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Influence of Climatic Factors on Dengue Transmission and Larval indices: A Comparative Analysis between Colombo and Nuwara Eliya districts, Sri Lanka

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Abstract

Dengue fever remains a major public health threat in Sri Lanka, with significant geographic and seasonal variability in incidence rates. This study investigated the impact of climatic variables - temperature, rainfall, and humidity- on dengue transmission dynamics in two ecologically contrasting districts: Colombo, a lowland urban tropical zone, and Nuwara Eliya, a high-altitude, cooler region. Using a mixed-methods approach, the study analysed quantitative data from 2017 to 2023 sourced from the Dengue Control Unit and the Department of Meteorology, including monthly dengue cases, precipitation, temperature, relative humidity, and vector indices such as the House Index (HI) and Breteau Index (BI). Qualitative insights were gathered through expert interviews. Findings revealed consistently higher dengue incidence in Colombo, with peak outbreaks aligning with the Yala monsoon season (May–August). In contrast, Nuwara Eliya exhibited lower overall transmission, with occasional peaks during the Maha season (September–December). Elevated HI and BI values in Colombo (HI = 16.6; BI = 25.3 in May 2022) reflect more favourable conditions for *Ae. aegypti* breeding, while cooler temperatures in Nuwara Eliya generally suppressed vector development, though a notable rise in indices in late 2023 suggested emerging risks due to climatic anomalies. A statistical analysis between dengue incidence and climatic variables, particularly temperature and rainfall were conducted. The study underscores the importance of integrating climate-sensitive entomological surveillance into public health strategies. Tailored vector control efforts, especially in high-risk urban zones like Colombo, and continuous monitoring in emerging-risk areas such as Nuwara Eliya, are essential for early warning and prevention.

Keywords: Climatic variables, dengue fever, larval indices, public health

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Introduction

Dengue fever, a mosquito-borne viral illness, remains a major public health concern in Sri Lanka, with outbreaks occurring regularly since the 1960s. All four dengue virus serotypes (DENV-1 to DENV-4) have been circulating for over three decades, with recent epidemics becoming more severe due to the emergence of new DENV-3 clades. Dengue's clinical spectrum ranges from mild undifferentiated fever to severe forms like dengue haemorrhagic fever (DHF), with incidence typically peaking during rainy seasons. This seasonal trend highlights the strong influence of climatic factors—particularly rainfall and temperature — on dengue transmission. Effective dengue control requires proactive vector management strategies, supported by climate forecasting and early warning systems to reduce morbidity and mortality (www.dengue.health.gov.lk, n.d; Sirisena & Noordeen, 2014).

The major dengue vectors in Sri Lanka are *Ae. aegypti* and *Ae. albopictus*. These mosquitoes exhibit skip-oviposition behaviour, laying eggs across multiple breeding sites within a single reproductive cycle. Their preferred habitats include artificial containers such as tires and water storage units, as well as natural environments like tree holes. *Ae. aegypti* can complete its life cycle in just 7–10 days under favourable conditions and can lay 50–100 eggs per blood meal, contributing to rapid population growth. Both species are widely distributed across the island, with *Ae. albopictus* also recognized as a highly competent dengue vector (Anoopkumar A N et al., 2017; Oliva et al., 2014).

Colombo, Sri Lanka's most populous urban center with over 5.6 million residents, reported the highest dengue incidence in 2023, with 16,948 cases (Fernandopulle, 2023; Udayanga et al., 2020). Accordingly, 6678 (Mawratanews.lk, 2023) and 57 dengue (SRI LANKA Second Quarter 2023 EPIDEMIOLOGY UNIT, n.d., p.4) cases were recorded in Colombo District and Nuwara Eliya Districts, respectively. Despite its lower incidence, dengue vectors are still present in certain low-altitude areas of Nuwara Eliya, necessitating ongoing surveillance. Previous research has established threshold levels for the House index (percentage of houses positive for larvae) and Berteau Index (percentage of positive larval containers per 100 houses) (Sanchez et al., 2006) in areas like Colombo and Kandy, allowing for early epidemic prediction through ROC analysis (Udayanga et al., 2020). These indices are crucial for informing timely interventions (Udayanga et al., 2020). Moreover, the growing impact of climate change has intensified dengue transmission, making it imperative to integrate climate adaptation and predictive data into national public health strategies to mitigate future risks (Udayanga et al., 2020).

This study employed a comparative case study approach, focusing on Colombo and Nuwara Eliya districts in Sri Lanka, selected for their distinct climatic profiles - Colombo being a warm, humid, lowland urban area, and Nuwara Eliya a cooler, high-altitude region. The research aimed to assess the influence of environmental and climatic factors on dengue prevalence in these two contrasting settings.

Materials and Methods

Data collection was conducted through primary research using secondary data sourced from the Dengue Control Unit under the Public Health Department and the Department of Meteorology, covering the period from 2017 to 2023. Quantitative data included annual and monthly dengue case numbers, HI and BI values were collected from the records at the Dengue Control Unit and climate indicators such as temperature, rainfall and humidity.

These were analysed to identify correlations and trends in dengue incidence relative to environmental conditions. Qualitative data were obtained through expert discussions with the Director of the Dengue

Control Unit, providing insights into epidemiological trends, climate change impacts, larval development, and control challenges. Supplementary literature from databases such as PubMed, Google Scholar, and ScienceDirect enriched the analysis by contextualising findings within global research on climate-sensitive vector behaviour and control strategies. An inductive analytical approach was used, enabling pattern identification without preset hypotheses. Statistical analysis was performed using Excel 2013 and SPSS, with descriptive measures such as mean, median, standard deviation, range, skewness, kurtosis, and confidence intervals calculated. Visual data representation was done via graphs and charts in SPSS and MS Word 2013. Additionally, larval growth patterns were compared through literature-based analysis to further clarify climate-linked vector dynamics. This comprehensive methodology supported a detailed investigation into climate-dengue relationships across diverse ecological zones.

Results

The analysis of dengue case data from 2014 to 2023 reveals a significant and persistent disparity in incidence rates between the Colombo and Nuwara Eliya districts. Colombo consistently recorded higher mean dengue cases compared to Nuwara Eliya throughout the 10 years. The highest mean cases in Colombo were observed in 2017 (mean annual cases= 3,681.75), with another major outbreak in 2019, when the total number of cases reached 28,939. In contrast, Nuwara Eliya recorded substantially lower figures, with the highest total of 476 cases also in 2019. Notably, both districts reported their lowest dengue incidence in 2020, likely due to COVID-19 lockdown measures that disrupted vector transmission cycles. This disparity may partly reflect population differences, as Colombo had a population of 2,460,000 compared to 781,000 in Nuwara Eliya, a ratio of about 3.14: 1 (Population and Population Density by District, Lanka Statistics, 2023).

Monthly analysis from 2019 to 2023 indicates clear seasonal patterns in both districts. Colombo exhibited dengue case peaks primarily during the Yala season (May to August), particularly in June and July, whereas Nuwara Eliya recorded peak cases during the Maha season (September to December), notably in October and November. Environmental data, including precipitation, relative humidity, and temperature, were examined for their potential influence on dengue trends in the study areas.

Precipitation

Monthly analysis from 2019 to 2023 indicates clear seasonal patterns in both districts. Colombo exhibited dengue case peaks primarily during the Yala season (May to August), particularly in June and July, whereas Nuwara Eliya recorded peak cases during the Maha season (September to December), notably in October and November. Environmental data, including precipitation, relative humidity, and temperature, were examined for their potential influence on dengue trends. In Colombo, the highest mean monthly precipitation was recorded in 2021 (Mean = 255.33 mm), while in Nuwara Eliya, the peak occurred in 2022 (Mean = 173.98 mm). Precipitation distributions were positively skewed in both districts (Colombo: Skewness = 1.44; Nuwara Eliya: Skewness = 1.23), reflecting occasional extreme rainfall events. Overall, according to the figure 01, average monthly rainfall in Colombo was higher than in Nuwara Eliya, particularly during the Maha season. November consistently showed the highest average rainfall in Colombo (414.4 mm), while October was the peak month in Nuwara Eliya (226.8 mm).

Temperature

Annual mean temperature in Colombo ranged between 30.9°C and 31.6°C, remaining within the optimal range for Aedes mosquito development. The highest mean temperature (31.59°C) was observed in 2020. In contrast, Nuwara Eliya exhibited significantly cooler temperatures, with an annual mean around 20.6°C in 2020 and 2023. The cooler conditions in Nuwara Eliya may inhibit rapid vector development and virus transmission cycles.

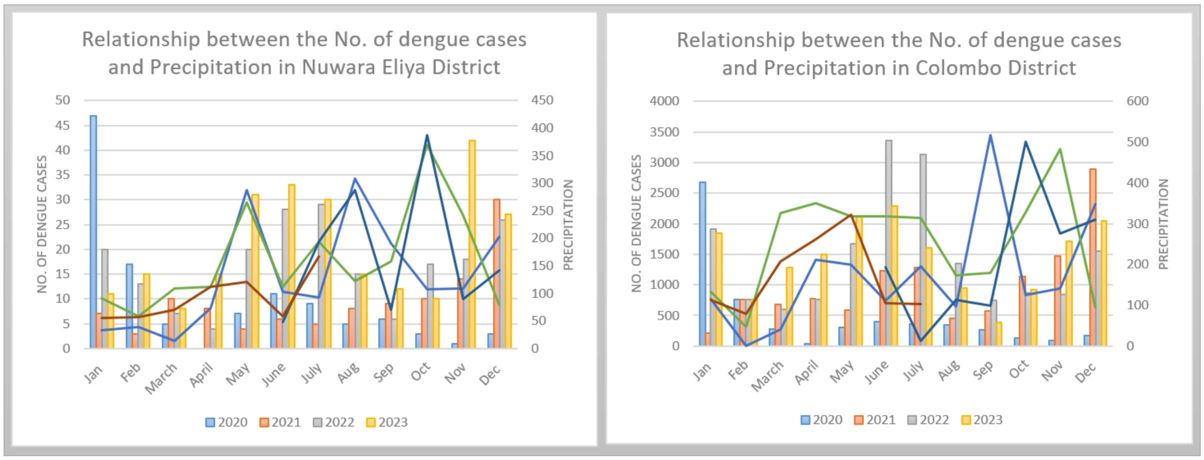

Figure 1: *Relationship of precipitation and no. of dengue cases in Colombo and Nuwara Eliya Districts*

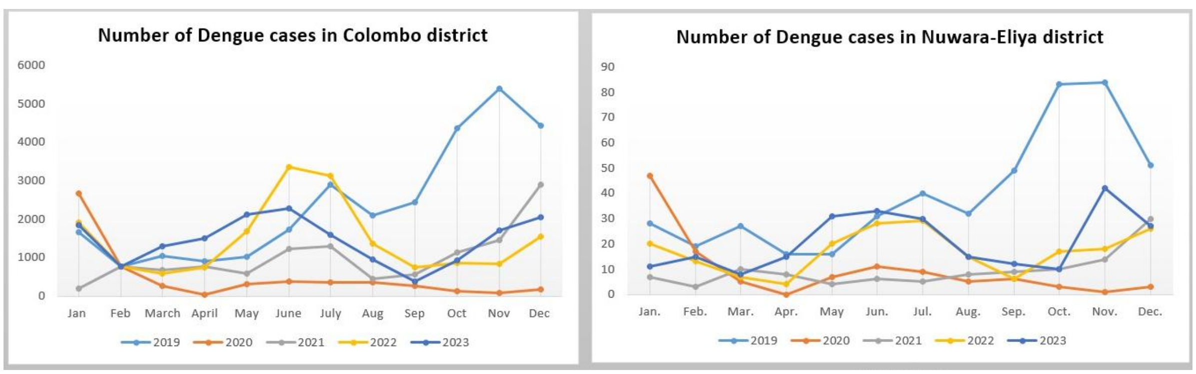

Figure 2: *Number of dengue cases filled within 2019-2023*

Relative Humidity

Relative humidity was consistently higher in Nuwara Eliya (Mean range: 76.8%–80.8%) than in Colombo (Mean range: 73.2%–75.9%). In both districts, relative humidity increased between January and March and declined toward the latter months of the year. Despite higher humidity, dengue incidence in Nuwara Eliya remained low, likely due to the moderating effect of temperature and altitude.

Seasonal Distribution of Dengue Cases

A seasonal breakdown revealed that dengue transmission in Colombo intensified during the Yala season (May–August), corresponding to high rainfall and temperature periods. Notably, 2019, 2022, and 2023 exhibited sharp rises during this time. Conversely, in Nuwara Eliya, dengue cases peaked during the Maha season (September–December), especially in 2019 and 2023, aligning with the second monsoon and cooler, wetter climate.

Figure 2, further support these observations, showing a positive association between monsoonal rainfall patterns and dengue incidence in both districts. The first inter-monsoon season (March–April) consistently recorded the lowest number of dengue.

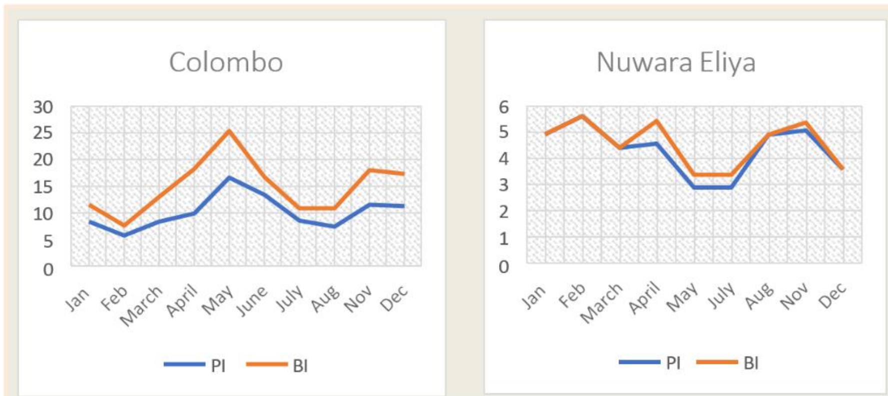

Figure 3*: The HI and BI indexes of Colombo and Nuwara Eliya Districts in the year 2022*

Accordingly, figure 3 represents the Vector surveillance data reinforce the disparity in dengue transmission potential between the two districts. In Colombo, both the House Index (HI) and Breteau Index (BI) were significantly elevated compared to Nuwara Eliya. The highest values were reported in May 2022 (HI = 16.6; BI = 25.3), corresponding to peak *Ae. aegypti* breeding season during the Yala rains. In Nuwara Eliya, the indices remained comparatively low throughout the study period, with HI = 5.06 and BI = 5.36 peaking in November, indicating a lagged breeding response possibly due to cooler temperatures and fewer artificial breeding habitats. The indices in Colombo displayed consistent elevation across the year, with minor dips in July–August, possibly reflecting temporary control interventions or ecological shifts. A secondary increase in both indices was noted in October–December, suggesting a resurgence of breeding following late Maha season rains.

The descriptive analysis revealed several key observations regarding the impact of climate on dengue transmission in Colombo and Nuwara Eliya districts, which are mentioned in Table 01 below. Colombo consistently experienced a significantly higher burden of dengue cases compared to Nuwara Eliya, with major outbreaks recorded in 2017 and 2019. In contrast, Nuwara Eliya remained a low-incidence region with only sporadic increases in dengue cases, particularly during the Maha season. Seasonal patterns were also evident, with peak dengue activity in Colombo aligning with the Yala season (May–August), while in Nuwara Eliya, peaks occurred during the Maha season (September–December). Vector indices, including the HI and BI, were markedly higher in Colombo, suggesting a denser and more widespread presence of *Aedes* mosquito populations. These findings collectively demonstrate that climatic variations, particularly changes in rainfall and temperature, play a critical role in shaping dengue transmission patterns. As a result, the study emphasises the need for localised, climate-responsive vector control strategies and public health interventions, particularly in high-risk urban centres like Colombo, to mitigate the growing threat of dengue.

Table 1: *Descriptive analysis of Precipitation, Relative humidity and Temperature of Colombo and Nuwara Eliya Districts*

Descriptive Statistics of precipitation in Nuwara- Eliya district						
Years	Range	Minimum	Maximum	Mean	Skewness	Kurtosis
2020	295.4	13.3	308.7	130.280	0.796	-0.417
2021	310.3	59.2	369.5	159.458	1.233	1.021
2022	340.2	47.4	387.6	173.986	0.891	-0.289
2023	112.6	55.1	167.7	91.686	0.973	-0.153
Descriptive Statistics of precipitation in Colombo district						
Years	Range	Minimum	Maximum	Mean	Skewness	Kurtosis
2020	517.6	0.1	517.7	175.683	1.443	2.505
2021	437.5	45.9	483.4	255.333	-0.102	-0.622
2022	488	13	501	214.83	0.729	0.351
2023	242.7	79.3	322.0	170.186	0.778	-1.126
Descriptive Statistics of Relative humidity in Nuwara-Eliya district						
Year	Range	Minimum	Maximum	Mean	Skewness	Kurtosis
2019	32	55	87	76.80	-1.268	2.198
2020	35	54.6	89.6	76.89	-1.237	1.642
2021	16.7	70.2	86.9	80.43	-0.652	-1.346
2022	19.6	68.3	87.9	80.1	-0.726	-0.642
2023	14.9	74	88.9	80.84	0.110	
Descriptive Statistics of Relative humidity in Colombo district						
Year	Range	Minimum	Maximum	Mean	Skewness	Kurtosis
2019	15.2	64.9	80.1	74.191	-0.568	-0.605
2020	17.4	63	80.4	73.2	-0.696	-0.484
2021	14.9	66	81	75.72	-0.957	0.447
2022	13.9	66.2	80.1	74.83	-0.731	-0.575
2023	13.4	68.6	82	75.975	-0.305	-0.633

Descriptive Statistics of Temperature in Colombo district						
Year	Range	Minimum	Maximum	Mean	Skewness	Kurtosis
2019	2.8	30.0	32.8	31.342	-0.197	-0.682
2020	3.3	30.0	33.3	31.592	0.258	-1.195
2021	2.3	29.8	32.1	30.933	0.068	-1.430
2022	2.5	29.9	32.4	31.000	0.500	-1.362
2023	2.1	30.2	32.3	31.350	-0.496	-0.828
Descriptive Statistics of Temperature in Nuwara- Eliya district						
Year	Range	Minimum	Maximum	Mean	Skewness	Kurtosis
2019	4.5	18.5	23.0	20.542	0.565	-0.884

2020	5.1	18.2	23.3	20.625	0.669	0.289
2021	3.5	19.0	22.5	20.233	0.882	0.469
2022	3.3	18.6	21.9	20.042	0.604	-0.806
2023	3.4	19.0	22.4	20.625	0.156	-1.182

Discussion

Dengue incidence decreased significantly in 2020, following an increase in 2019, 2021, 2022, and 2023 in Colombo and Nuwara-Eliya. Colombo had the highest monthly mean (3,681.75) and lowest mean infection (507), while Nuwara-Eliya had the highest monthly mean (88.50) and lowest mean infection (9.5). This decrease was confirmed by a Sri Lankan study, which found a notable rise in dengue infection in 2017 compared to previous surveillance (Tissera et al., 2020). The integration of HI, BI of larval indices have provided critical insight into the climate-dengue relationship in Colombo and Nuwara Eliya districts. The study found that mosquito breeding and larval infestations are consistently more prevalent in Colombo, as indicated by higher HI and BI values across multiple years. In 2022, peak breeding activity in Colombo was observed in May (HI = 16.6; BI = 25.3), while in 2023, the highest BI was in April (21.08) and HI in May (13.92). Conversely, Nuwara Eliya, known for its cooler highland climate, generally maintained lower mosquito indices, although a sharp increase in December 2023 (HI = 13.11; BI = 19.33) suggests a potential late-year outbreak and highlights growing susceptibility. Seasonal variation significantly affected dengue incidence, and more Aedes larvae were seen in the rainy season than in the winter and summer, according to a study on the impact of seasonal variation on dengue transmission prediction in Thailand (Wongkoon et al. 2013). Aedes mosquitoes shows a greater adaptation to salinity in groundwater and brackish water than freshwater bodies with a higher number of eggs laid (Surendran et al., 2021). These mosquitos oviposit various natural and artificial habitats where, they possess adaptations such as desiccation – resistant eggs and dormancy to withstand climatic stress (Udayanga et al., 2020).

These findings underline the strong influence of climatic factors—particularly temperature, rainfall, and humidity—on mosquito breeding and dengue incidence and A study suggested that the dengue fever incidence was significantly related to temperature, rainfall, and sunshine (Liu et al., 2020) also proves climatic factors affect the incidence of dengue. Colombo's warmer, wetter tropical climate (average 28–32°C) provides more favourable conditions for Aedes mosquito development compared to Nuwara Eliya's cooler (18–22°C), high-altitude environment. This supports existing literature, including studies by Liu et al., (2020) and Johansson et al., (2009) which identify temperature and precipitation as key predictors of vector density and dengue outbreaks. Seasonality was also shown to significantly impact dengue dynamics (Polwiang, 2015). In Colombo, the Yala season (May–August) corresponded with high HI/BI values and peak dengue cases, while in Nuwara Eliya, the Maha season (September–December) showed a similar association. Warmer and wetter conditions during these seasons accelerate the mosquito lifecycle, facilitating rapid vector population growth and increasing disease transmission risks, particularly when climatic anomalies occur. Notably, the recent increase in larval indices and dengue cases in Nuwara Eliya indicates a possible climatic shift that could alter its historical status as a low-risk area. This raises concerns about expanding dengue vulnerability zones due to climate change. Therefore, the use of HI, BI, and larval data in conjunction with climate metrics enhances the capacity for early detection and proactive response. The study emphasises the need for climate-adaptive, location-specific vector control strategies, particularly in urban, high-risk areas like Colombo, while closely monitoring emerging risks in previously low-incidence zones like Nuwara Eliya.

Conclusion

The findings demonstrate that climatic factors, particularly rainfall and temperature, strongly influence dengue transmission in Colombo and Nuwara Eliya. Colombo showed consistently higher incidence and vector indices, with peak outbreaks aligning with the Yala season, reflecting favourable lowland tropical conditions for Aedes breeding. In contrast, Nuwara Eliya recorded a lower incidence, though sporadic peaks during the Maha season suggest seasonal vulnerability influenced by cooler but wetter conditions. The rise in larval indices in late 2023 indicates emerging risks in traditionally low-incidence highland areas. These results highlight the need for climate-responsive, locally adapted vector control strategies to strengthen early warning systems and mitigate dengue risks across diverse environments.

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