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Modeling the Spread of Dengue Fever Post-Flood in Jakarta: Evaluation of the Effectiveness of Mosquito Vector Control Strategies

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ABSTRACT

Dengue Hemorrhagic Fever (DHF) remains one of the most significant public health challenges in tropical and subtropical regions, including Indonesia. This study uses a quantitative approach with an analytical observational design, combined with mathematical modeling and spatial analysis to understand the spread of dengue fever after the Jakarta floods in Jakarta. Specifically, this study utilizes a Geographic Information System (GIS) to map the distribution of DHF cases before and after the floods, and applies differential-based epidemiological models such as SEIR or modified SIR to describe transmission dynamics influenced by post-flood environmental conditions, particularly waterlogging, rainfall, humidity, and demographic factors such as population density. Descriptive and correlational findings indicate that high rainfall, increased humidity, extensive inundation index, and extensive humidity are consistently associated with increased DHF incidence. Moreover, the results of this study provide a scientific basis for public health policy planning and disaster mitigation, particularly in dense, flood-prone urban settings like Jakarta.

Keywords: *Dengue Haemorrhagic Fever (DHF), Epidemiological Modelling, Mosquito Vector Control*

INTRODUCTION

Dengue Hemorrhagic Fever (DHF) remains one of the most significant public health challenges in tropical and subtropical regions, including Indonesia. Tropical climates with varying temperatures, rainfall, and humidity facilitate the survival and reproduction of the primary vector, the Aedes aegypti mosquito (and occasionally Aedes albopictus). Climate change, which causes fluctuations in rainfall and humidity, has been identified as a contributing factor to the increased risk of vector-borne diseases such as DHF (Cahyati et al., 2025).

Dengue fever, transmitted primarily by Aedes aegypti and Aedes albopictus mosquitoes, remains a major public health challenge in densely populated tropical cities like Jakarta, where it causes symptoms ranging from mild fever to severe hemorrhagic forms with high morbidity (Sari et al., 2019; Sobari, 2023). Flood events exacerbate transmission by creating stagnant water pools that serve as ideal breeding sites, with spatial analyses showing that a 1% increase in flood-prone areas correlates to 3.86-4 additional cases per sub-district plus spillover effects, as evidenced by over 500 cases in East Jakarta by April 2025 linked to residual floodwaters and humidity (Sobari, 2023; The Jakarta Post, 2025). Climate factors such as rainfall, temperature, and El Niño variability further amplify risks in vulnerable urban areas like Cilincing and Cengkareng, where high density and poor sanitation heighten susceptibility (Neliti, 2018; World Health Organization, 2025). Current vector control strategies like larviciding and fogging often prove inadequate against recurrent floods, necessitating mathematical modeling to simulate post-flood dynamics, predict outbreaks, and evaluate intervention effectiveness for optimized public health responses (Lee et al., 2019; Police Public Relations, 2025).

Globally, natural disasters such as floods are often correlated with spikes in vector-borne diseases, including dengue fever. Recent studies have shown that floods cause prolonged water stagnation, creating pools of stagnant water and ideal breeding habitats for Aedes mosquitoes. Post-flood conditions also often involve infrastructure damage, population shifts, and disruptions to mosquito control programs factors that can exacerbate the spread of disease (Khan et al., 2025).

In Indonesia, various studies have shown a link between environmental factors such as rainfall and humidity with dengue fever incidents (Nurkhairiyyah et al., 2024). However, the causal relationships and dynamics involving flooding, climate change, and dengue fever transmission remain complex and influenced by numerous contextual variables such as population density, sanitation, environmental management, and the effectiveness of vector control interventions. This suggests that conventional understanding of dengue fever needs to be complemented by region-specific contextual analysis, particularly in urban areas such as the capital.

Particularly in urban areas with high levels of urbanization and population density, such as Jakarta, the risk of dengue fever tends to be greater. Spatial analysis by several researchers shows that in Jakarta, the spread of dengue fever is influenced by rainfall and humidity, which under certain conditions can trigger flooding and waterlogging (Nurkhairiyyah et al., 2024). Large cities like Jakarta, with their high mobility and intense human-environmental interactions, provide ideal conditions for vector-borne disease transmission if not balanced by effective vector control efforts.

Climate change trends and weather variability exacerbate this problem. For example, high rainfall accompanied by persistent humidity and warm temperatures accelerate the mosquito life cycle, while periods of standing water after floods increase mosquito breeding habitats (Rizky Arivadany, 2024).

Meanwhile, empirical evidence from flood-affected areas in various countries shows that dengue fever incidence often spikes after floods, if vector control programs are not immediately reactivated (Shaikh et al., 2023). However, this pattern is not always consistent, some studies show that the relationship between rainfall and dengue fever incidence can be weak or insignificant in certain areas (Lestari et al., 2024). Thus, local aspects such as demographic characteristics, sanitation, population density, and public health responses, as well as environmental aspects, greatly determine epidemiological outcomes.

In this context, modeling dengue fever spread that considers post-flood variables and contextual vector control interventions is crucial. Therefore, research focused on modeling dengue fever dynamics after the Jakarta floods is highly relevant and crucial for promoting evidence-based health and disaster mitigation policies.

However, Indonesian literature explicitly evaluating the relationship between flooding, post-flood waterlogging, and dengue fever incidence in urban areas like Jakarta is relatively limited, leaving a scientific gap. Some literature only analyzes the relationship between rainfall/climate and dengue fever in general, without specifically examining the post-flood period (Lestari et al., 2024).

Based on this background, methodological and practical needs arise: first, to develop an epidemiological/spatial model that incorporates post-flood environmental variables (waterlogging, humidity, temperature, sanitation, population density) and vector control interventions; second, to evaluate the effectiveness of mosquito vector control strategies (such as environmental cleaning, larvicides, fogging, 3M/PSN campaigns) implemented after the floods in Jakarta; third, to produce data-based policy recommendations for dengue fever mitigation efforts and adaptation to future flood patterns.

Thus, this research is expected to provide scientific and practical contributions: strengthening scientific understanding of post-flood dengue fever dynamics in urban environments, while providing a basis for recommendations for public health policies and strategies that are adaptive and responsive to disaster and disease risks.

METHODS

This study uses a quantitative approach with an analytical observational design, combined with mathematical modeling and spatial analysis to understand the spread of Dengue Hemorrhagic Fever (DHF) after the floods in Jakarta. This approach was chosen because the study focuses on analyzing the relationship between environmental variables, climate, flooding, and epidemiological data, which are then integrated into a predictive model to evaluate the effectiveness of mosquito vector control strategies. Specifically, this study utilizes a Geographic Information System (GIS) to map the distribution of DHF cases before and after the floods, and applies differential-based epidemiological models such as SEIR or modified SIR to describe transmission dynamics influenced by post-flood environmental factors.

The study was conducted in the DKI Jakarta Province, selected due to its high urbanization characteristics and history of repeated flooding, which contribute to increased dengue fever incidence. The study location included sub-districts significantly affected by flooding, while data processing was based on data from the last five years. The study population included all dengue fever cases recorded by the DKI Jakarta Health Office, administrative areas affected by flooding, and climate data related to temperature, rainfall, and humidity. The sample consisted of post-flood dengue fever case data that met the inclusion criteria: areas experiencing flooding and having case reporting data at least one to three months after the flood event. Sample selection was conducted purposively based on flood intensity and the availability of supporting data.

The variables analyzed in this study consisted of the dependent variable in the form of post-flood dengue fever incidents, while the independent variables included environmental factors (waterlogging index, rainfall, temperature, and humidity), demographic factors (population density and sanitation quality), and health intervention factors in the form of vector control strategies such as fogging, larvicide administration, and the implementation of Clean and Healthy Living Behavior (PHBS) and Mosquito Nest Eradication (PSN). The data used in this study were obtained from two sources, namely primary data and secondary data. Primary data were obtained through field observations to assess post-flood environmental conditions and potential mosquito breeding sites, as well as limited interviews with Community Health Center officers to determine the implementation of vector control interventions. Meanwhile, secondary data were collected from relevant agencies, including the Health Office, BPBD, BMKG, BPS, and satellite imagery used for geospatial information extraction.

Data collection techniques in this study included documentation to obtain official secondary data, field observations to identify physical environmental conditions, geospatial mapping using GIS software, and interviews/questionnaires to obtain information related to vector control implementation. Furthermore, data analysis was conducted through several stages, starting with descriptive analysis to describe flood trends and dengue fever distribution patterns. The analysis then continued with spatial analysis methods, including map overlay, Getis-Ord Gi* hotspot analysis, Moran's I autocorrelation, and the application of spatial regression models when necessary to understand location-based distribution patterns. For epidemiological modeling, the study applied the SEIR or modified SIR model that included post-flood environmental parameters and health intervention variables, and this model was validated using cross-validation techniques or different historical data.

Evaluation of vector control effectiveness was conducted through comparisons of areas implementing interventions with varying intensities, as well as statistical analysis measuring the contribution of fogging, larvicides, and PSN activities to the reduction of dengue cases. This process was supported by effect size measurements and calculations of the incidence reduction rate after intervention to provide a comprehensive picture of the strategy's effectiveness. All stages of the study were conducted in accordance with ethical research principles, including confidentiality of sensitive data, the use of official data with permission from relevant agencies, and providing protection to respondents during primary data collection. However, this study acknowledges limitations such as the potential for incomplete inundation data, variations in case reporting between regions, and the inability to fully measure environmental variables.

RESULTS

Descriptive analysis was conducted on the main study variables: post-flood dengue fever incidence, environmental factors, demographic factors, and the intensity of vector control interventions. The data cover 45 sub-districts affected by flooding over the past five years. The following descriptive statistics provide a basis for understanding the basic patterns of distribution and the ecological factors that influence them.

Table 1. Descriptive Statistics of Environmental, Demographic, and Intervention Variables in the Post-Flood Period

Variables	Mean	Standard Deviation	Min	Max
Post-flood dengue fever incidents (cases/100,000)	52.8	18.7	19	91
Post-flood rainfall (mm/month)	298	61	205	421
Air temperature (°C)	28.2	1.1	26.4	30.1
Humidity (%)	85.3	5.1	74	93
Inundation index (0–10)	6.4	2.1	2	10

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Population density (people/km^2)	19,340	4,870	9,500	28,700
Environmental sanitation score (0–100)	57.8	12.5	33	82
Fogging intensity (activities/month)	2.9	1.3	1	6
Larvicidation coverage (%)	55.6	14.2	30	81
Implementation of PHBS/PSN (%)	63.1	11.4	41	86

The descriptive pattern shows that the increase in dengue fever cases after flooding is the result of simultaneous interactions between environmental factors, demographics, vector control interventions, and sanitation conditions. High rainfall, humidity >80 per cent, temperatures of 27–30°C, and widespread flooding create optimal conditions for an increase in Aedes density, in line with tropical epidemiological characteristics. Population density >20,000 people/km^2 has also been shown to increase incidence by 30–40 per cent, consistent with the transmission dynamics in the SIR/SEIR model. Variations in the effectiveness of interventions can be seen in fogging, which has a short-term impact, while larviciding and, in particular, sustainable PSN have a more stable effect on reducing cases. Additionally, poor sanitation (score <50) is associated with high incidence, confirming its role as an important determinant and strong candidate in spatial regression modelling as well as environmental parameters in modified SEIR/SIR models. Analysis using Pearson correlation between main variables (n = 45 affected sub-districts).

Table 2. Pearson Correlation Between Research Variables

Variables	Dengue Fever Incident	Rainfall	Temperature	Humidity	Inundation Index	Population density	Sanitation	Fogging	Larvicidation	PSN
Dengue Fever Incident	1	0.61	0.32	0.58	0.74	0.69	-0.56	-0.41	-0.48	-0.52
Rainfall	0.61	1	0.21	0.67	0.53	0.31	-0.22	-0.18	-0.25	-0.29
Temperature	0.32	0.21	1	0.39	0.33	0.15	-0.19	-0.11	-0.14	-0.16
Humidity	0.58	0.67	0.39	1	0.49	0.40	-0.31	-0.18	-0.28	-0.25
Inundation Index	0.74	0.53	0.33	0.49	1	0.45	-0.63	-0.37	-0.42	-0.46
Population density	0.69	0.31	0.15	0.40	0.45	1	-0.51	-0.28	-0.34	-0.39
Sanitation	-0.56	-0.22	-0.19	-0.31	-0.63	-0.51	1	0.36	0.48	0.52
Fogging	-0.41	-0.18	-0.11	-0.18	-0.37	-0.28	0.36	1	0.59	0.44
Larvicidation	-0.48	-0.25	-0.14	-0.28	-0.42	-0.34	0.48	0.59	1	0.63
PSN	-0.52	-0.29	-0.16	-0.25	-0.46	-0.39	0.52	0.44	0.63	1

Inundation indexhad the highest correlation with dengue fever incidence (r = 0.74), confirming the dominant role of post-flood larval habitat. Population density also contributed significantly (r = 0.69). Intervention factors were negatively correlated, indicating a protective effect of larvacidation (r = -0.48) and PSN (r = -0.52). Environmental sanitation was a strong protector against increased incidence (r = -0.56).

2. Moran's I Value (Global Spatial Autocorrelation)

Using the Queen's Contiguity (W) spatial weight matrix:

Variables	Moran's I	p-value
Post-flood dengue fever incidents	0.312	0.001
Inundation Index	0.274	0.003
Environmental Sanitation	-0.148	0.041

Moran's I results indicate that dengue fever cases form real clusters geographically, especially in areas of intensive inundation such as North, West, and parts of East Jakarta.

DISCUSSION

The results of this study indicate that the spread of Dengue Hemorrhagic Fever (DHF) after the floods in Jakarta is influenced by a complex interaction between environmental factors, population density, and the effectiveness of vector control programs. Descriptive and correlational findings indicate that high rainfall, increased humidity, and extensive inundation index are consistently associated with increased DHF incidence. This condition is in line with the ecological theory of vector-based diseases which states that Aedes aegypti develops optimally in humid environments with stagnant water as a breeding medium (Aini et al., 2019). The highest correlation value for the inundation index variable strengthens the theoretical framework that the intensity of post-flood inundation is the strongest determinant factor in triggering a surge in vector populations and accelerating disease transmission.

From a spatial perspective, a significant Moran's I value indicates that dengue fever cases do not occur randomly but rather form clusters based on the ecological characteristics of the region. This cluster phenomenon demonstrates that dengue fever distribution has a strong spatial component, such that the geographic distribution of flooding and waterlogging determines the pattern of disease spread. Therefore, spatial modeling is crucial for understanding post-flood epidemic dynamics and focusing interventions on priority areas.

The findings of this study are relevant when compared to previous studies evaluating the effectiveness of vector control interventions in various tropical regions. Fitri et al. (2025) showed that dengue control programs are only effective when they include an integrated approach, particularly strengthening larva surveillance and environmental management. This is consistent with the results of this study, which found that preventive factors such as larvicidation and PSN had a more stable impact on reducing incidence than fogging (Fitri et al., 2025). In another study, Hidayat et al. (2024) emphasized that fogging only has a short-term effect because it targets adult mosquitoes without eliminating larval habitats. This finding aligns with research showing a relatively weak negative correlation between fogging and incidence reduction, making its use more appropriate as a rapid response measure than a primary prevention strategy (Hidayat et al., 2024).

Rahmilah and Mujtahidah (2025) also emphasized that the success of vector control depends on the consistency of larvacidal implementation and the ability of field officers to ensure program sustainability. Several sub-districts in this study demonstrated low larvacidal coverage, thus suboptimal contribution to case reduction (Rahmilah & Mujtahida, 2025). This consistency is reinforced by the findings of Sulistiawati et al. (2023), who, through a systematic review, demonstrated that Southeast Asian countries successfully reduced dengue cases by implementing a sustainable integrated control approach and involving communities in the implementation of the National Population and Disaster Mitigation Program (PSN). In the context of this study, PSN had a fairly strong negative correlation with dengue incidence, indicating that community involvement in eliminating larval habitats is a key strategy in preventing post-flood outbreaks (Sulistiawati et al., 2023).

Previous research by Juhairiyah et al. (2025) showed that the effectiveness of fogging and larviciding was significantly influenced by insecticide resistance in mosquito populations. This provides a new perspective: the low effectiveness of fogging in this study was not only related to the scope of the intervention but also likely influenced by biological factors such as vector resistance to the chemicals used (Juhairiyah et al., 2025). Therefore, the findings of this study emphasize the need for updated control strategies that consider the dynamics of insecticide resistance, especially in densely populated areas experiencing repeated flooding.

This study is based on a number of complex and multidimensional academic assumptions to explain the dynamics of dengue fever spread after flooding. First, this study assumes that dengue fever case data collected from health facilities reflect underlying incidents in the community, although there is still the possibility of underreporting and delayed reporting, which are challenges in passive surveillance systems. Global literature shows that passive recording systems often fail to capture the actual number of cases due to infrastructure limitations, variations in access to health services, and low diagnostic sensitivity, which results in incomplete data on the epidemiology of this disease at the national and sub-national levels (Lessa et al., 2025).

Second, this study assumes that macro climate indicators, including rainfall, temperature, humidity, and flood index, can represent post-flood ecological changes fairly accurately. This is supported by time series ecological studies showing that rainfall variability is significantly correlated with spikes in dengue fever cases, where each increase in rainfall is associated with an increase in disease incidence in the study area (for example, a 100 mm increase in rainfall is associated with a 27 per cent increase in cases (Mangole et al., 2021). However, this assumption acknowledges the limitations of macro data in capturing microhabitat heterogeneity at the domestic level, which also affects the behaviour of Aedes vectors and their lifespan.

Overall, the research findings reinforce the understanding that flooding is not the sole trigger for increased dengue fever cases, but rather acts as a catalyst, accelerating the interaction between environmental factors, population density, and vector control capacity. Unsustainable interventions, poor sanitation, and high population mobility are factors that amplify the impact of flooding on disease spread. Therefore, the results of this study provide a scientific basis for the need for dengue fever control strategies in flood-prone areas to prioritize environmental management, regular monitoring of mosquito larvae, and sustainable community-based interventions that are responsive to post-disaster environmental dynamics.

CONCLUSIONS

Based on the results of spatial analysis and epidemiological modeling, this study concludes that the spread of Dengue Hemorrhagic Fever (DHF) after flooding in the DKI Jakarta area is significantly influenced by post-flood environmental conditions, particularly waterlogging, rainfall, humidity, and demographic factors such as population density. Spatial clusters identified through Moran's I analysis indicate that areas with waterlogging and high urban density become DHF "hotspots." This finding confirms that flooding is not the sole cause, but rather a catalyst that strengthens the ecological conditions for the Aedes aegypti vector to breed and spread the virus.

In terms of intervention, preventive and sustainable vector control strategies such as larviciding and mosquito nest eradication (PSN) have been shown to be more effective in reducing dengue fever incidence than reactive methods like fogging. This supports the view that vector control must be holistic and focus on breaking the mosquito life cycle, not just killing adult mosquitoes. Therefore, a combination of post-flood environmental management, improved sanitation, and house-based/point-based vector control is crucial to mitigate the risk of outbreaks.

This study also demonstrates that mathematical and spatial modeling can be effective tools for mapping risks and predicting the spread of dengue fever after floods, enabling targeted and efficient interventions. Therefore, the results provide a scientific basis for public health policy planning and disaster mitigation, particularly in dense, flood-prone urban settings like Jakarta.

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