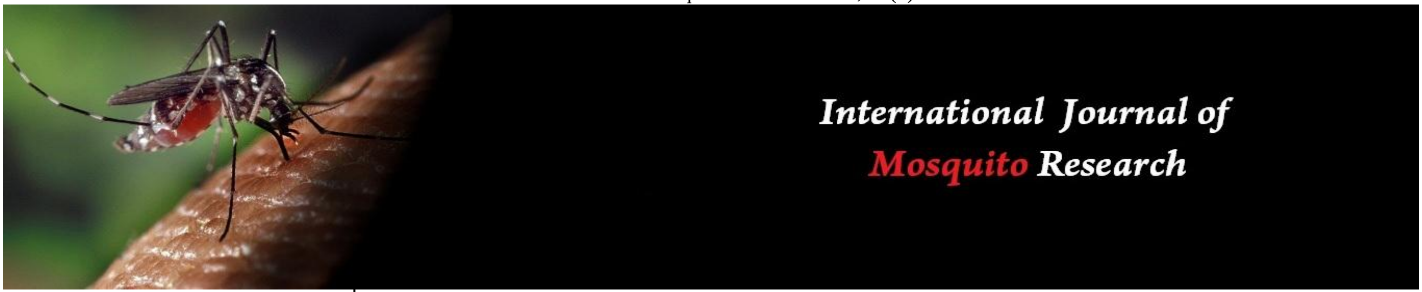

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Assessing short-term lagged effects of temperature and rainfall on dengue cases in Guyana

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Abstract
Dengue fever, an expanding arboviral threat in tropical and subtropical regions, has resurged sharply across the Americas and the Caribbean. Guyana has recorded one of the highest reported cases in the region, yet limited research has examined the climatic determinants of local transmission. This study investigated the relationship between dengue cases, rainfall, and temperature in Guyana between 2022 and 2024. Monthly dengue case data were obtained from OpenDengue, while rainfall and temperature records were compiled from national and international sources. Descriptive statistics, Pearson correlations with one- to three-month lags, and Seasonal-Trend Decomposition using Loess (STL) were applied. Dengue incidence increased nearly fourfold over the study period, rising from 11,811 cases in 2022 to 45,080 in 2024. Correlation analysis revealed statistically significant positive associations between dengue cases and minimum, mean, and maximum temperatures across all lags ($r = 0.423$-0.520, $p \leq 0.01$), with maximum temperature showing the strongest association at lag 0. Rainfall, however, exhibited weak and no significant negative correlations at all lags. Seasonal decomposition indicated recurring mid-year peaks coinciding with the May-July rainy season, and secondary surges during hotter, drier months (September-October). These findings suggest that temperature exerts a stronger and more consistent influence on dengue transmission dynamics in Guyana than rainfall, likely due to vector ecology and water-storage practices that decouple breeding from precipitation. The results emphasize the value of temperature-based early warning systems, enhanced vector control, and strengthened surveillance to mitigate dengue risk under changing climatic conditions.

Keywords: Dengue fever, *Aedes aegypti*, temperature, rainfall, climate variability, vector-borne disease, seasonal dynamics, Guyana

1. Introduction

1.1 Rising Global Burden of Dengue Fever

Dengue fever is an acute, mosquito-borne infection caused by one of four distinct but closely related serotypes of the dengue virus (DENV-1 to DENV-4) [58]. It is primarily transmitted by the *Aedes aegypti* mosquito and to a lesser extent, the *Aedes albopictus* [7, 20]. Dengue is known to spread quickly and can lead to severe and, potentially fatal complications. Most infected individuals experience only mild symptoms that typically resolve within a week. These symptoms include headache, fever, vomiting, joint and muscle pain and skin rash [58]. However, a smaller number of cases develop into severe dengue, which can cause plasma leakage, bleeding, organ failure and in some cases, shock [54]. Severe dengue is most common in children, the elderly, and individuals with prior dengue infections [24].

In December 2023, the World Health Organization (WHO) classified the global dengue upsurge as a grade 3 emergency, the highest level of alert. By April 2024, WHO reported a tenfold increase in dengue cases over the past two decades, with over 7.6 million infections and more than 3,000 deaths by April 2024 [58]. The Americas region remains the epicenter, with countries like Brazil and Argentina experiencing explosive outbreaks linked to environmental and social drivers [4, 40]. Similar trends have been observed in South Asia, where Bangladesh suffered its deadliest dengue epidemic in 2023, resulting in more than 1,700 fatalities and overwhelming of the health system [28]. These trends reflect both a rising disease burden and stronger transmission in previously endemic regions.

While case counts and mortality figures highlight the scale of the dengue burden, they do not fully capture its public health significance. Dengue control remains particularly challenging because of the absence of a universally safe and effective vaccine. The only licensed vaccine, Dengvaxia, is recommended only for individuals with documented prior dengue infection, leaving much of the population unprotected [58]. Additionally, immunity to dengue is complex: infection from one serotype provides lifelong protection against that strain but only partial and temporary protection against the other three, which can increase the risk of severe dengue during subsequent infections [53]. Moreover, treatment options are limited to supported care, as no specific antiviral therapy currently exists.

Global warming has extended the geographic distribution and transmission season of *Aedes* mosquitoes. Previously confined to tropical and subtropical zones, *Aedes aegypti* and *Aedes albopictus* are increasingly colonizing temperate and high-altitude regions as warmer winters and humid summers create favorable conditions [6]. For example, the expansion of *A. aegypti* has been documented in parts of Europe, where climate projections indicate an elevated risk of local dengue transmission [48]. In the Caribbean and Latin America, climate-driven increases in temperature and rainfall have been linked to earlier and more severe outbreaks, exemplified by the 2019-2024 dengue epidemic in South America [18].

1.2 Effects of Temperature and Rainfall on *Aedes aegypti and Aedes albopictus* Mosquitoes and Dengue Cases

Temperature and rainfall are well-established yet complex drivers of dengue transmission. Studies have shown that elevated temperatures accelerate the mosquito life cycle by reducing larval development time, increasing adult biting frequency, and shortening the extrinsic incubation period (EIP) of the dengue virus within the mosquito, thereby enhancing transmission efficiency [19]. Optimal temperatures ranging from 25-30 °C have been shown to accelerate larval development and shorten the EIP, which in turn increases the vectorial capacity of *Aedes aegypti* and *Aedes albopictus* mosquitoes [33]. Furthermore, shifts in rainfall patterns promote mosquito breeding, with moderate rainfall often lead to water accumulation in containers, tires, and other artificial habitats suitable for mosquito proliferation [51].

However, the effects of temperature and rainfall are non-linear and context dependent. Extreme temperature outside the optimal range can reduce mosquito survival and viral transmission [31]. For example, temperatures exceeding $40°C$ drastically reduce adult mosquito survival and inhibit the development of eggs and larvae, while at lower temperatures around 10 °C, both *Aedes aegypti and albopictus* mosquito larvae are unable to develop properly [39]. Excessive rainfall can flush out larvae and reduce breeding success [13, 38] while during drought, urban water storage practices can unintentionally enhance transmission by creating ideal breeding sites [5].

These interactions are further complicated by seasonal and regional variability. For example, research in Sri Lanka revealed that dengue cases peaked two to four months after heavy rainfall events, indicating a lag effect between rainfall and mosquito population growth [56]. In Bangladesh, annual rainfall and humidity were significant predictors of dengue incidence, though temperature played a more dominant role in urban centers like Dhaka compared to coastal regions such as Chittagong [2]. These findings reflect broader modeling studies showing that asynchronous seasonal peaks in rainfall and temperature can either amplify or delay outbreaks depending on their phase relationship [38].

Additionally, evidence from multiple regions supports the role of climatic anomalies in shaping dengue dynamics. In Thailand, cloud cover and temperature were positively associated with increased cases, whereas extreme rainfall and high sea-level pressure had a suppressive effect [15]. In Mexico and the Philippines, precipitation was found to be the dominant climatic variable influencing dengue incidence, followed by temperature and humidity [6]. These patterns reinforce the view that climate change not only affects mosquito ecology but also reshapes the temporal and spatial distribution of dengue outbreaks globally.

1.3 Dengue in Guyana: Climatic Context and Public Health Significance

Guyana's tropical climate is characterized by relatively stable high temperatures year-round and two distinct rainy seasons: May-July and November-January [50]. These conditions provide a near-constant baseline of mosquito breeding potential, while seasonal rainfall peaks amplify vector proliferation through increased availability of water-filled containers and other larval habitats. Previous studies in tropical South America have demonstrated that such rainfall-driven increases in larval habitats, coupled with optimal temperature conditions, can significantly elevate transmission risk within a lag period of one to three months [38].

Guyana has experienced a notable resurgence of dengue cases in recent years, reflecting broader patterns across the Caribbean and South America. According to the Pan American Health Organization (PAHO), Guyana reported 31,238 suspected dengue cases between epidemiological weeks 1 to 35 in 2024, an increase of 90% compared to 2023 and a cumulative incidence rate of 3,954 per 100,000 population [36], which is among the highest in the Caribbean region.

In Guyana, where health systems already face resource constraints, large outbreaks can quickly overwhelm hospitals and laboratories, delay diagnosis and limit care for severe cases. These challenges highlight the urgency to better understand the local drivers of dengue transmission in Guyana, specifically the effects of temperature and rainfall. While prior work has linked dengue risk to climatic variability at the global scale [6], there has been limited studies on the lagged effects of rainfall and temperature on dengue cases in Guyana. Therefore, the objective of this study is to investigate and quantify the relationship between rainfall, temperature and dengue cases in Guyana during 2022-2024.

2. Methodology

2.1 Study Location

This study examines dengue trends across Guyana, a tropical country on South America's northeastern coast (1-9°N, 56-62°W), during the three-year period from 2022 to 2024. With a population of approximately 789,000 in 2022 concentrated along the coastal plain, Guyana exhibits stark demographic contrasts, where its population density averages 4 people/km² but rises sharply in urban coastal zones like Demerara-

Mahaica [14]. The climate is tropical and characterized by a mean annual minimum and maximum temperatures of 24.7 °C and 30.7 °C, respectively, and an average annual rainfall of approximately 2,300mm (90 inches) [8]. Dengue cases data were analyzed at the country-level due to limited subregional data availability. The two rainy seasons (May-July, November-January) and the two dry seasons creates ideal breeding conditions for *Aedes aegypti*.

2.2 Data Collection
Dengue case data for January 2022 to December 2024 were obtained from the OpenDengue platform, which compiles country-level dengue reports from official and verified public health sources. Temperature data (minimum and maximum shade temperatures) were acquired from the Guyana Bureau of Statistics for January 2022 through June 2024; for the remaining months of 2024, supplementary temperature records were obtained from publicly available meteorological data repositories such as: Guyana Bureau of Statistics, 2024; Weather Spark, 2024; Weather Atlas, 2024 and Hydromet, 2024 to ensure completeness. Rainfall data for the full study period were collected from ClimateSERV, a platform providing satellite-based and gridded climate datasets. All datasets were aggregated to the country-level for analysis, as more granular regional or local data were unavailable.

2.3 Analysis
All analyses were conducted using R (version 4.4.2), utilizing the forecast and ggplot2 packages.

2.3.1 Descriptive Statistics
Temperature data were derived by averaging the minimum and maximum daily shade temperatures to produce a representative monthly mean. Descriptive statistics (mean, standard deviation, minimum, maximum, and interquartile range) were computed for dengue incidence, rainfall, and temperature variables to characterize central tendency, variability, and distributional patterns.

2.3.2 Correlation
Correlation analysis was performed to assess the linear association between monthly dengue cases and climate variables (temperature and rainfall). Since climatic effects on dengue cases are not always immediate, we included lags of one to three months to evaluate the delayed effects of temperature and rainfall on dengue cases.

2.3.3 Decomposition
Seasonal-Trend Decomposition using LOESS (STL) was applied to the monthly dengue cases. This approach enabled the decomposition of the observed cases into long-term trend, seasonal, and irregular components (not explained by trend or seasonality), proving insights into cyclical patterns and short - term fluctuations. The seasonal component was estimated using a smoothing window of 13 (Cleveland *et al.*, 1990).

Results

Table 1: Descriptive statistics for monthly climatic variables and dengue cases, Jan 2022-Dec 2024)

Variable	Count	Mean	Std. Dev. (SD)	Min	25%	Median	75%	Max
Rainfall (mm, CHIRPS)	36	198.08	123.81	36.33	76.50	196.94	295.17	443.87
Min. Temp (°C)	36	24.71	0.75	23.5	24.2	24.7	25.1	26.1
Max. Temp (°C)	36	30.73	1.26	28.3	29.8	30.75	31.55	33.6
Mean Temp (°C)	36	27.72	0.97	25.9	27.0	27.55	28.41	29.75
Dengue cases	36	2350.39	1903.84	447	924	1602	3958	8686

Table 1 shows that across the 36 monthly observations, monthly rainfall averaged 198.08 mm (SD = 123.81), ranging from 36.33 mm to 443.87 mm. Minimum temperatures were relatively stable, with a mean of 24.71 °C (SD = 0.75), varying between 23.5 °C and 26.1 °C. Maximum temperatures averaged 30.73 °C (SD = 1.26) and ranged from 28.3 °C to 33.6 °C, while mean monthly temperatures were 27.72 °C (SD = 0.97), spanning 25.9 °C to 29.75 °C. Dengue cases showed greater variability, with a monthly average of 2,350 cases (SD = 1,903.84), ranging from 447 to a maximum of 8,686 cases.

Table 2: Annual dengue cases and average climatic factors in Guyana, 2022-2024

Year	Total Dengue Cases	Avg. Annual Rainfall (mm)	Avg. Annual Min. Temp. (ºC)	Avg. Annual Temp. (ºC)	Avg. Annual Max. Temp. (ºC)
2022	11811	249.05	24.45	27.35	30.25
2023	27723	180.85	24.90	27.97	31.04
2024	45080	164.35	24.79	27.85	30.90

Table 2 shows a sharp increase in reported dengue cases between 2022 and 2024. Total reported cases more than doubled from 11,811 in 2022 to 27,723 in 2023, followed by a further significant increase to 45,080 cases in 2024. This represents a nearly fourfold overall increase in the national case burden in just two years. During this same period, the average annual rainfall showed a decreasing trend falling from 249.05 mm in 2022 to 180.85 mm in 2023 and 164.35 mm in 2024. The average annual minimum temperature ranged from 24.45 °C to 24.90 °C, while the maximum ranged from 30.25 °C to 31.04 °C. The average annual temperature remained relatively stable, between 27.35 °C and 27.97 °C.

Table 3: Average Dengue Cases and Climate by Month (Across All Years)

Month Number	Month	Avg. Dengue Cases	Avg. Rainfall (mm)	Avg. Min Temp. (ºC)	Avg. Temp. (ºC)	Avg. Max Temp. (ºC)
1	January	1896.33	176.48	24.27	26.93	29.60
2	February	1948.33	128.52	24.37	27.07	29.77
3	March	1902.67	131.72	24.90	27.67	30.43
4	April	1982.33	262.09	25.20	28.02	30.83
5	May	2343.33	405.87	25.03	27.70	30.37
6	June	3587.33	361.98	24.60	27.58	30.57
7	July	3261.00	267.41	24.20	27.33	30.47
8	August	2981.67	167.57	24.60	28.03	31.47
9	September	2806.00	99.02	25.07	28.55	32.03
10	October	2381.00	87.54	25.10	28.53	31.97
11	November	1791.67	117.57	24.80	27.92	31.03
12	December	1323.00	171.25	24.43	27.33	30.23

Reported dengue cases show distinct seasonal distributions that correspond to rainfall and temperature patterns (Table 3). The highest average dengue cases were recorded during mid-year, with June showing a peak average of 3,587 cases, followed by July (3,261) and August (2,982). This period coincided with substantial average monthly rainfall, particularly in May (405.87 mm) and June (361.98 mm), while average monthly temperatures remained around 27 °C. September and October also reported high dengue cases of 2806 and 3181 respectively. These months coincided with reduced average monthly rainfall (99.02 mm and 87.54 mm) and the highest average monthly temperatures (28.5 °C). The lowest reported average cases occurred in December (1,323 cases) and during the early months of January through March (1,896 -1,948 cases), when average monthly rainfall ranged from 128.52 to 176.48 mm, average monthly temperatures were cooler (26.93 °C - 27.67 °C) and ranged from 24.27 °C to 30.43 °C.

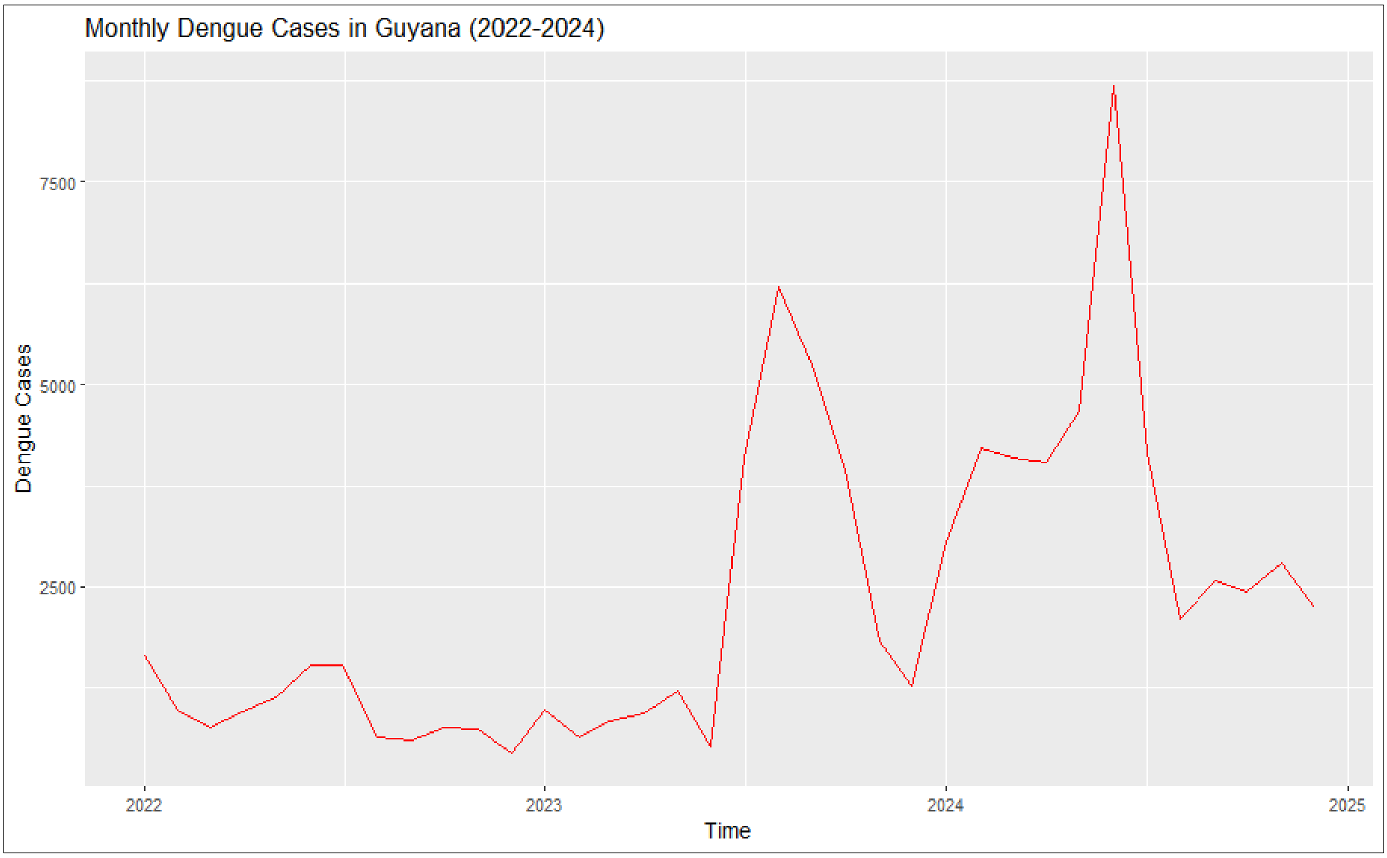

Fig 1: Monthly reported dengue cases in Guyana from January 2022 to December 2024

Figure 1 shows the time series plot for the reported monthly dengue cases in Guyana during the study period (2022-2024). Dengue cases were relatively low and stable throughout 2022 and early 2023, with monthly cases below 2,500. However, a sharp surge occurred in mid-2023 reaching around 6000 cases and followed by a rapid decline. Another major surge was observed in early to mid-2024, where monthly cases exceeded 7,500, representing the highest peak in the study period. Case counts declined after this surge but remained elevated compared to 2022 levels

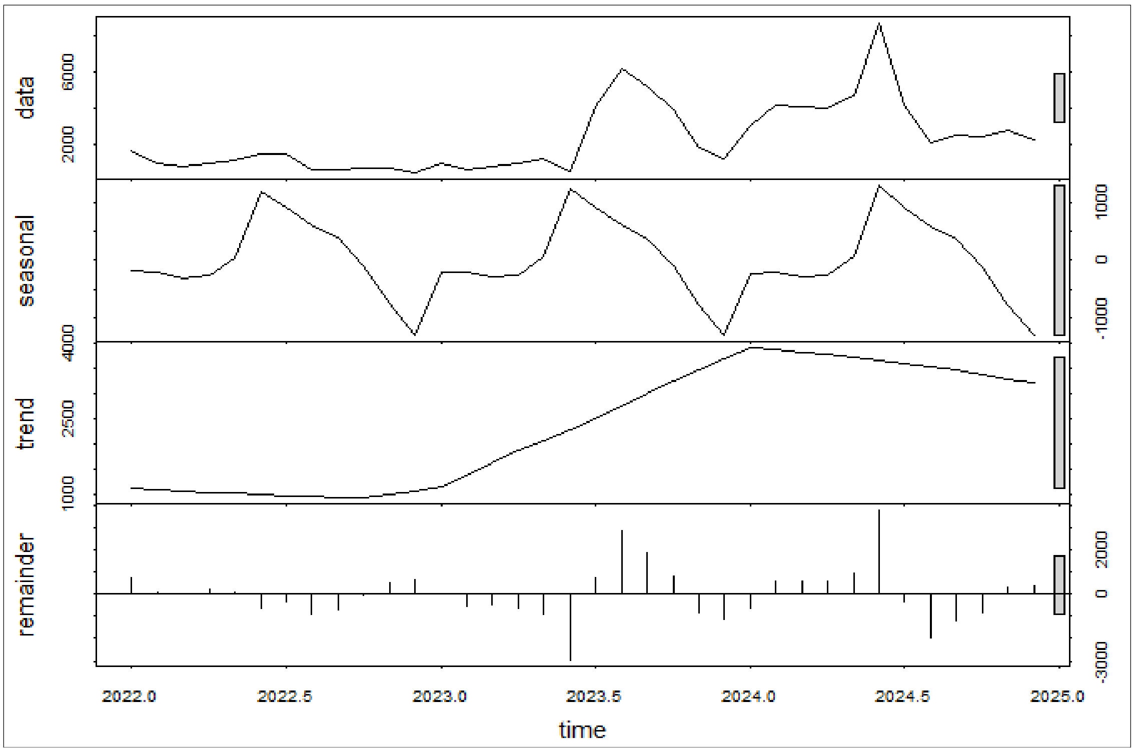

Fig 2: Seasonal-Trend decomposition using Loess (STL) of monthly dengue cases, 2022-2024.

Figure 2 which shows the STL decomposition plots for the monthly reported dengue cases in Guyana during the study period (2022-2024) revealed clear seasonal patterns and long-term trend effect. The seasonal component showed recurring fluctuations with peaks typically occurring around mid-year and troughs towards the end of each year. The trend component indicates an overall increase in dengue cases from early 2022 through mid-2024, followed by a slight decline in late 2024. The remainder component captured the short-term variability not explained by the seasonal or trend components.

Table 4: Pearson correlation coefficients between dengue cases, average rainfall, and mean temperatures at different monthly lags (0-3).

	Lag (months)	0	1	2	3
Rainfall	Cor. (r)	-0.136	-0.005	-0.052	-0.149
	95% CI	-0.444 - 0.202	-0.329 - 0.338	-0.383 - 0.291	-0.469 - 0.204
	p-value	0.430	0.976	0.771	0.407
Min. Temperature	Cor. (r)	0.423	0.483	0.520	0.505
	95% CI	0.110 - 0.660	0.179 - 0.703	0.221 - 0.730	0.196 - 0.723
	p-value	0.0101	0.003	0.002	0.003
Mean Temperature	Cor. (r)	0.477	0.468	0.481	0.436
	95% CI	0.176 - 0.697	0.160 - 0.693	0.170 - 0.704	0.109 - 0.678
	p-value	0.003	0.005	0.004	0.011
Max. Temperature	Cor. (r)	0.484	0.435	0.432	0.374
	95% CI	0.185 - 0.701	0.119 - 0.671	0.110 - 0.672	0.035 - 0.636
	p-value	0.003	0.009	0.011	0.032

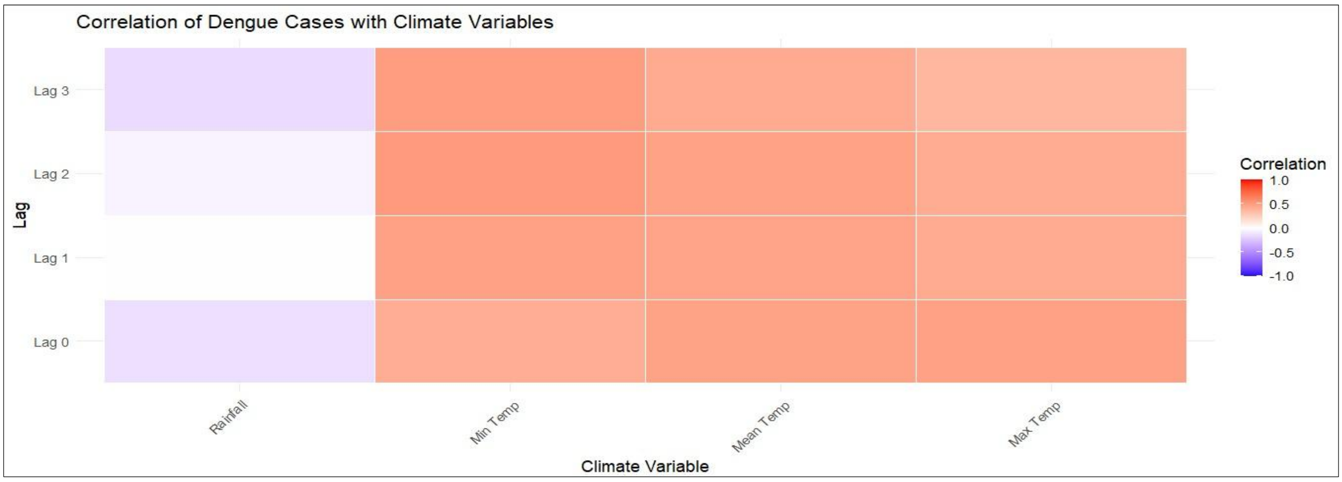

Fig 3: Correlation heat map between dengue cases, average rainfall, and mean temperatures at different monthly lags (0-3)

The correlation results for rainfall and temperature effects on dengue cases differed across monthly lags (Table 4 and Figure 3). Average monthly rainfall exhibited weak, negative and no significant correlations with dengue cases at all lags examined ($r = -0.005$ to -0.149, $p > 0.40$). In contrast, average monthly temperatures (minimum, mean, and maximum) showed statistically significant positive correlations with dengue cases across lags 0-3 months. Maximum temperature showed the strongest correlation ($r=0.484$, $p=0.003$) at lag 0, minimum temperature showed the strongest correlation ($r=0.483$ to 0.520, $p \leq 0.003$) for lags 1 to 3.

4. Discussion

This study examined the association between dengue cases and temperature and rainfall in Guyana during 2022-2024. The findings suggest that temperature, rather than rainfall, is more strongly associated with dengue cases in the short run. This result is consistent with studies from Guadeloupe [22], Brazil, Thailand and Barbados [37], which have similarly reported temperature as a key driver of *Aedes aegypti* dynamics and dengue outbreaks. Temperature directly influences mosquito development rates, biting frequency, and viral replication within the vector [33], which may explain the significant positive correlations observed across all lags in this study. Moreover, our findings align with the well-documented temperature window for dengue transmission (between 26-29 °C), a range in which mosquito vector competence and transmission potential are known to peak [31, 33]. This suggests that the prevailing temperatures in Guyana (minimum mean average: 25.90 °C, maximum mean average: 29.75 °C) during the study period provided highly suitable conditions for dengue transmission.

In contrast, rainfall did not show a statistically significant association with dengue cases at any lag examined. This result contradicts Boston & Kurup (2017) [9], who found a strong positive correlation between rainfall and dengue incidences ($r = 0.7$). While rainfall is often considered an important determinant of mosquito breading site availability, several studies have noted its effect is complex and context dependent. For example, a time-series analysis from Guangzhou China, used a distributed-lag nonlinear model (DLNM) and introduced prior water availability (8-week cumulative precipitation) as an effect modifier [16]. They found that heavy rainfall increased dengue risk at lags of ~24-55 days when prior water availability was low (peak IRR ≈ 1.37 at ~27 days), but the same heavy rainfall decreased risk when prior water availability was high (strongest negative effect at ~45-day lag). That study helps reconcile apparently contradictory past results by showing that the hydrologic "memory" of the landscape (dry vs. already-wet) flips the sign of heavy-rainfall impacts.

Similarly, a nationwide, province-level study from Lao PDR by Sugeno *et al*. (2023) [46] reported a nonlinear, lagged (delayed) association between rainfall and dengue: moderate weekly rainfall (peaking at ~82 mm/week) was associated with the highest dengue risk, while extremely heavy weekly rainfall (e.g., >~200 mm) became protective and consistent with a "flush-and-recover" pattern where intense rain destroys larval habitats and temporarily suppresses vector populations, but moderate rain creates and sustains breeding sites with subsequent increases in cases after a delay. The weak negative association observed may be explained by water-storage practices in Guyana, where mosquitoes often breed in artificial containers such as drums and barrels. Because these habitats are not dependent on rainfall, and heavy rains can sometimes wash larvae away dengue transmission here may be less tightly linked to rainfall than in settings where natural rain-fed breeding sites dominate. This pattern has been observed in other Caribbean countries where piped water access is limited and household water storage is common [49].

The sharp increase in dengue burden between 2022 and 2024 aligns with the broader regional resurgence of arboviral diseases reported by PAHO/WHO (2024) [36, 58]. The nearly fourfold increase in reported cases over two years may be attributable not only to climatic variability but also to other non-climatic drivers such as viral serotype shifts, increased vector resistance to insecticides, population mobility, and gaps in vector-control interventions. For instance, recent outbreaks in Brazil have been linked to the re-emergence of DENV-3 after years of absence [41]. Without virological data, it is difficult to determine the role of serotype dynamics in the Guyana epidemic, but the scale of the increase suggests that climatic factors alone cannot fully account for the observed surge.

Seasonal decomposition of the time series confirmed well-defined peaks in dengue cases around mid-year, consistent with findings from other regions. In French Guiana, Adde *et al*. (2016) [1] linked epidemics to mid-to-late year, while in the Philippines, Xu et al. (2020) [59] identified a recurring mid-year peak (July-August), with occasional later surges. Similarly, a recent systematic review of Caribbean studies [18] reported strong intra-annual cycles across multiple islands, typically peaking in the middle to latter half of the year. Interestingly, while peak cases coincided with the May-June rainy season, additional surges occurred during relatively drier and hotter months (September-October). This finding supports the earlier statement that temperature may exert a more consistent influence on dengue transmission dynamics than rainfall in Guyana's context.

A possible limitation to this study is the relatively short observation period of 36 months. Although this timeframe allows for the detection of broad seasonal and trend patterns, it may not capture interannual climate variability or longer-term dengue cycles. Unfortunately, data on monthly dengue cases in Guyana are not readily available for longer periods. Future with extended datasets would be valuable win strengthening the evidence base.

5. Conclusion and Recommendations

This study demonstrates that temperature, rather than rainfall, is the dominant short-term climatic driver of dengue transmission in Guyana during 2022-2024. Temperature within the optimal range (26–29 °C) likely amplify mosquito vector competence and viral replication, contributing to the strong positive associations observed across all lags examined (lags 0-3). By contrast, rainfall exhibited weak negative effects with dengue cases at all lags examined (0-3). In Guyana, many households rely on artificial water-storage containers, which reduce the link between dengue risk and rainfall. The negative relationship may also be attributed to the "washout effect" during heavy rainfalls.

The nearly fourfold rise in dengue cases over two years highlights the urgent public health challenge posed by the disease in Guyana. Although favorable climatic conditions are important contributors, the magnitude of the increase suggests additional influences such as serotype shifts and gaps in public health interventions. The seasonal decomposition analysis further confirmed predictable mid-year peaks, with occasional surges during hotter, drier months.

These findings emphasize the need for implementing temperature-based early warning systems to anticipate outbreaks and strengthening core public health measures – such as vector control programs, community education on water storage, and surveillance, to mitigate the drivers of dengue transmission.

Future research should prioritize securing longer-term data to better capture year-to-year climate variability, and on including virological and serological information to better understand how climate, immunity, and viral factors interact to drive dengue dynamics.

Compliance with ethical standard

6. Acknowledgment

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7. Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

8. Disclosure of conflict of interest

The authors certify that this submission is original work and is not under review at any other publication. The authors hereby declare that this manuscript does not have any conflict of interest.

9. Statement of informed consent

The authors declare that informed consent was obtained from all individual participants included in the study. All work utilized in this study was fully cited and referenced so authors of prior researches are given their due credentials for their work.

10. Data Availability

Data will be made available on request.

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