ORIGINAL ARTICLE

Spatial analysis of dengue incidence and linear effects with climate conditions in Bandung City Indonesia in 2021-2023

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ABSTRACT

The dengue problem is getting more serious in Indonesia, there has been a threefold increase in dengue cases compared to the previous year. Bandung City is one of the areas contributing the most cases in 2024 (1,741 cases). As climate change progresses, rising temperatures are expected to exacerbate dengue incidence in Indonesia. This study aims to spatially analyze the impact of population density, altitude, and climatic conditions on dengue incidence in Bandung City. An ecological study was conducted using secondary data from all sub-districts in Bandung City from January 2021 to December 2023. Data on dengue cases, population density, altitude, and climatic conditions were analyzed using spatial analysis, correlation, and multiple linear regression. The highest dengue incidence was recorded in the Bojongloa Kaler sub-district, with 203, 337, and 116 cases in 2021, 2022, and 2023, respectively. Bojongloa Kaler also had the highest population density (402 people/ha) and is located at an altitude of ≥720 m above sea level. Correlation analysis revealed significant associations between dengue incidence and population density (R^2 = 0.221), minimum temperature (R^2 = 0.08), and maximum temperature (R^2 = 0.07). Climatic conditions significantly affected dengue incidence (p=0.017), explaining 30.7% of the variance. Climatic conditions, along with population density, play a crucial role in dengue transmission. Effective intervention strategies should prioritize areas with high case numbers and involve coordinated cross-sectoral efforts to address climate-related transmission risks.

Key words:
dengue, aedes aegypti, climate, spatial, Indonesia

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INTRODUCTION

Dengue is the fastest growing arbovirus in the world, and its incidence has increased in recent decades in tropical and subtropical countries, thus becoming a global public health problem.[1] Over 7.6 million dengue cases, including 3.4 million confirmed cases, over 16,000 severe cases, and over 3000 deaths, had been reported to the WHO as of April 30, 2024. Although there has been a noticeable increase in dengue cases reported worldwide over the past five years, this increase has been most noticeable in the Americas Region, where by the end of April 2024, there will have been more than seven million cases, exceeding the 4.6 million cases that were reported annually in 2023. In the South-East Asia Region, all states have the environmental conditions conducive to dengue endemic transmission, and all have systematically reported dengue cases. There are clear seasonal patterns in dengue incidence, which are associated with the climate patterns in respective countries. Countries that experienced an increase in cases in 2024 were Indonesia, Bangladesh, Nepal and Thailand.[2] In 2024, as of July 1, 149,866 confirmed cases of dengue fever have been reported in Indonesia. This number has approximately tripled compared to the same period in 2023. The cases were reported from 465 districts across 38 provinces in Indonesia, resulting in 884 deaths.[3] Regions with the highest dengue fever cases this year include Tangerang Regency (2,540 cases), Bandung City (1,741 cases), and West Bandung Regency (1,422 cases).[4]

The increasing trend of dengue cases can be influenced by the density of Aedes sp. mosquitoes in the area. The increase in vector density can be influenced by the presence of containers that hold water. The higher the number of these containers holding water, the more breeding sites of Aedes mosquitoes there are, which will increase the risk of contracting the dengue virus.[5] Other factors that can encourage an increase in cases are rapid and unplanned urbanisation,[6] climate change,[7] population growth,[8] population density,[9] population mobilisation,[10] and the presence of larvae.[11] Environmental factors related to dengue can be examined from a spatial (geographical) perspective using spatial analysis.[12] Spatial analysis tools and Geographic Information Systems (GIS) are increasingly used in surveillance and epidemiological investigations.[13]

As climate change progresses, rising temperatures are expected to exacerbate dengue incidence globally and in Indonesia.[3] The emergence and behaviour of Aedes spp. mosquitoes are highly dependent on climatic and environmental conditions, which in turn affect their temporal and geographic distribution.[14] It is well known that the life cycle and population dynamics of Aedes spp. are strongly influenced by rainfall and temperature.[15] In addition, the distribution and movement of Aedes mosquitoes are strongly influenced by the availability and density of larval breeding sites, the built environment and vegetation areas close to human settlements.[16] Several studies have used spatial analytic approaches to understand the distribution and identify areas most affected by dengue infection.[17]

Spatial analysis allows different ways of approaching the problem, viz: mapping areas of vulnerability, susceptibility, and risk; studying habitat adaptation or dispersal patterns; processing multi-source information and integrating it into predictive models; identifying and visualising spatio-temporal co-occurrence across multiple clusters.[18] Ultimately, spatial analysis of dengue can facilitate surveillance of vector-borne diseases by allowing decision makers to allocate resources to combat outbreaks and will help governments take appropriate control measures.[19]

Spatial analysis of dengue incidence has been applied in many countries including Brazil, Colombia, and Malaysia.[20–22] Spatial analysis of dengue incidence has also been conducted in several regions in Indonesia. In Gorontalo, a spatial study of dengue cases found a relationship between physical environmental variables (rainfall, air temperature, air humidity and wind speed) and dengue incidence. Research in Bali Province, with cases of dengue infection reported during 2012-2017, had similar results: the incidence of dengue in Bali Province was spatially clustered. A study in Semarang City showed that dengue incidence was spatially associated with population density.[23] Most recently, a spatial analysis of dengue was conducted in Bandung. The model showed that the spatial clustering of the relative risk of dengue incidence remained relatively unchanged for 3 years. High risk areas for dengue were concentrated in the southern and southeastern parts of Bandung, while low risk areas were found mostly in the western and northeastern regions.[24]

Focus of current research is on the clustering of cases, hotspots of dengue transmission, and the correlation between climate and dengue incidence. In this study, we explain how big the role of climate factors on dengue incidence using linear regression analysis. Given the importance of knowing the significant role climate plays in the increase of dengue cases in Indonesia, the incidence of dengue in Indonesia is also often associated with the altitude of the region. Consequently, the aim of this study is to analyse the influence of population density, altitude, and climatic conditions on dengue incidence at the spatial level. The findings of this study will provide fundamental information for the development of emergency plans for vector-borne diseases such as dengue, which continues to represent a significant public health concern in Indonesia.

MATERIALS AND METHODS

Study Design

This ecological study aimed to examine the spatial distribution and determinants of dengue incidence in Bandung City, Indonesia, from January 2021 to December 2023. Bandung is the capital city of West Java Province in Indonesia and the third largest city in Indonesia (Figure 1). Bandung is a dengue endemic area with a very high incidence rate compared to other districts/cities.

Figure 1. Geographical Location of Bandung City

Population and sample

The study utilized secondary data from all 30 sub-districts in Bandung City, covering a population of approximately 2.5 million residents.

Data collection

Data on dengue cases were obtained from the Bandung City Health Department, while data on population density, altitude, and climatic conditions (temperature, humidity, rainfall) were sourced from the Indonesian Meteorological Agency and local government records.

Research Variables

This study examines both independent and dependent variables. The independent variables include population density, altitude, and various climate conditions. Population Density is defined as the ratio of the population to land area (hectares) within each sub-district. Altitude refers to the topographical condition of sub-districts in Bandung City, measured in meters above sea level (ASL). Climate conditions are assessed through several metrics: Maximum Temperature represents the highest recorded temperature from January 2021 to December 2023, measured in degrees Celsius (°C); Minimum Temperature denotes the lowest recorded temperature over the same period, also in degrees Celsius; and Average Temperature is the mean temperature for the same timeframe. Minimum Humidity and Maximum Humidity are the lowest and highest recorded humidity levels, respectively, from January 2021 to December 2023, expressed as percentages (%). Average Humidity is the mean humidity for this period. Rainfall is quantified as the height of rainwater collected in millimeters (mm) using a rain gauge. Wind Speed is measured in knots, representing the air flow from high pressure to low pressure over the same timeframe.

The dependent variable in this study is Total Dengue Cases, which refers to the number of dengue cases reported by location and month from January 2021 to December 2023. This structured approach ensures a comprehensive analysis of the factors influencing dengue incidence in Bandung City.

Data Analysis

The data analysis for this study employed both spatial and statistical techniques to explore the relationships between dengue incidence and several independent variables. Spatial Analysis was performed using ArcGIS software (Version 10.8.1) to map and analyze the spatial distribution of dengue cases, dengue-related deaths, population density, and elevation. This analysis utilized classification and symbology features to visually differentiate categories based on their values. Dengue cases were categorized into four groups: fewer than 50 cases (green), 50-100 cases (yellow), 101-200 cases (orange), and more than 200 cases (red). For Case Fatality Rate (CFR), the categories were CFR = 0 (green), CFR ≤ 1% (yellow), and CFR > 1% (red). Population density was classified as low (< 150 inhabitants/ha, green), medium (151 - 200 inhabitants/ha, yellow), high (201 - 400 inhabitants/ha, orange), and very dense (> 400 inhabitants/ha, red). Elevation was categorized into two groups: less than 720 meters above sea level (yellow) and 720 meters or more (orange). These classifications were selected based on standard public health criteria and local epidemiological data, facilitating clear visualization of spatial patterns and identification of hotspots.

Simple Linear Regression analysis was utilized to evaluate the impact of individual variables on dengue incidence. These variables included population density, altitude, and various climate factors such as maximum temperature, minimum temperature, average temperature, minimum humidity, maximum humidity, average humidity, rainfall, and wind speed. Each independent variable was analyzed separately to determine its unique effect on dengue incidence. The significance of each regression model was assessed using the F distribution, and the proportion of variance explained by each variable was quantified using the determination coefficient (R-squared). Simultaneous Analysis involved a multiple linear regression model to assess the collective influence of climatic conditions on dengue incidence. This model incorporated all climate variables simultaneously to evaluate their combined effect. The overall model effect was tested using the F test, and the explanatory power of the model was measured with the R-squared statistic.

Model Fit and Validation were rigorously evaluated to ensure the reliability of the regression models. The goodness-of-fit was assessed using R-squared and adjusted R-squared values, while residual analysis was performed to check for homoscedasticity and normality. Cross-validation techniques were applied to verify the robustness and generalizability of the models.

RESULTS

Figure 2 illustrates the spatial distribution of dengue cases and the corresponding Case Fatality Rate (CFR) in Bandung City across three consecutive years (2021-2023). The maps depict a noticeable increase in dengue cases from 2021 to 2022, with a subsequent decline in 2023. Notably, the highest concentration of cases in 2021 and 2022 is observed in the sub-districts of Arcamanik, Bojongloa Kaler, Mandalajati, and Sukajadi, each reporting over 200 cases. By 2023, this clustering diminishes, with no sub-district exceeding 200 cases, indicating a potential improvement in dengue control efforts or shifts in environmental conditions.

The CFR maps reveal a more complex pattern of disease severity. In 2021, most sub-districts experienced low CFRs, with a few exceptions such as Panyileukan and Ujung Berung, where CFRs exceeded 1%. The situation improved slightly in 2022, with only Astana Anyar and Buah Batu exceeding the 1% CFR threshold. However, in 2023, the spatial distribution of high CFRs becomes more widespread, affecting six sub-districts, including Regol, which exhibits a markedly high CFR of 3.3%. This trend suggests that while overall dengue incidence may have decreased, the lethality in specific areas has increased, possibly due to factors like delayed treatment or varying healthcare access.

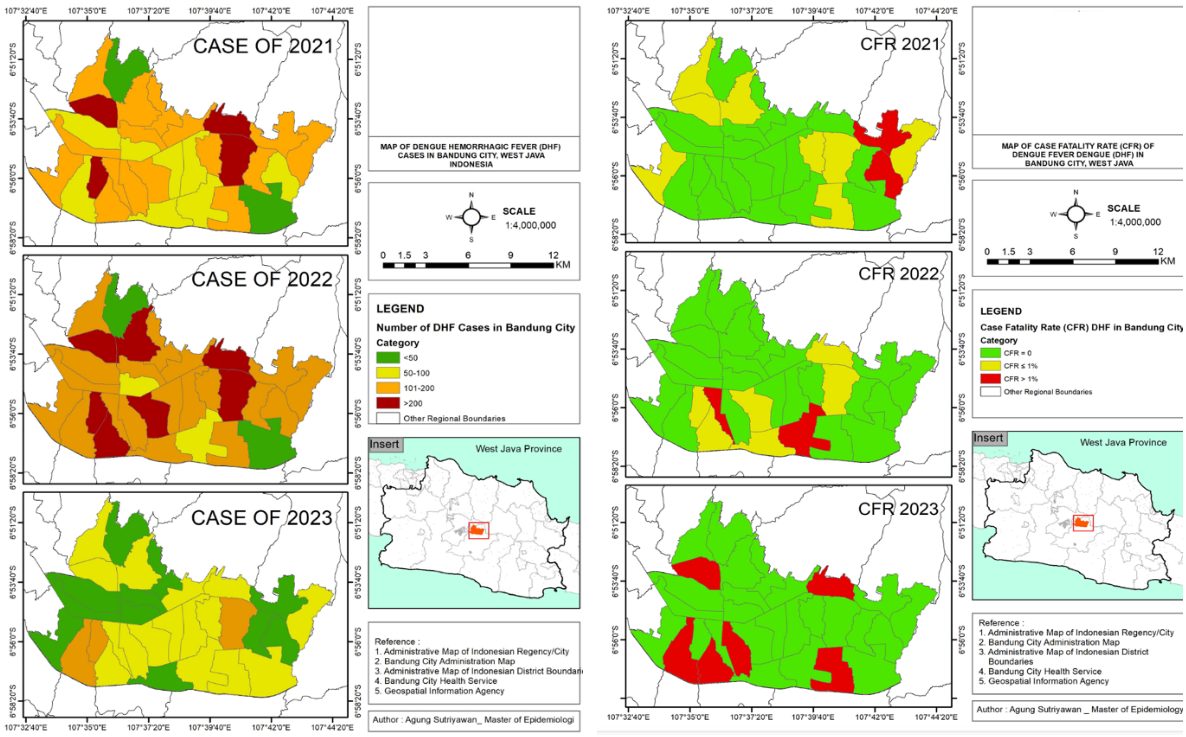


Figure 2. Total Cases and Case Fatality Rate of Dengue in 2021-2023

Figure 2 shows the spatial distribution of population density in Bandung City from 2021 to 2023, alongside the altitude map. In 2021, most sub-districts are categorized as low-density, with only six areas showing high density. By 2022, Kiaracondong saw an increase in population density, and in 2023, Bojongloa Kaler reached a "very high" density level. The altitude map indicates that all sub-districts are located below 1,000 meters, with the majority around 720 meters, which is conducive to Aedes aegypti mosquito habitats.

These trends suggest that increasing population density in specific sub-districts, particularly Bojongloa Kaler, may elevate the risk of dengue transmission, given the optimal altitude for mosquito breeding. The spatial concentration of high-density areas may require targeted public health interventions to prevent outbreaks, especially in regions where population growth coincides with favorable conditions for vector proliferation.

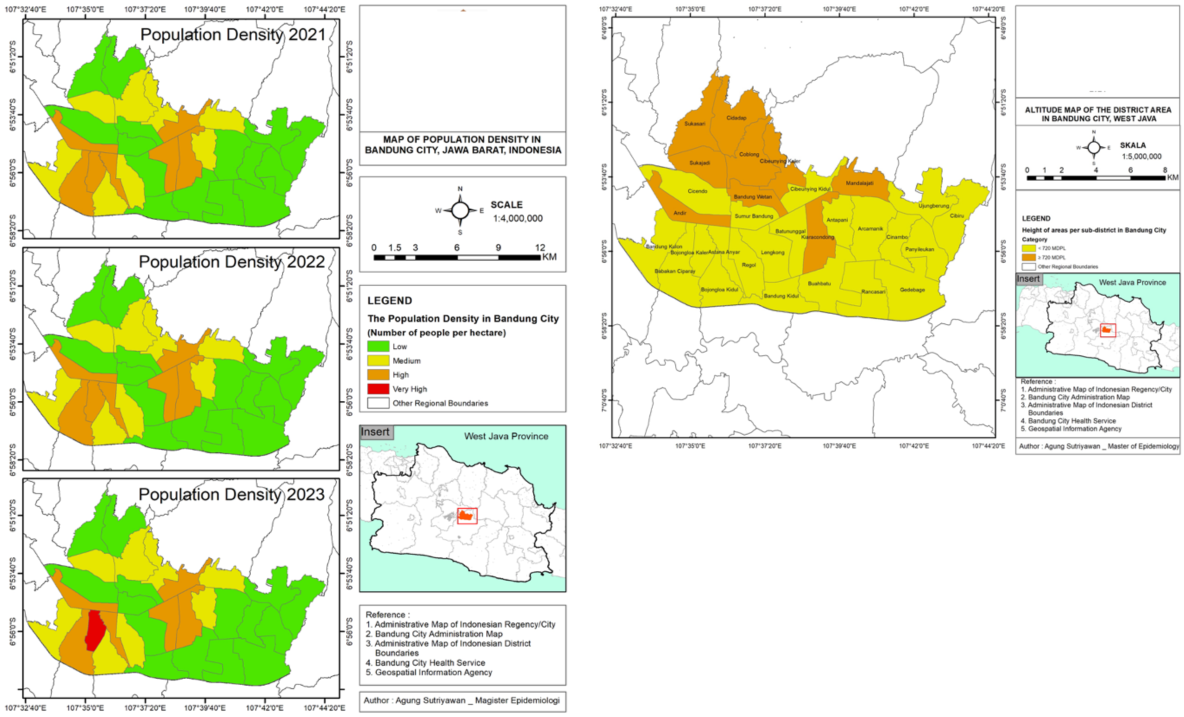
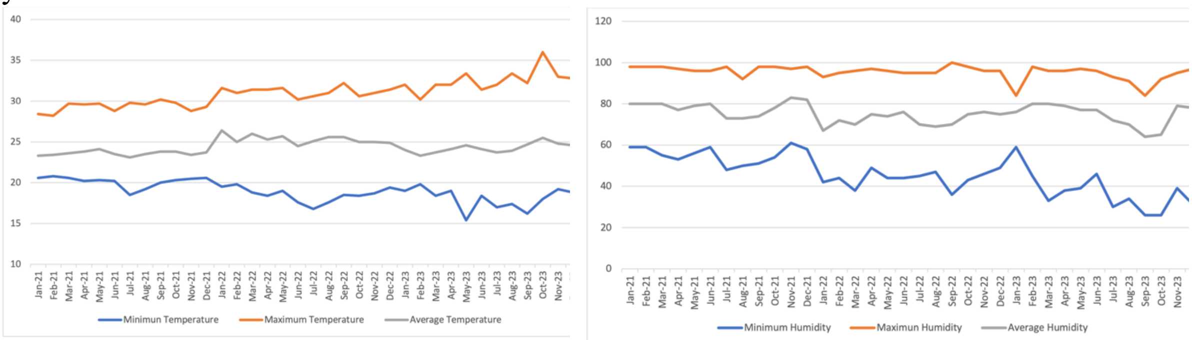


Figure 3. Population Density and Altitude Map of Bandung City

Figure 4 shows the trends in temperature, humidity, rainfall, and wind speed in Bandung City from 2021 to 2023. Maximum temperatures increased each year, from an average of 29.3°C in 2021 to 32.5°C in 2023, while minimum temperatures decreased from 20.2°C to 18.1°C, indicating a widening temperature range. Humidity levels generally declined, with minimum humidity dropping sharply from 55.3% in 2021 to 37.2% in 2023. Rainfall varied, peaking at 192.6 mm in 2022 before declining to 145.9 mm in 2023, and wind speeds fluctuated, with the highest speeds of 9 knots recorded in early 2021, dropping to an average of 3.1 knots by 2023.

These climatic changes may influence dengue transmission, as higher maximum temperatures and lower humidity levels create favorable conditions for the proliferation of Aedes aegypti mosquitoes. The fluctuations in rainfall and wind speed could also impact mosquito breeding sites and virus spread, potentially contributing to the observed dengue incidence patterns during this period. Specifically, the increase in temperature and decline in humidity could enhance mosquito survival and virus replication, while variations in rainfall might affect the availability of breeding sites, influencing the overall dengue risk in Bandung City.



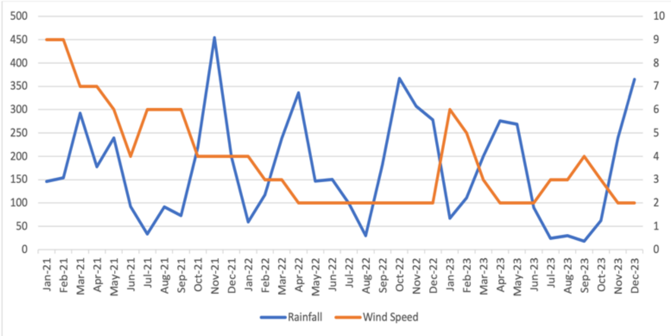


Figure 4. Temperature, Humidity, Rainfall, and Wind Speed Conditions in Bandung City in 2021-2023

Figure 5 shows partial regression plots on the effects of population density and altitude on dengue incidence in Bandung City. The left plot reveals a moderate positive correlation ($R^2 = 0.221$) between population density and dengue cases, indicating that denser urban areas are more prone to outbreaks, likely due to increased human-mosquito interactions.

The right plot shows that altitude has an insignificant impact on dengue incidence ($R^2 = 0.004$), suggesting that within the studied altitude range, it does not meaningfully affect transmission. These results suggest that public health efforts should focus on densely populated areas rather than altitude when addressing dengue in Bandung City.

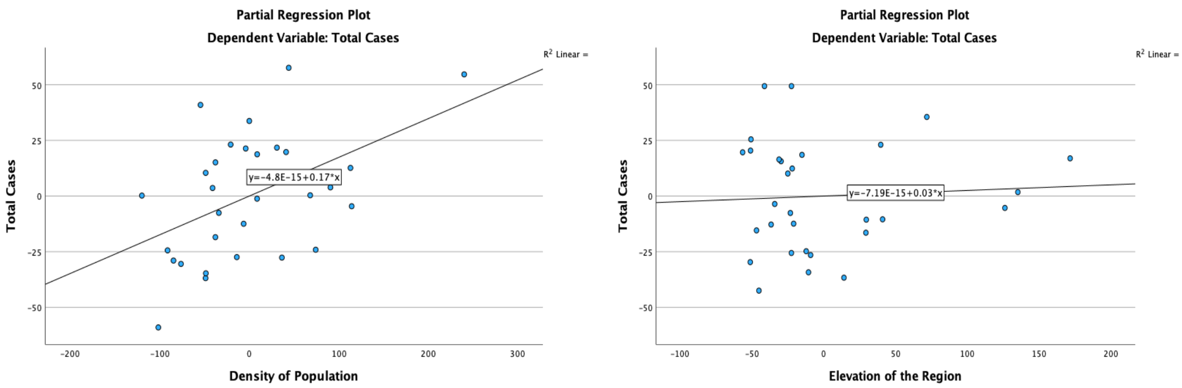


Figure 5. Effect of Population Density, Altitude on Dengue Incidence

Figure 6 presents partial regression plots illustrating the relationship between various climatic factors and dengue incidence in Bandung City from 2021 to 2023. The plots show that minimum temperature has a weak positive correlation with dengue incidence ($R^2 = 0.08$), suggesting that higher minimum temperatures may slightly increase the number of cases. Conversely, maximum temperature shows a weak negative correlation ($R^2 = 0.07$), indicating that lower maximum temperatures might be associated with a minor increase in dengue cases.

However, the R^2 values for both correlations are low, indicating that temperature alone does not strongly predict dengue incidence. The influence of other factors, such as average temperature, humidity, rainfall, and wind speed, is negligible, as reflected by the near-zero R^2

values in their respective plots. This suggests that while temperature may play a minor role, it is not a dominant factor in determining dengue incidence, and other environmental or socio-economic variables likely contribute more significantly to the observed patterns in Bandung City.

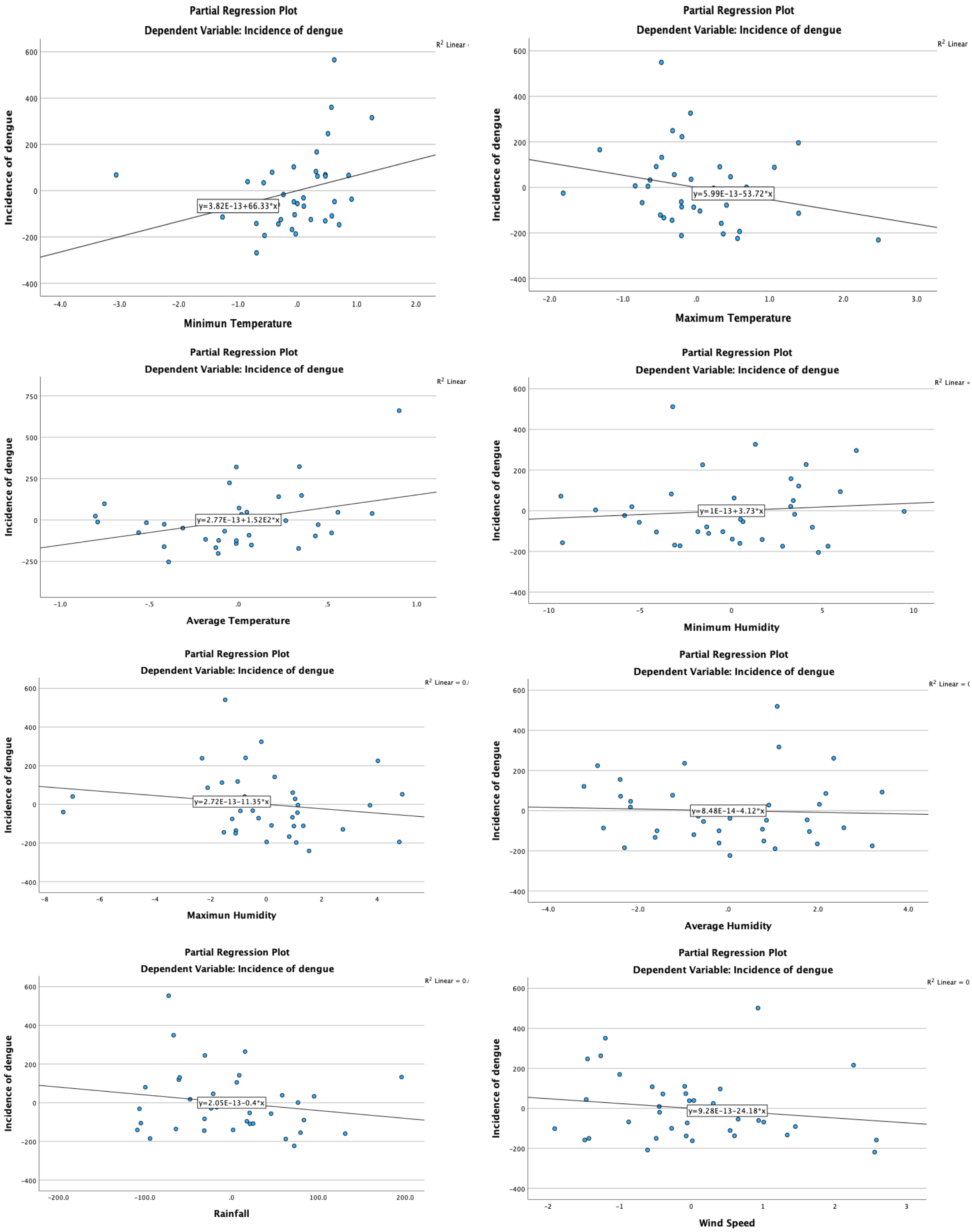


Figure 6. Climate Conditions and Dengue Incidence in Bandung City

Table 1 presents the results of an F-test analyzing the impact of various climatic conditions on dengue incidence in Bandung City. The F-statistic of 2.937 with a p-value of 0.017 indicates that climatic conditions, as a group, have a statistically significant effect on dengue incidence. However, the R^2 value of 0.465 and an adjusted R^2 of 0.307 suggest that these climatic factors explain only about 30.7% of the variability in dengue cases. This relatively low explanatory power indicates that while climate is a contributing factor, other variables not included in this study likely play a more substantial role in influencing dengue incidence. These findings underscore the complexity of dengue transmission and the need to consider additional environmental, social, and biological factors in future research.

Table 1. F-test on Climate Conditions and Dengue Incidence

Climate	F	*P value*	R square	Adjusted R Square
Minimum Temperature Maximum Temperature Average Temperature Minimum Humidity Maximum Humidity Average Humidity Rainfall Wind Speed	2,937	0,017	0,465	0,307

DISCUSSION

Our results confirm that dengue fever cases in Bandung have a clustering distribution pattern among sub-districts. In 2021, dengue cases were centered in three sub-districts namely Antapani, Kiaracondong, and Sukajadi. In 2022, cases increased in areas around these sub-districts, which means that dengue cases are clustered. We believe that denser urban areas are more vulnerable to outbreaks, it is proven that areas with high dengue cases are areas with high population density. This area is one of the most economically productive areas in Bandung, where most of the best public services (education, government, health), industries, commercial enterprises, and recreation facilities are concentrated and the population growth rate is considered higher compared to other areas due to higher birth rates and urbanization.[24] These results support previous studies showing that DHF incidence is correlated with urban growth and urbanization.[25] Population density is one of the factors that influence the transmission process of dengue from one person to another.[26] Without adequate prevention efforts, the denser the population, the more conducive the breeding of the Aedes aegypti mosquito vector, which can lead to an increase in dengue cases.[27]

In addition, Bandung is known as a fairly cold area. Because all areas of Bandung City have an altitude below 1,000 meters above sea level. Elevation is an important factor that can affect the presence of mosquito vectors of dengue. This factor affects the temperature and humidity of the air in a place, which will affect the development of mosquito vectors and dengue viruses. The incidence of dengue has also spread from low altitudes to more than 1000 m above sea level.[28] Additional studies conducted in Indonesia suggest that altitude plays a role in increasing the incidence of dengue.[29] Findings from Sri Lanka suggest that Aedes aegypti breeding sites are found below 1000 m above sea level, and mosquito populations in lowland areas (<500 m) are higher than those in mountainous regions (>500 m).[30]

The identification of exposure-response relationships, especially thresholds, will provide important information for the timely implementation of public health measures and risk prediction to prevent and control the disease, in particular, when the average temperature reaches 28°C, dengue fever is expected to be the highest, and when the temperature is higher, the epidemic rate is expected to decrease. Our findings prove that maximum temperature is positively correlated with dengue incidence, while minimum temperature shows a negative correlation. The maximum temperature in Bandung City from January 2021 to December 2023 was 31.0°C and the minimum temperature was 18.9°C. Only a few studies have examined temperature thresholds related to dengue, for example, one previous study based on monthly data, reported a threshold of 18.25°C in the relationship between monthly minimum temperature and dengue incidence.[31] Other studies, while not identifying a precise temperature threshold, suggest that the most appropriate maximum temperature for dengue transmission ranges from 21.6-32.9°C.[32] The mechanism underlying this may be related to mosquito breeding and survival. Higher temperatures, within a certain range, may shorten mosquito growth, incubation period and virus development rate, as well as increase infective mosquitoes, thus increasing the probability of dengue infection.[33]

In this study, other climatic factors such as average temperature, humidity, rainfall, and wind speed were not partially correlated with dengue incidence. However, they were simultaneously associated with dengue incidence. Changes in maximum and minimum temperatures were also caused by changes in other climatic factors such as humidity, rainfall, wind speed and air pressure. Temperature and rainfall are important environmental factors that affect all biological processes of Aedes aegypti. In fact, there is a mathematical expression that relates the rate of development to temperature.[34] The speed at which mosquitoes acquire and transmit viruses also depends on temperature.[35,36] Rainfall events are critical in dengue transmission.[37] The abundance of Ae. aegypti is regulated by rainfall during the water-dependent stages (egg, larva, and pupa), which provides breeding sites and stimulates egg hatching.[38,39]

Dengue is a tropical mosquito-borne infectious disease caused by an arbovirus.[40] In Bandung City, the mosquito species commonly encountered are Ae. aegypti and Ae. Albopictus. These mosquitos can survive at low temperatures, in the range of 10^0C. Its metabolism will decrease and can even stop when the temperature drops below the critical temperature of 4.5^0C. At temperatures higher than 35^0C, it also changes in the sense that physiological processes are slower, the optimum average temperature for mosquito growth is $25\text{-}30^0$C. Air temperature affects virus development in the mosquito body, biting speed, resting and mating behavior, dispersal and the length of the gonotrophic cycle.[41] Previous studies suggest that changes in temperature and humidity are significantly associated with increased incidence of dengue fever.[42]

The relationship between lower temperatures, rain, and mosquito population size is usually studied in countries with temperate climates, where excessive rain facilitates egg hatching, but lower temperatures can be fatal to larvae.[43] However, the tropical climate in Indonesia can provide sufficient temperatures for vector breeding even in winter. Therefore, the researchers suggest that winter rainfall events may have played an important role in the first mosquito generation of that year.

A larger initial population, if combined over several reproductive cycles, could lead to epidemic outbreaks in the summer [39]. Besides climatic factors, there are also several other factors that can potentially increase the incidence of dengue. The researchers believe about 69.3% of dengue incidence is caused by other factors. Some findings state that the cause of high dengue can be caused by environmental, socioeconomic, behavioural, and genetic factors, as well as demographics, which are known to determine the pattern of dengue spread.[44,45]

CONCLUSION

The spatial distribution of dengue incidence demonstrated an increase in total cases from 2021 to 2022, followed by a decrease in 2023. The spatial map of population density in 2023 revealed that one sub-district exhibited a notable increase in population density, reaching a very high level, namely Bojongloa Kaler. The spatial map of area altitude indicates that all sub-districts are situated below 1,000 metres above sea level, which is the preferred altitude of the Aedes aegypti mosquito. The results of the partial regression plot demonstrate that there is an influence of population density on the incidence of dengue, with a positive pattern. However, the altitude of the area does not appear to influence the incidence of dengue. The findings of this study demonstrate that minimum temperature exerts a significant influence on dengue incidence, exhibiting a positive pattern. Conversely, maximum temperature exerts a negative influence on dengue incidence, exhibiting a negatively patterned relationship. Therefore, it can be concluded that a decrease in maximum temperature can potentially increase the incidence of dengue. Furthermore, climatic conditions (temperature, humidity, rainfall, wind speed, and air pressure) were found to be significantly associated with dengue incidence. It is recommended that policymakers improve the implementation of epidemiological surveillance, especially in areas with the highest number of cases, and enhance early awareness of dengue, especially before entering the peak season of dengue cases.

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