International Journal of Public Health Science (IJPHS)
Vol. 13, No. 2, June 2024, pp. 715~726
ISSN: 2252-8806, DOI: 10.11591/ijphs.v13i2.23304

Dengue hemorrhagic fever prediction in coastal area using geographically weighted regression

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Article Info

Article history:

Received Apr 16, 2023
Revised Sep 26, 2023
Accepted Oct 7, 2023

Keywords:

Coastal areas
Dengue hemorrhagic fever
Geographically weighted Regression
Spatial statistics

ABSTRACT

Dengue hemorrhagic fever (DHF) is still a health problem globally, including in Indonesia. Geographical and climatic conditions in coastal areas are different from other areas, which may impact differences in environmental risk factors for dengue. This study aims to create a prediction model for the incidence of DHF in coastal areas. The research was conducted in Bantul Regency, Indonesia, involving data from 2015-2019. Dengue incidence data were collected from the health office. Climatic data were from climatology station. Data on altitude and shoreline distance were obtained by geographic information system (GIS) processing. Population density and wide settlement area are obtained from the Bureau of Statistics. The geographically weighted regression (GWR) analysis was carried out using GWR4. The results showed that GWR with a weighting of Fixed Bi-Square Kernel obtained an R2 value of 0.7768, better than the global model (R2 0.5254). It indicates that DHF (Y) in Bantul Regency is 77.68% determined by population density (X1), altitude (X2), settlement area (X3), shoreline distance (X4) and rainfall (X5) and the remaining 22.32% are influenced by other variables which are not investigated. Geographically, the predictor variables explain the DHF incidence with a strong category in the central region, and weak in coastal area.

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1. INTRODUCTION

Dengue is the fastest-growing vector-borne disease in the world. Globally, dengue fever has spread from the tropics to sub-tropics, such as in Europe [1]. The impact of dengue infection in the community can cause death, panic, and reduce life expectancy [2]. Indonesia is the country with the second-most cases among 30 endemic countries in the world. The incidence of DHF in Indonesia from year to year fluctuates with an increasing trend and expanded from one province in 1968 to 34 provinces in 2017. In 2016 Yogyakarta Province was included in the seven provinces with the largest incidence rate (IR) in Indonesia (167.9/100,000 population) [3].

Efforts to control dengue hemorrhagic fever (DHF) in Indonesia have been carried out since 1992, but the results are considered not good. The current disease control relies on environmental management as there are no antiviral drugs [4] and established vaccines [5]. In environmental management, the role of local communities is needed because community involvement is the key to a successful implementation of a program [6]. Community involvement will be successful if it involves community leaders (traditional elite) [7]. In order for community mobilization to participate in environmental management to be efficient and effective, accurate information is needed regarding the location of vulnerable areas and the factors that influence these locations. The information that is meant is a predictive model regarding the location of DHF-susceptibility and its risk factors.

The incidence of DHF is locally based on the influencing climate [8]. However, it can also be locally based on other factors, such as population, road density and socioeconomic status [9]. Prediction models that consider regional (local) variations have the advantage of being able to provide information on risk factors that affect each region specifically. It shows that geographical characteristics can affect the incidence of DHF in an area. Furthermore, it is hoped that the government can use this model to control DHF by focusing more on the dominant risk factors at the village level so that the control program can be more effective and efficient.

Bantul Regency is an endemic area of dengue fever in the Special Region Yogyakarta Province, Indonesia, which borders the Indonesian Ocean, so it has a coastal area in the south and a mainland area in the middle and north. Coastal areas have different climatic characteristics from the mainland. A study comparing climate change that occurs between the coast and the mainland shows that in the last decade it has shown that there has been less rainfall on the coast than on the mainland; coastal temperatures are higher than on land [10]. The humidity of the coastal area is lower [11], [12] than the mainland [12]. In addition to climate, there are differences in geographical and environmental conditions such as altitude, population density and land cover. The difference in geographical and climatic conditions between the coast and the mainland may have implications for the different risk factors for the incidence of DHF in the Bantul Regency.

This paper presents a predictive model for DHF-susceptible areas in Bantul Regency by considering regional variations using geographically weighted regression (GWR) with a village-scale study unit. Geographically weighted regression can predict the incidence of DHF in each village with specific risk factors for each village throughout Bantul Regency. The risk factors used as predictors are shoreline distance, altitude, population density, settlement area and climate, namely rainfall, humidity, and temperature. The modeling results can be used to predict the incidence of dengue fever in each village in Bantul Regency, along with information on risk factors that affect each village and can be applied with factual data. This study aims to obtain a DHF incidence prediction model that can be applied at the smallest Indonesia's government unit (village), so that it can be used as the basis for DHF prevention programs at the village level. Thus, it is hoped that prevention programs can be more effective and efficient.

2. METHOD

The research was conducted in Bantul Regency, Special Region Yogyakarta Province, Indonesia. This research is an analytic observational ecological research with a cross-sectional approach. The dependent variable was the incidence of DHF. The predictor variables included a distance from the beach, population density, altitude, land cover, rainfall, humidity, and temperature. The research unit was the village because the village is the smallest government unit in Indonesia, so it is hoped that the model results can be useful to support DHF control programs based on specific risk factors in a narrower area.

2.1. Variable operational definition

What is meant by the incidence of DHF is the number of cases of DHF in each village in the period 2015-2017. The diagnosis of DHF will be carried out by the local health authorities, with provisions in accordance with the 2007 ministry of health if a suspected DHF patient has an increase in hematocrit up to >20% or a haemagglutination inhibition examination (HI) positive or Immunoglobulin-G (IgG) alone or IgG and Immunoglobulin-M (IgM) positive on the rapid dengue test. The provision for suspected DHF based on WHO (1997) is if you experience symptoms of sudden high fever without cause, occurring for 2-7 days in a row, followed by symptoms of bleeding and/or thrombocytopenia (<100,000/µl). The distance to the coastline is the distance between the centroid of the village and the nearest coastline (m). Population density is the number of people per km^2. The settlement area is the area of settlement of each village (km^2). Altitude is the height at the centroid of each village (meters above sea level). Rainfall is the average annual rainfall from 2015-2017 (mm). Humidity is the average relative humidity in a year from 2015-2017 (%). Temperature is the average temperature in the year from 2015-2017 (ºC).

2.2. Data collection

Data on the incidence of DHF in 2015-2017 were obtained from the Bantul District Health Office. The distance to the coast data was obtained using the distance function in a geographic information system (GIS) from a digital map. Wide settlement data were obtained from the statistics agency (BPS) in Bantul Regency.

Altitude data was obtained by interpolating contour data (interval 0.5 m) with the triangular network terrain (TIN) method. Contour data were obtained from contour maps obtained by downloading from Inageoportal at the web address http://tanahairindonesia.go.id. The interpolation results in the form of raster data were then converted into point data, then jointed with the village centroid data to become the height attribute data for each village. The data were obtained in the form of continuous data and stored in excel form.

Population density data were obtained from Regency Bureau of Statistics. Data on average rainfall, humidity and temperature were obtained from Meteorology Climatology and Geophysics Council of Yogyakarta Province. It was carried out using the spatial interpolation method from several observation points in the Bantul area and its surroundings to obtain rainfall data for each sub-district. Data were not obtained at several observation points for humidity and temperature data, thus failing to obtain humidity and temperature data per village.

2.3. Data analysis

Spearman rank test correlation analysis was carried out on DHF risk factors to determine predictors, and the results have been published in the journal JCR 2020; 7(15): 257-266. Pre-GWR analysis, namely Morans' I spatial autocorrelation analysis, was used to determine the geographic distribution pattern of DHF incidence. The GWR analysis was used to obtain a predictive model for the incidence of DHF in each Village in Bantul Regency.

3. RESULTS AND DISCUSSION

3.1. Study areas

Bantul is part of the Yogyakarta Province, located in the southern part, bordering the southern sea. Geographically, Bantul Regency is a lowland area with an average height of 42 m above sea level (12-200 m above sea level). Bantul Regency occupies an area of 506.85 km2 (sq km) which stretches between 14º04'50" - 27º50'50" South Latitude and 110º10'41" - 110º34'40" East Longitude. According to BPS data (2021), the total population of Bantul Regency in 2020 is 985,770 (491,033 males and 494,737 females), with an average population density of 1944.89 people/km2.

Judging from the landscape, the Bantul Regency area consists of a plain area in the middle, hilly areas in the east and west, and a coastal area in the south. Administratively, Bantul Regency consists of 17 sub-districts and 75 villages, with regional boundaries as follows: in the east, it is bordered by Gunungkidul Regency, in the north by Yogyakarta City and Sleman Regency, in the west by Kulon Progo Regency, while in the south, it borders the Indonesian Ocean [13].

According to the Koppen climate classification, [14] and data in local Government, Bantul Regency has a tropical monsoon climate. The rainy season occurs between October-March and the dry season in April-September. The average rainfall is 90.76 mm, with the highest rainfall in December-February. Air temperature is relatively consistent throughout the year, with an average of 30 ºC.

There were 5,044 DHF cases from 2014-2017 in the Bantul district spreading over 27 community health centers called Puskesmas. Figure 1 shows that geographically, the incidence of dengue fever is almost every year in the central region bordering the city (north), although there is a trend extending to the south. The modeling results are presented based on the sequence of the GWR analysis process. The order includes determination of predictor variables, pre-GWR test in the form of spatial autocorrelation and GWR test.

3.2. Determination of predictor variables

The determination of predictor variables is based on the research results on the correlation between several risk factors and the incidence of DHF in Bantul Regency [15]. The risk factors that correlate with the incidence of DHF in Bantul Regency are humidity, temperature, rainfall, altitude, distance to the coastline, area of settlement and population density. The correlation test results showed that temperature, residential area, and population density were positively and strongly correlated with the incidence of DHF. Precipitation is a moderate correlation, while humidity and shoreline distance are weakly correlated with the incidence of DHF. Altitude was not significantly correlated with the incidence of DHF but showed a negative relationship.

3.3. Pre-GWR analisis analysis

Spatial autocorrelation. The results of the spatial autocorrelation analysis using Morans'I showed that the incidence of DHF in all years had a positive spatial autocorrelation, but in 2015 data, it had the highest Moran's I index value compared to other years' Moran's I index as shown in Table 1. Thus, the 2015 data was decided for modeling using GWR. Description of research variable data consisting of minimum value, maximum value, the average and standard deviation of population density (X1), altitude (X2), settlement area (X3), shoreline distance (X4), rainfall (X5) and the incidence of DHF (Y) in Bantul Regency in 2015 is shown in Table 2.

Table 2 shows that humidity and temperature data based on the geographical distribution (75 villages) in the Bantul region cannot be obtained from the planned predictor variables as they are sourced from one data (global). The average humidity in 2015 in all regions was 82.92%, and the temperature was 26.08 C. Thus, the humidity and temperature data cannot be included in the GWR modeling. It is unfortunate because humidity and temperature are correlated with the global incidence of DHF in Bantul Regency.

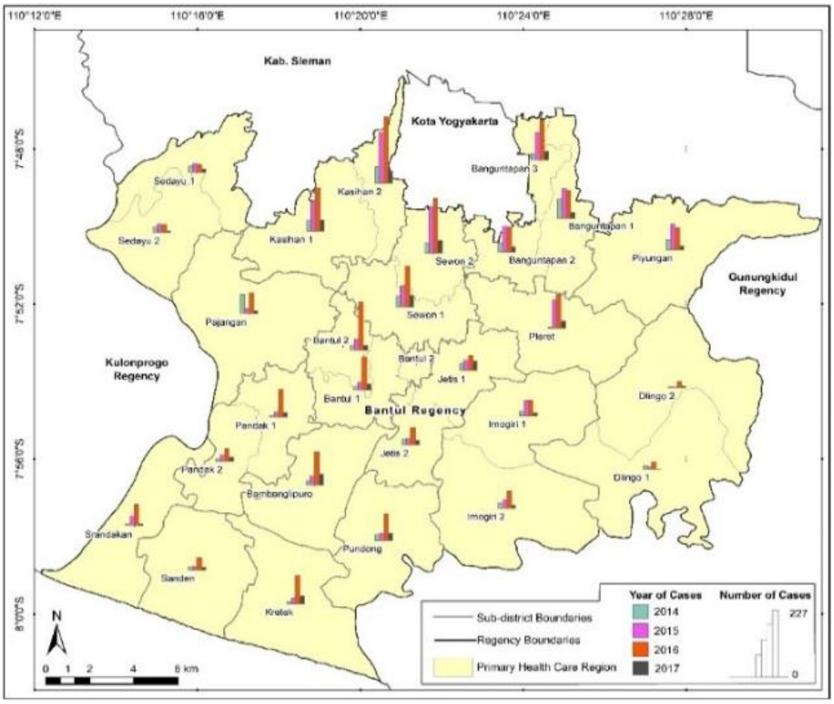

Figure 1. Distribution of DHF incidence by primary health care in Bantul Regency in 2014-2017

Table 1. Moran's, I value of spatial autocorrelation test

Year	Moran's I	Interpretation
2014	0.621	Positive spatial autocorrelation
2015	0.624	Positive spatial autocorrelation
2016	0.565	Positive spatial autocorrelation
2017	0.527	Positive spatial autocorrelation

Table 2. Descriptive statistics of research variables of DHF incidence in Bantul Regency in 2015

Variables	N (villages)	Minimum	Maximum	Mean	Std. Deviation
DHF cases	75	1.00	95.00	19.33	21.00
Population density (/km^2)	75	482.00	13,715.00	2,426.06	2,051.31
Altitude (m asl)	75	6.25	306.25	82.62	71.77
Width of settlements (km^2)	75	00.00	350.48	102.69	75.77
Shoreline distance (m)	75	1,100.00	27,559.00	14,244.61	6858.99
Humidity	75	82.92	82.92	82.92	00.00
Temperature	75	26.08	26.08	26.08	00.00
Rainfall	75	189.41	270.51	231.99	16.11

3.4. Multicollinearity test

Multicollinearity test using linear regression aims to determine whether there is a relationship among all independent variables included in the model. Suppose some data are mutually influential (collinear). In that case, the variable should be excluded from the modeling unless the variable is theoretically considered important in influencing the incidence of DHF. Decision-making is based on the value of tolerance or variance inflation factor (VIF). Tolerance values >0.10 or VIF <10.00 indicate that data multicollinearity does not occur. The results of the multicollinearity test of this research showed that all independent variables could be included in the modeling because the Tolerance value >0.10 and VIF value was <10.00 as presented in Table 3.

Table 3. Multicollinearity test for independent variables

No	Variable	Tolerance	VIF
1	Population density (X_1)	0.604	1.656
2	Altitude (X_2)	0.765	1.308
3	Settlement area (X_3)	0.769	1.301
4	Shoreline distance (X_4)	0.643	1.556
5	Rainfall (X_5)	0.869	1.151

3.5. Geographically weighted regression analysis

Model Fit Test an F test was performed in the GWR analysis to determine whether the GWR model had significance compared to global (conventional) regression analysis. If the calculated F value is greater than the F_{table} value, the GWR model is more suitable than the global (conventional) regression model. The form of the hypothesis is H_0: There is no difference between Global Regression and GWR, and H_1: There is a difference between Global Regression and GWR. The results of the model suitability test (goodness of fit) obtained a value of F_{count} 3.386, greater than F_{table} 1.99 at a significance of 0.05, so it was decided to reject H_0.

3.6. Determination of weights

The GWR analysis also determines the optimum bandwidth to select the appropriate weighting based on the value of R^2. In this test, it is known that the *Fixed Bi-Square Kernel* weighting is more suitable for weighting in GWR because the R^2 value is higher than the *Fixed Gaussian Kernel* weighting. Thus, it was decided to use a spatial modeling GWR with weighted Fixed Bi-Square Kernel. In this case, geographical factors significantly influence the incidence of DHF (Y), and the influencing factors are population density (X_1), altitude (X_2), settlement area (X_3), shoreline distance (X_4) and rainfall (X_5).

3.7. Coefficient of determination

Calculations using GWR4 for the Global model obtained an R2 value of 0.525348 or 52.54%, which means that there is an effect of 52.54% of population density (X_1), altitude (X_2), the width of settlements area (X_3), shoreline distance (X_4) and rainfall (X_5) on the incidence of DHF (Y), while other unexamined variables influenced the other 47.46%. At the same time, the calculation for the GWR model obtained an R^2 value of 0.776815 or 77.68% as shown in Table 4 (see Appendix), which means that there is an effect of 77.68% of the same variables on the incidence of DHF (Y), while other unstudied variables influenced the other 22.32%. Thus, it can be concluded that the GWR model is better than the Global model.

3.8. Regression coefficient significance test for the GWR model

The DIFF of Criterion value indicates whether the research variable has a spatial effect or not. A positive DIFF of Criterion value indicates that the research variable has no spatial effect and vice versa. In this study, the DIFF of Criterion values for each variable of density (X_1), altitude (X_2), area (X_3), distance (X_4) and rainfall (X_5) were -20.7447, 6.6622, -3.6728, - 82.2865 and -20.9857. Based on these results, information showed that only the variables of density (X_1), area of settlement (X_3), shoreline distance (X_4) and rainfall (X_5) had a spatial effect on the incidence of DHF (Y). The altitude variable (X_2) had no spatial effect on the incidence of DHF (Y). The results are similar if based on the calculated F value of each variable compared to the F_{table} value on the degrees of freedom for the F distribution (DOF for F test).

3.9. GWR regression equation at village level

Based on the GWR regression test results, the regression coefficients for each village were obtained, as shown in Table 4. The GWR regression equation for each village was compiled based on the data in Table 4. For example, the prediction of the incidence of dengue in Baturetno Village is as (1):

$$Y = 8887.61 - 3.53 (X_2) + 5.91 (X_3) + 4.51 (X_4) + 3.23 (X_5) \quad (1)$$

In (1) shows that the incidence of DHF in Baturetno Village is determined by 4 factors, namely altitude, area of settlement, shoreline distance and rainfall. In every 1 m increase in altitude, there will be a decrease in the incidence of 3.53 DHF cases. However, if other factors remain, the number of dengue cases will increase by 5.91 for every additional 1 ha of the settlement area. The number of DHF occurrences will increase by 4.51 every time the distance from the shoreline increases by 1 m if other factors remain the same. If other factors remain the same, the number of dengue cases will increase by 3.23 for every 1 mm increase in rainfall. The constant number 8887.61 indicates the number of dengue cases in Baturetno Village if the predictor variable value is 0 (zero). In fact, the incidence of DHF is determined by all the factors involved in the model, even by factors not involved in the modeling. In this model, the predictor variables involved can explain the incidence of DHF in Baturetno Village by 61%, and the remaining 39% is influenced by other factors that are not included as predictor variables. The same explanation for the equation model in other villages is based on Table 3. In Table 3, it can also be seen that several villages have the same determining factors. The similarity of the determinants of DHF incidence between villages is visualized in Figures 2(a)-(e), while Figure 2(f) shows the distribution of the determinant coefficient of GWR results by the village in Bantul Regency.

In Figures 2(a)-(e), it appears that the determinants of the incidence of DHF tend to be the same in the adjacent village area. Visually, population density affects the incidence of DHF in the central region (Capital of Regency) to the west of Bantul Regency. Altitude affects DHF in the northeast region of Bantul Regency. The width of settlements and shoreline distance have more influence on the incidence of DHF in the central region to the border of the northern part of Bantul Regency, bordering Yogyakarta City. The rainfall only affects DHF in a few areas in the northern part of the Bantul Regency, which protrudes into the western and eastern parts of Yogyakarta City.

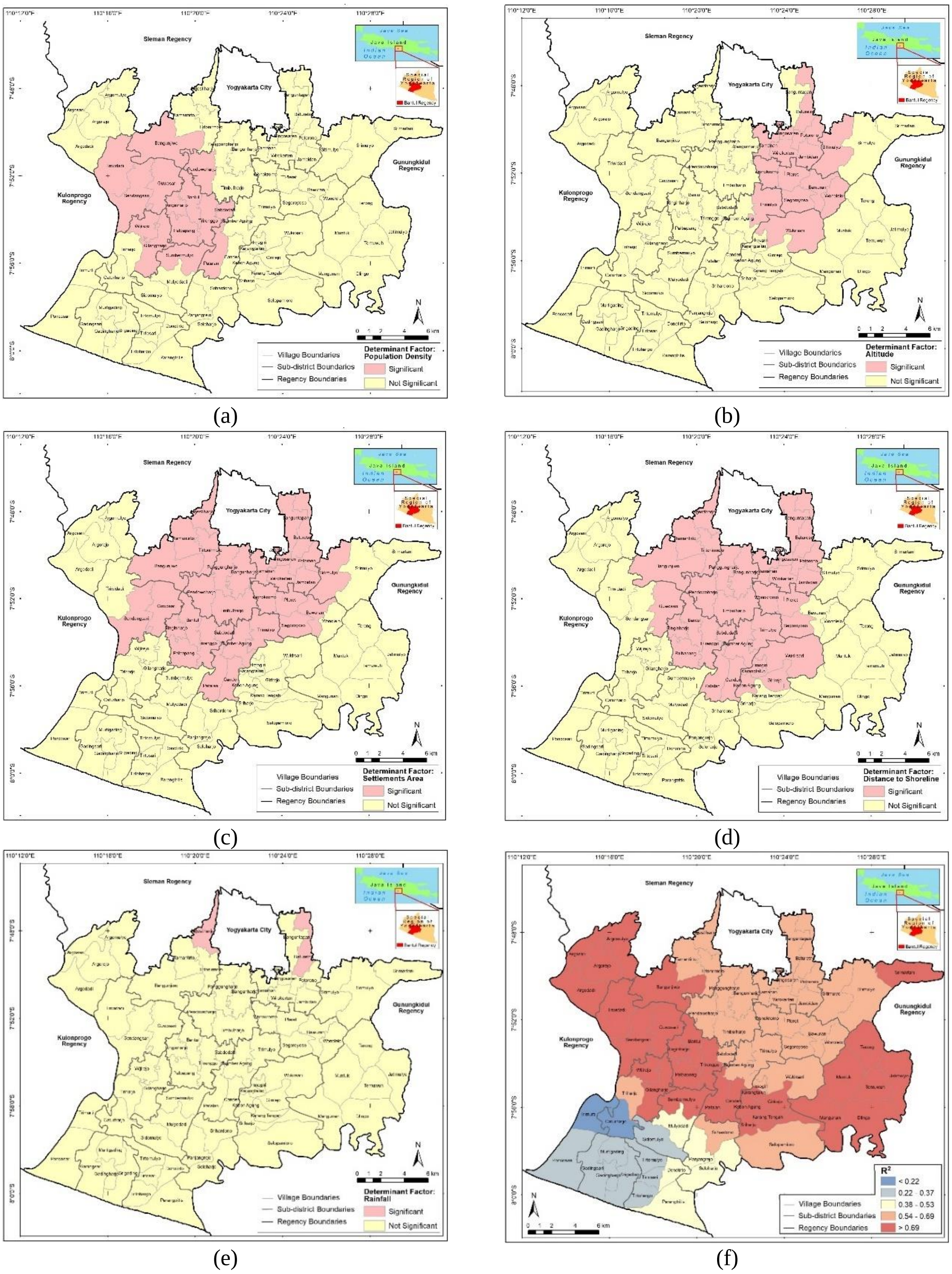

Figure 2. Determinants of DHF incidence in 2015 based on villages in Bantul Regency (a) population Density, (b) altitude, (c) settlement area, (d) distance to shoreline, (e) rainfall, and (f) regression coefficient distribution/(R^2) each village as the result of GWR modeling

Furthermore, Figure 2(f) shows that based on the value of the determinant coefficient (R^2), GWR modeling to predict the incidence of DHF at the village level in Bantul Regency shows the following results: predictor variables of population density (X_1), altitude (X_2), wide of settlement area (X_3), shoreline distance (X_4) and rainfall (X_5) can explain >69.00% (R^2 0.69) the incidence of DHF in several villages located in the center, stretching from West to East, can explain 54-69% (R^2 0.54-0.69) DHF incidence in most villages in the central and northern parts of Bantul Regency and only <37% (R^2<0.37) the incidence of DHF in areas bordering the coastline.

3.10. The distribution of dengue fever in Bantul Regency in 2014-2017

The incidence of DHF from 2014-2017 in Bantul Regency was mostly in the north-central region bordering the city of Yogyakarta, and there was a tendency to spread to the southern region. The area of the Bantul Regency which borders the city is called the rur-ban area (rural-urban). According to Brontowiyono and Lupiyanto [16], a rur-ban can be affected by the character of the city both physically and non-physically. Physically, the area develops into densely populated settlements, while non-physical changes lead to individualism in society. The location of border areas far from the center of government can escape the government's attention, although development in all sectors, including the economy and health, aims to improve people's welfare [17].

The development of border areas lacking attention can lead to social and health problems, including dengue fever. The occurrence of DHF involves environmental factors, human behavior (host) and the presence of *Aedes mosquitoes* (vector). The denser settlements in the border areas of the city, if not followed by good regional planning, will lead to a conducive environment for dengue transmission.

Settlements density will increase the possibility of dengue transmission through: i) Transmission is more efficient because vector mosquitoes suck blood intermittently. Prior to being full of blood, *Aedes mosquitoes* can suck the blood of more than one person so that the possibility of people who will be infected through mosquito bites will increase [18]. In addition, dense settlements cause the distance between houses to be narrow so that it is in accordance with the short flight ability of the *Aedes mosquito* (an average of 83.4 m); [19] ii) Dense settlements will create ideal conditions for vector mosquito life. Dense settlements that are not followed by the availability of sufficient clean water and good sanitation will cause many people to collect clean water for their daily needs using containers such as water tanks, buckets, and barrels, which are usually not tightly closed. Stagnant clear water will become a breeding place for *Aedes*, so the number of water reservoirs will increase the breeding place for vector mosquitoes. In addition, dense settlements will cause less lighting, less air circulation in the house and high humidity because there is not enough space for windows. These conditions will cause the *Aedes mosquito* to survive. The *Aedes aegypti* prefers dark, damp places close to its breeding sites inside the houses [20].

A tendency for dengue fever to spread to the south of Bantul Regency needs careful thought, possibly related to the development of tourism potential in the area. The tourism development of Bantul Regency is focused on three clusters, namely the south coast cluster, the Kasongan-Tembi-Wukirsari cluster and the urban cluster. The south coast cluster is concentrated on developing tourism potential along the southern coast of Bantul Regency, namely in the Gumuk Pasir area, Aerospace area and southern cross road [21]. In general, the facilities developed to meet the needs of beach tourism include clean water facilities, various festivals, and various types of arts [22] and shade trees [11].

Research on the relationship between climate and the incidence of DHF in urban-coastal areas has been carried out in Chao-Shan, China, showing that the average daily temperature affected the incidence of DHF, with the temperature most at risk of transmission being 25 ºC [23]. The influence of temperature on the incidence of DHF through changes in the mechanism of vectors and viruses [24], accelerating the virus incubation in mosquitoes [25] and human exposure to mosquitoes [23]. This statement is supported by the results of a laboratory study by Goindin *et al.* [26], that a temperature of 27°C allowed female *Aedes* to develop a gonotrophic cycle, increasing the frequency of blood-feeding so that more contact with humans. Another climatic factor that affects the life of *Aedes* is humidity. Air humidity in coastal areas tends to be lower (about 62%) than in areas further from the coast [12]. Low humidity does not support the development of *Aedes mosquitoes* development because *Aedes aegypti* lives optimally at 80% humidity and will reduce the fertility of mosquito eggs at 60% of humidity [27]. There are no data on temperature and humidity in the coastal area of Bantul Regency, but it is estimated that the construction of tourism facilities will make the environment comfortable and suitable for *Aedes* life, such as cooler ambient temperatures, increased humidity, and lots of shady places. Thus, it needs to be investigated further.

Risk factors for dengue fever as predictor. The risk factors for the incidence of DHF in Bantul Regency based on the results of previous studies are the width of settlement, temperature, population density (strong influence), rainfall (moderate effect), humidity and shoreline distance (weak effect) [15]. The altitude variable does not affect the incidence of DHF in Bantul Regency, but it appears to have a negative relationship.

The predictor variables in GWR modeling include settlement area, population density, rainfall, shoreline distance, and altitude decided based on its effect on the incidence of DHF in Bantul. Humidity and temperature cannot be used as predictors in the GWR analysis because temperature and humidity data for each village are not available. Although globally, the altitude variable does not affect the incidence of DHF in Bantul Regency, the research results in a neighboring area (Sleman Regency) [28] show that altitude plays a role in the incidence of DHF, so altitude is still included in the GWR modeling in Bantul Regency.

Geographically weighted regression results. The results of the GWR analysis are in the form of a formula for predicting the incidence of DHF based on risk factors that influence each village so that the prediction formula differs from village to village. However, geographically, it appears that the determinants of the incidence of DHF between adjacent villages tend to be the same. In Bantul Regency, geographically, dengue-endemic areas can be grouped based on the determinants of population density, area of settlement, shoreline distance, rainfall, and altitude.

The incidence of DHF in the central region (Bantul City) to the west of Bantul Regency is influenced by population density. The area includes the capital of the Bantul Regency and the development area of Bantul City. According to the Bantul Regency Regulation number 4 2011, the western part of Bantul is projected for the Bantul City Mandiri area, so development in the area is very rapid, both for settlements and trade and education. The development of settlements will cause an environment suitable for the breeding of Aedes mosquitoes to increase, especially if adequate clean water facilities do not follow it. Intermittent water supply and water shortage during drought increase the risk of dengue transmission [29].

The condition will get worse if the community is not educated enough about environmental management to prevent DHF. According to Sutriyawan *et al.* [30], the most dominant epidemiological determinant of the incidence of DHF is mosquito larvae. People who live in homes where there are mosquito larvae have a 4.1-fold chance of contracting dengue. It shows that public education about dengue prevention through environmental management is very important. In addition to public education, financial development with administrative effectiveness and avoiding corruption are important in creating a quality environment [31].

The area where the incidence of dengue fever is affected by population density coincides with the area where the incidence of dengue fever is affected by the area of settlement, namely in the central part of Bantul (Bantul City) to the north, which borders the city of Yogyakarta. The border area with the city of Yogyakarta is a suburban area that has the characteristics of very fast physical growth but has received less attention from the government due to its location far from the center of government, causing the emergence of slum settlements. Slum and dense settlements will cause high dengue transmission. It happens because the distance between houses that are close to a high population causes the transmission of DHF to be more efficient. The nature of the *Aedes mosquito* that sucks blood several times with different hosts before being full of blood (interrupted feeding) [18] and the short flight distance (average 83.4 m) [19] support efficiency transmission in slums and densely populated areas.

Furthermore, the distance to the beach affects the incidence of DHF in the central to the northern region. According to Said and Sudradjat [32], the coastal wind blows towards the mainland during the day (14.00-18.00 pm) with a speed of 2.5-3.5 m/s within a range of 50 km. The furthest distance from the beach in the Bantul Regency area is 27,559 km, so the entire Bantul Regency area is included in the range of the coastal winds. Suppose it is related to the time of sucking the blood of Aedes mosquitoes which are active in the morning and afternoon at 14.00-16.00 pm. In that case, mosquitoes that are actively looking for prey may also be moved by the coastal winds to the north. More Aedes mosquitoes suck blood in the northern part of the Bantul district, supported by suitable environmental conditions for dengue transmission. Thus, it needs to be further proven.

Altitude globally does not significantly affect the incidence of DHF in Bantul Regency, but with GWR, it appears that altitude affects the incidence of DHF in some areas in Bantul Regency, namely in some areas with an altitude of 50-125 meters above sea level, in a negative direction. The higher the plateau is, the lower the incidence of dengue fever will be. At an altitude of 50-125 m asl, the incidence of dengue fever may not be affected by temperature because, according to Purwantara [33], a decrease in temperature of 0.6 ºC occurs for every 100 m asl increase in altitude from 26.3 ºC at 0 m asl. Thus, at an altitude of 50-125 meters above sea level, the environmental temperature is estimated to be the same as the temperature conditions in lower areas, and it is still in a good temperature range for vector mosquito life and even has high viability [34]. The effect of altitude in this area is probably because, in higher areas, the water flows well so that there is no puddle which becomes a breeding place for Aedes. Although the reason has not been explained, many studies show the same symptom, namely altitude, which shows a negative but less significant correlation. The exception is if the research is conducted in an area that has a significant variation in altitude, the role of altitude will also be significant for the incidence of DHF, for example, in Sleman Regency, Indonesia [28], America [35], and Nepal [36].

The rainfall variable only affects the incidence of DHF in a few areas in the northern part of the Bantul Regency, namely in the area that protrudes into the western and eastern parts of Yogyakarta City as shown in Figure 2(e). It is probably because the area has the same risk factors as the city of Yogyakarta. According to Vicente *et al* [37] the same risk factors can influence the incidence of disease in adjacent areas. It shows that the influence of risk factors on the incidence of DHF does not recognize administrative boundaries but according to geographical conditions.

Rainfall did not affect the incidence of DHF in the southern part of the Bantul Regency, possibly because the rain in the coastal areas will soon dry up due to high wind speeds and relatively higher coastal temperatures. Further, research in Guangzhou, China, has proven that wind speed is associated with a decrease in the incidence of DHF due to a decrease in the number of mosquito populations and the ability to fly [38]. Thus, further research is needed on the effect of wind speed on the incidence of dengue fever in the Bantul Regency.

Figure 2(f) shows that based on the value of the determinant coefficient (R^2), GWR modeling to predict the incidence of DHF at the village level in Bantul Regency can explain >69.00% (R^2 0.69) of the incidence of DHF in several villages located in the center, stretching from West to East (strong contribution), 54-69% (R^2 0.54-0.69) of DHF incidence in most villages in the central and northern parts of Bantul Regency (moderate contribution) and <37% (R2 <0.37) of the incidence of DHF in areas bordering the coastline (weak contribution). The moderate predictive power in the northern region of Bantul might be due to the influence of the condition of the city of Yogyakarta, considering that the northern region is a border with urban areas. The influence of urban conditions in the city's border areas is likely to be community behavior [39]–[41], socio-economic conditions [42] which are different from the Bantul community in general, thus reducing the power of the GWR modeling predictions. The predictive power in the southern region of Bantul Regency is weak, possibly because the incidence of DHF in coastal areas is heavily influenced by temperature and humidity factors. Meanwhile, these two climatic factors cannot be involved in modeling due to the unavailability of data variations by location. Thus, it needs to be further proven.

4. CONCLUSION

GWR modeling with Fixed Bi Kernel weighting of DHF incidence in Bantul Regency with predictors of population density, settlement area, altitude, rainfall, and shoreline distance proved that adjacent areas tend to have the same risk factors. Geographically, the central region to the north is influenced by population density, residential area, and distance from the coast. The northeast region is affected by altitude. The model was produced to indicate a strong prediction model to forecast the incidence of DHF in the central region stretching from west to east, moderate in the central region to the north and weak in the coastal area of Bantul Regency.

ACKNOWLEDGEMENTS

The authors would like to thank the staff of the Yogyakarta Climate Station, Regency Health Office, and Regency Statistics Bureau for their assistance in offering data related to this study. This work was supported by grants from the Institute for Research Development and Community Service (LP3M) Universitas Muhammadiyah Yogyakarta by the number of 034/PEN-LP3M/I/2020.

APPENDIX

Table 4. GWR regression coefficient by village

No	Village	Intercept	*t*_ Pop-Dens	*t*_ Altitude	*t*_ Settlements	*t*_ Shore-Dis	*t*_ Rainfall	Local R^2
1	Mulyodadi	2.29	0.78	0.01	0.38	0.83	-0.14	0.51
2	Sidomulyo	-6.57	0.76	0.16	0.24	0.30	0.18	0.32
3	Sumbermulyo	16.32	**2.73**	0.29	1.44	1.51	-1.20	0.72
4	Baturetno	-887.61	-0.46	**-3.53**	**5.91**	**4.51**	**3.23**	0.61
5	Potorono	-354.88	0.09	**-4.39**	**4.94**	**3.67**	1.66	0.63
6	Jambidan	-33.44	0.64	**-4.54**	**4.17**	**2.89**	-0.12	0.65
7	Tamanan	-129.75	0.81	**-3.47**	**5.07**	**5.02**	0.91	0.63
8	Wirokerten	-107.71	0.73	**-4.29**	**5.09**	**4.43**	0.62	0.64
9	Singosaren	-250.45	0.43	**-3.93**	**5.54**	**4.83**	1.73	0.62
10	Jagalan	-312.09	0.35	**-3.61**	**5.64**	**4.95**	2.10	0.61
11	Banguntapan	-1535.33	-0.67	-1.36	**6.61**	**5.22**	4.39	0.59
12	Palbapang	21.12	**4.50**	0.44	**2.62**	**2.40**	-1.81	0.73
13	Trirenggo	15.85	**3.33**	-0.80	**3.18**	**4.93**	-1.62	0.71
14	Bantul	4.15	**4.26**	-0.66	**3.30**	**4.89**	-1.27	0.72
15	Ringinharjo	12.23	**5.47**	0.00	**2.99**	**3.38**	-1.56	0.73
16	Sabdodadi	2.06	**2.36**	-1.78	**3.66**	**5.93**	-1.17	0.69

Table 4. GWR regression coefficient by village (*continue*)

No	Village	Intercept	*t*_ Pop-Dens	*t*_ Altitude	*t*_ Settlements	*t*_ Shore-Dis	*t*_ Rainfall	Local R^2
17	Dlingo	97.05	0.96	-0.24	-0.53	-0.39	-0.78	0.75
18	Temuwuh	147.26	1.25	-0.32	-0.74	-0.40	-1.35	0.83
19	Mangunan	41.44	0.69	-0.78	-0.21	0.48	-0.72	0.77
20	Terong	194.19	0.53	-1.56	-0.56	-0.27	-1.50	0.72
21	Jatimulyo	167.41	1.40	-0.09	-0.69	-0.43	-1.13	0.85
22	Muntuk	115.82	0.81	-1.29	-0.59	-0.05	-1.19	0.76
23	Wukirsari	24.27	1.31	**-2.42**	1.28	**2.79**	-0.88	0.69
24	Girirejo	16.28	1.48	-1.31	0.90	**2.48**	-0.84	0.72
25	Karangtalun	16.10	1.95	-1.37	1.59	**3.42**	-1.16	0.71
26	Imogiri	13.67	1.85	-1.90	1.87	**3.89**	-1.08	0.69
27	Kebon Agung	17.54	1.79	-0.69	1.26	**2.70**	-1.18	0.72
28	Karang Tengah	15.13	1.18	-0.81	0.75	2.13	-0.82	0.73
29	Sriharjo	14.12	0.83	-0.73	0.52	1.84	-0.66	0.73
30	Selopamioro	7.25	0.36	-0.60	0.14	0.93	-0.14	0.67
31	Trimulyo	-9.22	1.46	**-3.24**	**3.57**	**5.55**	-0.63	0.67
32	Sumber Agung	7.60	2.03	-2.12	**3.16**	**5.41**	-1.21	0.69
33	Patalan	20.36	**2.77**	-0.07	1.82	**2.69**	-1.53	0.73
34	Canden	19.33	2.07	-0.38	1.46	**2.69**	-1.35	0.72
35	Bangunjiwo	-129.43	**4.12**	-0.24	**2.36**	**3.66**	1.26	0.70
36	Tamantirto	-299.10	2.03	0.17	**2.46**	**5.30**	2.84	0.65
37	Tirtonirmolo	-170.22	1.58	-0.71	**3.32**	**5.60**	1.78	0.64
38	Ngestiharjo	-661.85	0.49	1.46	**3.27**	**6.26**	**4.72**	0.56
39	Tirtohargo	-13.16	0.13	0.18	0.11	0.24	0.25	0.34
40	Parangtritis	1.74	-0.03	0.05	0.05	0.39	0.01	0.40
41	Donotirto	0.95	0.18	0.06	0.11	0.52	0.01	0.38
42	Tirtosari	-8.40	0.24	0.18	0.13	0.23	0.19	0.35
43	Tirtomulyo	-10.15	0.50	0.21	0.19	0.17	0.25	0.29
44	Triwidadi	-2.65	**5.69**	0.71	1.78	0.53	-0.37	0.74
45	Sendangsari	12.84	**6.03**	0.80	**2.30**	0.36	-1.09	0.74
46	Guwosari	-1.93	**5.96**	-0.20	**2.84**	**2.77**	-1.00	0.73
47	Wijirejo	23.35	**4.71**	0.76	2.17	1.10	-1.70	0.73
48	Gilangharjo	16.41	**3.22**	0.41	1.66	1.12	-1.20	0.71
49	Triharjo	3.76	1.38	0.06	1.03	0.56	-0.28	0.54
50	Caturharjo	-19.52	0.86	0.28	0.24	-0.12	0.39	0.15
51	Sitimulyo	-25.49	0.36	**-3.70**	**2.88**	1.78	-0.11	0.65
52	Srimulyo	1.47	0.20	-2.04	0.72	1.20	-0.17	0.68
53	Srimartani	-133.18	0.07	-0.58	-1.18	1.17	0.36	0.72
54	Wonokromo	-52.69	1.12	**-3.87**	**4.67**	**5.35**	0.12	0.66
55	Pleret	-6.67	0.95	**-4.35**	**4.04**	**4.02**	-0.49	0.66
56	Segoroyoso	13.02	1.08	**-3.69**	**2.72**	**3.43**	-0.69	0.67
57	Bawuran	95.54	0.81	**-3.85**	**2.33**	1.60	-1.34	0.67
58	Wonolelo	125.63	0.78	**-2.99**	0.99	0.72	-1.45	0.69
59	Seloharjo	8.31	0.07	-0.11	0.10	0.83	-0.20	0.48
60	Panjangrejo	6.48	0.26	-0.09	0.18	0.98	-0.20	0.49
61	Srihardono	12.03	0.39	-0.26	0.34	1.46	-0.49	0.63
62	Gadingsari	-29.38	0.38	0.18	0.31	-0.07	0.44	0.28
63	Gadingharjo	-23.85	0.33	0.22	0.23	0.02	0.39	0.29
64	Srigading	-18.83	0.27	0.23	0.17	0.11	0.33	0.31
65	Murtigading	-23.21	0.56	0.28	0.25	-0.09	0.41	0.25
66	Argomulyo	-334.59	1.70	0.09	0.81	0.94	1.06	0.75
67	Argosari	-253.97	1.15	-0.32	0.80	0.37	0.56	0.76
68	Argorejo	-240.27	2.11	0.06	1.03	0.97	0.80	0.76
69	Argodadi	-107.96	1.81	-0.07	1.42	0.85	0.42	0.72
70	Timbulharjo	-36.06	1.76	-2.51	**4.29**	**6.26**	-0.20	0.68
71	Pendowoharjo	-50.02	**2.84**	-1.35	**3.58**	**5.72**	0.11	0.69
72	Bangunharjo	-101.00	1.15	-2.62	**4.56**	**5.52**	0.73	0.64
73	Panggungharjo	-108.22	1.42	-1.76	**4.02**	**5.70**	0.92	0.65
74	Poncosari	-36.80	0.39	0.00	0.40	-0.16	0.50	0.26
75	Trimurti	-22.32	0.74	0.15	0.23	-0.11	0.40	0.06

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