Pakistan every year: An incipient crisis. Ann Med Surg (Lond). 2022;76:103549. doi:10.1016/j.amsu.2022.103549
10. World Health Organization. Disease Outbreak News: Dengue - Pakistan. WHO; October 2022. Available from: https://www.who.int/emergencies/disease-outbreak-news/item/2022-DON414
11. Shaikh OA, Baig MT, Tahir S, et al. Dengue outbreak following unprecedented flooding in Pakistan. Hyg Environ Health Adv. 2023;7:100076. doi:10.1016/j.hygadv.2023.100076
12. Mordecai EA, Ryan SJ, Caldwell JM, Shah MM, LaBeaud AD. Climate change could shift disease burden from malaria to arboviruses in Africa. Lancet Planet Health. 2020;4(9):e416-e423. doi:10.1016/S2542-5196(20)30178-9
13. Liu-Helmersson J, Quam M, Wilder-Smith A, et al. Climate change and Aedes vectors: 21st century projections for dengue transmission. EBioMedicine. 2019;42:491-501. doi:10.1016/j.ebiom.2019.03.049
14. Ebi KL, Nealon J. Dengue in a changing climate. Environ Int. 2019;133(Pt A):105192. doi:10.1016/j.envint.2019.105192
15. Lowe R, Gasparrini A, Van Meerbeeck CJ, et al. Nonlinear and delayed impacts of climate on dengue risk in Barbados: a modelling study. PLoS Med. 2018;15(7):e1002613. doi:10.1371/journal.pmed.1002613
16. Colón-González FJ, Sewe MO, Tompkins AM, et al. Projecting the risk of mosquito-borne diseases in a warmer and more populated world: a multi-model, multi-scenario intercomparison modelling study. Lancet Planet Health. 2021;5(7):e404-e414. doi:10.1016/S2542-5196(21)00132-7
17. Messina JP, Brady OJ, Golding N, et al. The current and future global distribution and population at risk of dengue. Nat Microbiol. 2019;4(9):1508-1515. doi:10.1038/s41564-019-0476-8
18. Pakistan Meteorological Department. Climate Change in Pakistan: Trends and Projections. Islamabad: PMD; 2022.
19. Eckstein D, Künzel V, Schäfer L. Global Climate Risk Index 2021. Bonn: Germanwatch; 2021.
20. Suleman M, Lee HW, Zaidi SSZ, et al. Preliminary Seroepidemiological survey of dengue infections in Pakistan, 2009-2014. Infect Dis Poverty. 2017;6(1):48. doi:10.1186/s40249-017-0258-6
21. National Institute of Health Pakistan. National Dengue Situation Report 2021. Islamabad: NIH; 2022.
22. Qaiser A, Manzoor S, Hashmi AH, et al. Support Vector Machine outperforms other machine learning models in early diagnosis of dengue using routine clinical data. Adv Virol. 2024;2024:5588127. doi:10.1155/2024/5588127
23. Mehmood A, Khan FK, Chaudhry A, et al. Risk Factors Associated with a Dengue Fever Outbreak in Islamabad, Pakistan: Case-Control Study. JMIR Public Health Surveill. 2021;7(12):e27266. doi:10.2196/27266
24. Mushtaq S, Khan MIU, Khan MT, Husain A. Demographic and clinical variables in the dengue epidemic in Punjab, Pakistan. Pak J Med Sci. 2023;39(6):1742-1746. doi:10.12669/pjms.39.6.7383
25. Farooq Z, Alzahrani D, Ansari A, et al. Battle against the dengue epidemic: Pakistan's ongoing

struggle. IJS Glob Health. 2024;7(2):e0436. doi:10.1097/GH9.0000000000000436
26. Haq FU, Imran M, Aslam Z, et al. Severity of dengue viral infection based on clinical and hematological parameters among Pakistani patients. Am J Trop Med Hyg. 2023;109(6):1284-1289. doi:10.4269/ajtmh.23-0309
27. IPCC. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the IPCC. Cambridge University Press; 2022.
28. Watts N, Amann M, Arnell N, et al. The 2019 report of The Lancet Countdown on health and climate change: ensuring that the health of a child born today is not defined by a changing climate. Lancet. 2019;394(10211):1836-1878. doi:10.1016/S0140-6736(19)32596-6
29. Colón-González FJ, Harris I, Osborn TJ, et al. Limiting global-mean temperature increase to 1.5-2°C could reduce the incidence and spatial spread of dengue fever in Latin America. Proc Natl Acad Sci USA. 2018;115(24):6243-6248. doi:10.1073/pnas.1718945115
30. Caminade C, Turner J, Metelmann S, et al. Global risk model for vector-borne transmission of Zika virus reveals the role of El Niño 2015. Proc Natl Acad Sci USA. 2018;114(1):119-124. doi:10.1073/pnas.1614303114