Seasonal SEIR Model for Dengue Transmission Dynamics

Júlia A. C. Marinho[1],*
[1]Federal Rural University of Pernambuco, Department of Statistics and Informatics, Brazil
*email: julia.aguiar@ufrpe.br

ABSTRACT

Dengue is a mosquito-borne viral disease transmitted by Aedes aegypti, with transmission rates strongly influenced by climatic factors such as temperature and rainfall. This study presents a SEIR (Susceptible–Exposed–Infectious–Recovered) compartmental model incorporating seasonal variation in the transmission parameter $\beta(t)$ to simulate dengue outbreaks in a hypothetical population. The seasonal effect is modeled through a sinusoidal function reflecting annual climate cycles, impacting vector population dynamics. Simulations are implemented in Python using the Euler method over a three-year period. Results indicate that infection peaks align with periods of high $\beta(t)$, emphasizing the importance of including seasonality in outbreak predictions. This approach offers a computationally efficient tool to improve forecasting and optimize resource allocation for dengue control programs.

Introduction

Dengue remains a major public health concern, especially in tropical and subtropical regions. The Aedes aegypti mosquito, the primary vector, thrives under climatic conditions that vary throughout the year. Increased rainfall and higher temperatures typically lead to a surge in mosquito populations, raising transmission rates.

Several studies have incorporated seasonal effects into compartmental models to improve outbreak predictions. Johansson et al. (2009) demonstrated that temperature-driven changes in mosquito dynamics significantly alter dengue transmission patterns, while Nagao and Koelle (2008) showed that seasonal forcing in SEIR models improves the accuracy of epidemic forecasts in tropical climates. Massad et al. (2010) applied a similar approach in the Brazilian context, highlighting the relationship between rainfall and mosquito abundance.

Traditional epidemiological models often assume constant transmission parameters, overlooking seasonal variations that significantly affect outbreak patterns. In this study, we develop a SEIR model incorporating seasonal fluctuations in $\beta(t)$, providing a more realistic representation of dengue dynamics. The approach demonstrates how integrating climatic effects into mathematical models can support public health decision-making and improve outbreak preparedness.

Results

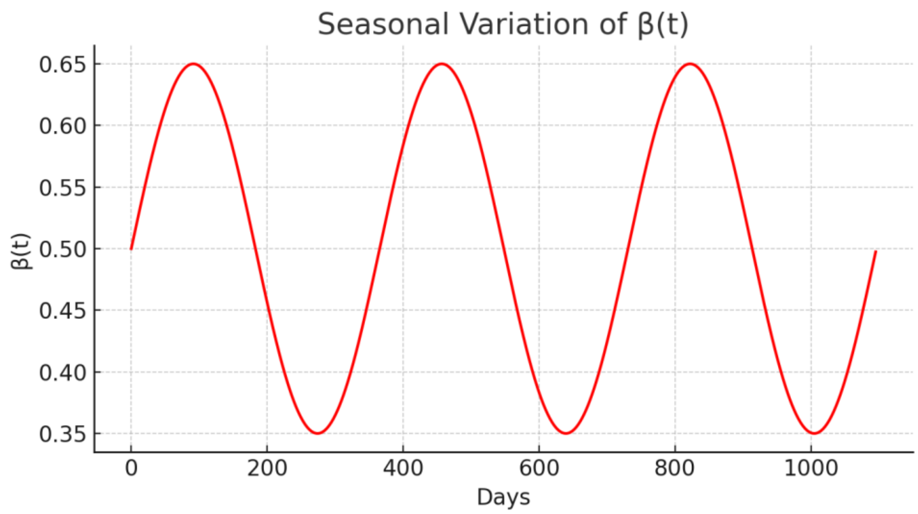

Figure 1. Seasonal variation of β(t) over the simulation period.

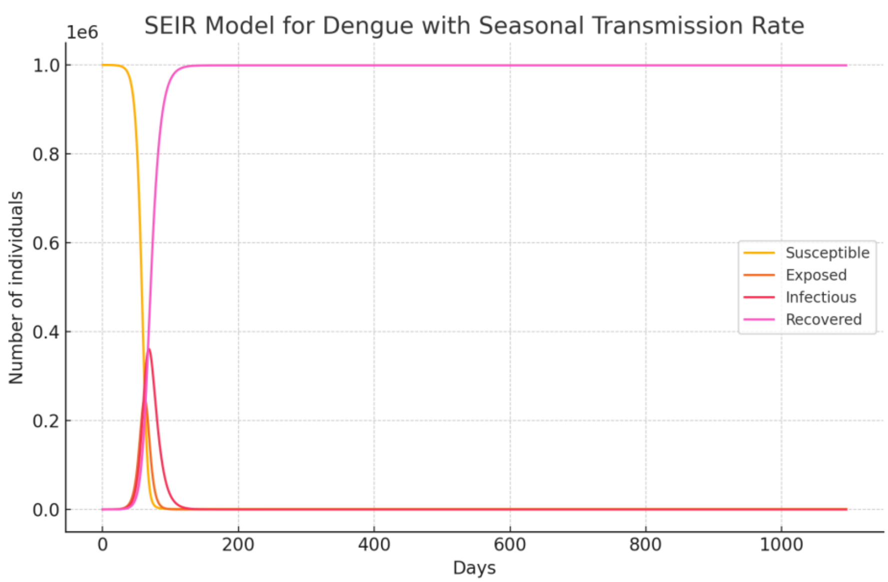

Figure 2. Evolution of compartments (S, E, I, R) over three years.

The simulation produces recurrent annual peaks in the number of infected individuals, corresponding to seasonal increases in β(t). The amplitude of these peaks is strongly dependent on the baseline transmission rate β_0 and the magnitude of seasonal variation. A comparison with a constant β scenario reveals that ignoring seasonality underestimates peak case numbers and misaligns the predicted outbreak timing. The β(t) curve itself follows a sinusoidal pattern, simulating the effect of yearly climatic cycles on mosquito abundance.

Figures generated from the simulation include:
- The compartmental evolution of S, E, I, and R over three years.
- The $\beta(t)$ seasonal variation curve over the same period.

Discussion

The seasonal SEIR model highlights the critical role of climate in dengue transmission dynamics. While simplified, the approach captures the timing and intensity of outbreaks more accurately than constant-rate models.
One limitation is the absence of explicit vector population modeling; instead, climate effects are approximated through $\beta(t)$. Future work could integrate entomological parameters, real climate datasets, and stochastic elements to improve realism.
This framework can be extended to other vector-borne diseases with seasonal patterns, offering a fast and adaptable tool for educational purposes, preliminary outbreak assessments, and public health planning.

Methods

The SEIR model divides the population (N) into four compartments: Susceptible (S), Exposed (E), Infectious (I), and Recovered (R). The model equations are:

$$dS/dt = -\beta(t) * S * I / N$$
$$dE/dt = \beta(t) * S * I / N - \sigma * E$$
$$dI/dt = \sigma * E - \gamma * I$$
$$dR/dt = \gamma * I$$

The transmission rate varies seasonally:

$$\beta(t) = \beta_0 * [1 + 0.3 * \sin(2\pi t / 365)]$$

Where:
- $\beta_0 = 0.5$ (baseline transmission rate)
- $\sigma = 1/5$ days^{-1} (average incubation period)
- $\gamma = 1/10$ days^{-1} (average infectious period)
- N = 1,000,000 individuals

The simulation runs for 3 years with initial conditions $S_0 = N - 30$, $E_0 = 20$, $I_0 = 10$, $R_0 = 0$. The Euler method is used for numerical integration, and Python (NumPy, Matplotlib) provides computation and visualization.

Conclusion

This work demonstrates the relevance of including seasonal variation in SEIR models for dengue. By incorporating a sinusoidal $\beta(t)$, outbreak peaks align with high-transmission seasons, improving predictive accuracy.
The method is computationally efficient and easily adaptable to real-world datasets, supporting health authorities in planning vector control measures and resource allocation.

References

1. Johansson, M. A., Cummings, D. A. T., Glass, G. E. Multiyear climate variability and dengue—El Niño Southern Oscillation, weather, and dengue incidence in Puerto Rico, Mexico, and Thailand: A longitudinal data analysis. PLoS Medicine 6, e1000168 (2009).
2. Nagao, Y., Koelle, K. Decreases in dengue transmission may act to increase the incidence of dengue hemorrhagic fever. Proceedings of the National Academy of Sciences 105, 2238–2243 (2008).
3. Massad, E., Ma, S., Burattini, M. N., Coutinho, F. A. B. Modelling the impact of climate change on the epidemiology of dengue. Epidemiology and Infection 138, 1429–1437 (2010).
4. Keeling, M. J., Rohani, P. Modeling Infectious Diseases in Humans and Animals. Princeton University Press (2008).
5. World Health Organization. Dengue and severe dengue. https://www.who.int/news-room/fact-sheets/detail/dengue-and-severe-dengue (2023).