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Analysis of The Causes of Flooding in Samarinda City Using Spatial Statistics: Geographically Weighted Regression

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Abstract. This study discusses the analysis of the causes of flooding in Samarinda City using geographically weighted regression (GWR) method of spatial statistics. Samarinda City has an area that is prone to flooding. Floods in Samarinda City occur due to excess surface runoff and not being accommodated in the Mahakam watersheds so that water overflows. The factors that cause flooding in Samarinda City are natural factors such as high rainfall, the topography of the area, and the tides of the Mahakam watersheds. The second factor is humans, mainly due to the element of population growth followed by an increase in the need for infrastructure, housing, clean water facilities, education, and other community services. The results of spatial statistical analysis obtained that the best model was the GWR model with R^2 of 0.92 and MSE value of 0.202. Based on these results, the concept of flood control in Samarinda City was divided into three parts, namely flood control in the upstream, middle and downstream areas. The upstream flood control concept could be implemented by repairing damaged watersheds conditions and increasing watersheds resistance. The concept of flood control in the middle area could be implemented by reducing flooding and reducing surface runoff. Meanwhile, the concept of flood control in the downstream area could be implemented by facilitating the flow of existing drainage done by increasing the capacity of the drainage channel water and protecting the flow in the channel from the influence of the tide of the Mahakam River.

INTRODUCTION

Samarinda as the capital of East Kalimantan Province is one of the cities in Indonesia which has rapid growth and development. The development of this city is influenced by the rate of population growth which results in an increase in the need for urban land. The development of urban areas with changes in vegetation cover, the soil becoming a watertight surface with little or no water storage capacity, has resulted in Samarinda City still suffering from flood problems. The phenomenon of flooding that occurs in Samarinda City does not only occur during the rainy season but also when it rains with a duration of 3 hours it can cause flooding, as happened at Pramuka Street, Simpang Empat Sempaja Selatan, PM. Noor Street, Antasari Street, Lambung Mangkurat Street, and Panjaitan Street. These conditions are very concerning to Samarinda City residents and also disrupt community activities.

Based on its geography, Samarinda City has an area of 718 square kilometers, of which 180,000 square meters is a water catchment area, making Samarinda City potential to cause flooding [1]. Based on the hydrological conditions, Samarinda City was built by around 20 watersheds. Apart from the Mahakam watershed, there is the Karang Mumus River with a watershed area of about 218.80 km, where up to now the Karang Mumus River has been used by the people of Samarinda City as a place to live, bathe, wash and dispose of rubbish, this condition has worsened Samarinda City to become prone to flooding.

Flood prevention efforts in Samarinda that have been carried out by the Samarinda Regional Government include the construction of flood canals, river normalization, river maintenance, and others. The prevention was technical in nature and has not yet met any significant results. One solution was based on theoretical aspects, where the relationship between the Mahakam watersheds in Samarinda City was used as a sample with the resulting flood discharge.

Rivers have an important role in human life, because there are many benefits that can be taken from rivers. These benefits are as a source of irrigation water for agricultural areas, a source of drinking water, etc. Rivers are places and containers as well as water drainage networks from springs to estuaries limited to the right and left and along their flow by boundary lines [2]. Rivers can have a bad impact on human life due to human actions that do not maintain the balance of nature. Losses caused by flooding can have a systematic impact because the floods that occur, especially in the Samarinda area, last a long time and have a large discharge [3].

Based on the above background, research was conducted on the analysis of the causes of flooding in Samarinda City based on data from the Mahakam watershed in Samarinda, climate and rainfall in the Mahakam watershed, hydrology, physiological and topographic conditions, and water discharge in the Mahakam watershed in Samarinda. In this study, the Geographically Weighted Regression (GWR) method was used. Mapping was carried out based on the GWR method and as a comparison the Nonparametric GWR method was used. The purpose of this study was to determine the distribution of floods in Samarinda City and to identify the causes of flooding in Samarinda City.

CHARACTERISTICS OF THE MAHAKAM WATERSHED IN SAMARINDA

Geographical Location of the Mahakam Watershed

The Mahakam Watershed is one of the areas in East Kalimantan which includes the districts of West Kutai, East Kutai, Malinau, Kutai Kartanegara and Samarinda City. Mahakam River is the main river that divides Samarinda City. The sub-watersheds that include the tributaries that empties into the Mahakam river are the Karang Mumus River, the Palaran River, and other tributaries, namely the Loa Bakung River, Lao Bahu, Bayur, Betepung, Muang, Pampang, Buffalo, Sambutan, Lais, Tas, Anggana, Loa Janan, Handil Bhakti, Loa Hui, Rapak Dalam, Mangkupalas, Bukuan, Ginggang, Pulung, Payau, Balik Buaya, Banyuur, Sakatiga, and Bantuas River [4].

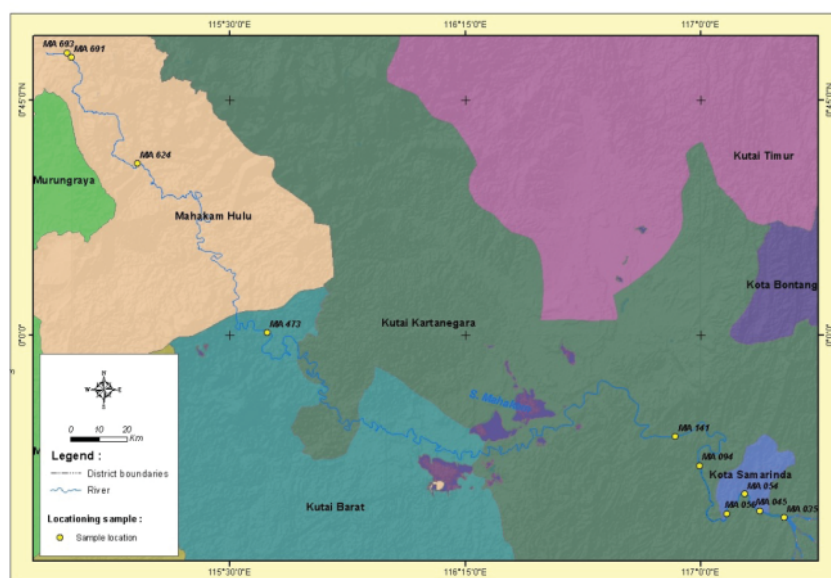


FIGURE 1. Map of Monitoring Point Distribution of Mahakam Watershed in East Kalimantan Province

The Mahakam watershed has an area of approximately 7,724,365 hectares. Geographically it is located 01°55' North Latitude and 01°09' South Latitude, and between 113°49' East Longitude and 117°41' West Longitude [5]. Figure 1 shows the image of the location of the Mahakam watershed and the surrounding government administration areas. The Mahakam watershed in Samarinda City consists of 10 sub-watershed points, namely Mahakam Nyan River, Mahakam Boh, Long Bangun, Tering, Bloro, Kumala Island, Kalamur, Governor's Office, Palaran, and Anggana [5,6].

Climate and Rainfall

The climatic conditions in the Mahakam watershed are relatively the same as the climatic conditions in the East Kalimantan Province in general, namely tropical climates and have two seasons: the dry season and the rainy season. The dry season usually occurs from May to October, while the rainy season occurs from November to April. This situation continues every year which is interspersed with a transitional season in certain months. However, in recent years, the seasonal conditions in the region have been at times erratic. In the months that should be rainy, in reality there is no rain at all or vice versa in the months that should be dry, there is rain with a much longer season.

In general, the values of the climate elements such as air temperature, air humidity, atmospheric pressure, wind velocity, monthly rainfall and duration of sunshine at several meteorological stations in the East Kalimantan Province are presented in detail in Table 1.

TABLE 1. Meteorological Data of Several Stations in East Kalimantan Province

The Climate Element	Meteorological Station		
	Samarinda	Balikpapan	Tanjung Redeb
1 Temperature (°C)			
Minimum	22.2	22.3	22.3
Maximum	35.2	33.8	34.4
2 Relative Humidity (%)	80	82	85
3 Atmospheric Pressure (mb)	1,012.9	1,011.7	1,010.9
4 Wind Velocity (Knot)	4	4	4
5 Rainfall (mm)	2,097.8	2,149.8	1,363.4
6 Duration of Sunshine (%)	46.8	52.5	50.8

Source: BPS [7]

Table 1 shows that in general the area of East Kalimantan Province has a hot climate with air temperatures ranging from 22.2°C to 35.2°C especially at the Samarinda Meteorology Station. The tropical area with forest habitats that have the lowest humidity is at the Samarinda Meteorological Station by 80%, while the highest is at the Tanjung Redeb Meteorological Station by 85%. The lowest air pressure is at the Tanjung Redeb Meteorological Station of 1,010.9 mb and the highest is at the Samarinda Meteorological Station of 1,012.9 mb [7].

Physiology and Topography of the Mahakam Watershed

The physiographic and topographic conditions of the Mahakam watershed were described using the altitude of sea level and the clarity data of the Mahakam watershed. Table 2 shows the area according to the altitude in the Mahakam watershed in detail.

TABLE 2. Altitude and Area in the Mahakam Watershed

Obs.	Altitude (m)	Area (Ha)	Area (%)
1.	≤ 75	2.709.037	35.1
2.	> 75 - 150	1.271.891	16.5
3.	> 150 - 300	792.730	10.3
4.	> 300 - 450	560.320	7.3
5.	> 450 - 600	521.057	6.7
6.	> 600 - 750	520.440	6.7
7.	> 750 - 1000	703.631	9.1
8.	> 1000 - 1500	557.653	7.2
9.	> 1500 - 2000	72.968	0.9
10.	> 2000	14.638	0.2
	Total	7.724.365	100.0

Source: Directorate General of Land Rehabilitation and Social Forestry, Watershed Management Office [5].

Table 3 shows the category of slope in the Mahakam watershed, which is dominated by sloping (2-15%) and slightly steep (15-40%), respectively 46.2% and 26.3% of the Mahakam watershed area [6].

TABLE 3. Map of Slope Range and Area in the Mahakam Watershed

No.	Slope Range (%)	Category	Area (Ha)	Area (%)
1.	0 – 2%	Flat	1.663.993	21.5
2.	2 – 15%	Sloping	3.578.918	46.3
3.	15 – 40%	Slightly Steep	2.032.488	26.3
4.	> 40%	Steep	448.967	5.8
Total			7.724.365	100.0

Source: Directorate General of Land Rehabilitation and Social Forestry, Watershed Management Office [5].

SPATIAL STATISTICS ANALYSIS: GEOGRAPHICALLY WEIGHTED REGRESSION METHOD

Geographically Weighted Regression Model

Geographically Weighted Regression (GWR) is a local form of classical linear regression that considers spatial aspects or geographic locations in the form of point coordinates (u_i, v_i) . In GWR, the estimated value of the regression parameters obtained for each observation location is different. One of the objectives of this method is to solve the problem of spatial heterogeneity in the data. Spatial heterogeneity occurs when one predictor variable gives different responses at different locations in one research area. GWR model produces estimates of model parameters that are local for each point or location where the data is observed. In GWR model, the response variable is estimated by a predictor variable, each of which has a regression coefficient depending on the location where the data is observed.

The GWR model [8], [9] for the relationship between the response variable y and the predictor variables $x_1, x_2, \dots, x_p$ at the i -th location:

$$y_i = \beta_0(u_i, v_i) + \sum_{k=1}^p \beta_k(u_i, v_i)x_{ki} + \varepsilon_i, i = 1, 2, \dots, n \quad (1)$$

where:

- y_i : The value of the response variable at the i -th observation location
- x_{ki} : The k -th predictor variable in the i -th location observation
- (u_i, v_i) : Geographical coordinates (Longitude and Latitude) of the i -th observation location
- $\beta_0(u_i, v_i)$: The intercept of GWR
- $\beta_k(u_i, v_i)$: The k -th parameter at the i -th location which corresponds to the predictor variable x_{ki} .
- ε_i : The error at the i -th location point which is assumed to be independently, identically and normally distributed with zero mean and variance σ^2

One of the methods of estimating the parameters of GWR model in Equation (1) is Weighted Least Square (WLS) method. The principle of WLS method is to provide different weights for observations at each location where the data is collected. $\hat{\beta}(u_i, v_i)$ was obtained by using WLS method [8].

$$\hat{\beta}(u_i, v_i) = (X^T W(u_i, v_i) X)^{-1} X^T W(u_i, v_i) y \quad (2)$$

If $x_i^T = [1 \quad x_{i1} \quad x_{i2} \quad \dots \quad x_{ip}]$ is the i -th row element of the matrix X , then the estimated value for y at the i -th observation location:

$$\hat{y}_i = x_i^T \hat{\beta}(u_i, v_i) = x_i^T (X^T W(u_i, v_i) X)^{-1} X^T W(u_i, v_i) y \quad (3)$$

If there are n sample locations, the estimations for each row and local matrix for the parameters of all locations are as follows:

$$\hat{\beta} = \begin{bmatrix} \hat{\beta}_0(u_1, v_1) & \hat{\beta}_1(u_1, v_1) & \hat{\beta}_2(u_1, v_1) & \cdots & \hat{\beta}_p(u_1, v_1) \\ \hat{\beta}_0(u_2, v_2) & \hat{\beta}_1(u_2, v_2) & \hat{\beta}_2(u_2, v_2) & \cdots & \hat{\beta}_p(u_2, v_2) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \hat{\beta}_0(u_n, v_n) & \hat{\beta}_1(u_n, v_n) & \hat{\beta}_2(u_n, v_n) & \cdots & \hat{\beta}_p(u_n, v_n) \end{bmatrix} \quad (4)$$

Geographical weighting used in this research was Gaussian Kernel [11] and Bisquare Kernel [12]. The weighting of Gaussian Kernel is expressed in Equation (5).

$$w_j(u_i, v_i) = \phi\left(\frac{d_{ij}}{\sigma b}\right), j = 1, 2, \dots, n \quad (5)$$

where ϕ is the standard normal density function and σ shows the standard deviation of the distance vector d_{ij} . The weighting value approaches one if the distance is less than or equal to the bandwidth value and if the distance between the i -th location and j -th location is greater or equal to the bandwidth, then the location will be assigned a zero value.

Furthermore, $d_{ij} = \sqrt{(u_i - u_j)^2 + (v_i - v_j)^2}$ in Equation (5) is the euclidean distance between location (u_i, v_i) to location (u_j, v_j) and b is a non-negative parameter called the smoothing parameter (bandwidth) whose value is always positive. The weighting of Bisquare Kernel is expressed in Equation (6).

$$w_j(u_i, v_i) = \left\{ \left(1 - \left(\frac{d_{ij}}{b} \right)^2 \right)^2, \text{ for where } d_{ij} \leq b, \quad \text{for } d_{ij} > b \right\} \quad (6)$$

To obtain the best geographical weighting, an optimum bandwidth value is needed. In this study, the optimum bandwidth value was determined using the following cross validation (CV) method:

$$CV = \sum_{i=1}^n \left(Y_i - \hat{Y}_{\#i}(b) \right)^2 \quad (7)$$

where $\hat{Y}_{\#i}(b)$ is the estimated values for Y_i at the observation location (u_i, v_i) which is omitted from the estimation process.

Nonparametric Geographically Weighted Regression (NGWR) Model

Mathematically, the form of the relationship between the response variable y_i and the predictor variables $(x_{1i}, x_{2i}, \dots, x_{li})$ at the i -th location for the NGWR model [10], [12], is shown in Equation (8).

$$y_i = \beta_0(u_i, v_i) + \sum_{l=1}^p \sum_{j=1}^m \beta_{lj}(u_i, v_i) x_{li}^j + \sum_{l=1}^p \sum_{k=1}^r \delta_{l,m+k}(u_i, v_i) (x_{li} - K_{lk})_+^m + \varepsilon_i \quad (8)$$

where y_i is the response variable at the i -th location, for $i = 1, 2, \dots, n$, x_{li} is the i -th predictor variable at the i -th area where $p = 1, 2, \dots, l$, K_{lk} is the l -th knot point, $\beta_{lj}(u_i, v_i)$ is the parameter coefficient of the polynomial component, $\beta_{pj}(u_i, v_i)$ is the j -th parameter from the l -th predictor variable at the i -th area, $\delta_{l,m+k}(u_i, v_i)$ is the parameter coefficients of the nonparametric regression function at the k -th knot point and the l -th predictor variable at the i -th area.

RESULT AND DISCUSSION

Geographically Weighted Regression Model

The first step in GWR analysis is to determine the weighting matrix. The weighting matrices used in this study were the Gaussian Kernel (5) and the Bisquare Kernel (6). Table 4 shows the results of geographical weighting calculations, bandwidth and CV values.

TABLE 4. Geographical Weighting on the GWR Model.

Weighting Functions	Bandwidth	Cross Validation (CV)
Gaussian Kernel	1.6924	26.77
Bisquare Kernel	2.0256	32.28

From the two weighting functions, it was found that the best model was to use Gaussian Kernel weighting with a CV value that is smaller than the CV value of Bisquare Kernel.

In the regression model, the parameter estimator values (coefficients) are taken into account the large contribution of the predictor variable to the response variable. The negative coefficient shows that the predictor variable has a negative contribution to Y, while the positive coefficient shows the predictor variable has a positive contribution to Y. Table 5 shows the results of GWR model parameter estimation for data of Mahakam watershed water discharge.

TABLE 5. Estimation Results of the GWR Model Parameters for Data of Mahakam Watershed Water Discharge

River	Mahakam Watershed Water Discharge (Y)	Estimator of Mahakam Watershed Water Discharge ($\hat{y}$)	Estimator of River Length ($\hat{\beta}_1$)	Estimator of PH ($\hat{\beta}_2$)	Estimator of DHL ($\hat{\beta}_3$)	Estimator of TDS ($\hat{\beta}_4$)	Estimator of BOD ($\hat{\beta}_5$)
Sub Sungai Mahakam Nyan	426.5	425.83	7.24	4510.43	298.19	-640.85	951.94
Sub Mahakam-Boh	1152	1067.36	6.93	4251.82	293.67	-630.73	888.87
Sub Long Bangun	860.5	1061.23	0.15	-1458.17	194.34	-407.86	-519.16
Sub Tering	1829	1815.50	7.24	4512.52	298.23	-640.93	952.45
Sub Bloro	4057	3759.70	-17.50	-18730.94	-51.87	91.30	-11571.42
Sub Pulau Kumala	5326	4640.55	-15.41	-18052.40	-35.49	48.85	-12114.08
Sub Kalamur	3897.5	3892.43	-12.08	-17175.42	-15.81	-1.80	-12807.76
Sub Kantor Gubernur	6476.5	6590.95	-10.66	-16841.79	-9.80	-17.35	-13055.53
Sub Palaran	2948	3990.38	-8.95	-16471.87	-3.37	-33.89	-13329.39
Sub Anggana	5123.5	4814.22	-5.78	-15814.24	4.71	-55.03	-13773.00

Source: Data Processing Results

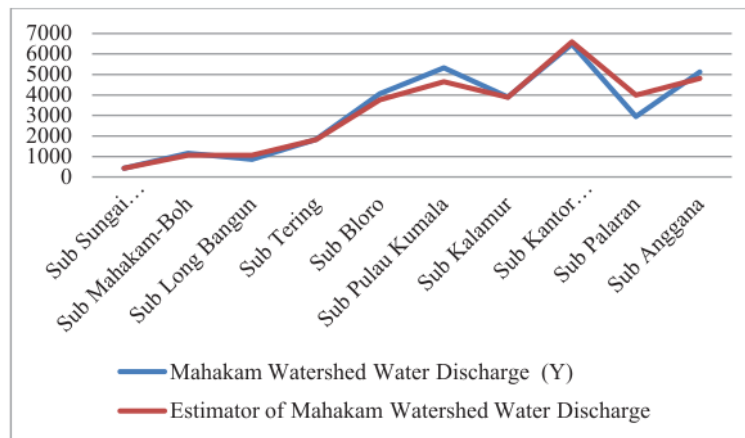


FIGURE 2. GWR Analysis of Water Discharge in the Mahakam Watersheds

The comparison of the y estimator and the actual y value in the GWR Analysis of Water Discharge in the Mahakam Watershed is given in Fig. 2. The best model indicator was determined based on the coefficient of determination R^2 and the smallest value of mean square error (MSE). A summary of the model criteria is given in Table 6.

TABLE 6. Criteria for the Best Model

Model	R^2	MSE	AIC
OLS	0.67	0.465	199.34
GWR	0.92	0.202	16.203
NGWR	0.91	0.214	17.612

The weighting used was Gaussian Kernel. Figure 3 shows the mapping of the Mahakam watershed locations and Fig. 4 shows the mapping of the analysis results of the causes of flooding in the Samarinda City using GWR method.

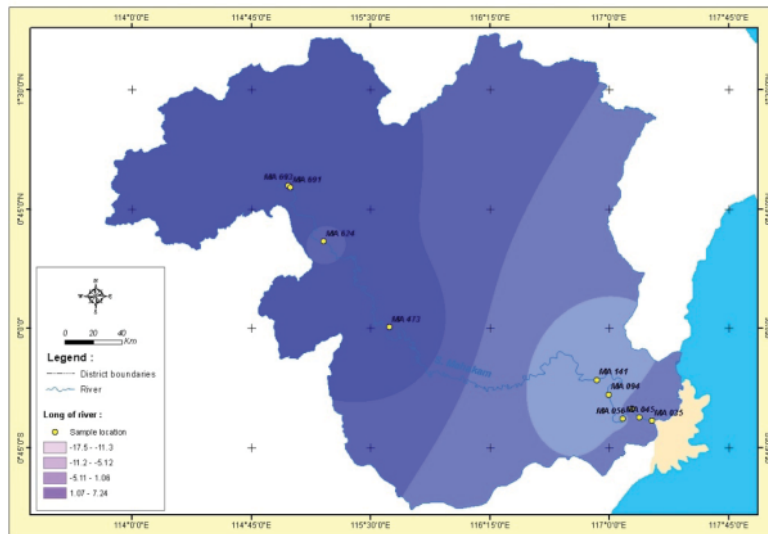


FIGURE 3. Map of the Spatial Distribution of the Mahakam Watershed Locations

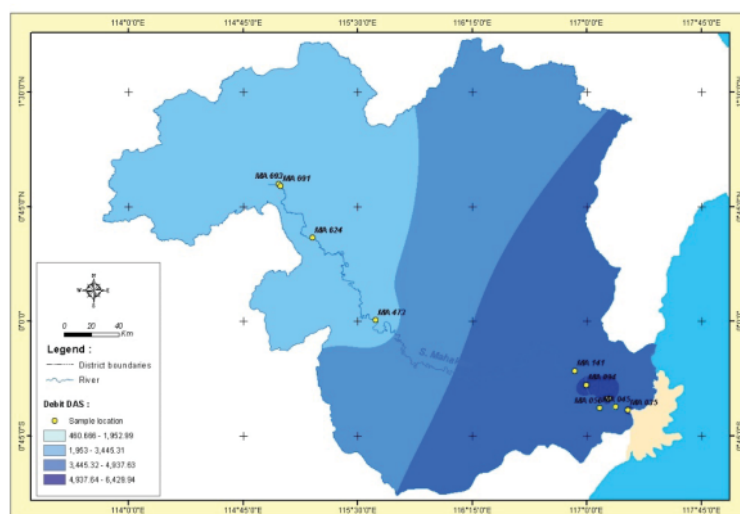


FIGURE 4. Map of the Spatial Distribution of GWR Analysis Result of Water Discharge in Mahakam Watershed

Analysis of the Causes of Flooding in Samarinda City

Samarinda City is a flood-prone area. Floods in Samarinda City occur due to excess surface runoff and not being able to collect the runoff in the river so that the water overflows. The first factor that causes flooding in Samarinda City is natural factor such as high rainfall, the topography of the area, the ebb and flow of the Mahakam watershed. The second factor is humans, mainly due to the element of population growth followed by an increase in the need for infrastructure, housing, clean water facilities, education, and other community services. In addition, population growth will also be followed by the need for business land for agriculture, plantations, and industry. The sources of inundation (flooding) in Samarinda City, especially those that have an impact on community activities, are divided into 3 types, the first is sent flood, the second is local flood, and the third is flooding due to the tide of the Mahakam river.

Analysis of the causes of flooding and the concept of flood control in Samarinda City were divided into three parts, namely flood control in the upstream, middle and downstream areas. The concept of flood control in the upstream area could be implemented by repairing damaged watershed conditions and increasing watershed resistance. Improving watershed conditions aimed to reduce the potential for flooding in the upstream area. The concept of improving watershed conditions could be carried out by creating watershed conservation, development and revitalization of natural reservoirs, currently in the form of swamps and other natural basins and artificial reservoirs. This concept has been applied in flood control in Samarinda City with the development of several dams in the Karangmumus watershed.

The concept of flood control in the middle area could be implemented by reducing flooding and reducing surface runoff done by minimizing changes in land use, including curbing land use that was not in accordance with the spatial layout of Samarinda City. Apart from land conservation, both structural and non-structural, river channel normalization was also carried out. The concept of flood control in the downstream area could be implemented by facilitating the flow of the existing drainage done by increasing the water capacity of the drainage channel and protecting the flow of the channel from the influence of the tide of the Mahakam River.

In addition to the concept of control based on the upstream, middle and downstream watersheds, the concept of flood control could also be carried out by means of a social approach to flood problems and socialization, institutions involving community organizations, private agencies and government agencies as well as regulatory enforcement.

CONCLUSION

The GWR method with a Gaussian Kernel weighting function was more effectively used to model the causes of flooding in Samarinda City. The best GWR model was obtained with R^2 of 0.92 and MSE value of 0.202. Based on the results of the GWR analysis, the causes of flooding and the flood control concept in Samarinda City were divided into three parts, namely flood control in the upstream, middle and downstream areas. The upstream flood control concept could be implemented by repairing damaged watershed conditions and increasing watershed resistance. The concept of flood control in the middle area could be implemented by reducing flooding and reducing surface runoff done by minimizing changes in land use, including curbing land use that was not in accordance with the spatial layout of Samarinda City. Meanwhile, the concept of flood control in the downstream area could be implemented by facilitating the flow of the existing drainage done by increasing the water capacity of the drainage channel and protecting the flow of the channel from the influence of the tide of the Mahakam River.

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