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Examining the Relationships Between Climate Variables and Dengue Incidence in Nepal

Pralad Kadel [1*], Dr. Suman Thapaliya [2], Rohit Prasad Pandey [3], Dipak Adhakari [4]
[1] Department of Information Technology, Texas College of Management and IT, Nepal
[2] Department of Information Technology, Lincoln University College, Malaysia
[3, 4] Texas College of Management and IT, Lincoln University College, Malaysia

* Corresponding Author: **Pralad Kadel**

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Abstract
Dengue has emerged as a major public health concern in Nepal, with increasing geographic spread and recurrent seasonal outbreaks over recent years. While climatic factors such as temperature, rainfall, and humidity are known to influence dengue transmission, limited research in Nepal has systematically examined their delayed effects using national-level data.
This study investigates the time-lagged relationships between climate variables and monthly dengue incidence across 75 districts of Nepal aggregated nationally from 2022 to 2025. A retrospective time-series design was employed using official epidemiological records and meteorological data. Pearson correlation analysis was conducted using same-month and lagged climate variables (one- and two-month lags). The findings revealed weak same-month associations but substantially stronger correlations when rainfall and temperature were lagged by one to two months. Rainfall demonstrated the strongest delayed relationship with dengue incidence, indicating a 1-2month lag effect consistent with mosquito breeding and viral incubation cycles. Humidity showed a relatively stronger immediate association.
These results highlight the importance of incorporating lagged climate indicators into early warning systems. Understanding delayed climate effects can support more proactive dengue preparedness, improve resource allocation, and strengthen climate-sensitive public health planning in Nepal.

Keywords: Dengue, Climate Variability, Time Lag, Rainfall, Temperature, Humidity, Nepal

1. Introduction

Dengue fever has emerged as a major public health concern in Nepal over the past decade, with increasing geographic spread and recurrent seasonal outbreaks. Initially confined to the Terai region, dengue transmission has expanded into hill regions and major urban centers, including the Kathmandu Valley[1, 2]. Seasonal outbreaks are now reported across most districts, indicating a transition from sporadic occurrences to a more persistent and widespread public health challenge. This rising burden places increasing pressure on Nepal's healthcare system, particularly during the monsoon and post-monsoon periods when cases typically surge [3].
Climatic conditions play a critical role in shaping dengue transmission dynamics by influencing mosquito breeding, survival, and viral development. Temperature affects mosquito development rates and viral replication, rainfall creates breeding habitats through water accumulation, and humidity enhances mosquito survival and activity [4, 5]. However, the relationship between climate and dengue incidence is not instantaneous. Biological processes, including the mosquito life cycle and viral incubation period, introduce a time delay between climatic variation and observed dengue cases [6].
Although the climate–dengue relationship has been widely explored in global literature, studies in Nepal remain limited in scope and are often descriptive in nature. Few studies have systematically examined time-lagged climatic effects using national-scale, district-level data [1, 7]. Understanding whether climatic variables influence dengue transmission immediately or with a delay of one to two months is essential for improving outbreak preparedness. Evidence on lag structures can support climate-informed

interventions, enabling proactive vector control measures before peak transmission periods.
This study therefore investigates the time-lagged relationships between key climate variables temperature, rainfall, and humidity and dengue incidence across 75 districts of Nepal from 2022 to 2025 using same-month and lagged correlation analysis (1- and 2-month lags).

1.1. Contributions
This paper makes the following contributions:

- Provides national evidence on climate–dengue relationships using district-reported dengue and DHM climate records (2022–2025), aggregated to monthly national series.
- Quantifies delayed climatic effects using 1-2 months lag correlations with statistical significance testing.
- Identifies rainfall as the strongest delayed driver (1-2 months), with humidity showing a more immediate association.
- Translates findings into actionable guidance for climate-informed dengue preparedness in Nepal.

2. Literature Review
2.1. Climate Determinants of Dengue Transmission
Dengue transmission is strongly influenced by climatic conditions that shape mosquito ecology and viral development. Temperature affects mosquito growth rates, biting frequency, and the incubation period of the dengue virus [1, 6]. Within optimal temperature ranges, mosquito populations increase more rapidly and viral replication accelerates, enhancing transmission potential.
Rainfall plays a crucial role in creating mosquito breeding habitats. In urban and peri-urban environments, accumulated rainwater in artificial containers provides suitable sites for Aedes mosquito larvae. Relative humidity further influences mosquito survival and activity, increasing the likelihood of human–vector contact. Global evidence suggests that climate variability, particularly rising temperatures and altered precipitation patterns, may intensify vector-borne disease risk [5].
Because mosquito development and viral incubation require time, climatic effects on dengue incidence often occur with delay. These biological processes create a lag between environmental changes and observed case increases.

2.2. Evidence of Time-Lagged Effects
Several international studies have demonstrated that rainfall and temperature show stronger associations with dengue incidence when lagged by one or two months rather than evaluated contemporaneously [4, 8]. Rainfall frequently exhibits the most pronounced delayed effect, reflecting the time required for mosquito breeding and virus transmission cycles. Temperature-related effects may also appear with delay due to their influence on mosquito maturation and viral replication rates.
These findings indicate that same-month correlations may underestimate the true impact of climate variables. Incorporating lagged indicators improves understanding of outbreak timing and enhances early warning potential.
However, lag structures vary across geographic contexts due to differences in monsoon intensity, urbanization, and vector control practices. Therefore, country-specific analysis is essential for operational public health application.

2.3. Dengue Epidemiology in Nepal
Nepal has experienced a significant rise in dengue incidence in recent years, with transmission expanding from the Terai region to hill districts and major urban centers. National surveillance records indicate large-scale outbreaks in 2022 and 2023, with 2022 representing the most severe peak during the study period. Cases consistently increase during monsoon and post-monsoon months (July–October), suggesting strong seasonal influence.
Climate change and environmental variability have been identified as contributing factors in Nepal's expanding dengue risk [1, 7]. Studies assessing climatic suitability suggest that warming trends may enable vector persistence at higher elevations [9].
Despite growing evidence of climate sensitivity, Nepal-based research has largely focused on descriptive epidemiological trends or spatial suitability analysis. Few studies have systematically examined time-lagged climate relationships using national district-level monthly data. As a result, there remains limited evidence on how delayed climatic signals influence outbreak timing in Nepal. Given Nepal's strong ecological gradients (Terai–Hill–Mountain), climate–dengue relationships may vary spatially, which motivates future district-level lag analyses.

2.4. Research Gap
Based on the reviewed literature, the following gaps are identified:

- Limited national-level analysis of time-lagged climate-dengue relationships in Nepal
- Insufficient quantification of 1 and 2-month lag effects for rainfall, temperature, and humidity
- Limited translation of climatic evidence into actionable public health preparedness strategies

This study addresses these gaps by analyzing delayed climate effects across 75 districts of Nepal using monthly panel data from 2022–2025.

3. Methodology
3.1. Study Design
This study employed a retrospective ecological time-series design to investigate the relationship between climate variability and dengue incidence in Nepal. The analysis focused on identifying both contemporaneous and time-lagged associations between climatic factors and reported dengue cases. A national-level monthly aggregation approach was adopted to examine temporal patterns from 2022–2025, summarizing overall temporal coupling between climate variability and dengue incidence while minimizing district-level reporting noise; district-level modeling is recommended for future research.
The time-series framework allowed assessment of whether climatic variables influence dengue transmission immediately or after a short delay consistent with biological processes such as mosquito breeding cycles and viral incubation periods.

3.2. Study Area
Nepal is characterized by diverse ecological zones, including the Terai plains, hill regions, and mountainous areas. Climatic conditions vary substantially across these regions,

particularly in terms of rainfall distribution and temperature patterns. The monsoon season, typically extending from June to September, contributes the majority of annual precipitation and plays a critical role in shaping environmental conditions conducive to Aedes mosquito breeding.
Given the national scope of dengue transmission, this study utilized data aggregated from 75 districts, ensuring comprehensive geographic representation while maintaining consistency with available meteorological records.

3.3. Data Sources
3.3.1. Dengue Incidence Data
Monthly dengue case data were obtained from official epidemiological surveillance records published by national public health authorities [3]. Reported district-level case counts were aggregated to national monthly totals for consistency with climate data.

3.3.2. Climate Data
Climate data were obtained from the Department of Hydrology and Meteorology (DHM), Nepal [10]. The following variables were included:
- Average monthly temperature (°C)
- Total monthly rainfall (mm)
- Average monthly relative humidity (%)

Rainfall was aggregated as monthly cumulative totals, while temperature and humidity were aggregated using monthly means.

Table 1: Climate Variable Aggregation Methods

Climate Variable	Aggregation Method	Justification
Rainfall	Monthly total	Represents cumulative precipitation influencing breeding sites
Temperature	Monthly mean	Reflects average thermal conditions affecting mosquito development
Humidity	Monthly mean	Indicates atmospheric moisture influencing mosquito survival

3.4. Data Processing
The dengue and climate datasets were merged using month and year identifiers to create a unified national monthly dataset covering January 2022 to December 2025.
Lagged climate variables were constructed to examine delayed effects:
- 1-month lag (t−1)
- 2-month lag (t−2)

For example, rainfall at month t−1 was aligned with dengue incidence at month t. After lag construction, initial rows containing missing values due to shifting were removed. The final analytical dataset consisted of approximately 44–46 monthly observations depending on lag structure.

3.5. Statistical Analysis
Pearson correlation analysis was conducted to quantify the strength and direction of association between dengue incidence and climate variables. Correlation coefficients (r) were calculated for:
- Same-month climate variables
- One-month lag variables
- Two-month lag variables

Statistical significance was evaluated using two-tailed tests, with $p < 0.05$ considered statistically significant and $p < 0.01$ considered highly significant.
All analyses were performed using Python in a reproducible computational environment.

4. Results and Analysis
4.1. Descriptive Overview of Dengue and Climate Trends

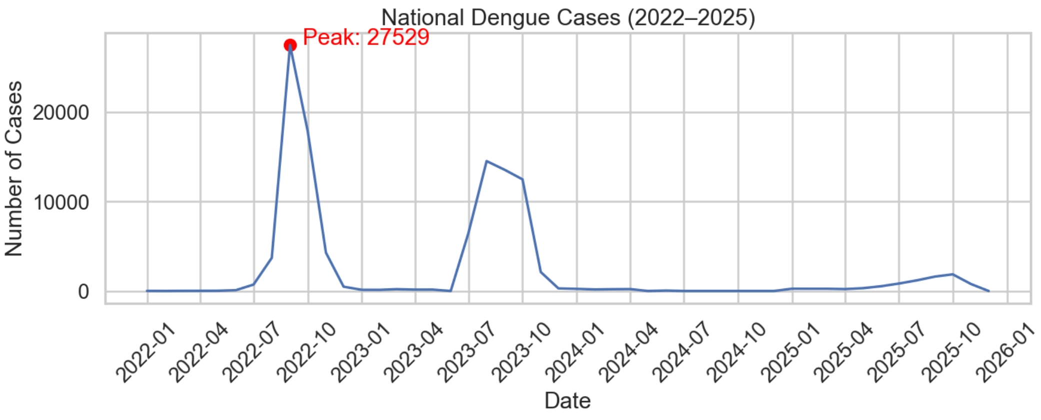

Fig 1: National Monthly Dengue Cases in Nepal (2022–2025)

During the study period (2022–2025), dengue incidence in Nepal exhibited pronounced seasonal fluctuations (Figure 1). Case counts increased during monsoon months (June–September), with peak transmission typically observed in August and September. The year 2022 recorded the highest national outbreak within the analyzed timeframe, followed by a moderate resurgence in 2023. Subsequent years demonstrated comparatively lower but consistent seasonal patterns.

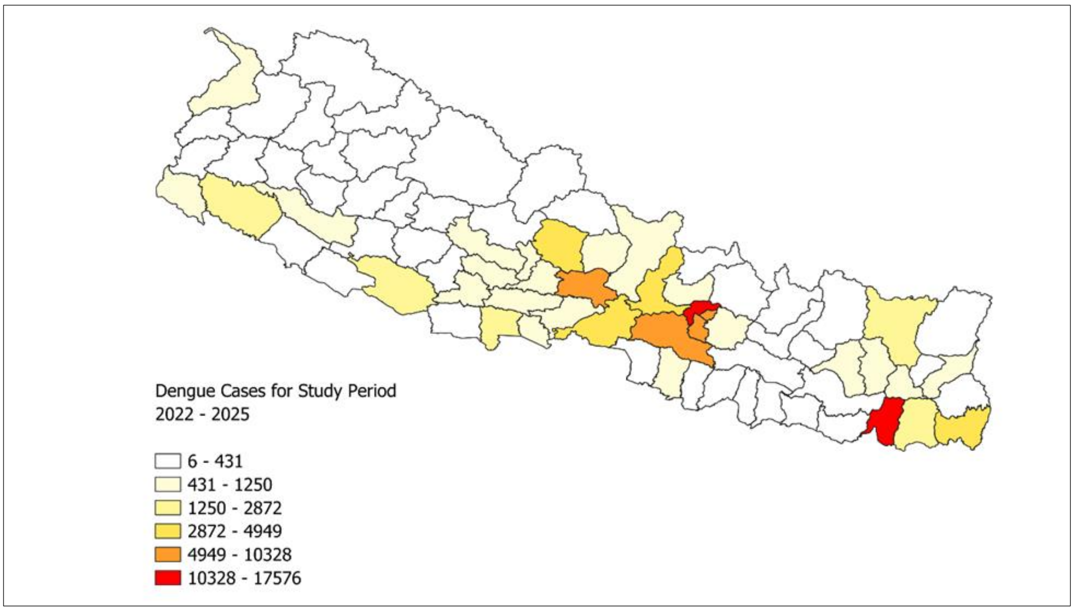

Fig 2: Spatial Distribution of Dengue Cases Across Districts of Nepal (2022–2025)

The map reveals clear spatial heterogeneity in dengue incidence. High case concentrations are observed in major urban centers and Terai districts, particularly Kathmandu and parts of the southern plains. Several hill districts also reported moderate case counts, indicating the geographic expansion of dengue transmission beyond traditional lowland regions. These spatial patterns support previous findings that dengue risk in Nepal is increasingly influenced by urbanization, population mobility, and climatic suitability.

Climatic variables displayed clear seasonality. Rainfall peaked during monsoon months, temperature showed gradual annual variation with higher values during summer, and relative humidity increased during the rainy season. The temporal alignment between monsoon rainfall and dengue peaks suggests a potential environmental influence. However, the observed timing of peak cases indicates that climatic effects may operate with a short temporal delay.

4.2. Time-Lagged Correlation Analysis

Pearson correlation analysis was conducted to examine associations between dengue incidence and climatic variables at same-month, one-month lag, and two-month lag intervals.

Table 2: Pearson Correlation Between Dengue Cases and Climate Variables (National Monthly Data, 2022–2025)

Climate Variable	Same Month (r)	1-Month Lag (r)	2-Month Lag (r)
Rainfall	0.268	0.435**	0.459**
Temperature	0.128	0.260	0.316*
Humidity	0.408**	0.420**	0.285

Note: * $p < 0.05$; ** $p < 0.01$. Sample size (n) = 44–46 monthly observations.

As shown in Table 2, rainfall demonstrated the strongest delayed association with dengue incidence. While the same-month correlation was weak and statistically non-significant ($r = 0.268$, $p > 0.05$), the relationship strengthened substantially at one-month lag ($r = 0.435$, $p < 0.01$) and further increased at two-month lag ($r = 0.459$, $p < 0.01$). This pattern indicates a pronounced delayed effect of rainfall on dengue transmission.

Temperature exhibited a weak same-month association ($r = 0.128$, $p > 0.05$). Although the one-month lag remained statistically non-significant, a moderate and statistically significant association emerged at two-month lag ($r = 0.316$, $p < 0.05$), suggesting a delayed but comparatively weaker influence.

Relative humidity showed a statistically significant contemporaneous association with dengue incidence ($r = 0.408$, $p < 0.01$), and this relationship persisted at one-month lag ($r = 0.420$, $p < 0.01$). However, the two-month lag was not statistically significant. These findings suggest that humidity may exert a more immediate influence compared to rainfall.

Overall, rainfall exhibited the strongest delayed relationship, temperature demonstrated a moderate delayed effect, and humidity showed relatively stronger contemporaneous association. These results support the hypothesis that climatic drivers influence dengue transmission through distinct temporal pathways rather than immediate effects alone.

5. Discussion

This study examined the time-lagged relationships between climate variables and dengue incidence in Nepal using national monthly data from 2022–2025. The findings demonstrate that climatic influences on dengue transmission operate through distinct temporal patterns rather than immediate effects alone.

5.1. Interpretation of Rainfall Effects

Rainfall exhibited the strongest delayed association with dengue incidence, with statistically significant correlations observed at one- and two-month lags. This pattern aligns with biological plausibility. Increased rainfall during monsoon seasons creates breeding habitats through water accumulation in containers and stagnant pools. However, the mosquito life cycle - from egg to adult - requires time, typically ranging from one to several weeks. Additionally, the dengue virus undergoes an extrinsic incubation period within the mosquito before transmission becomes possible.

The strengthening of correlation at 1–2month lags suggests that rainfall contributes to transmission after these biological processes unfold. This delayed effect is consistent with findings from other monsoon-driven countries, where rainfall has been identified as a primary climatic driver of dengue outbreaks.

5.2. Temperature and Delayed Transmission

Temperature demonstrated a modest but statistically significant association at two-month lag. Temperature influences mosquito development rate and viral replication within the vector. Higher temperatures within optimal thresholds can accelerate mosquito maturation and shorten viral incubation periods. However, the moderate magnitude of correlation observed in this study suggests that temperature may act as a facilitating factor rather than a dominant driver in the Nepalese context.

Given Nepal's diverse topography, temperature variability across ecological zones may also dilute national-level associations when data are aggregated.

5.3. Humidity and Immediate Influence

Relative humidity showed a stronger contemporaneous association with dengue incidence compared to rainfall. Humidity influences mosquito survival and activity levels, potentially affecting biting frequency and vector longevity in the short term. The significant same-month relationship suggests that humidity may have a more immediate ecological impact, unlike rainfall which requires time to translate into increased vector density.

The decline in correlation at two-month lag further supports the interpretation that humidity effects are more immediate rather than delayed.

5.4. Public Health Implications

The identification of lagged climatic effects has important implications for dengue preparedness in Nepal. Since rainfall showed a strong 1-2month delayed association, increases in monsoon rainfall may serve as an early warning signal for intensified surveillance and vector control efforts.

Public health authorities could incorporate lagged rainfall indicators into seasonal preparedness planning. For example:

- Strengthening vector control activities 4-6 weeks after heavy rainfall
- Enhancing community awareness campaigns during early monsoon periods
- Allocating medical resources in anticipation of delayed case surges

By integrating time-lagged climate indicators into decision-making processes, Nepal can move toward more proactive rather than reactive outbreak management.

5.5. Study Limitations

Several limitations should be acknowledged. First, the analysis was conducted using national aggregated monthly data, which may mask regional heterogeneity. Second, correlation analysis does not imply causation and does not account for potential confounding factors such as population density, urbanization, vector control interventions, or human mobility. Third, the relatively short time period (2022–2025) limits long-term climate variability assessment.

Additionally, autocorrelation and shared seasonality may inflate correlations in time-series data; future studies may apply regression or distributed lag models to adjust for these effects. Future research may extend this analysis to district-level modeling and incorporate additional socio-environmental variables.

6. Conclusion

This study investigated the time-lagged relationships between climate variables and dengue incidence in Nepal using national monthly data from 2022 to 2025. The findings demonstrate that climatic influences on dengue transmission operate through distinct temporal patterns rather than immediate effects alone.

Rainfall exhibited the strongest delayed association, with significant correlations observed at one- and two-month lags. This suggests that monsoon rainfall contributes to increased dengue transmission after a short biological delay, likely reflecting mosquito breeding cycles and viral incubation periods. Temperature showed a moderate delayed effect, becoming statistically significant at two-month lag. In contrast, humidity demonstrated a relatively stronger contemporaneous association, indicating a more immediate ecological influence on transmission dynamics.

These findings highlight the importance of incorporating lagged climatic indicators into dengue preparedness strategies in Nepal. Rather than responding only after case numbers increase, public health authorities may use rainfall and humidity trends as early warning signals to initiate vector control, surveillance intensification, and community awareness measures.

Although the analysis is limited to national aggregated data and does not establish causality, the results provide empirical evidence supporting climate-sensitive dengue planning in Nepal. Integrating time-lagged climate signals into public health decision-making frameworks could strengthen outbreak preparedness and improve timely response.

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