



Climatic Determinants of Vector-Borne Disease Transmission in Eastern Uttar Pradesh: Evidence from Temperature, Rainfall and Humidity

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Abstract : Vector-borne diseases (VBDs) in Eastern Uttar Pradesh display pronounced seasonal and spatial variation shaped by the interaction of climatic and ecological conditions. This paper examines temperature, rainfall and relative humidity as major climatic determinants of malaria, dengue and Japanese encephalitis (JE), using climatic normals for 1991–2020 and disease surveillance data from NCVBDC. The analysis combines monthly and district-level climatic data, disease seasonality, climate–disease correlations and lag relationships. Mean monthly temperature rises from 15.8°C in January to 32.5°C in May, while rainfall is strongly concentrated from June to September and relative humidity exceeds 80% during July–September. Disease occurrence follows this climatic rhythm but with disease-specific timing: malaria and JE intensify during the monsoon, whereas dengue peaks later in the post-monsoon period. The correlation matrix reports strong positive associations of rainfall with malaria ($r=0.888$) and JE ($r=0.970$), and positive associations of humidity with malaria ($r=0.749$), dengue ($r=0.672$) and JE ($r=0.704$). Lag analysis further indicates that rainfall-related disease peaks occur approximately one to two months after climatic exposure. These findings show that climate operates through temporally delayed and disease-specific pathways rather than as an instantaneous determinant. The paper argues for climate-informed surveillance, pre-monsoon preparedness and geographically differentiated vector-control strategies in Eastern Uttar Pradesh.

IndexTerms - climate variability; vector-borne diseases; malaria; dengue; Japanese encephalitis; temperature; rainfall; relative humidity; Eastern Uttar Pradesh; GIS

1. Introduction

Climate-sensitive vector-borne diseases represent an important public-health challenge in Eastern Uttar Pradesh, where monsoonal rainfall, high seasonal humidity, flood-prone plains, irrigated agriculture and dense settlements create favourable conditions for mosquito vectors. Temperature influences vector development, biting activity and pathogen incubation; rainfall creates and replenishes breeding habitats; and humidity affects adult mosquito survival and longevity. Their effects are interdependent and frequently delayed, making the climate–disease relationship seasonal rather than static.

The paper identifies malaria, dengue and Japanese encephalitis as the principal diseases for detailed investigation and analyses their relationship with climatic variability over a thirty-year period. The regional climatic record shows increasing minimum-temperature tendencies, substantial rainfall variability and a pronounced monsoon humidity maximum. At the same time, disease surveillance shows a broad June–November risk period, with different diseases reaching their peaks at different points within and after the monsoon.

This paper isolates the climatic component and focuses specifically on three variables—temperature, rainfall and relative humidity—to evaluate how their seasonal and spatial patterns correspond with the timing of malaria, dengue and JE transmission.

2. Objectives

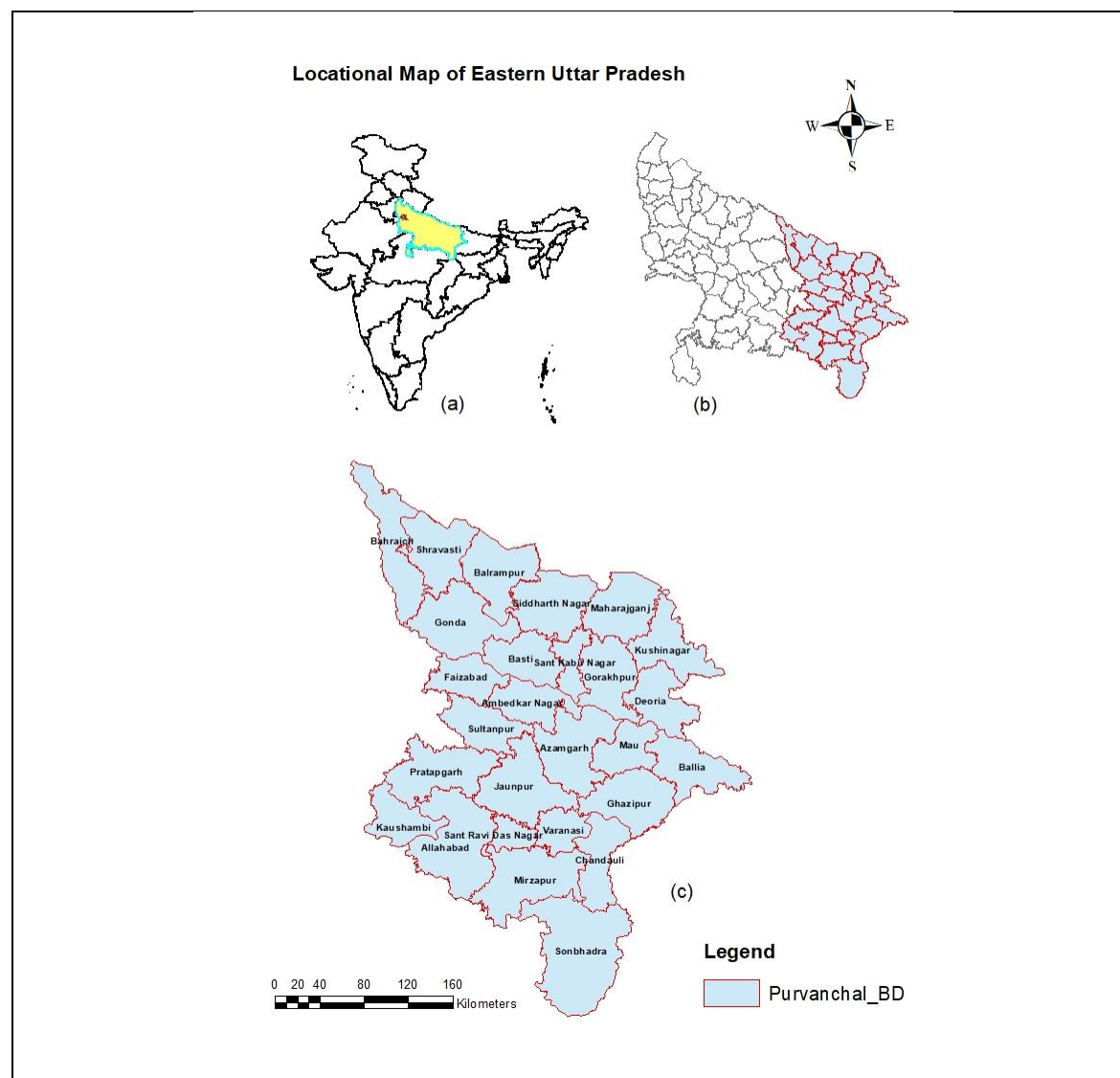
The objectives of the research paper are:

1. To examine the seasonal and spatial variation of temperature, rainfall and relative humidity in Eastern Uttar Pradesh.
2. To analyse the association between climatic variables and malaria, dengue and Japanese encephalitis.
3. To identify disease-specific lag relationships between climatic exposure and reported disease occurrence.
4. To provide a GIS-oriented framework for mapping climatic suitability and climate-sensitive VBD risk.

3. Study Area

Eastern Uttar Pradesh comprises 27 districts and extends across the Middle Ganga Plain, from the Nepal-bordering northern districts to the Vindhyan uplands in the south. The study area lies approximately between 23°50' N–28°25' N and 81°10' E–84°40' E, covering about 85,803 km². The region is characterised by a monsoonal climate with three distinct seasons: a hot and dry pre-monsoon (March–mid-June), a warm and humid monsoon (mid-June–September) and a cooler post-monsoon/winter period (October–February).

Map 1. Location of the Study Area: Eastern Uttar Pradesh



Source: Generated by the author in ArcGIS

4. Data and Methodology

4.1 Data Sources

Temperature and rainfall were derived from India Meteorological Department (IMD) gridded datasets ($0.25^\circ \times 0.25^\circ$ for rainfall; $1.0^\circ \times 1.0^\circ$ for temperature), while relative humidity was derived from CRU TS 4.08. Disease data for malaria, dengue and JE were compiled from NVBDCP/NCVBDC and IDSP surveillance sources. The principal analytical period is 1991–2020.

4.2 Analytical Approach

The analytical framework follows as: descriptive climatic normals, district-wise spatial comparison, disease seasonality, Pearson correlation analysis, lag-correlation analysis and GIS-based spatial interpretation. The paper is based on Mann–Kendall and Sen’s slope analyses for long-term climatic trends. ArcGIS maps are presented for annual mean temperature, annual rainfall, annual relative humidity and an integrated climate-suitability/VBD-risk surface.

5. Results

5.1 Seasonal Pattern of Temperature, Rainfall and Humidity

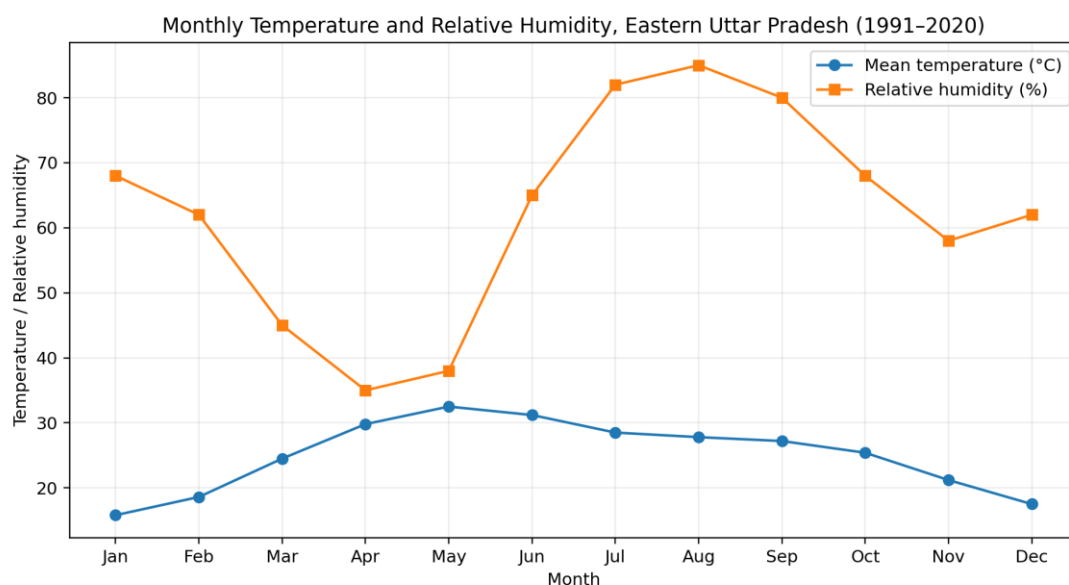
The climatic normal demonstrates a sharply defined annual cycle. Mean temperature increases from 15.8°C in January to 32.5°C in May. Maximum temperature reaches 41.2°C in May, after which monsoon onset moderates daytime temperature. Rainfall rises abruptly in June and reaches its maximum in July (312.4 mm), remaining high in August (298.6 mm) and September (215.4 mm). Relative humidity follows the rainfall regime, increasing from 35–38% in April–May to 82% in July and 85% in August.

Table 1. Monthly Climatic Normals for Eastern Uttar Pradesh (1991–2020)

Month	Mean Temp ($^\circ\text{C}$)	Max Temp ($^\circ\text{C}$)	Min Temp ($^\circ\text{C}$)	Rainfall (mm)	RH (%)
Jan	15.8	23.5	8.2	12.4	68
Feb	18.6	26.8	10.5	15.2	62
Mar	24.5	33.2	15.8	8.6	45
Apr	29.8	38.5	21.2	5.4	35
May	32.5	41.2	24.8	12.8	38
Jun	31.2	38.8	26.5	145.6	65
Jul	28.5	34.2	25.8	312.4	82
Aug	27.8	33.5	25.2	298.6	85
Sep	27.2	33.8	24.5	215.4	80
Oct	25.4	32.5	20.8	68.5	68
Nov	21.2	29.8	15.4	12.8	58
Dec	17.5	25.2	9.8	8.6	62

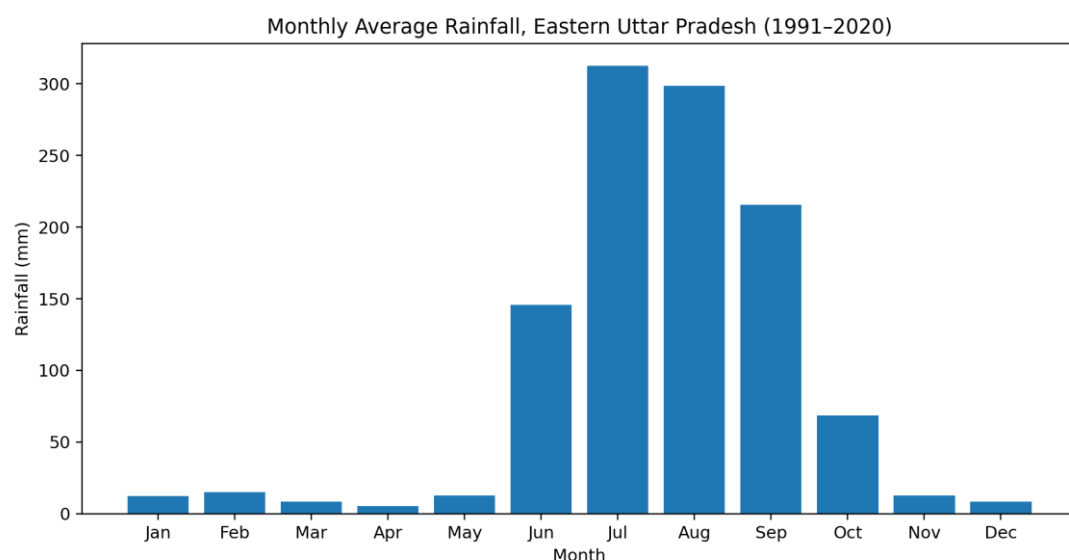
Source: Based on IMD gridded data and CRU TS 4.08.

Figure 1. Monthly temperature and relative humidity in Eastern Uttar Pradesh (1991–2020)



Source: Generated by the author in R Studio

Figure 2. Monthly average rainfall in Eastern Uttar Pradesh (1991–2020)



Source: Generated by the author in R Studio

5.2 Spatial Variation in Climatic Determinants

The district-level data reveal a clear climatic gradient. Annual mean temperature (Map 2) is lower across several northern districts, including Kushinagar (24.3°C), Siddharthnagar (24.4°C), Maharajganj (24.4°C) and Bahraich (24.4°C), whereas Prayagraj reaches 26.3°C. Rainfall (Map 3) displays an opposite spatial tendency: Siddharthnagar records 1,378 mm annually, Kushinagar 1,330 mm and Maharajganj 1,311 mm, while Prayagraj (769 mm), Mirzapur (777 mm) and Pratapgarh (808 mm) are substantially drier. Annual relative humidity (Map 4) similarly declines toward the drier south-west, ranging from 67.9% in Balrampur, Gonda and Siddharthnagar to 55.9% in Kaushambi.

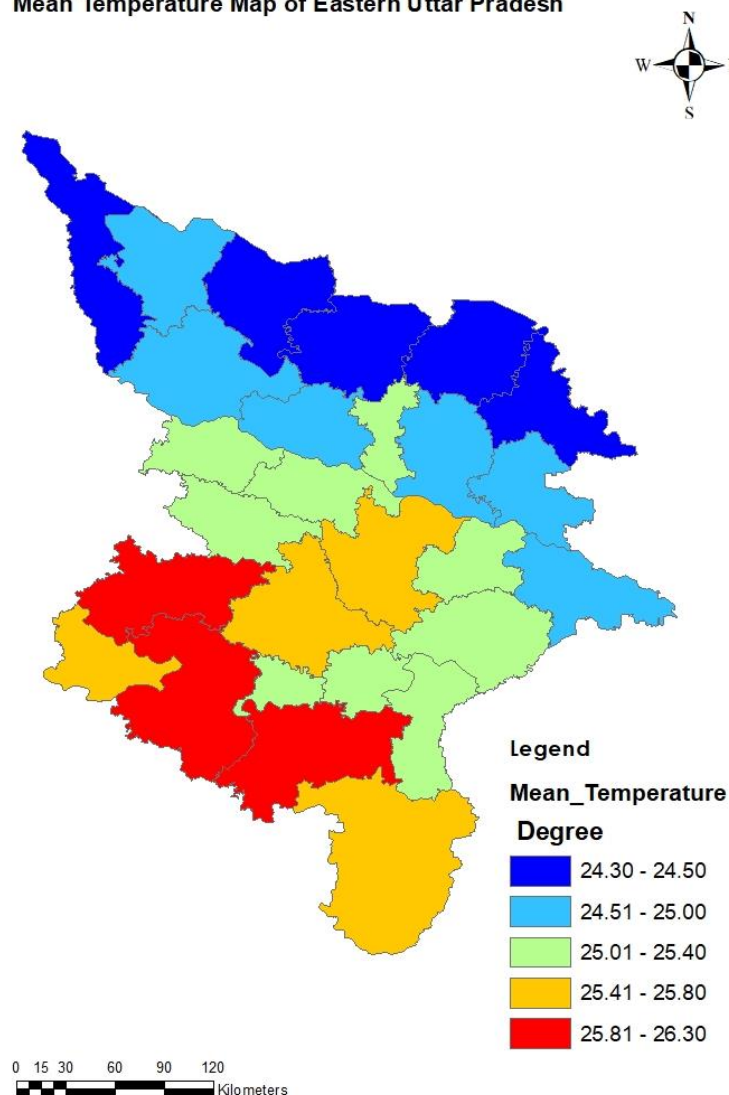
5.3 Disease Seasonality and Climatic Windows

The disease series follows the monsoon climatic cycle but does not peak simultaneously. Malaria begins to rise strongly in June and reaches its maximum in August. JE also intensifies during the monsoon and peaks in August. Dengue develops later, increasing through August and September and reaching its maximum in October. The temporal separation is consistent with differences in vector ecology and with the time required for breeding, pathogen amplification and case detection.

Table 2. Disease-Specific Transmission Windows and Peaks

Disease	Principal transmission window	Peak month	Interpretation
Malaria	June–October	August	Strong monsoon association; risk persists into post-monsoon
Dengue	July–November	October	Delayed post-monsoon peak after heavy rainfall
Japanese encephalitis	June–October	August	Monsoon peak associated with wet agricultural/flood environments

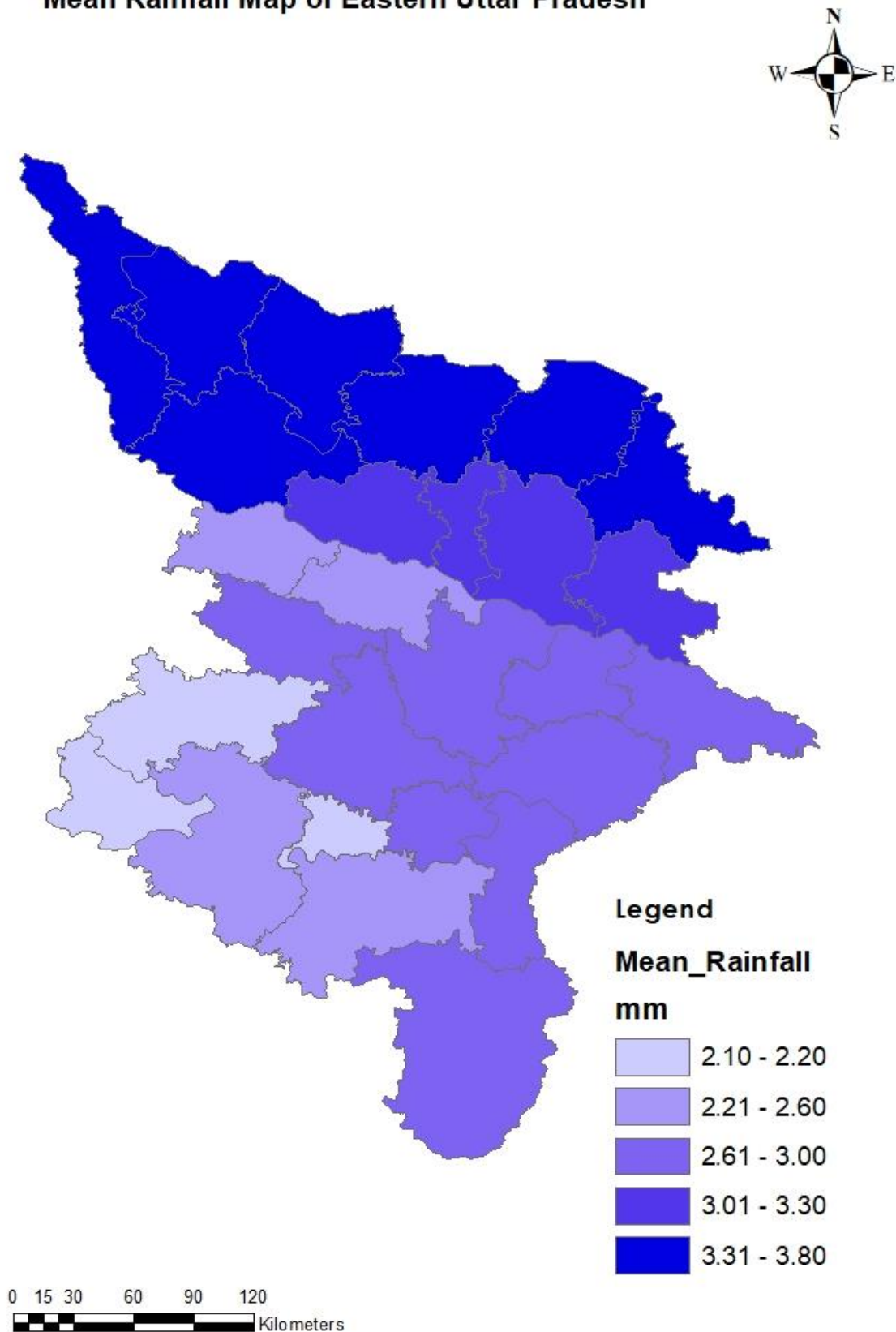
Source: Compiled from NCVBDC/IDSP surveillance data.

Map 2. Annual Mean Temperature in Eastern Uttar Pradesh (1991–2020)**Mean Temperature Map of Eastern Uttar Pradesh**

Source: Prepared by the author in ArcGIS from district-wise temperature data / IMD grid.

Map 3. Annual Rainfall in Eastern Uttar Pradesh (1991–2020)

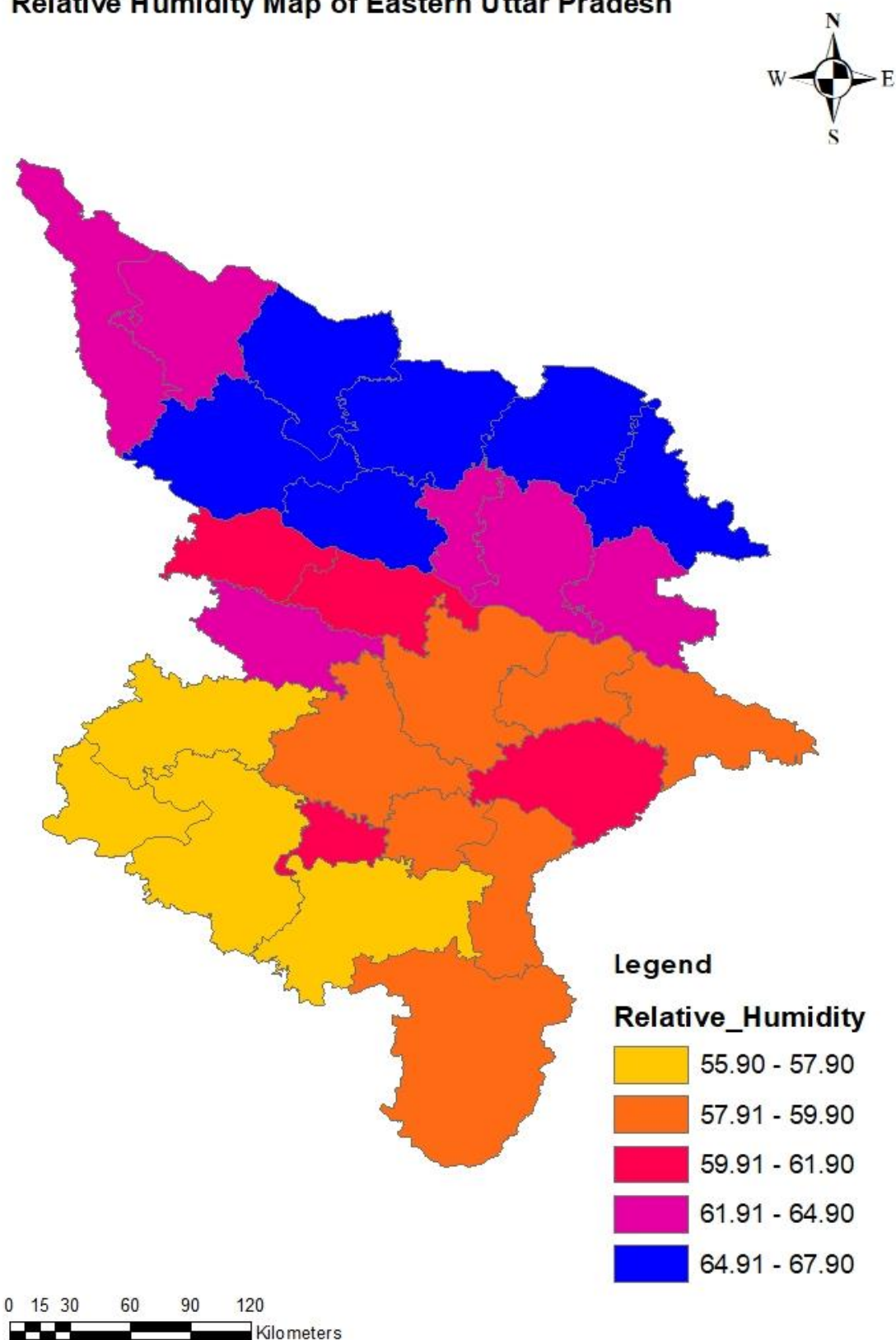
Mean Rainfall Map of Eastern Uttar Pradesh



Source: Prepared by the author in ArcGIS from district-wise rainfall data / IMD grid.

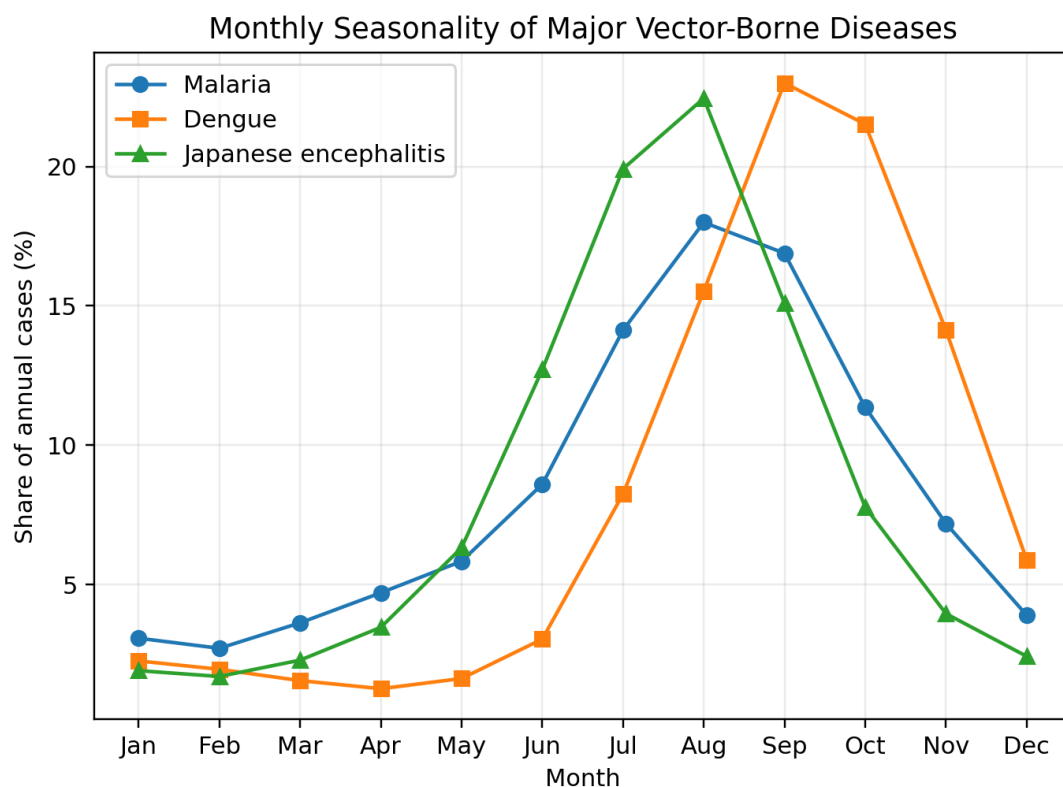
Map 4. Annual Mean Relative Humidity in Eastern Uttar Pradesh (1991–2020)

Relative Humidity Map of Eastern Uttar Pradesh



Source: Prepared by the author in ArcGIS from district-wise humidity data / CRU TS 4.08.

Figure 3. Monthly seasonality of malaria, dengue and Japanese encephalitis.



Source: Generated using R Studio

5.4 Climate–Disease Correlations

The correlation matrix (Figure 4) shows that rainfall has the strongest overall association with malaria and JE. Rainfall correlates with malaria at $r=0.888$ and with JE at $r=0.970$, while its association with dengue is lower ($r=0.452$). Relative humidity is positively associated with all three diseases, with coefficients of 0.749 for malaria, 0.672 for dengue and 0.704 for JE. Temperature shows a moderate positive association with JE ($r=0.525$) and malaria ($r=0.427$), but almost no contemporaneous association with dengue ($r=0.011$). This weak same-month dengue coefficient is compatible with the later dengue peak and underlines the importance of lagged analysis.

Table 3. Pearson Correlation Coefficients Between Climatic Variables and Disease Incidence

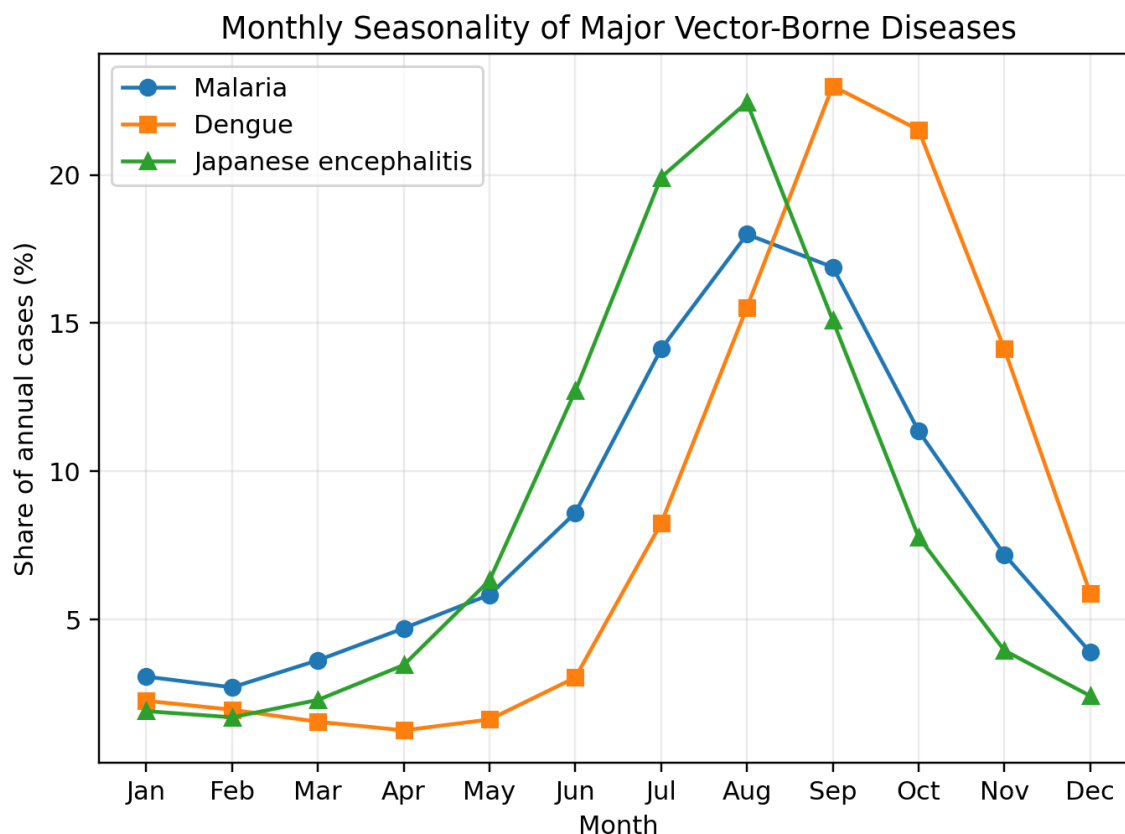
Climatic determinant	Malaria (r)	Dengue (r)	JE (r)
Temperature	0.427	0.011	0.525
Rainfall	0.888	0.452	0.970
Relative humidity	0.749	0.672	0.704

Source: Analysis using R Studio

5.5 Lagged Effects

The lag analysis is particularly important because climatic exposure precedes disease occurrence. As shown in Table 4, malaria shows its highest reported rainfall correlation at lag 1 ($r=0.916$), dengue at lag 2 ($r=0.944$), and JE at lag 0 ($r=0.970$), although the accompanying narrative describes the JE response as occurring approximately 1–1.5 months after peak rainfall. Temperature correlations also strengthen at longer lags for all three diseases. These patterns indicate that climate-based early-warning systems should incorporate disease-specific lag structures rather than relying only on same-month weather.

Figure 4. Climate–disease correlation matrix.



Source: Generated using R Studio

Table 4. Lag-Correlation Analysis: Temperature and Rainfall with Disease Incidence

Disease	Temp Lag 0	Temp Lag 1	Temp Lag 2	Rain Lag 0	Rain Lag 1	Rain Lag 2
Malaria	0.427	0.630	0.772	0.888	0.916	0.507
Dengue	0.011	0.262	0.509	0.452	0.862	0.944
JE	0.525	0.717	0.816	0.970	0.730	0.123

Source: Analysis using R Studio.

5.6 Evidence from Disease-Specific Studies

The studies also incorporate published evidence from Eastern Uttar Pradesh that supports the observed climatic sensitivity. A Varanasi hospital study for 2004–2013 reported an increase of five malaria cases with a 1°C rise in minimum monthly temperature and one additional case with a 1% rise in relative humidity. For Gorakhpur, a generalized additive model for 2001–2016 estimated that one-unit increases in mean temperature, minimum temperature, rainfall and relative humidity were associated with increases in JE admissions of 22.23%, 17.83%, 0.66% and 5.22%, respectively; corresponding mortality increases were 13.27%, 11.77%, 0.94% and 3.27%. The strongest climate associations were reported at lags of roughly 1–1.5 months, with significant effects extending up to 60 days.

Table 5. Reported Effect Sizes from Disease-Specific Studies in Eastern Uttar Pradesh

Variable	Effect on JE admissions	Effect on JE mortality	Reported lag
Mean temperature (°C)	+22.23%	+13.27%	1–1.5 months
Minimum temperature (°C)	+17.83%	+11.77%	1–1.5 months
Rainfall (mm)	+0.66%	+0.94%	1–1.5 months
Relative humidity (%)	+5.22%	+3.27%	1–1.5 months

Source: Singh et al. (2020).

6. Discussion

The results demonstrate that the climatic determinants of VBD transmission in Eastern Uttar Pradesh operate through a seasonal sequence. Pre-monsoon warming establishes thermal conditions favourable for vector and pathogen development, monsoon rainfall expands aquatic breeding habitats, and high monsoon humidity increases adult-vector survival. Disease peaks then emerge with different delays according to vector ecology. This sequence explains why rainfall and humidity show strong relationships with malaria and JE, while dengue exhibits a later post-monsoon maximum. Similar seasonal sequences have been documented across India, where temperature and rainfall patterns shape the transmission intensity of climate-sensitive diseases.

Rainfall appears to be the most consistent climatic determinant in the dataset, particularly for malaria and JE. However, rainfall should not be interpreted as a simple linear driver. Heavy rainfall may create breeding habitats but can also flush larvae, while irregular rainfall and subsequent water storage can favour *Aedes* breeding. The spatial rainfall gradient also interacts with land use: northern districts combine higher rainfall and humidity with flood-prone plains and extensive paddy cultivation, conditions especially relevant to *Culex*-mediated JE. This is consistent with the finding that rainfall has a generally positive but saturating effect on JE risk in Uttar Pradesh, with incidence rising up to moderate-high levels before plateauing.

Temperature exerts a more complex effect. The warmest pre-monsoon months are not necessarily the months of highest disease incidence because extreme heat can reduce vector survival. The malaria pattern is more consistent with a moderate thermal window during the monsoon, while JE shows a positive temperature association combined with strong rainfall sensitivity. The thermal biology of mosquito-borne disease indicates that vector and parasite vital rates respond nonlinearly to temperature, with optimal ranges varying by pathogen and vector species. Dengue's very low same-month temperature correlation in the matrix should therefore not be interpreted as climatic independence; its lagged rainfall response and post-monsoon peak indicate a delayed climatic pathway. Lag-effect studies from India have shown that dengue risk increases with mean temperatures in the 28–30°C range with a 3–8-week lag, and that moderate rainfall (60 mm) with a 8–12 week lag is significantly associated with elevated dengue risk.

Relative humidity acts as a persistence factor by extending adult mosquito survival. The rise to more than 80% humidity in July–September coincides with the principal transmission period for malaria and JE and precedes the dengue peak. The combined effect of moisture availability, humidity and suitable temperature is therefore more epidemiologically meaningful than any single climatic variable considered in isolation.

7. Public-Health and Planning Implications

The climatic evidence supports a shift from reactive outbreak response toward climate-informed preparedness. Rainfall and humidity monitoring can provide an operational signal for strengthening surveillance before expected disease peaks. For malaria and JE, intensified vector control should begin before and during the monsoon; dengue source reduction requires continuation into the post-monsoon period because its peak occurs later. District-specific climatic maps can help prioritise areas where high rainfall, high humidity and suitable temperatures coincide.

The lag structure is particularly useful for early warning. A one- to two-month interval between climatic conditions and disease peaks creates time for larval-source management, community communication, diagnostic preparedness and health-system mobilisation. Integrating IMD/CRU-derived climate indicators with routine disease surveillance at district level would therefore strengthen seasonal preparedness. Given that JE is closely associated with precipitation, flooding and rice production systems in Uttar Pradesh, such preparedness is especially critical for the northern flood-prone districts.

8. Limitations

The analysis is ecological and primarily district/month based; it does not establish individual-level causality. Climatic conditions interact with land use, irrigation, flooding, water storage, vector abundance, socio-economic conditions, surveillance quality and public-health interventions. Disease reporting may also vary spatially and temporally. The composite GIS map should be described as exploratory unless its weighting scheme is statistically validated. While the correlations reported are statistically meaningful, the analysis does not account for non-climatic confounders such as vector-control interventions, population immunity or reporting artefacts. Future work should incorporate these factors to strengthen causal inference.

9. Conclusion

Temperature, rainfall and relative humidity jointly structure the seasonal environment for vector-borne disease transmission in Eastern Uttar Pradesh. Rainfall and humidity show the strongest and most consistent relationships with disease occurrence in the dataset, particularly for malaria and Japanese encephalitis, while dengue demonstrates a delayed post-monsoon response. Temperature modifies these relationships by determining the thermal suitability of vectors and pathogens. The evidence therefore supports a climate–vector–disease pathway characterised by strong seasonality and disease-specific lags. Climate-informed surveillance, ArcGIS-based spatial targeting and pre-emptive vector control can translate these climatic signals into practical public-health action.

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