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THE MODELLING OF EARTHQUAKE MAGNITUDE IN THE SOUTHERN PART OF JAVA ISLAND USING GEOGRAPHICALLY WEIGHTED REGRESSION

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Abstract: One of the aspect of the Sustainable Development Goals (SDGs) is to build the sustainable cities and communities, making cities inclusive, safe, strong and sustainable. One form of sustainable development, that is a good city, apart from a green city, is development that is alert and responsive to disasters. Earthquakes are one of the natural disasters that often occur in Indonesia and cause many casualties. The purpose of this study is to obtain an overview of the earthquake magnitude and the factors that influence it in the southern part of Java Island using Geographically Weighted Regression (GWR). The data used is earthquake magnitude and depth which obtained from the Indonesian Meteorology, Climatology and Geophysics Agency (BMKG) website. The data is the earthquake that occurred in the southern part of Java Island in 2019-2021. The modelling of earthquake magnitude in southern Java Island using GWR based on the best weighted of Adaptive Bisquare Kernel produced a R^2 value of 98.96% and an MSE of 0.002 and an optimal bandwidth of 4. The results of this analysis can be used as a reference in making disaster mitigation solutions and in determining the location of airports and ports in an area.

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1. INTRODUCTION

According to the National Development Planning Agency (Bappenas), the Sustainable Development Goals (SDGs) is an agenda to realize the benefit of a decent life in the world. One of these aspects is the 11th aspect which states that building the sustainable cities and communities, makes cities inclusive, safe, strong and sustainable. One form of sustainable development, that is a good city, apart from a green city, is a construction that is alert and responsive to disasters.

Indonesia is located at the convergence of three of the world's main plates, namely the Eurasian, Indo-Australian, and Pacific Plates so that Indonesia is known as the Ring of Fire region [1, 2]. Therefore, earthquakes and volcanic eruptions often occur in Indonesia. Earthquakes that happened in Indonesia have different magnitudes. The magnitude of the earthquake carries information about the strength of the earthquake based on the energy which felt on the earth's surface, while the depth of the earthquake is the basis for classifying the type of earthquake. Earthquakes are divided into three types based on their depth, that are deep, medium, and shallow earthquakes. Based on this, this study used the depth of the earthquake as the factor that affects the magnitude of the earthquake.

The earthquake magnitude was modeled using spatial regression analysis. Spatial regression analysis is the development of a simple regression model in order to obtain the observed information that is influenced by the effect of space or location. The characteristic of spatial modeling is the existence of a weighted matrix which is a marker of the relationship between one region and another [3]. The regression model used in this study is Geographically Weighted Regression (GWR). GWR is a modeling technique which designed to address the spatial non-stationarity, for example, the mean value varied by location [4]. GWR is able to model the spatial variation in the relation between the dependent and independent variables.

Several studies related to earthquakes have been carried out using several methods. Sofyan et al. [5] conducted a spatial autocorrelation analysis of the earthquake magnitude in Aceh. Sofyan et al. [5] concluded that there is a spatial autocorrelation of the earthquake that occurred in Aceh. Then, Cheng et al. [6] investigated the relation between heat flow and the earthquake seismicity in the global tectonic active zone based on the geographic detector method. Cheng et al. [6] concluded that the heat flow and the seismicity of an earthquake are inversely proportional when the heat flow is below 84 mW/m^2, and directly proportional when the heat flow is above this figure. These two studies did not examine the relation between magnitude and depth of earthquakes, especially in the southern part of Java Island. In fact, there are implications for megathrust earthquakes and tsunamis from seismic gaps in the southern part of Java Island [7]. Thus, this study analyzes the spatial relationship between earthquake magnitude and depth in the southern part of Java Island.

Researchers used the GWR method in this study. The study which used the GWR method has been carried out in several natural disasters. Hong et al. [8] examined the factors that influence the movement of landslides in Xing Guo, China using several methods such as GWR, Support Vector Machine (SVM), and Logistic regression. The result of this study indicated that the GWR method has the best performance compared to other methods. Purwaningsih et al. [9] also modelled the flood cases in Central Java using GWR with 4 significant factors, namely rainfall, rainy days, humidity and rainy area.

This study analysed the influence of the caused factors of earthquakes, that is the depth of the earthquake on the magnitude of earthquakes in Indonesia based on the results of the GWR analysis. These results become the basis for determining the mitigation solutions for fishermen regarding the depth of the sea that is prone to earthquakes. In addition, so far, there has been no research that discussed the analysis of the factor which is causing the magnitude of the earthquake using GWR. Thus, these two things are the novelty (state of the art) of this study.

2. PRELIMINARIES

2.1 Earthquake Magnitude

Earthquake magnitude is a measure of the size, or amplitude, of the seismic waves generated by an earthquake source and recorded by seismographs. It is necessary for purposes of comparison to compress the range of wave amplitudes measured on seismograms by means of a mathematical device because the size of earthquakes varies enormously. It has long been observed that the relationship between the frequency and the magnitude of seismic events in a given region follows the power law [10]. In other words, when observing earthquake occurrences over time we expect the earthquakes of small magnitude to be much more frequent than the earthquakes of large magnitude.

2.2 Earthquake Depth

The depths of earthquakes, and the width of the band, depend on the type of plate boundary. Mid-ocean ridges and transform margins have shallow earthquakes (usually less than 30 km deep), in narrow bands close to plate margins. Subduction zones have earthquakes at a range of depths, including some more than 700 km deep [11].

2.3 Spatial Data Analysis

Spatial data analysis refers to a set of techniques designed to find pattern, detect anomalies, or test hypotheses and theories, based on spatial data. More rigorously, a technique of analysis is spatial if and only if its results are not invariant under relocation of the objects of analysis, in other words, location matters. The data that are subjected to spatial data analysis must record the locations of phenomena within some space, and very often that is the space of the Earth's surface and near-surface, in other words the geographic domain [12].

2.4 Geographically Weighted Regression (GWR)

Geographically Weighted Regression (GWR) method is a technique used in spatial regression model that takes the framework of a simple regression model by weighted regression. Each parameter value is estimated for each point of the geographical location. So, every point geographic location has different values of regression parameters. If the values of regression parameters are constant in each geographic region, the GWR models are called as global models. It means that each geographical region has the same model [13].

3. MAIN RESULTS

Based on Table 1 below, the earthquake that occurred in the southern part of Java Island had an average magnitude of 5.6629 on the Richter scale and a depth of 62.3 kilometers. The earthquake with the highest magnitude occurred in the Indian Ocean, located near Sempu Island, Malang, East Java which was 6.05 on the Richter scale. While the earthquake with the lowest magnitude and depth occurred in the Indian Ocean, which is located near Banyuwangi, East Java, which was 5.53 on the Richter scale and 10 kilometers.

Variables	Mean	Standard Deviation	Median	Minimum	Maximum
Y	5.6629	0.1781	5.62	5.53	6.05
X_1	62.3	68.1	37.4	10	201.9

TABLE 1. The Descriptive Statistics of Response and Predictor Variables

Regression analysis was conducted to determine the causal relationship between predictor variables and response variables. Meanwhile, spatial regression analysis studies the relationship between predictor variables and response variables by involving the spatial or location effects [3]. Spatial effect is a phenomenon which observations that conducted at a location have a strong dependence on observations that conducted at a nearby location. Spatial effects are divided into two that are spatial dependence and spatial heterogeneity [3].

Furthermore, the spatial dependency test was carried out to see whether the observations at a location have an effect on the observations at other locations that are close by. The calculation of the spatial dependence assumption using Moran's I method obtained the P-value of 0.03708 which is less than the α value of 5%. Therefore, it is concluded that there is a spatial dependence in the data. It means that the earthquake magnitude data in the southern part of Java Island has met the assumption of the spatial dependency test.

Meanwhile, the spatial heterogeneity test was conducted to determine whether there are difference characteristics at each of observation location. If there is a spatial heterogeneity in the data, the model will produce different regression parameters at each of observation location. The calculation of spatial heterogeneity using the Breusch-Pagan test which obtained the P-value of 0.0134 which is less than the α value of 5%. Thus, it is concluded that there is a spatial heterogeneity in the data. It means that the earthquake magnitude data in the southern part of Java Island has met the assumption of the spatial heterogeneity test.

Furthermore, the modelling using Geographically Weighted Regression (GWR) by determining the best weighted first was conducted. The determination of the best weighted was done by selecting the weights that have the smallest AIC value. The following Table 2 presents the AIC, R^2 and MSE values of each weight.

Type of Weight	**AIC**	$\boldsymbol{R^2}$	**MSE**
Fixed Gaussian Kernel	0.147260	0.109685	0.036
Adaptive Gaussian Kernel	-0.076541	0.158633	0.035
Adaptive Bisquare Kernel	-24.012764	0.989584	0.002

TABLE 2. AIC, R^2 and MSE values of each weight

Table 2 shows that the Adaptive Bisquare Kernel weight has the smallest AIC value of -24.012764 with the highest R^2 value of 98.96% and the smallest MSE of 0.002. Thus, the best weighted that will be used for the GWR model in this study is the Adaptive Bisquare Kernel weight. The Adaptive Bisquare Kernel function has a minimum CV value of 0.113 which obtained the optimal bandwidth value of 4.

Furthermore, the model suitability test was carried out to see whether the GWR model which produced was accordance with the earthquake magnitude data in the southern part of Java Island. The model suitability test obtained the F value of $21.498830 > F_{(0.05,\ 4.021,\ 0.979)}$ value of 21.0027 so that it is concluded that the obtained GWR regression model is suitable for the earthquake magnitude data in the southern part of Java Island.

The next stage is to conduct the partial significance test on the parameters at each location. The statistic test which used to obtain that the predictor variable significantly affects the response variable with α value of 10% is the T test. The criterion test which used is to reject H_0 if $|T_{ki}| > t_{(0.05,0.979)} = 6.548318$. Table 3 below shows the grouping of predictor variables that have a significant effect on the response variable at each location.

Locations	**Significantly Affected by The Predictor Variable**
Indian Ocean (near Kalapagenep, Cikalong, Tasikmalaya, West Java), Indian Ocean (near Kesilir, Seloagung Village, Siliragung, Banyuwangi, East Java), Indian Ocean (near Karanganjar, Sindangkerta, Cipatujah, Tasikmalaya, West Java), Indian Ocean (near Gradjagan, Sumberjati, Grajagan, Purwoharjo, Banyuwangi, East Java) and Majenang, Cilacap. Central Java	No
Indian Ocean (near Sempu Island, Hutan, Tambakrejo, Sumbermanjing, Malang, East Java) and Indian Ocean (near Kondang Merak Beach, Sumberbening, Bantur, Malang, East Java)	Yes

TABLE 3. The Grouping Location Based on The Significantly Affected Predictor Variable

Based on Table 3, the estimated GWR model for each location was obtained. Meanwhile, the estimated of magnitude earthquake model using GWR approach in each location is presented in Table 4 below.

Locations	GWR Model
Indian Ocean (near Sempu Island, Hutan, Tambakrejo, Sumbermanjing, Malang, East Java)	$\hat{y} = 5.430673 + 0.007011X_1$ (It means that the spatial effect affects the relationship between predictor and response variables in this model with the R^2 value of 98.96%)
Indian Ocean (near Kalapagenep, Cikalong, Tasikmalaya, West Java)	$\hat{y} = 5.559793$ (It is concluded that the model is constant which means the spatial effect did not affect the relationship between predictor and response variables)
Indian Ocean (near Kesilir, Seloagung Village, Siliragung, Banyuwangi, East Java)	$\hat{y} = 5.460228$ (It is concluded that the model is constant which means the spatial effect did not affect the relationship between predictor and response variables)
Indian Ocean (near Karanganjar, Sindangkerta, Cipatujah, Tasikmalaya, West Java)	$\hat{y} = 5.540784$ (It is concluded that the model is constant which means the spatial effect did not affect the relationship between predictor and response variables)
Indian Ocean (near Gradjagan, Sumberjati, Grajagan, Purwoharjo, Banyuwangi, East Java)	$\hat{y} = 5.535091$ (It is concluded that the model is constant which means the spatial effect did not affect the relationship between predictor and response variables)
Majenang, Cilacap. Central Java	$\hat{y} = 5.527225$ (It is concluded that the model is constant which means the spatial effect did not affect the relationship between predictor and response variables)
Indian Ocean (near Kondang Merak Beach, Sumberbening, Bantur, Malang, East Java)	$\hat{y} = 5.428609 + 0.007069X_1$ (It means that the spatial effect affects the relationship between predictor and response variables in this model with the R^2 value of 98.96%)

TABLE 4. Estimated Model of Earthquake Magnitude in The Southern Part of Java Island Using GWR Approach for Each Location

This analysis can be used as a reference to make the earthquake disaster mitigation solutions, especially in coastal areas. It is because the earthquakes that often occurred were located at sea based on the obtained data. Therefore, the results of the GWR analysis can also be used as a reference to determine the location of ports and airports in an area considering that an earthquake which occurs at sea and has a shallow depth will cause a great damage [14]. This is also evidenced by the analysis results which show that the magnitude is directly proportional to the depth of the earthquake.

CONFLICT OF INTERESTS

The author(s) declare that there is no conflict of interests.

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