# DENGUE DISEASE PREDICTION USING RAINFALL VARIATION IN THE COLOMBO DISTRICT, SRI LANKA

**Piyumi Chathurangika, Kushani De Silva and Sanjeewa Perera**

Research & Development Center for Mathematical Modeling, Department of Mathematics, University of Colombo,
Sri Lanka

**ABSTRACT:** *Dengue is a rapidly emerging pandemic disease in many of the tropical countries in the world. Dengue mosquito emergence highly impacts dengue disease transmission in the human community. Since mosquito emergence is affected by environmental factors the study of environmental impact on dengue emergence within a community is crucial. Dengue disease is serologically confirmed in Sri Lanka since 1960 and annually over 50,000 dengue infections are reported all around the country. The highest number of dengue cases are reported in the Colombo District throughout the year. Sri Lanka being a tropical country, the governing and most favorable environmental factor for dengue disease emergence is rainfall. The South- West monsoon and Northeast monsoon bring a seasonal variation to rainfall on the island. The reported dengue cases also show seasonal variation and thus the main aim of this study is to capture the seasonality of dengue disease emergence by quantifying the per capita vector density by means of rainfall variation.*

**Keywords:** Dengue transmission model, Per-capita vector density, Seasonal rainfall, Colombo District

## 1. INTRODUCTION

Dengue disease is a pandemic reported commonly in tropical countries all around the world. The disease is transmitted by mosquitoes of the species Aedes. The two main forms of the dis- ease are Dengue Fever (DF) and Dengue Hemorrhagic Fever (DHF). Annually over 360 million cases are reported worldwide which also accounts for over 22,000 deaths [1]. The countries with the highest number of reported dengue cases are Brazil, Vietnam, and Peru. Many Asian countries also report a significantly high number of dengue cases owing to the favorable tropical conditions for mosquito breeding. The main reason for dengue disease emergence is the favorable environmental conditions such as rainfall, temperature, and humidity. These environmental factors affect the origination of dengue breeding sites. Moreover, under favorable conditions, efficient virus transmission occurs due to the mosquito genetic factors such as the incubation period.

When it comes to the recorded highest number of dengue cases, Sri Lanka is in the top 5 countries in South East Asia and is in the first 30 countries in the world. Dengue disease was first serologically confirmed in Sri Lanka in 1962. Since then, a significant number of dengue cases are reported each year and the most recent outbreak occurred in 2017 reporting over 80,000 dengue-infected humans within the country. Approximately 43% of the total dengue cases in the country are reported in the Western Province (WP) out of which the highest number of cases are from the Colombo District (CD).

The main reason for a high number of dengue cases reported in Sri Lanka is the favorable environmental conditions. Sri Lanka having relatively warm temperature conditions, the main fluctuation of dengue occurrence is seen due to the seasonal trend in rainfall. Sri Lanka experiences abundant rainfall throughout the year due to monsoon rains. South West Monsoon and the North East monsoons are the two main rainy seasons experiences in the country [14]. Due to these two rainy seasons, the dengue occurrence also shows significant seasonal changes. This study is conducted to identify and estimate the dengue cases caused by the seasonal trends of rainfall. In order to identify the disease transmission among a community together with the rainfall, compartmental models can be used as they give a descriptive visualization of virus transmission between vectors and hosts [5, 7].

In the next section of this paper, a dengue transmission model is introduced to illustrate the dengue virus transmission between vectors and hosts. The effect of rainfall accounted for the model is illustrated in section 2 together with the methodology followed. Section 3 shows the results and the discussions made throughout the study. The conclusion brought up by this study is presented in section 4 together with the future work.

## 2. METHODOLOGY

### 2.1 Data Collection and Research Area

The highest number of dengue cases are reported in the CD in Sri Lanka. Thus, this study is conducted in the CD. For this district, weekly reported dengue cases based on recorded MOH area data were obtained from the National Dengue Control Unit (NDCU) of Sri Lanka. The environmental data for this study were obtained from the NASA Webpage. The daily rainfall data within the CD was extracted which were later summed up to get the weekly rainfall data.

### 2.2 Disease Transmission Dynamics

The human population can be divided into 3 compartments namely susceptible, infected and recovered and the vector population can be divided into 2 compartments, susceptible and infected. Dengue disease transmission between these compartments can be visualized by Figure 1.

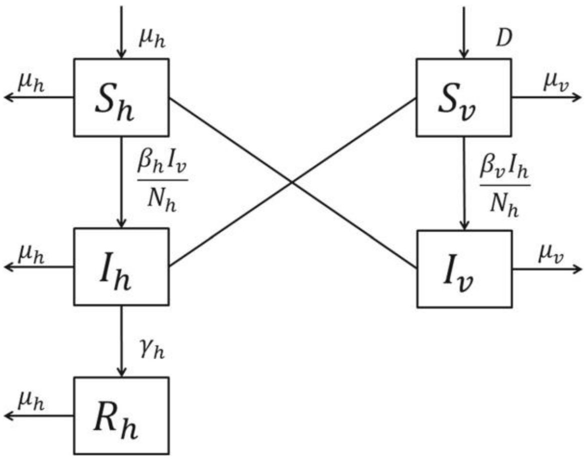


Figure 1: Dengue transmission compartmental schematic diagram

The disease transmission dynamics can mathematically be identified by means of ordinary differential equations as follows [11].

$$\frac{dS_h}{dt} = \mu_h(N_h - S_h) - \frac{\beta_h}{N_h} S_h I_v \quad (1a)$$

$$\frac{dI_h}{dt} = \frac{\beta_h}{N_h} I_v S_h - (\mu_h + \gamma_h) I_h \quad (1b)$$

$$\frac{dR_h}{dt} = \gamma_h I_h - \mu_h R_h \quad (1c)$$

$$\frac{dS_v}{dt} = D N_v - \mu_v S_v - \frac{\beta_v}{N_h} I_h S_v \quad (1d)$$

$$\frac{dI_v}{dt} = \frac{\beta_v}{N_h} I_h S_v - \mu_v I_v \quad (1e)$$

The parameters and the variables used in this 5D model are as given in Table 1.
The above model can be converted to a population density model and can be simplified to a 3D model [11].

where,

Table 1: Parameters of the 5D model

| Parameter | Description |
|---|---|
| $N_h$ | Total human population |
| $N_v$ | Total vector population |
| $S_h$ | Susceptible human population |
| $I_h$ | Infected human population |
| $R_h$ | Recovered human population |
| $S_v$ | Susceptible vector population |
| $I_v$ | Infected vector population |
| $\mu_h$ | Host reproduction & mortality rate |
| $\mu_v$ | Vector reproduction & mortality rate |
| $\gamma_h$ | Host recovery rate |
| $\beta_h$ | Transmission rate from vector to host |
| $\beta_v$ | Transmission rate from host to vector |

$$\frac{dI}{dt} = \beta_h z V(1 - I - R) - (\mu_h + \gamma_h)I, \tag{2a}$$
$$\frac{dR}{dt} = \gamma_h I - \mu_h R, \tag{2b}$$
$$\frac{dV}{dt} = \beta_v(1 - V)I - \mu_v V \tag{2c}$$

where

Table 2: Parameters of the 3D model

| Parameter | Description |
|---|---|
| $I$ | Infected human population density |
| $R$ | Recovered human population density |
| $V$ | Infected vector population density |
| $z$ | Per-capita vector density |

## 2.3 Rainfall Variation in Sri Lanka

Sri Lanka experiences two main monsoon seasons annually. The South West monsoon originates from the Indian Ocean during May-June and the North East monsoon originated from the Bay of Bengal during December-January. Due to these monsoon seasons, the rainfall variation in Sri Lanka shows two peaks each year as shown in Figure 2.

These monsoon rains directly impact the dengue mosquito emergence in the WP due to the generation of mosquito breeding sites. Thus, the impact of dengue mosquito emergence is also seasonal and it follows the rainfall pattern. As a result, the dengue disease emergence is also seasonal and follows the rainfall pattern.

It was found by previous studies that the impact of rainfall on dengue emergence happens with a specific time lag [13]. In this study, it is considered that the rainfall effects the dengue disease emergence with 10 weeks time lag.

Due to the seasonal increasing and decreasing pattern of rainfall, this study is considered taking 4 seasons per year considering the 10 weeks time lag as well. The 4 seasons are from January - March, April- June, July-September and October-December.

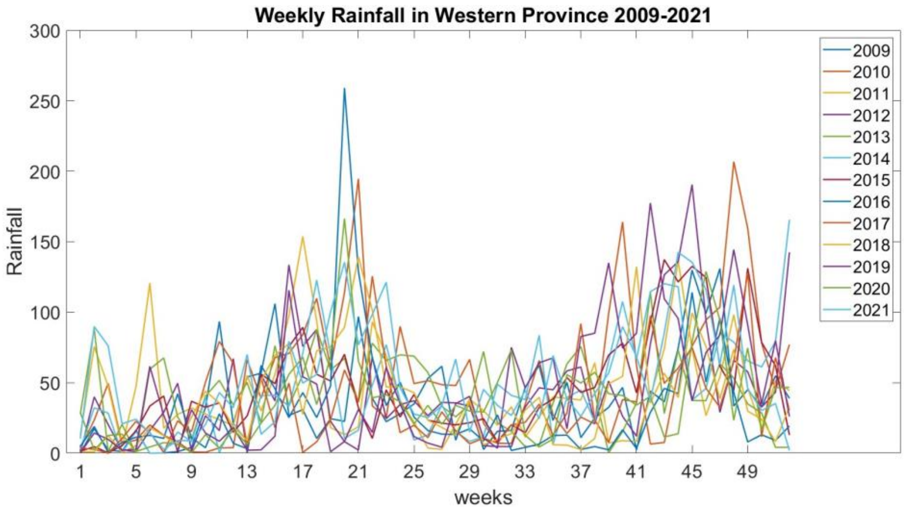


Figure 2: Weekly rainfall experienced in each year from 2009 - 2021. Two peaks can be seen from May-June and October-December.

### 2.4 Per-Capita Vector Density

Since there is no reliable data available for dengue mosquito count, this study uses the parameter z to estimate the dengue mosquito impact on dengue disease emergence. Per-capita vector density (z) is defined as the number of mosquitoes per person. Rainfall causes the production of breeding sites and favorable conditions for mosquitoes to spread the disease among humans. Therefore, it is clear that the number of mosquitoes is dependent on rainfall. Therefore, in this study per-capita vector density (z) is estimated using weekly rainfall data. In order for the per-capita vector density to follow the rainfall values the relationship was obtained as

$$z = aR(t) \tag{3}$$

where,

$$R(t) = \frac{Weekly\ Rainfall}{Average\ weekly\ rainfall} \tag{4}$$

### 2.5 Data Analysis

The constant a is taken to be a seasonal parameter that is synchronized with the annual monsoon seasons. Since 4 different seasons were identified for each year, the value a is a seasonal constant that has 4 different values for each year. Depending on the availability of data, the estimation of the parameter a (Seasonal rainfall coefficient) is done using a trial-and-error method that would minimize the lease square error,

$$Min\ SSE = \sum \left( I_{obs} - \int \frac{d}{dt} I(a, R) dt \right)^2 \tag{5}$$

The study is conducted for 4 identified seasons per year. Within a season, the rainfall values with the respective time lags [13] are fed to z using equation 3. For a given value of a equation 2 is solved to estimate the dengue-infected human population density. The result obtained is then compared with the reported data (see Eq. (5)). For the $i^{th}$ season, the initial values were taken from the estimated infected density from the $(i-1)^{st}$ season.

## 3. RESULTS AND DISCUSSION

### 3.1 Simulated Results in the WP

The method mentioned in the previous section is followed to obtain the results presented in this section which includes the simulated results and the seasonal rainfall coefficient a. The simulated dengue-infected human density from 2009-2022 is as shown in figure 3.

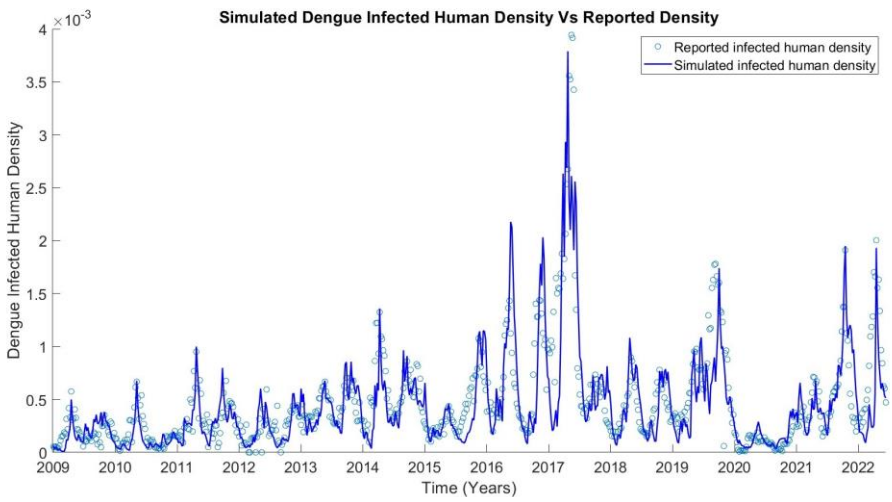


Figure 3: Dengue infected human population density simulated using the rainfall data and per- capita vector density. Different values for a are used to obtain simulations that are comparable with the actual dengue-infected human population density shown in blue dots.

The seasonal rainfall coefficient (a) values selected for each season show significant clusters as shown in Figure 4

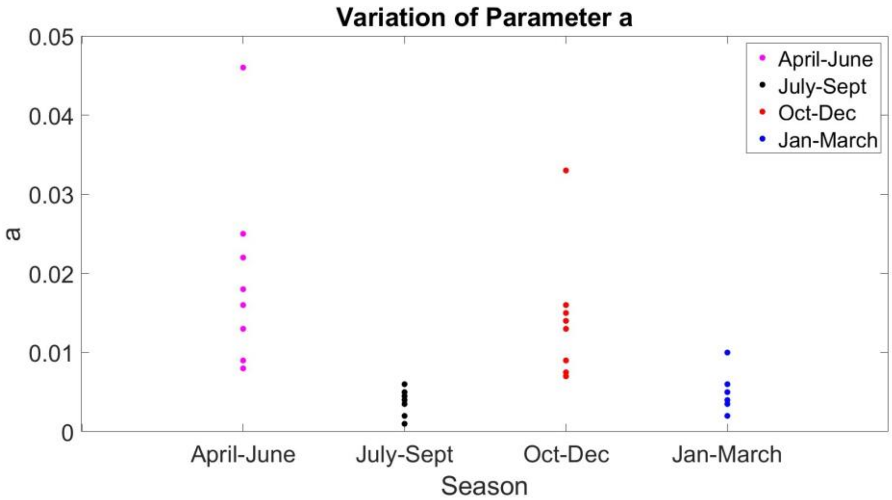


Figure 4: Seasonal rainfall coefficient (*a*) chosen are clustered according to the seasons in each year.

### 3.2 Predicted Results in the WP

In order to validate the method 70% of the data are used as the trial data and 30% are used as test data. The simulation results are obtained for the trial data and a values are recorded. The mean of the recorded a values for each separated season is calculated. Using these mean values, the test results are obtained as shown in Figure 5. These test results are predictions for the upcoming years.

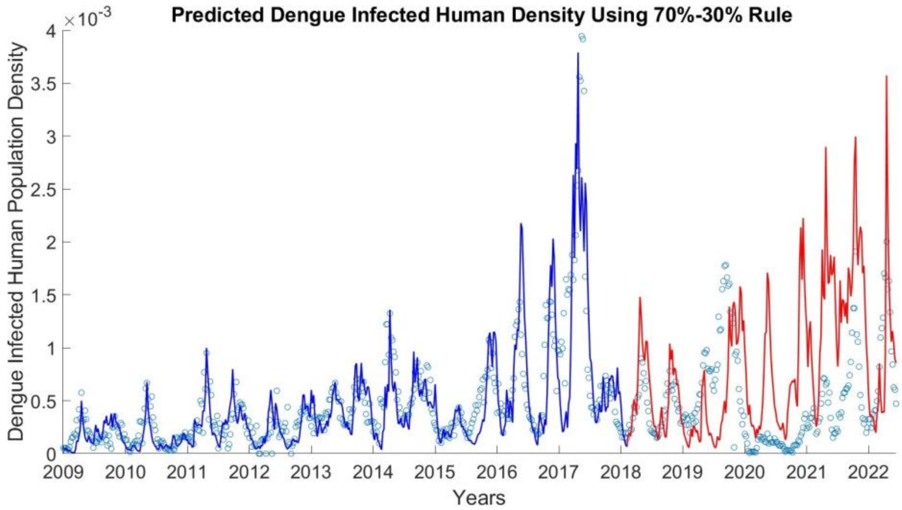


Figure 5: Simulated results given in blue are obtained using a values chosen. The predicted results given in red are obtained using the mean values of a used for the trial data for each separate season.

According to Figure 5 the prediction results shown in red are accurate for three seasons when compared with the reported dengue-infected human density values. However, as the prediction continues, the difference between the predicted and actual values becomes large. Since the endpoint results of each season are considered as the initial values for the next season, the error in each season is accumulated in the next season. Thus, this method provides inaccurate results when conducted for a longer period of time. However, using rainfall values and past results, this method can be utilized to predict the dengue emergence for at least three upcoming seasons.

## 4. Conclusions & Future Work

Dengue is a pandemic that forces social and economic threats to tropical countries that are battling to prevent it. Many studies have been conducted so far to analyze and predict dengue cases. Studies conducted in Sri Lanka also use several methods to understand and mitigate the dengue disease threat. Since the main impact on dengue emergence is from rainfall, this study is conducted to analyze and predict dengue emergence using weekly rainfall values. The classical SIR model is an effective method to estimate the dengue disease transmission among vectors and hosts. Out of the parameters in the SIR model, per-capita vector density is the most crucial parameter as it is rapidly changing due to external factors such as rainfall. Per-capita vector density found using the variation of rainfall shows that it follows the rainfall seasonality. Dengue emergence in the CD is also followed by the seasonal variation of rain- fall. Thus, the estimated value a can be used to obtain the per-capita vector density using rainfall data in each season. These results can be used to predict the upcoming dengue cases season-wise.

However, the results obtained in this study show that the prediction can be done only for a limited time. Accurate predictions can be obtained for three upcoming seasons and further predictions can give false results due to error accumulation. Moreover, this study is carried out by estimating the seasonal rainfall coefficient a, using a trial-and-error method. This may result in large uncertainties in the predictions and accumulated uncertainties in the forecasting. For future work therefore it's important to estimate the seasonal coefficient using a proper quantitative measure to reduce the uncertainty in the estimates.

In conclusion, seasonal trends in rainfall can be used to predict the dengue emergence in a selected region so that a community can prepare in advance either to mitigate the issue or to allocate funds to minimize the damage the dengue pandemic may incur.

**REFERENCES**

World Health Organization. (n.d.). Dengue and severe dengue. World Health Organization. Retrieved October 29, 2022.

Khatua, A., & Kar, T. K. (2020). Dynamical behavior and control strategy of a dengue epi- demic model. The European Physical Journal Plus, 135(8), 1-22.

Rather, I. A., Parray, H. A., Lone, J. B., Paek, W. K., Lim, J., Bajpai, V. K., & Park, Y. H. (2017). Prevention and control strategies to counter dengue virus infection. Frontiers in cellular and infection microbiology, 7, 336.

Chen, S. C., & Hsieh, M. H. (2012). Modeling the transmission dynamics of dengue fever: implications of temperature effects. Science of the total environment, 431, 385-391.

Van den Driessche, P., & Watmough, J. (2002). Reproduction numbers and sub-threshold endemic equilibria for compartmental models of disease transmission. Mathematical bio- sciences, 180(1-2), 29-48.

Syafruddin, S., & Noorani, M. S. M. (2012). SEIR model for transmission of dengue fever in Selangor Malaysia. In International Journal of Modern Physics Conference Series (Vol. 9, pp. 380-389).

Syafruddin, S., & Noorani, M. S. M. (2012). SEIR model for transmission of dengue fever in Selangor Malaysia. In International Journal of Modern Physics Conference Series (Vol. 9, pp. 380-389).

Pandey, A., Mubayi, A., & Medlock, J. (2013). Comparing vector–host and SIR models for dengue transmission. Mathematical biosciences, 246(2), 252-259.

Coudeville, L., Baurin, N., & Vergu, E. (2016). Estimation of parameters related to vaccine efficacy and dengue transmission from two large phase III studies. Vaccine, 34(50), 6417- 6425.

de los Reyes, A. A., & Escaner IV, J. M. L. (2018). Dengue in the Philippines: model and analysis of parameters affecting transmission. Journal of biological dynamics, 12(1), 894-912.

Erandi, K. K. W. H., Perera, S. S. N., & Mahasinghe, A. C. (2021). Analysis and forecast of dengue incidence in urban Colombo, Sri Lanka. Theoretical Biology and Medical Modelling, 18(1), 1-19.

Chaiphongpachara, T., Yusuk, P., Laojun, S., & Kunphichayadecha, C. (2018). Environ- mental factors associated with mosquito vector larvae in a malaria-endemic area in ratch- aburi province, Thailand. The Scientific World Journal, 2018.

Chathurangika, P., De Silva, K., & Perera, S. (2022). Dengue Disease Prediction with Seasonality of Environmental Factors.

Sri Lanka Weather: Red dot tours. (n.d.). Retrieved January 9, 2023