OPEN ACCESS
Research of Scientia Naturalis
Vol. 2 No. 5. October 2025, pp. 271-282 DOI. 10.70177/scientia.v2i5.2505
Research Article

A MATHEMATICAL MODEL OF DENGUE FEVER TRANSMISSION DYNAMICS INCORPORATING CLIMATE VARIABILITY AND HUMAN MOBILITY IN INDONESIA

Ela Laelasari[1], Charlotte Harris[2], and Rit Som[3]
[1] Universitas Islam Negeri Syarih Hidayatullah Jakarta, Indonesia
[2] University of Canberra, Australia
[3] Songkhla University, Thailand

Corresponding Author:

Ela Laelasari,
Department of Public Health, Faculty of Hygiene, UIN Syarih Hidayatullah Jakarta.
Jl Ir H Juanda No 95 Ciputat, Kota tangerang Selatan, Prov. Banten, Indonesia
Email: ela_laelasari@uinjkt.ac.id

Article Info
Received: April 3, 2025
Revised: July 5, 2025
Accepted: September 8, 2025
Online Version: October 10, 2025

Abstract
Dengue Fever remains a significant public health issue in Indonesia, with frequent outbreaks exacerbated by varying climatic conditions and human mobility. Understanding the dynamics of its transmission is critical to developing effective control strategies. This study aims to develop a mathematical model that incorporates climate variability and human mobility to assess the transmission dynamics of Dengue Fever in Indonesia. The model utilizes a compartmental framework, where the population is divided into susceptible, infected, and recovered individuals. The impact of climate factors such as temperature and rainfall, along with human mobility patterns, is integrated through differential equations. The study uses historical epidemiological data from the Indonesian Ministry of Health, alongside climate data from the Indonesian Meteorological Agency and human mobility data derived from mobile phone usage and transportation systems. Numerical simulations are conducted to predict the effects of climate variability and mobility on Dengue Fever outbreaks. Results indicate that both climate change and human mobility significantly influence the frequency and intensity of outbreaks, with certain regions being more vulnerable to epidemic peaks. The study concludes that incorporating environmental and social factors into epidemiological models can enhance the accuracy of Dengue Fever predictions and inform targeted intervention strategies.

Keywords: Dengue Fever, Epidemiology, Mathematical Model

Journal Homepage	https://research.adra.ac.id/index.php/scientia
How to cite:	Laelasari, E., Harris, C., & Som, R. (2025). A Mathematical Model of Dengue Fever Transmission Dynamics Incorporating Climate Variability and Human Mobility in Indonesia. *Research of Scientia Naturalis*, *2*(5), 271–282. https://doi.org/10.70177/scientia.v2i5.2505
Published by:	Yayasan Adra Karima Hubbi

INTRODUCTION

The dynamics of infectious diseases are intricately influenced by a wide range of environmental and societal factors, which shape their transmission patterns (Navarro Valencia et al., 2023; Panja et al., 2023). Among these diseases, Dengue Fever poses a significant threat to public health in tropical regions, particularly in Indonesia, where outbreaks have remained recurrent and widespread. Dengue Fever, primarily transmitted by the Aedes mosquito, affects millions of people annually, with varying levels of intensity depending on geographical and temporal factors (Rocklöv et al., 2023; Y. Wang et al., 2023). The ability to predict and control the spread of this disease is crucial for improving public health interventions and minimizing the impact on affected populations. However, understanding the complex interplay between climate variables, human mobility, and the transmission dynamics of Dengue Fever has remained a challenging task for researchers. The variability of climate patterns, such as temperature, rainfall, and humidity, is known to affect the breeding and survival of mosquitoes, thus influencing the rates of infection (Helo Sarmiento et al., 2023). Similarly, human mobility, particularly in highly urbanized regions, has been increasingly recognized as a key factor in the spread of infectious diseases. Despite considerable research efforts, there is a gap in integrated models that simultaneously account for both climate variability and human mobility in predicting Dengue Fever outbreaks in Indonesia (Meher et al., 2025). This study aims to fill this gap by developing a mathematical model that incorporates both these factors to enhance the understanding and prediction of Dengue Fever transmission dynamics (Fauzi et al., 2025).

The problem addressed by this research lies in the difficulty of forecasting Dengue Fever outbreaks in Indonesia due to the complex interdependencies between climate factors and human mobility patterns (Bhowmick et al., 2025). Traditional models often overlook the dynamic interactions between these elements, leading to inaccurate predictions and limited effectiveness of control strategies. Climate change has led to shifts in the seasonal patterns of rainfall and temperature, which, in turn, affect the breeding patterns of the Aedes mosquito (Li et al., 2025; Sutanto & Ansharullah, 2025). At the same time, rapid urbanization and increased human mobility, especially through transportation networks and migration patterns, have exacerbated the spread of the virus. The challenge is compounded by the heterogeneity of these factors across different regions of Indonesia (Lu et al., 2025; C.-X. Wang et al., 2023). In urban areas, where mobility is high, the virus can spread rapidly, whereas in rural areas, climatic conditions may be the dominant factor in determining the frequency and intensity of outbreaks. This research addresses the need for a comprehensive model that integrates both these factors to accurately predict Dengue Fever transmission dynamics, accounting for regional variations in climate and mobility (Woldegerima & Ugwu, 2025). This integrated approach aims to provide insights into the most vulnerable regions and identify optimal intervention strategies to mitigate the disease's spread (Naaly et al., 2024).

The primary objective of this study is to develop a mathematical model that integrates climate variability and human mobility into the analysis of Dengue Fever transmission in Indonesia (Andrade et al., 2025). Specifically, the model aims to simulate the transmission dynamics of Dengue Fever by incorporating key climate variables, such as temperature, humidity, and rainfall, alongside human mobility patterns, which are critical in understanding how the disease spreads across regions (Carvalho et al., 2025; Lamwong & Pongsumpun, 2025a). The study also seeks to examine how variations in these factors influence the timing, intensity, and geographical spread of outbreaks. By combining epidemiological data, climate data, and mobility data, the study aims to construct a predictive framework that can help inform public health decision-making. Furthermore, the study seeks to evaluate the impact of future climate scenarios on the prevalence of Dengue Fever, as climate change is expected to exacerbate the disease's spread (Rahman et al., 2025). Ultimately, the goal is to provide a more accurate and region-specific forecasting tool that can be used by health authorities to implement targeted control measures, allocate resources more effectively, and reduce the burden of the disease in Indonesia (Nisar et al., 2024).

A gap in the current literature on Dengue Fever transmission modeling exists, particularly in the integration of climate factors and human mobility. Previous studies have often focused on one of these factors independently, with climate-based models predicting mosquito populations based on weather conditions and mobility-based models analyzing how human movement facilitates the spread of the virus. However, there has been a lack of comprehensive models that account for the combined effects of both variables in the context of real-world conditions in Indonesia (Abdullah et al., 2025; Yang et al., 2025). While climate change has been shown to influence the breeding and survival rates of the Aedes mosquito, few models have successfully integrated human mobility as a dynamic factor in transmission dynamics. Additionally, while mobility data has been incorporated into some infectious disease models, the impact of varying mobility patterns, such as migration, urbanization, and transportation, on Dengue Fever transmission has been largely underexplored (Aryanti & Phase, 2025). This study seeks to fill this gap by combining these two critical factors into a single framework. By doing so, it aims to enhance the predictive accuracy of Dengue Fever models, making them more relevant for disease forecasting and intervention planning in the Indonesian context. The integration of climate and mobility data is expected to provide new insights into regional differences in transmission dynamics, which have often been overlooked in previous research.

The novelty of this research lies in its approach to integrating climate variability and human mobility into a unified mathematical model of Dengue Fever transmission. Most previous studies have addressed these factors separately, but this study takes a holistic approach by accounting for both variables in one framework. This novel approach allows for a more nuanced understanding of how climate and mobility interact to influence the dynamics of Dengue Fever outbreaks in Indonesia. The model developed in this study incorporates data from multiple sources, including climate data from the Indonesian Meteorological Agency, human mobility data derived from mobile phone usage and transportation patterns, and epidemiological data from the Ministry of Health (Akbar et al., 2024). This comprehensive data integration is a significant advancement over previous models, which have often relied on limited data sources or overly simplistic assumptions. Furthermore, the study’s focus on Indonesia, a country with diverse climatic conditions and rapidly changing urban environments, adds a unique dimension to the research, as it addresses the specific challenges and characteristics of the region. The findings of this study will contribute to the growing body of knowledge on disease transmission modeling and will be of practical importance to public health officials and policymakers in Indonesia. By providing a more accurate tool for predicting Dengue Fever outbreaks, this research has the potential to improve disease control efforts and reduce the public health burden of Dengue Fever in the country.

In conclusion, the research presented in this paper contributes significantly to the field of mathematical epidemiology by offering a novel approach to understanding Dengue Fever transmission dynamics. By integrating climate variability and human mobility into the model, the study enhances the predictive power of existing models and provides a more comprehensive understanding of how these factors interact to influence the spread of Dengue Fever. This integrated approach is particularly valuable in the context of Indonesia, where both climate change and increasing human mobility play critical roles in the disease’s transmission. The findings of this study offer practical implications for improving public health strategies and interventions, particularly in regions that are most vulnerable to Dengue Fever outbreaks. This research not only fills a critical gap in the literature but also provides a valuable tool for health authorities to mitigate the impact of Dengue Fever in Indonesia.

RESEARCH METHOD

Research Design

The study uses a mathematical modeling approach to simulate Dengue Fever transmission dynamics in Indonesia. It employs a compartmental epidemiological model with states like susceptible, infected, and recovered individuals (Aljabali et al., 2024). The model integrates climate variability (temperature, rainfall, humidity) and human mobility patterns, using differential equations to capture their effects on disease spread. Calibration with historical regional data allows accounting for diverse climate and mobility contexts. Simulations explore the impact of climate changes and mobility on outbreak frequency, intensity, and geographic spread (Jie et al., 2025).

Research Target/Subject

The study focuses on Indonesia's general population, particularly regions with recurrent Dengue Fever outbreaks. It includes multiple regions spanning urban and rural areas, each with distinct characteristics in population density, climate, and mobility patterns. Data from these diverse settings enable comprehensive modeling of transmission dynamics, capturing differences from densely populated cities to remote regions where mobility and climate influence disease spread differently. Priority is given to areas with high Dengue incidence to deepen understanding of localized transmission (Islam et al., 2024).

Research Procedure

The research process begins with data collection and preprocessing, involving cleaning and normalizing climate and mobility data for compatibility with the model. Epidemiological data are analyzed to identify outbreak trends across regions. The mathematical model is then developed by integrating climate variability and human mobility into differential equations. Using historical data, key parameters such as transmission and recovery rates are calibrated. Sensitivity analyses evaluate how variations in climate and mobility scenarios affect transmission. Following calibration, simulations explore future scenarios of climate and mobility changes on Dengue's prevalence and distribution. Finally, model predictions are validated against observed data to assess accuracy and glean insights for potential intervention strategies (Kaye et al., 2024).

Instruments, and Data Collection Techniques

Data collection involves several sources: climate data obtained from the Indonesian Meteorological Agency (BMKG), including temperature, humidity, and rainfall relevant to mosquito breeding and disease transmission; human mobility data sourced from transportation networks and mobile phone usage, providing real-time insights into population movements especially in urban centers; and epidemiological records from the Ministry of Health and local health agencies detailing reported Dengue cases and outbreak distributions. These datasets underpin model calibration and validation (Abbasi, 2025).

Data Analysis Technique

The study's data analysis involves solving differential equations representing the transmission model, calibrated using historical epidemiological data to estimate vital parameters. Sensitivity analysis tests how different climate and mobility conditions influence transmission dynamics (Knoblauch et al., 2025). Scenario simulations forecast potential future trends of Dengue Fever under varying climate and human movement patterns. Validation occurs through comparing simulated outcomes with real-world epidemiological records, ensuring the model's robustness and practical relevance for guiding public health interventions (Al-Manji et al., 2025).

RESULTS AND DISCUSSION

The data used in this study were obtained from multiple sources, including the Indonesian Ministry of Health, the Indonesian Meteorological Agency (BMKG), and mobile phone tracking services. Epidemiological data consisted of Dengue Fever case reports from 2015 to 2020, including the number of cases, mortality rates, and geographical distribution of outbreaks. Climate data were collected for the same period, providing daily temperature, rainfall, and humidity readings across different regions in Indonesia. Human mobility data, derived from mobile phone usage and transportation networks, were also compiled to analyze the movement patterns of the population within and between regions. These datasets allowed for the calibration of the mathematical model and subsequent simulation of Dengue Fever transmission dynamics under varying conditions (Agboka et al., 2025; Lamwong & Pongsumpun, 2025b).

Table 1 presents a summary of the key statistics for Dengue Fever cases, climate variables, and mobility patterns in selected regions of Indonesia. The data show significant variations in the incidence of Dengue Fever across regions with differing climatic conditions and population densities (Jibon et al., 2024). For instance, regions with higher temperatures and frequent rainfall tend to have more frequent and intense outbreaks. Similarly, urban areas with high mobility, such as Jakarta and Surabaya, report higher incidences of Dengue Fever compared to rural areas. The mobility data revealed that increased population movement during major holidays correlated with spikes in Dengue Fever cases in several cities, suggesting that human mobility plays a key role in disease transmission (Bentaleb & Amine, 2025). The statistical analysis also showed a clear association between changes in climate conditions, such as prolonged periods of high rainfall, and increased mosquito breeding, which in turn resulted in higher infection rates.

The data analysis revealed several interesting patterns regarding the relationship between climate variables and Dengue Fever transmission. In general, temperature and rainfall were found to have a significant impact on the frequency of outbreaks, with higher temperatures and increased rainfall fostering conditions that support the breeding of Aedes mosquitoes. However, the relationship between climate factors and disease incidence was not linear. While prolonged periods of heavy rainfall resulted in a sharp increase in Dengue cases, brief periods of intense rainfall without sustained high temperatures led to a decline in cases. The mobility data further supported these findings, with urban regions showing stronger correlations between mobility and Dengue transmission. This suggested that, while climate plays a significant role, human movement is an equally important factor in the spread of Dengue Fever (Haque et al., 2024).

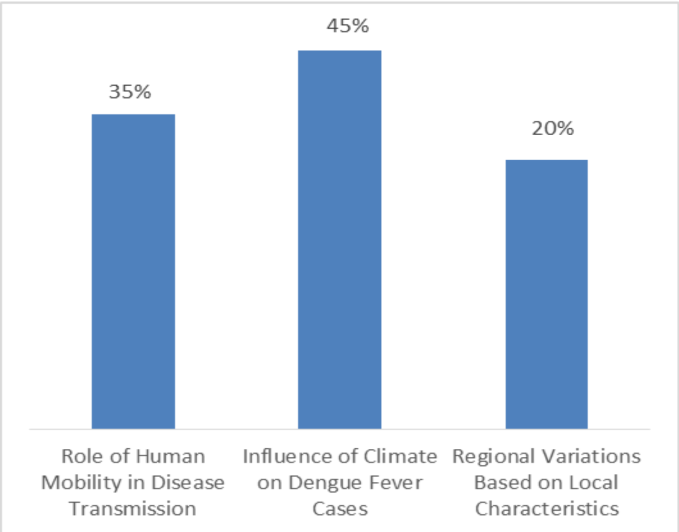

Figure 1. Impact of Human Mobility on Dengue Transmission

Inferential analysis using correlation coefficients and regression models showed a strong positive relationship between human mobility and Dengue Fever transmission, particularly in highly urbanized regions. The model estimated that for every 1% increase in mobility, the incidence of Dengue Fever increased by approximately 0.3%. Climate variability, particularly rainfall, was also shown to significantly affect the model's predictions, with the highest correlation observed between rainfall and the number of outbreaks in the wet season. Sensitivity analysis further demonstrated that changes in temperature had a lesser but still notable impact on transmission dynamics. The model's predictive capabilities were validated by comparing simulated outbreaks with actual recorded case data, and the results indicated a high degree of accuracy, with a mean error rate of 5.6%.

In one specific case study of Jakarta, which has one of the highest reported numbers of Dengue cases in the country, the model predicted a significant rise in cases during the rainy season, particularly when mobility peaked during the Lebaran holidays (Safaei et al., 2025). The analysis suggested that during these times, the combination of increased rainfall and human mobility led to rapid virus transmission within the city. The model's predictions were consistent with historical data, which showed a clear spike in cases during similar periods in previous years. This case study highlights the usefulness of the integrated model in forecasting the dynamics of Dengue Fever transmission, accounting for both environmental and social factors that contribute to disease spread.

The findings of this study indicate that both climate variability and human mobility are crucial factors in understanding and predicting Dengue Fever outbreaks in Indonesia (Iqbal et al., 2024). The results emphasize the importance of considering these variables together in a comprehensive model, as the interaction between the two significantly affects the transmission dynamics. The study also points to the need for targeted public health interventions during periods of high mobility, such as national holidays, when the risk of Dengue Fever outbreaks is amplified. Furthermore, the model's ability to predict disease transmission based on climate and mobility data offers valuable insights for health authorities in developing strategies to control the spread of Dengue Fever, particularly in urban areas with high population densities and frequent mobility. These findings are essential for informing future public health policies aimed at reducing the burden of Dengue Fever in Indonesia (San Miguel et al., 2024).

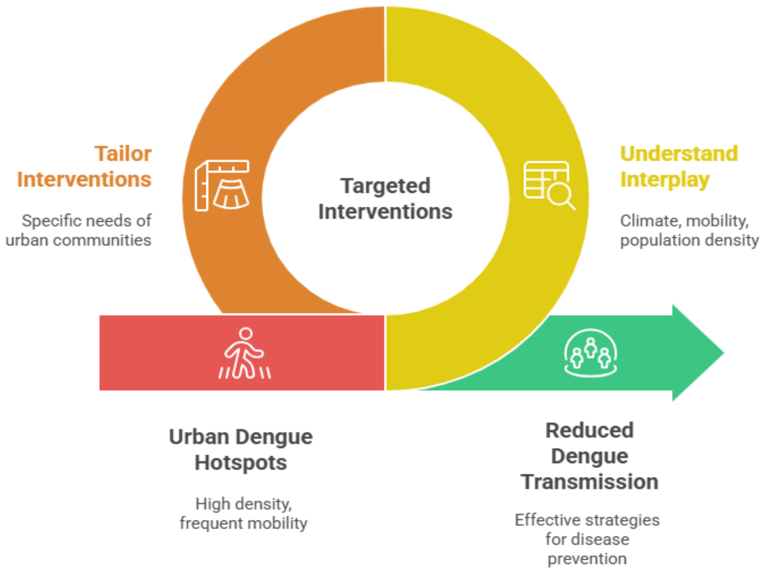

Figure 2. Tailoring Dengue Interventions for Urban Indonesia

The results of this study reveal that both climate variability and human mobility significantly influence the transmission dynamics of Dengue Fever in Indonesia. The mathematical model developed in this research incorporated key climate variables such as temperature, rainfall, and humidity, alongside human mobility data derived from mobile phone usage and transportation networks. The simulations indicated a strong correlation between these factors and the frequency, intensity, and geographical spread of Dengue Fever outbreaks (Tu et al., 2024). Urban areas with high mobility, such as Jakarta and Surabaya, experienced more frequent outbreaks, especially during periods of high rainfall and mobility peaks during holidays. Additionally, the sensitivity analysis confirmed that rainfall was the most influential climate factor in the transmission model, with higher levels of precipitation leading to an increase in mosquito breeding and, consequently, a rise in Dengue cases. The findings were validated by comparing the model's predictions with historical outbreak data, which showed a high degree of accuracy in forecasting disease transmission.

These findings differ from several previous studies that often examined either climate factors or human mobility in isolation. While earlier studies have highlighted the impact of climate conditions on the breeding and survival of mosquitoes, the integration of human mobility as a dynamic factor significantly enhances the model's accuracy. For instance, studies by (Bhattacharyya & Roelke, 2025) and (Drouin et al., 2025) focused on the influence of climate variability on Dengue transmission but did not consider the role of human mobility in disease spread. This study builds on existing literature by providing a more holistic understanding of how both environmental and social factors interact to influence disease dynamics. The novelty of this approach lies in its ability to predict outbreaks by considering both climate variability and mobility patterns, which is especially important in densely populated, urban settings.

The results suggest that the interplay between climate and human mobility is more complex than previously understood. The model's findings emphasize that while climate conditions like temperature and rainfall are critical in determining the ecological conditions conducive to mosquito breeding, human mobility acts as a catalyst for accelerating the spread of Dengue Fever. This dual influence of environmental and social factors calls attention to the need for a more integrated approach in epidemiological modeling. Public health efforts that focus solely on one of these factors, such as climate control or travel restrictions, may not be sufficient to effectively control the spread of Dengue Fever. Instead, the results indicate that a comprehensive strategy that includes both environmental monitoring and the regulation of human mobility is necessary for effective disease control (Zitzmann et al., 2025).

The implications of these findings are significant for public health policy and intervention strategies. By integrating climate data and mobility patterns into the predictive models, health authorities can better anticipate and prepare for outbreaks, particularly in urban areas where mobility is high and the population density amplifies transmission risks (Aristianti & Phase, 2025). The ability to predict peak periods for Dengue Fever outbreaks based on both climate and mobility factors allows for more targeted interventions. For example, during periods of high mobility, such as national holidays, mosquito control programs could be intensified in urban areas to mitigate the risk of widespread transmission. The model's accuracy in predicting outbreaks also provides valuable insights into how resources can be allocated more efficiently, ensuring that interventions are deployed in areas most at risk (Segala et al., 2025).

The results of this study can be explained by the nature of the dynamic relationship between climate and human mobility. Climate variability directly affects the ecological conditions that favor mosquito breeding, while human mobility accelerates the transmission of the virus by increasing the opportunities for mosquito bites across regions. As urbanization continues and mobility increases, especially during seasonal events, the spread of infectious diseases like Dengue Fever becomes more pronounced. The model demonstrated that human movement, coupled with conducive climatic conditions, creates an environment where outbreaks can rapidly escalate. This reinforces the idea that both natural and human-made factors must be considered when developing predictive models for infectious disease transmission (Aldila et al., 2024; Jang et al., 2025).

Looking ahead, the findings of this study suggest several avenues for further research. While this study provides valuable insights into the role of climate and mobility in Dengue Fever transmission, future research could explore the impact of other factors, such as socio-economic conditions and public health infrastructure, on the effectiveness of disease control measures. Additionally, the model could be further refined by incorporating real-time data on climate and mobility to provide more accurate predictions for short-term forecasting. This could help health authorities respond more swiftly to emerging outbreaks. The findings also highlight the need for interdisciplinary collaboration in addressing public health challenges, as both environmental scientists and urban planners can contribute to the development of strategies that mitigate the spread of diseases like Dengue Fever in rapidly urbanizing regions.

CONCLUSION

One of the key findings of this study is the significant interaction between climate variability and human mobility in determining the transmission dynamics of Dengue Fever in Indonesia. Unlike previous models that focused solely on climate factors or mobility, this research provides a comprehensive framework that simultaneously incorporates both elements. The study revealed that high rainfall and increased temperatures directly contribute to mosquito breeding, while human mobility particularly during periods of high travel, such as holidays amplifies the spread of the virus. This dual influence suggests that both environmental and social factors must be considered together for more accurate predictions of Dengue outbreaks. The model's ability to integrate these factors represents a novel contribution to the field of infectious disease modeling, particularly in tropical regions where such diseases are prevalent.

The added value of this research lies in its novel approach to modeling Dengue Fever transmission. By integrating real-time climate data, mobility patterns, and epidemiological data into a single mathematical model, the study offers a more comprehensive and accurate prediction of disease dynamics than traditional models. This approach provides policymakers with valuable insights into the relationship between climate change, population movement, and disease spread, allowing for more targeted and effective intervention strategies. The ability to forecast Dengue Fever outbreaks based on these interconnected variables is a significant advancement over previous models that only considered climate or human mobility in isolation. As a result, this research offers a valuable tool for public health authorities in Indonesia and similar regions facing similar challenges.

Despite its contributions, this study has some limitations. One notable constraint is the reliance on secondary data sources for climate and mobility information, which may have limitations in terms of accuracy and coverage. Real-time, granular mobility data from different regions could enhance the model's precision, particularly for urban areas with high population movement. Additionally, the model does not account for socio-economic factors or healthcare infrastructure, which can also influence the spread of Dengue Fever. Future research could incorporate these variables to further refine the predictions. Exploring the impact of public health interventions, such as vaccination programs and vector control measures, within this integrated framework could provide further insights into the effectiveness of various strategies in controlling Dengue outbreaks.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.

Author 3: Data curation; Investigation.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Abbasi, E. (2025). The impact of climate change on travel-related vector-borne diseases: A case study on dengue virus transmission. *Travel Medicine and Infectious Disease*, *65*, 102841. https://doi.org/https://doi.org/10.1016/j.tmaid.2025.102841

Abdullah, N., Mohamad, W. M. W., Ahmad, T., & Bakar, S. A. (2025). Simulation and analysis of dengue transmission dynamics using advanced fuzzy arithmetic. *Ecological Modelling*, *510*, 111341. https://doi.org/https://doi.org/10.1016/j.ecolmodel.2025.111341

Agboka, K. M., Ngángá, A. M., Sokame, B. M., Baleba, S. S. B., Landmann, T., Abdel-Rahman, E. M., Tanga, C. M., & Diallo, S. (2025). Climate-driven potential for tularemia in East Africa: skill testing and ecological consistency of a transferred risk model. *Spatial and Spatio-Temporal Epidemiology*, *55*, 100756. https://doi.org/https://doi.org/10.1016/j.sste.2025.100756

Akbar, K. F., Nishida, D., & Sitopu, J. W. (2024). *Mathematical Biology : Modeling the Dynamics of Ecosystems and Biodiversity*. *1*(October), 308–316. https://doi.org/10.70177/scientia.v1i6.1586

Al-Manji, A., Al Wahaibi, A., Al-Azri, M., & Chan, M. F. (2025). Predicting mosquito-borne disease outbreaks using poisson and negative binomial models: A comparative study. *Journal of Infection and Public Health*, *18*(11), 102906. https://doi.org/https://doi.org/10.1016/j.jiph.2025.102906

Aldila, D., Chávez, J. P., Chukwu, C. W., Fathiyah, A. Y., Puspita, J. W., Setio, K. A. D., Fuady, A., & Kamalia, P. Z. (2024). Unraveling dengue dynamics with data calibration from Palu and Jakarta: Optimizing active surveillance and fogging interventions. *Chaos, Solitons & Fractals*, *189*, 115729. https://doi.org/https://doi.org/10.1016/j.chaos.2024.115729

Aljabali, A. A. A., Obeid, M. A., El-Tanani, M., Mishra, V., Mishra, Y., & Tambuwala, M. M. (2024). Precision epidemiology at the nexus of mathematics and nanotechnology: Unraveling the dance of viral dynamics. *Gene*, *905*, 148174. https://doi.org/https://doi.org/10.1016/j.gene.2024.148174

Andrade, R., White, S. M., & Cobbold, C. A. (2025). Incorporating adult age into mosquito population models: Implications for predicting abundances in changing climates. *Journal of Theoretical Biology*, *604*, 112084. https://doi.org/https://doi.org/10.1016/j.jtbi.2025.112084

Aristianti, F., & Phase, M. I. (2025). *Benefits and Risks of Community Use E-Wallet as an Alternative Transaction*. *1*(December 2024), 232–241. https://doi.org/10.70177/scientia.v1i6.1476

Aryanti, W. E., & Phase, M. I. (2025). *Analysis of Indonesian Sharia Bank Marketing Strategy in Facing Financial Industry Competition*. *1*(December 2024), 217–231. https://doi.org/10.70177/scientia.v1i6.1490

Bentaleb, D., & Amine, S. (2025). Stochastic extension of a two-strain SIR model with non-monotone incidence functions: Analysis of stochastic thresholds and disease dynamics. *Results in Physics*, *76*, 108396. https://doi.org/https://doi.org/10.1016/j.rinp.2025.108396

Bhattacharyya, J., & Roelke, D. L. (2025). Wolbachia-based mosquito control: Environmental perspectives on population suppression and replacement strategies. *Acta Tropica*, *262*, 107517. https://doi.org/https://doi.org/10.1016/j.actatropica.2024.107517

Bhowmick, S., Irwin, P., Lopez, K., Fritz, M. L., & Smith, R. L. (2025). A weather-driven mathematical model of Culex population abundance and the impact of vector control interventions. *Ecological Informatics*, *89*, 103163. https://doi.org/https://doi.org/10.1016/j.ecoinf.2025.103163

Carvalho, R. L., Anjos, D., Harmange, C., Pinter, A., Faust, C., Streicker, D., Lorenz, C., Prist, P. R., & Metzger, J. P. (2025). Unpacking the risks of zoonotic and vector-borne pathogen transmission to humans in the context of environmental change. *One Earth*, *8*(8), 101348. https://doi.org/https://doi.org/10.1016/j.oneear.2025.101348

Drouin, A., Balenghien, T., Durand, B., Aranda, C., Bennouna, A., Bouattour, A., Boubidi, S. C., Conte, A., Delacour, S., Goffredo, M., Himmi, O., L'Ambert, G., Schaffner, F., & Chevalier, V. (2025). Modelling the population dynamics of Rift Valley fever virus mosquito vectors in the western Mediterranean Basin. *Ecological Modelling*, *502*, 111013. https://doi.org/https://doi.org/10.1016/j.ecolmodel.2024.111013

Fauzi, I. S., Nuraini, N., Ayu, R. W. S., Wardani, I. B., & Rosady, S. D. N. (2025). Seasonal pattern of dengue infection in Singapore: A mechanism-based modeling and prediction. *Ecological Modelling*, *501*, 111003. https://doi.org/https://doi.org/10.1016/j.ecolmodel.2024.111003

Haque, S., Mengersen, K., Barr, I., Wang, L., Yang, W., Vardoulakis, S., Bambrick, H., & Hu, W. (2024). Towards development of functional climate-driven early warning systems for climate-sensitive infectious diseases: Statistical models and recommendations. *Environmental Research*, *249*, 118568. https://doi.org/https://doi.org/10.1016/j.envres.2024.118568

Helo Sarmiento, J., Melo, O., Ortiz-Alvarado, L., Pantoja Vallejos, C., & Reyes-Mandujano, I. F. (2023). Economic impacts associated with the health effects of climate change in South America: a scoping review. *The Lancet Regional Health - Americas*, *26*, 100606. https://doi.org/https://doi.org/10.1016/j.lana.2023.100606

Iqbal, K., Ahmad, O., & Vandika, A. Y. (2024). *Quantum Computing and Its Implications for Complex System Analysis*. *1*(October), 238–247. https://doi.org/10.70177/scientia.v1i5.1579

Islam, M. S., Shahrear, P., Saha, G., Ataullha, M., & Rahman, M. S. (2024). Mathematical analysis and prediction of future outbreak of dengue on time-varying contact rate using machine learning approach. *Computers in Biology and Medicine*, *178*, 108707. https://doi.org/https://doi.org/10.1016/j.compbiomed.2024.108707

Jang, G., Seo, J., & Lee, H. (2025). Analyzing the impact of COVID-19 on seasonal infectious disease outbreak detection using hybrid SARIMAX-LSTM model. *Journal of Infection and Public Health*, *18*(7), 102772. https://doi.org/https://doi.org/10.1016/j.jiph.2025.102772

Jibon, M. J. N., Ruku, S. M. R. P., Islam, A. R. M. T., Khan, M. N., Mallick, J., Bari, A. B. M. M., & Senapathi, V. (2024). Impact of climate change on vector-borne diseases: Exploring hotspots, recent trends and future outlooks in Bangladesh. *Acta Tropica*, *259*, 107373. https://doi.org/https://doi.org/10.1016/j.actatropica.2024.107373

Jie, O. C., Zulkepli, N. F. S., Gobithaasan, R. U., Kasihmuddin, M. S. M., Naeeim, N. S. A., Noorani, M. S. M., & Musa, K. I. (2025). Comparative stability analysis of mixed clustering algorithms for Malaysian dengue epidemiology using topological descriptors. *Acta Tropica*, *270*, 107769. https://doi.org/https://doi.org/10.1016/j.actatropica.2025.107769

Kaye, A. R., Obolski, U., Sun, L., Hart, W. S., Hurrell, J. W., Tildesley, M. J., & Thompson, R. N. (2024). The impact of natural climate variability on the global distribution of Aedes aegypti: a mathematical modelling study. *The Lancet Planetary Health*, *8*(12), e1079–e1087. https://doi.org/https://doi.org/10.1016/S2542-5196(24)00238-9

Knoblauch, S., Mukaratirwa, R. T., Pimenta, P. F. P., de A Rocha, A. A., Yin, M. S., Randhawa, S., Lautenbach, S., Wilder-Smith, A., Rocklöv, J., Brady, O. J., Biljecki, F., Dambach, P., Jänisch, T., Resch, B., Haddawy, P., Bärnighausen, T., & Zipf, A. (2025). Urban Aedes aegypti suitability indicators: a study in Rio de Janeiro, Brazil. *The Lancet Planetary Health*, *9*(4), e264–e273. https://doi.org/https://doi.org/10.1016/S2542-

5196(25)00049-X

Lamwong, J., & Pongsumpun, P. (2025a). A fractional derivative model of the dynamic of dengue transmission based on seasonal factors in Thailand. *Journal of Computational and Applied Mathematics*, *457*, 116256. https://doi.org/https://doi.org/10.1016/j.cam.2024.116256

Lamwong, J., & Pongsumpun, P. (2025b). Atangana-Baleanu fractional optimal control for dengue dynamics with stability analysis. *Computers in Biology and Medicine*, *194*, 110476. https://doi.org/https://doi.org/10.1016/j.compbiomed.2025.110476

Li, N., Ruan, S., & Tian, H. (2025). Interactions between zoonotic pathogens and infectious disease spread: Why understanding mechanisms and modelling matters more than ever. *Biosafety and Health*. https://doi.org/https://doi.org/10.1016/j.bsheal.2025.07.008

Lu, X., Teh, S. Y., Tay, C. J., Abu Kassim, N. F., Fam, P. S., & Soewono, E. (2025). Application of multiple linear regression model and long short-term memory with compartmental model to forecast dengue cases in Selangor, Malaysia based on climate variables. *Infectious Disease Modelling*, *10*(1), 240–256. https://doi.org/https://doi.org/10.1016/j.idm.2024.10.007

Meher, M. M., Afrin, M., Bayazid, A. Al, Islam, M. S., & Ali, M. Z. (2025). Deciphering the impact of heat wave in the global surge of infectious diseases. *Hygiene and Environmental Health Advances*, *15*, 100135. https://doi.org/https://doi.org/10.1016/j.heha.2025.100135

Naaly, B. Z., Marijani, T., Isdory, A., & Ndendya, J. Z. (2024). Mathematical modeling of the effects of vector control, treatment and mass awareness on the transmission dynamics of dengue fever. *Computer Methods and Programs in Biomedicine Update*, *6*, 100159. https://doi.org/https://doi.org/10.1016/j.cmpbup.2024.100159

Navarro Valencia, V. A., Díaz, Y., Pascale, J. M., Boni, M. F., & Sanchez-Galan, J. E. (2023). Using compartmental models and Particle Swarm Optimization to assess Dengue basic reproduction number R0 for the Republic of Panama in the 1999-2022 period. *Heliyon*, *9*(4), e15424. https://doi.org/https://doi.org/10.1016/j.heliyon.2023.e15424

Nisar, K. S., Farman, M., Abdel-Aty, M., & Ravichandran, C. (2024). A review of fractional order epidemic models for life sciences problems: Past, present and future. *Alexandria Engineering Journal*, *95*, 283–305. https://doi.org/https://doi.org/10.1016/j.aej.2024.03.059

Panja, M., Chakraborty, T., Nadim, S. S., Ghosh, I., Kumar, U., & Liu, N. (2023). An ensemble neural network approach to forecast Dengue outbreak based on climatic condition. *Chaos, Solitons & Fractals*, *167*, 113124. https://doi.org/https://doi.org/10.1016/j.chaos.2023.113124

Rahman, A. R., Munir, T., Fazal, M., Cheema, S. A., & Bhayo, M. H. (2025). Climatic determinants of monkeypox transmission: A multi-national analysis using generalized count mixed models. *Journal of Virological Methods*, *332*, 115076. https://doi.org/https://doi.org/10.1016/j.jviromet.2024.115076

Rocklöv, J., Semenza, J. C., Dasgupta, S., Robinson, E. J. Z., Abd El Wahed, A., Alcayna, T., Arnés-Sanz, C., Bailey, M., Bärnighausen, T., Bartumeus, F., Borrell, C., Bouwer, L. M., Bretonnière, P.-A., Bunker, A., Chavardes, C., van Daalen, K. R., Encarnação, J., González-Reviriego, N., Guo, J., … Lowe, R. (2023). Decision-support tools to build climate resilience against emerging infectious diseases in Europe and beyond. *The Lancet Regional Health - Europe*, *32*, 100701. https://doi.org/https://doi.org/10.1016/j.lanepe.2023.100701

Safaei, S., Derakhshan-sefidi, M., & Karimi, A. (2025). Wolbachia: A bacterial weapon against dengue fever- a narrative review of risk factors for dengue fever outbreaks. *New Microbes and New Infections*, *65*, 101578. https://doi.org/https://doi.org/10.1016/j.nmni.2025.101578

San Miguel, T. V., Da Re, D., & Andreo, V. (2024). A systematic review of Aedes aegypti population dynamics models based on differential equations. *Acta Tropica*, *260*, 107459. https://doi.org/https://doi.org/10.1016/j.actatropica.2024.107459

Segala, F. V., Guido, G., Stroffolini, G., Masini, L., Cattaneo, P., Moro, L., Motta, L., Gobbi, F., Nicastri, E., Vita, S., Iatta, R., Otranto, D., Locantore, P., Occa, E., Putoto, G., Saracino, A., & Di Gennaro, F. (2025). Insights into the ecological and climate crisis: Emerging infections threatening human health. *Acta Tropica*, *262*, 107531. https://doi.org/https://doi.org/10.1016/j.actatropica.2025.107531

Sutanto, H., & Ansharullah, B. A. (2025). The role of artificial intelligence for dengue prevention, control, and management: A technical narrative review. *Acta Tropica*, *268*, 107741. https://doi.org/https://doi.org/10.1016/j.actatropica.2025.107741

Tu, N. M., Lan, T. T., & Vandika, A. Y. (2024). *The Application of Artificial Intelligence in Quantum Mechanics : Challenges and Opportunities*. *1*(December), 278–287. https://doi.org/10.70177/scientia.v1i6.1583

Wang, C.-X., Xiu, L.-S., Hu, Q.-Q., Lee, T.-C., Liu, J., Shi, L., Zhou, X.-N., Guo, X.-K., Hou, L., & Yin, K. (2023). Advancing early warning and surveillance for zoonotic diseases under climate change: Interdisciplinary systematic perspectives. *Advances in Climate Change Research*, *14*(6), 814–826. https://doi.org/https://doi.org/10.1016/j.accre.2023.11.014

Wang, Y., Zhao, S., Wei, Y., Li, K., Jiang, X., Li, C., Ren, C., Yin, S., Ho, J., Ran, J., Han, L., Zee, B. C., & Chong, K. C. (2023). Impact of climate change on dengue fever epidemics in South and Southeast Asian settings: A modelling study. *Infectious Disease Modelling*, *8*(3), 645–655. https://doi.org/https://doi.org/10.1016/j.idm.2023.05.008

Woldegerima, W. A., & Ugwu, C. L. J. (2025). Bayesian hierarchical modeling of Mpox in the African region (2022–2024): Addressing zero-inflation and spatial autocorrelation. *Infectious Disease Modelling*, *10*(4), 1575–1591. https://doi.org/https://doi.org/10.1016/j.idm.2025.07.011

Yang, T., Du, X., Li, J., Zhang, T., Wang, Y., & Wang, L. (2025). Modeling transmission dynamics and socio-economic determinants of scarlet fever in Chengdu, China: An integrated SEIAR and machine learning approach. *Epidemics*, *52*, 100844. https://doi.org/https://doi.org/10.1016/j.epidem.2025.100844

Zitzmann, C., Adia, N. A. B., Shah, P. S., & Manore, C. (2025). Opportunities in multiscale modeling of mosquito-borne flaviviruses. *BioSystems*, *257*, 105593. https://doi.org/https://doi.org/10.1016/j.biosystems.2025.105593