Dengue hemorhagic fever and climate change in Surakarta: Pre-study for community-based clinical immunology

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Abstract. This study aims to analyze the correlations between climatic factors (rainfall, humidity, temperature) and environmental sanitation (waste volume) with the incidence of Dengue Hemorrhagic Fever (DHF) in Surakarta. Using a retrospective observational design, this research analyzed aggregated secondary data from 2022 to 2024. The results revealed highly volatile DHF incidence: 166 cases in 2022, 99 in 2023, and 220 in 2024. The analysis demonstrated strong positive correlations between DHF cases and both the number of rainy days and air humidity. Conversely, air temperature showed a non-linear relationship, rising consistently while cases fluctuated. Notably, environmental sanitation played a disproportionate role; a modest 5.66% increase in solid waste volume was associated with a 122.22% surge in DHF cases. The study concludes that while rainfall creates breeding sites, poor waste management significantly exacerbates transmission risk. These environmental dynamics provide the critical epidemiological context for future community-based clinical immunology studies, particularly regarding the risk of severe secondary infections due to high vector density. Integrated surveillance of weather and waste management is recommended as a primary prevention strategy.

1 Introduction

Dengue Hemorrhagic Fever (DHF) is a significant and escalating mosquito-borne viral disease, posing a substantial public health challenge in tropical and subtropical regions globally [1,2]. Indonesia, in particular, reports one of the highest burdens of DHF in Asia, with the disease being endemic across its archipelago and a primary cause of hospitalization among children [3,4]. The incidence of DHF is notoriously cyclical, characterized by seasonal variations and periodic epidemics that are strongly influenced by local environmental conditions [5,6].

This cyclical pattern is clearly evident in Surakarta City, where DHF case numbers have demonstrated significant volatility. According to local data, 166 cases were reported in 2022,

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followed by a sharp decrease to 99 cases in 2023. However, this was immediately followed by a significant resurgence, with cases surging to a three-year high of 220 in 2024. This drastic fluctuation highlights the instability of dengue transmission and underscores the critical role of underlying environmental and climatic drivers [7].

The relationship between DHF incidence and environmental factors is well-established. Climatic variables are key determinants of vector proliferation and virus transmission[8,9]. An increased number of rainy days, for example, directly expands the availability of stagnant water, which serves as the primary breeding habitat for the Aedes aegypti vector. Data from Surakarta supports this, showing a clear positive correlation between the number of rainy days and DHF cases. This was observed in the 2022-2023 period, where a drop in rainy days (from 205 to 116) was correlated with a decline in DHF cases (from 166 to 99), and in 2023-2024, where an increase in rainy days (from 116 to 145) was followed by a significant surge in cases (from 99 to 220). Similarly, high air humidity extends the lifespan and increases the activity of adult mosquitoes. This trend was also observed in Surakarta, where a strong positive correlation was found, with both humidity and cases falling in 2023 and rising together in 2024.

Similarly, high air humidity extends the lifespan and increases the activity of adult mosquitoes. This trend was also observed in Surakarta, where a strong positive correlation was found, with both humidity and cases falling in 2023 and rising together in 2024. Beyond climate, urban environmental sanitation and excellent waste management are critical modulators of dengue risk [10–13]. Unmanaged solid waste, such as discarded containers, bottles, and tires, collects rainwater and creates abundant artificial breeding sites for Aedes mosquitoes in proximity to human populations. The data from Surakarta highlights this danger: a modest 5.66% increase in waste volume from 2023 to 2024 was associated with a dramatic 122.22% surge in DHF cases.

However, a critical research gap remains in the current literature. While numerous studies have analyzed climatic variables and DHF incidence independently, fewer studies have explicitly examined the concurrent, amplifying interaction between macro-climatic volatility (rainfall and temperature) and anthropogenic factors (waste volume) within a short-term, high-fluctuation period. Furthermore, previous research often assumes a linear relationship between rising temperatures and disease transmission, a model that frequently fails to account for local contexts where transmission decouples from thermal drivers due to other limiting factors. This study introduces novelty by utilizing Surakarta's unique high-low-high incidence pattern (2022–2024) as a natural experiment to disentangle these variables. Unlike previous broad-scale studies, this research explicitly quantifies the non-linear influence of temperature and the disproportionate impact of solid waste volume, offering a more precise, localized model of urban DHF dynamics.

Therefore, this study aims to analyze the relationships between key climatic factors (number of rainy days, air humidity, and air temperature) and environmental sanitation factors (annual waste volume) with the dynamics of Dengue Hemorrhagic Fever incidence in Surakarta City during the 2022–2024 period.

2 Methods

This study utilized a quantitative, observational design employing a retrospective approach. The research protocol, which involved the analysis of aggregated secondary data, received ethical clearance from the Research Ethics Committee (KEP) of Sebelas Maret University Hospital (RS UNS) before accessing the data. The study's objective was to analyze correlations between environmental factors and public health outcomes, specifically the incidence of Dengue Hemorrhagic Fever (DHF).

The research was conducted in Surakarta City, Central Java, Indonesia, spanning a data period from January 1, 2022, to December 31, 2024. All data used in this study were secondary and aggregated, obtained from official government bodies. Epidemiological data, specifically the total annual number of DHF cases, were sourced from the official surveillance records of the Surakarta City Health Office (Dinas Kesehatan Kota Surakarta). Climatological data were obtained from the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG). Environmental data regarding annual solid waste volume were procured from the relevant municipal agency responsible for waste management.

The primary dependent variable for this analysis was the total number of reported DHF cases per year. The independent variables, representing environmental and climatic factors, included average annual air humidity (%), average annual air temperature (°C), the cumulative total of annual rainy days, and the total annual waste volume (in tons). Data for climatological factors and DHF cases covered the whole 2022-2024 period, while data for waste volume were available for the 2023-2024 period.

Data analysis was performed using descriptive statistics. The annual total or average for each independent environmental variable was calculated and tabulated. This data was then directly compared against the yearly trend of the total DHF cases. This correlational analysis was observational in nature, aiming to describe the direction (positive or negative) and consistency of the relationships between the identified environmental variables and the fluctuating incidence of DHF over the three-year study period.

3 Results

The analysis of data from Surakarta City, spanning 2022 to 2024, reveals a highly dynamic story of DHF transmission and its strong connection to environmental factors. As shown in Table 1, the total number of DHF cases reported in Surakarta City showed significant fluctuation over the three-year study period. The analysis began in 2022, which recorded a total of 166 DHF cases. Following this, the incidence saw a substantial decrease in 2023, with the total number of cases dropping to 99. This marked the lowest point of DHF incidence during this timeframe. However, this decline was sharply reversed in 2024, when the number of cases experienced a dramatic surge, rising to a three-year high of 220. This sharp increase in 2024 highlights the volatility of DHF transmission within the city.

Table 1. Total DHF Cases in Surakarta

Year	Total DHF Cases
2022	166
2023	99
2024	220

As shown in Table 2, a strong positive correlation was observed between the average annual air humidity and the number of DHF cases. The data shows that the trends for both variables moved in the same direction across the study period. In 2022, a high average humidity of 79.25% was recorded alongside 166 DHF cases. This was followed in 2023 by a significant drop in both metrics: the average humidity fell to 73.92%, and the case count correspondingly declined to 99. The correlation persisted into the subsequent year, as 2024 saw a rebound in average humidity to 77.50%, accompanied by a dramatic surge in DHF cases to 220. This consistent, parallel movement suggests that higher humidity, which can extend the life of the Aedes aegypti mosquito, is a key factor associated with increased DHF incidence in Surakarta.

Table 2. Comparison of Average Air Humidity and DHF Cases

Year	Average Air Humidity (%)	Total DHF Cases
2022	79.25	166
2023	73.92	99
2024	77.5	220

As shown in Table 3, and similar to humidity, the trend in DHF cases showed a clear positive correlation with the total annual number of rainy days. The connection between rainfall and case numbers was distinct. In 2022, there were 205 rainy days, which corresponded to a high case count of 166. A significant environmental shift occurred in 2023, when the total number of rainy days decreased substantially to 116. This drop was mirrored by a sharp decrease in DHF cases to 99. Following this, in 2024, the number of rainy days increased again to 145, and a significant surge in DHF cases immediately followed, rising to 220. This pattern strongly indicates that a higher number of rainy days, which creates more stagnant water puddles, is directly linked to an increase in vector breeding sites and DHF cases

Table 3. Comparison of Total Rainy Days and DHF Cases

Year	Total Rainy Days	Total DHF Cases
2022	205	166
2023	116	99
2024	145	220

As shown in Table 4, in contrast to the other climatic factors, the relationship between average air temperature and DHF cases was found to be non-linear. The data show that temperature alone was not the primary driver of DHF incidence. For instance, from 2022 to 2023, the average temperature actually increased from 26.85°C to 27.47°C. However, instead of rising, DHF cases significantly decreased from 166 to 99 during this same period. This suggests the influence of other stronger factors, such as the significant decrease in rainfall observed that year. The temperature continued to rise slightly in 2024 to 27.60°C, and this time, it was accompanied by a surge in cases to 220. This suggests that while warmer temperatures support transmission, their influence is secondary to, or dependent on, other factors such as rainfall.

Table 4. Comparison of Average Air Temperature and DHF Cases

Year	Average Air Temperature (°C)	Total DHF Cases
2022	26.85	166
2023	27.47	99
2024	27.6	220

As shown in Table 5, the data available for 2023 and 2024 indicated a clear and dramatic positive relationship between waste volume and DHF cases. In 2023, the year with the lowest DHF count of 99 cases, the total waste volume was 135,997 tons. In 2024, the waste volume increased to 143,696 tons. While this represents a relatively modest increase in waste volume of only 5.66%, it was accompanied by a disproportionately large and dramatic surge in DHF cases, which skyrocketed by 122.22% to 220 cases. This stark association suggests that even a slight increase in unmanaged waste, which provides artificial breeding sites like bottles and cans, has a significant amplifying effect on DHF transmission.

Table 5. Comparison of Waste Volume and DHF Cases

Year	Waste Volume (tons)	Total DHF Cases
2023	135997	99
2024	143696	220

4 Discussions

This study's findings confirm that the significant fluctuations in DHF incidence in Surakarta from 2022 to 2024 are not arbitrary but are strongly correlated with specific, measurable environmental factors. The data reveal a complex interplay between climate variables and human environmental factors, providing a straightforward narrative of DHF risk. The most compelling findings are the strong, positive correlations observed between DHF cases and both the total number of rainy days and the average annual air humidity. This was most evident in the striking contrast between 2023, which saw the lowest case count (99), the lowest number of rainy days (116), and the lowest average humidity (73.92%), and the surge in 2024, where all three metrics rose concurrently.

This biological mechanism for this is well-established. Rainfall is the primary determinant of Aedes aegypti breeding sites, as the female mosquito requires stagnant water for oviposition. The strong correlation found in this study aligns with extensive research across Southeast Asia, such as a time-series analysis in Malaysia by Hii et al., which identified rainfall as a significant predictor of dengue outbreaks, often with a lag period of several weeks [6]. The finding that increased humidity is correlated with a higher number of cases is equally critical. High humidity (above 70%) is known to enhance vector competency by increasing adult mosquito survival, host-seeking activity, and biting frequency, as the vector is less prone to desiccation [7]. The conditions in 2023 may have suppressed the vector population by not only limiting breeding sites but also by reducing adult mosquito lifespan, creating a clear natural experiment that demonstrates the environment's intense regulatory pressure on DHF transmission.

Perhaps the most critical public health insight from this analysis is the disproportional impact of solid waste volume. The data indicated that a relatively modest 5.66% increase in waste volume from 2023 to 2024 was associated with a massive 122.22% surge in DHF cases. This strongly supports the hypothesis that improperly managed urban waste creates abundant, artificial habitats for larval development. These cryptic breeding sites—such as discarded bottles, cans, and plastic containers—are highly effective because they are often water-filled and protected from sunlight. Research by Saputra and Yudhastuti in Banyuwangi [3] and Purba et al. [4] confirms that environmental risk factors, specifically the presence of artificial containers and poor waste management, are significant drivers of DHF incidence. This demonstrates a mechanism by which transmission can become decoupled from natural rainfall patterns, as artificial containers retain water even during drier spells.

Conversely, the relationship observed between average air temperature and DHF cases was non-linear. The data clearly show that while the average annual temperature consistently increased from 2022 to 2024, DHF cases nonetheless plummeted in 2023. This implies that temperature, while a known catalyst for transmission, was not the primary limiting factor in this ecosystem; its influence was likely superseded by water availability. This aligns with mechanistic models by Mordecai et al. [6], Tesla et al. [5], and Liu et al. [7], which demonstrate that dengue transmission has a complex, parabolic relationship with temperature. Transmission peaks at a thermal optimum (approx. 29°C) but can decrease or plateau if other physiological constraints are met. It is plausible that while Surakarta's

temperatures were conducive to transmission, the lack of breeding sites (rainfall) in 2023 rendered the thermal effect moot.

The findings from Surakarta are highly consistent with the broader epidemiological context of Indonesia. Harapan et al. have established that DHF is hyper-endemic in Indonesia, with cyclic epidemics driven by a combination of climate and sociodemographic factors [8]. Similar patterns have been observed in Southeast Sulawesi by Tosepu et al., who found that climate variability was a key determinant of disease dynamics [9]. Moreover, the importance of human behavior in sanitation, as highlighted by the waste volume data, echoes findings by Wirantika and Susilowati, who emphasized that health education and behavior change regarding breeding site elimination are crucial for breaking the transmission chain in school and community settings [10].

A significant gap highlighted by the original intent of this review is the absence of immunological data to explain the severity of the 2024 resurgence. While environmental factors explain the transmission risk, they do not fully account for the clinical magnitude. The surge of 220 cases could be exacerbated if the population had a high prevalence of antibodies from a previous infection with a different serotype. As noted by Guzman and Harris [11] and the WHO [12], secondary infection with a heterologous serotype is a primary risk factor for severe dengue due to Antibody-Dependent Enhancement (ADE). Given the co-circulation of all four DENV serotypes in the region [8] and evidence from Rojas et al. [13] and Zini et al. [14] regarding the complex circulation of arboviruses and serotypes in similar tropical settings, the 2024 outbreak likely involved complex immunological interactions. This underscores the complexity of managing arboviral diseases where multiple viruses or serotypes co-exist.

This study is subject to several significant limitations. First, this is an ecological study based on aggregated annual data, which can be subject to the ecological fallacy—wherein correlations observed at a city-wide level may not apply at the individual or household level. Second, the temporal resolution is coarse. Using annual totals masks crucial seasonal dynamics and time-lags. DHF outbreaks typically follow several weeks after peak rainfall, and this analysis cannot capture that fine-grained temporal relationship. Monthly or weekly data would be required for a more precise analysis. Third, this study lacked data on crucial confounding variables, particularly the implementation and coverage of vector control programs (e.g., fogging, 3M-PSN campaigns) and human mobility, both of which are known to significantly influence disease spread.

This analysis provides strong evidence that DHF incidence in Surakarta is driven by a combination of uncontrollable climatic factors (rainfall, humidity) and controllable environmental factors (waste management). The most actionable insight is the disproportionate impact of waste volume, underscoring the importance of robust solid waste management. Future public health strategies should adopt a One Health approach as suggested by Saputra and Oktaviannoor [15], integrating meteorological forecasting with entomological surveillance and waste audits. This would create an effective early warning system, enabling health authorities to allocate resources before an outbreak, such as the one in 2024, fully emerges.

5 Conlusion

The analysis of data from 2022 to 2024 in Surakarta City reveals a strong positive correlation between increases in Dengue Hemorrhagic Fever (DHF) cases and three key environmental factors: higher air humidity, more rainy days, and higher waste volume. These factors collectively create ideal conditions for the breeding of the Aedes aegypti mosquito. Conversely, the relationship with air temperature was non-linear; warmer temperatures

appear to act as a supporting factor that accelerates transmission only when other environmental conditions (such as adequate rainfall) are met.

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