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ORIGINAL

Implementation of GWR and MGWR in Modelling Gross Regional Domestic Product (GRDP) in East Java

Implementación de GWR y MGWR en la modelización del Producto Interno Bruto Regional (PIBR) en Java Oriental

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ABSTRACT

Introduction: one important indicator of national development success is the increase in real Gross Regional Domestic Product (GRDP), which reflects regional economic performance. The GRDP growth rate, calculated as the percentage increase from the previous year, serves as a critical measure for evaluating economic progress. In the case of East Java, identifying the factors influencing GRDP growth is essential to support more effective and region-specific policy-making. This research aims to analyze those influencing factors using spatial regression methods.
Method: in this research, Geographically Weighted Regression and Mixed Geographically Weighted Regression methods are used to model the factors that influence the growth rate of GRDP in East Java.
Results: based on the results of the research that has been analyzed, it is known that the GWR model has an AICc score of 136,646, while the MGWR model has an AICc score of 134,3184, so it can be concluded that the MGWR method with a fixed gaussian kernel has better performance in modeling the factors that influence the GRDP growth rate in East Java.
Conclusions: globally, the General Allocation Fund and the Open Unemployment Rate significantly affect GRDP growth. Locally, the Percentage of Poor Population, Average Minimum Wage, Local Original Income, and Production Agglomeration show significant effects in specific areas. On the other hand, the Human Development Index and Population Density do not exhibit significant influence on GRDP growth, either globally or locally.

Keywords: Spatial Analysis; Geographically Weighted Regression; East Java; GRDP Growth Rate; Mixed Geographically Weighted Regression; Economic Growth.

RESUMEN

Introducción: un indicador importante del éxito del desarrollo nacional es el aumento del Producto Interno Bruto Regional (PIBR) real, que refleja el desempeño económico regional. La tasa de crecimiento del PIBR,

calculada como el incremento porcentual con respecto al año anterior, constituye una medida crucial para evaluar el progreso económico. En el caso de Java Oriental, identificar los factores que influyen en el crecimiento del PIBR es esencial para respaldar una formulación de políticas más eficaz y específica para cada región. Este estudio busca analizar dichos factores influyentes mediante métodos de regresión espacial.
Método: en esta investigación, se utilizan los métodos de Regresión Ponderada Geográficamente y Regresión Ponderada Geográficamente Mixta para modelar los factores que influyen en la tasa de crecimiento del PIBR en Java Oriental.
Resultados: con base en los resultados de la investigación analizada, se sabe que el modelo GWR tiene una puntuación AICc de 136,646, mientras que el modelo MGWR tiene una puntuación AICc de 134,3184. Por lo tanto, se puede concluir que el método MGWR con un kernel gaussiano fijo presenta un mejor rendimiento en la modelización de los factores que influyen en la tasa de crecimiento del PIBR en Java Oriental.
Conclusiones: a nivel global, el Fondo General de Asignación y la Tasa de Desempleo Abierto afectan significativamente el crecimiento del PIBR. A nivel local, el Porcentaje de Población Pobre, el Salario Mínimo Promedio, el Ingreso Local Original y la Aglomeración Productiva muestran efectos significativos en áreas específicas. Por otro lado, el Índice de Desarrollo Humano y la Densidad de Población no muestran una influencia significativa en el crecimiento del PIBR, ni a nivel global ni local.

Palabras clave: Análisis Espacial; Regresión Ponderada Geográficamente; Java Oriental; Tasa de Crecimiento del PIB; Regresión Ponderada Geográficamente Mixta, Crecimiento Económico.

INTRODUCTION

The regional economy is an important part of the national economy, so regional economic development plays a strategic role in achieving national development success.[1] A good economy will also reduce crime.[2] An increase in real GRDP is one of the benchmarks for successful national development because it projects regional economic growth.[3] The GRDP rate is important because it provides an overview of a region's economic size and health. It can be used to measure growth and decline and identify economic trends.[4] Based on the value of Gross Domestic Product (GDP) at constant prices of Rp. 2454,7 trillion in 2022, the East Java economy is the second largest contributor to Indonesia's economy after Jakarta, with a contribution to national GDP of 14,26 %. East Java's economic growth rate is equal to or greater than the national rate. Apart from its contribution to the national economy, East Java is a province with the largest number of districts and cities. The development of East Java is inseparable from unequal economic growth among its regions. Understanding local factors in a region is important for the government to plan development more efficiently.

Economists and researchers often analyze and predict the growth rate of GRDP to understand economic performance and predict future development.[5] Jiang et al.[6] examined the impact of the agglomeration phenomenon in Yangtze River Delta cities on their economic growth using the Spatial Autoregression (SAR) Model analysis method. Muzzakar et al.[7] modeled GRDP in all Indonesian provinces using Geographical Weighted Regression (GWR). Putria et al.[8] analyzed the factors influencing GRDP using the Fixed Effect (FE) estimation method. Alya et al.[9] modeled the poverty level in Central Java using the GWR and Mixed Geographically Weighted Regression (MGWR) method. And the last, Rantini et al.[10] modeled the NEET (Not in Education, Employment, or Training) data using spatial area approach.

In general, social and economic phenomena emerge from different spatial processes at various regional scales. Using GWR models to study factors affecting China's economy can lead to deviation.[11] Fotheringham et al.[12] noted that the Multiscale Geographically Weighted Regression method effectively addresses this issue. In 2019, Yu et al.[13] refined the statistical inference of the Multiscale Geographically Weighted Regression model so that it could be used in many empirical studies. However, the concept of development in a particular region may not be applied with the same level of success in other regions due to differences in local environmental factors. Nevertheless, it can help us understand the structure of an economy and identify areas of economic growth and decline in each region.[14]

This research aims to model the Gross Regional Domestic Product (GRDP) of East Java Province using Geographically Weighted Regression (GWR) and Mixed Geographically Weighted Regression (MGWR) methods. This will allow us to compare the modeling results obtained using the GWR and MGWR methods. This research uses the following variables: GRDP growth rate, percentage of people living in poverty, human development index, open unemployment rate, regional minimum wage, regional original income, general allocation fund, production agglomeration value, and population density based on regency/city in East Java Province in 2022.

METHOD

Data Set

The data used in this research are secondary data obtained from several government agencies, namely the

Central Bureau of Statistics of East Java Province and the Directorate General of Fiscal Balance of the Ministry of Finance. The variables used in this research consist of one response variable (Y) and eight predictor variables (X) as in table 1.

Table 1. List of Research Variables

Notation	Explanation
Y	GRDP growth rate per capita based on constant 2010 prices by Regency and City
X_1	Percentage of population by Regency and City
X_2	Human development index by Regency and City
X_3	Average Minimum Wage by Regency and City
X_4	Total population density by Regency and City
X_5	Total original regional income by Regency and City
X_6	Total general allocation funds by Regency and City
X_7	Percentage of agglomeration by Regency and City
X_8	Percentage of open unemployment rate by Regency and City
ui	Longitude of each Regency and City in East Java
vi	Latitude of each Regency and City in East Java

Source: Central Bureau of Statistics

In implementing this research, the data structure used in this research can be seen in table 2.

Table 2. Research Data Structure

Code	(Longitude, Latitude)	Y	X_1	X_2	…	X_8
1	(u_1,v_1)	Y_1	X_{11}	X_{12}	…	X_{18}
2	(u_2,v_2)	Y_2	X_{21}	X_{22}	…	X_{28}
⋮	⋮					
38	(u_{38},v_{38})	Y_{38}	X_{381}	X_{382}	…	X_{388}

Geographically Weighted Regression (GWR) Model

Geographically Weighted Regression (GWR) Model is a statistical method used in spatial regression analysis to understand spatial variability in the relationship between predictor variables and response variable. GWR has a general form as in equation (1) which is a development of the Ordinal Least Square model into a weighted regression model while maintaining spatial effects.(15) The GWR model calculates parameters at each observation location, so that in the GWR regression model, the predictor variables have different regression coefficients depending on the observation location with more accurate and contextual estimates of spatial patterns in the data.(16) Therefore, this parameter estimator is used to predict each point or location in the data being observed.(9)

$$Y_i = \beta_0(u_i, v_i) + \sum_{k=1}^{p} \beta_k(u_i, v_i)\, x_{ik} + \varepsilon_i \quad (1)$$

Where Y_i is the observed value of the i-th response variable, x_ik is the observed value of the i-th predictor variable, (u_i, v_i) is the coordinates of the i-th observation location, β_0 (u_i, v_i) is the intercept value of the regression model, β_k (u_i, v_i) is the k-th regression coefficient at the i-th observation location point, and ε_i is the error at the i-th location point.

Parameter Estimation

One way to estimate the GWR parameters is to use the Weighted Least Squares (WLS) method where each point in the observation area (u_i, v_i) will be given a different weight value w_{ij}, forj = 1,2,3,…,n. Furthermore, the results of the parameter estimation that have been given the weight value will be minimized by the sum of the squared errors by equating it to zero, which then obtains a parameter estimation model as in equation (2).

$$\sum_{j=1}^{n} w_j(u_i, v_i)\varepsilon_j^2 = \sum_{j=1}^{n} w_j(u_i, v_i)\left[y_j - \beta_0(u_i, v_i) - \sum_{k=1}^{p} \beta_k(u_i, v_i)x_{jk}\right] \quad (2)$$

Equation (2) can be expressed in matrix form as equation (3):

$$\varepsilon^T W(u_i,v_i)\varepsilon = y^T W(u_i,v_i)y - 2\beta^T(u_i,v_i)X^T W(u_i,v_i)y + \beta^T(u_i,v_i)X^T W(u_i,v_i)X\beta(u_i,v_i) \quad (3)$$

Where:

$$\beta(u_i,v_i) = [\beta_0(u_i,v_i)\ \beta_1(u_i,v_i)\ \vdots\ \beta_p(u_i,v_i)\ ] = \ diag[w_1(u_i,v_i), w_2(u_i,v_i), \cdots, w_n(u_i,v_i)]$$

Using WLS, equation (4) is obtained which is an estimate for the GWR model parameters at each research location (u_i, v_i).

$$\hat{\beta}(u_i,v_i) = (X^T W(u_i,v_i)X)^{-1}X^T W(u_i,v_i)y \quad (4)$$

Parameter Hypothesis Test

Model parameter testing at each research location (u_i, v_i) is carried out by testing the parameters partially. This test is conducted to determine the parameters of the predictor variables that have a significant influence on the response variables at each observation location. Using the α as the level of significance, the following are the hypotheses used in the GWR model parameter test.

- H_0: β_k (u_i, v_i)= 0; the predictor variable (β_k) has no effect on the response variable; for k = 1,2,…,p; i = 1,2,…,n
- H_1: β_k (u_i, v_i)≠ 0; the predictor variable (β_k) has an influence on the response variable; for k = 1,2,…,p; i = 1,2,…,n

With statistical tests as in equation (5).

$$t_{gwr} = \frac{\beta\hat{}_k(u_i,v_i)}{\sigma\hat{}\sqrt{g_{kk}}} \quad (5)$$

Where g_{kk} is an element of the diagonal of the ggT matrix, with:

$$\sigma\hat{} = \sqrt{\frac{SSE_{GWR}}{\delta}}\ ,\ \delta = ((I-S)^T(I-S)^i)\ ,\ g = [X^T W(u_i,v_i)X]^{-1}X^T W(u_i,v_i)$$

Then, H_0 is rejected if:

$$|t_{gwr}| > t_{\left(\frac{\alpha}{2},n-p-1\right)}$$

Or if the value p-value < α.

Spatial Variability Test

To determine the coefficients of global and local variables, a spatial variability test is carried out on the research data used. It can be known which variables have an influence on location and which variables do not have an influence.[17] The following is the hypothesis used in the variability test for the Mixed Geographically Weighted Regression (MGWR) model parameters.

- H_0: β_k (u_1, v_1)=β_k (u_2, v_2)=⋯=β_k (u_n, v_n); for k = 1,2,…,p
- H_1: there is at least one β_k (u_i, v_i)≠β_k (u_j, v_j); for i ,j= 1,2,… ,n; k = 1,2,…,p

With statistical tests as in equation (6).

$$F_{test} = \frac{\frac{V_j^2}{c_1}}{Y^t(I-S)^t(I-S)Y/b_1} \quad (6)$$

Where:

$$V_j^2 = \frac{1}{n}\sum_{i=1}^{n}\left(\beta\hat{}_j(u_i,v_i) - \frac{1}{n}\sum_{i=1}^{n}\beta\hat{}_j(u_i,v_i)\right)^2 = \frac{1}{n}\beta_j^t\left[I - \frac{1}{n}J\right]\beta_j$$

J is the n × n matrix with all values in its elements are 1, c_k is the vector of size k+1 with value 1 for the j -th element and 0 for other elements.

$b_1 = ([(I-S)^t(I-S)]^i)$, $c_1 = ([(I-H)(I-S)^t(I-S)^i])$, $S = S_l + (I-S_l)X_g\left[X_g{}^t(I-S_l)^t(I-S_l)\right]^{-1}X_g{}^t(I-S_l)^t(I-S_l)$,

$\overrightarrow{\beta_J} = [c_1^t(X^tW(u_1,v_1)X)^{-1}X^tW(u_1,v_1)\ c_2^t(X^tW(u_2,v_2)X)^{-1}X^tW(u_2,v_2)\ \vdots\ c_k^t(X^tW(u_n,v_n)X)^{-1}X^tW(u_n,v_n)\ ]$

Then, H_0 can be rejected if the $F_{test} > F_{\alpha;(df1,df2)}$, as for the degree of freedom values for df_1=tr[(I-S_2)-(I-S_1)] and df_2=tr[(I-S_1)].

Mixed Geographically Weighted Regression (MGWR) Model

Mixed Geographically Weighted Regression (MGWR) is a spatial regression model that combines global regression models and local regression models. The global regression model assumes that the relationship between the dependent variable and the independent variable is constant, while the local regression model assumes that the relationship varies according to the observation location.[18] Equation (7) is a general model of MGWR.

$$Y_i = \beta_0(u_i,v_i) + \sum_{k=1}^{q} \beta_k(u_i,v_i)x_{ik} + \sum_{k=q+1}^{p} \beta_k x_{ik} + \varepsilon_i \quad (7)$$

Where i is the location, Y_i is the observed value of response variable at location i, x_{ik} is the value of predictor variable k at observation point i, β_0 (u_i, v_i) is the coefficient or constant of MGWR model, β_k (u_i, v_i) is the regression coefficient of predictor variable k at location i (local parameter), β_k is the regression coefficient of predictor variable k at all locations (global parameter), and ε_i is the error model for location i.

Parameter Estimation

The WLS method is used to estimate parameters in the MGWR model, by first identifying local and global variables. Equation (8) is used to estimate local variables using the Maximum Likelihood Estimation (MLE) method.[9]

$$\hat{\beta}_l(u_i,v_i) = (X_l{}^tW(u_i,v_i)X_l)^{-1}X_l{}^tW(u_i,v_i)\left(y - X_g\hat{\beta}_g\right) \quad (8)$$

Where X_g is the global predictor variable matrix, X_l is the local response variable matrix, $\hat{\beta}_g$ is the global predictor variable parameter vector, $\hat{\beta}_l$ (u_i, v_i) is the local predictor variable parameter matrix, and:

$$W = diag[w_1(u_i,v_i), w_2(u_i,v_i), \cdots, w_n(u_i,v_i)]$$

Then equation (9), global variables are estimated using the Ordinary Least Square (OLS) method.[9]

$$\hat{\beta}_g = \left(X_g{}^t(I-S_l)^t(I-S_l)X_g\right)^{-1}X_g{}^t(I-S_l)^t(I-S_l)Y \quad (9)$$

Parameter Hypothesis Test

Significance tests are performed on global and local parameters. Each parameter will be tested simultaneously and partially.

Simultaneous testing of global parameters

Using the α value as the significance level, the following is the hypothesis used in the simultaneous test of the global parameters of the MGWR model.

- H_0: β_{q+1} (u_i, v_i)= β_{q+2} (u_i, v_i)=⋯=β_p (u_i, v_i)=0; for i = 1,2,…,n
- H_1: there is at least one β_k (u_i, v_i)≠0; for k=q+1,q+2,…,p; i= 1,2,…,n

With test statistics that can be written as in equation (10).

$$F = \frac{\dfrac{Y^t[(I-S_l)^t(I-S_l) - (I-S)^t(I-S)]Y}{c_I}}{Y^t(I-S)^t(I-S)Y/u_I} \quad (10)$$

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Where c_l= ([(I-S_l)^t (I-S_l)-(I-S)^t (I-S)]^i) and u_l = ((I-S)^t (I-S)^i). Then, H_0 can be rejected if the p-value < α or F > Fα;(d_{f1},d_{f2}).

Simultaneous testing of local parameters

Using the α value as the significance level, the following is the hypothesis used in the simultaneous test of the global parameters of the MGWR model.

- H_0: β_1 (u_i, v_i)= β_2 (u_i, v_i)=⋯=β_q (u_i, v_i)=0; for i = 1,2,…,n
- H_1: there is at least one β_k (u_i, v_i)≠0; for k = 1,2,,…,q; i = 1,2,…,n

With test statistics that can be written as in equation (11).

$$F = \frac{\frac{Y^t[(I-S_l)^t(I-S_l)-(I-S)^t(I-S)]Y}{c_I}}{Y^t(I-S)^t(I-S)Y/u_I} \quad (11)$$

Where c_l = ([(I-S_l)^t (I-S_l)-(I-S)^t (I-S)]^i) and u_l = ((I-S)^t (I-S)^i). Then, H_0 can be rejected if the p-value < α or F > Fα;(d_{f1},d_{f2}).

Partial testing of global parameters

Using the value of α as the level of significance, the following are the hypotheses used in the partial test of the global parameters of the MGWR model.

- H_0: β_k=0 or the global variable X_k at the i-th location does not have a significant effect; for k=q+1,q+2,…,p; i=1,2,…,n
- H_1: β_k≠0 or the global variable X_k at the i-th location has a significant effect; for k=q+1,q+2,…,p; i=1,2,…,n

With test statistics that can be written as in equation (12).

$$t_{global} = \frac{\beta\hat{}_j(u_i, v_i)}{\sigma\hat{}\sqrt{g_{kk}}} \quad (12)$$

Where g_{kk} is the element with the -th diagonal in the GG^t matrix.

$$G = \left[X_g^t(I-S_l)^t(I-S_l)X_g\right]^{-1}X_g^t(I-S_l)^t(I-S_l), \text{ and } \sigma\hat{} = \frac{Y^t(I-S)^t(I-S)Y}{((I-S)^t(I-S))}$$

Then, H_0 can be rejected if the p-value < α or $|t_{global}|>t_{(\alpha/2;\ df)}$.

Partial testing of local parameters

Using the α value as the level of significance, the following are the hypotheses used in the partial test of the local parameters of the MGWR model

- H_0: β_k (u_i, v_i)=0 or the local variable X_k at the i-th location does not have a significant effect; for k=1,2,…,q; i=1,2,…,n
- H_1: β_k≠0 or the local variable X_k at the i-th location has a significant effect; for k=1,2,…,q; i=1,2,…,n

With test statistics that can be written as in equation (13).

$$t_{local} = \frac{\beta\hat{}_j(u_i, v_i)}{\sigma\hat{}\sqrt{m_{kk}}} \quad (13)$$

Where m_{kk} is the element with the k-th diagonal in the MM^t matrix.

$$M = [X_l^t(I-S_l)^t(I-S_l)X_l]^{-1}X_l^t(I-S_l)^t(I-S_l) \text{ and } \sigma\hat{} = \frac{Y^t(I-S)^t(I-S)Y}{((I-S)^t(I-S))}$$

Then, H_0 can be rejected if the p-value < α or $|t_{local}|>t_{(\alpha/2;\ df)}$.

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Model Selection

In determining the best model, it can be done by looking at the value of R^2 and the value of Akaike Information Criterion Corrected (AICc). AICc is a development of equation (14) which is a test statistic of the Akaike Information Criterion (AIC) which is commonly used as a measuring tool for statistical models, because in its calculations it uses the principle of parsimony and avoids over-fitting to the GWR and MGWR models.[15]

$$AIC = 2nln(\hat{\sigma}) + nln(2\pi) + n + tr(L) \quad (14)$$

Where:

$$\hat{\sigma} = \sqrt{\frac{Y^T(I-S)^T(I-S)Y}{n}} \text{ and } L = X_i^T(X^TW(u_i - v_i)X)^{-1}X^TW(u_i - v_i)).$$

However, bias often occurs in the use of AIC if the data has less than 50 observations, so a correction is made to the AIC calculation by adding a penalty for the number of parameters as in equation (15).[19]

$$AIC_c = AIC + \frac{2k(k+1)}{n-k-1} \quad (15)$$

Research Flow

The stages carried out in this research are as explained below:

1. Collecting data used in this research, regarding the GRDP Growth Rate of Regency/City of East Java Province, Percentage of Poor Population, Human Development Index, Open Unemployment Rate, Regional Minimum Wage, Regional Original Income, General Allocation Fund, and Production Agglomeration value based on Regency/City in East Java Province in 2022. The data is secondary data taken from the website of the Central Bureau of Statistics of East Java Province and the Directorate General of Fiscal Balance of the Ministry of Finance.
2. Conducting descriptive analysis and making visualizations with thematic maps on each research variable, to gain a general understanding of the data used in this research.
3. Conducting a heterogeneity test with Breusch-Pagan test (9) on the data to determine whether there is spatial variation in the relationship between the variables used in the model, namely when the p-value test result is smaller than the significance level used.
4. Determine the Euclidean distance and bandwidth based on the smallest Cross Validation (CV) [20] between fixed Gaussian, fixed bisquare, fixed tricube, adaptive Gaussian, adaptive bisquare, and adaptive tricube weights.
5. Conduct analysis using the Geographically Weighted Regression (GWR) model, the following are the analysis stages:
    a. Find the parameter estimate of the GWR model with optimal bandwidth.
    b. Conduct partial tests to determine the parameters that are significant for each observation location partially.

6. Conduct spatial variability tests to determine which predictor variables are significant, to be used as local predictor variables in the Mixed Geographically Weighted Regression (MGWR) analysis. In addition, this stage is also used to determine the global and local variables that will be used in the analysis using the MGWR model.
7. Conduct analysis using Mixed Geographically Weighted Regression (MGWR), the following are the analysis stages:
    a. Initiate the global and local variables that will be used, according to the results of the previous stage.
    b. Finding the parameter estimates of the MGWR model with optimal bandwidth.
    c. Conducting simultaneous tests on the global parameters of the MGWR model to determine global variables that simultaneously have a significant effect on the dependent variable.
    d. Conducting simultaneous tests on the local parameters of the MGWR model to determine local variables that simultaneously have a significant effect on the dependent variable.
    e. Conducting partial tests on the global parameters of the MGWR model to determine global variables that partially have a significant effect on the dependent variable in each research area.
    f. Conducting partial tests on the local parameters of the MGWR model to determine local variables that partially have a significant effect on the dependent variable in each research area.

8. Selection of the best model between GWR and MGWR based on the smallest AICc value of the data used in this research.
9. Making conclusions based on the results of the analysis that has been carried out.

The stages of research carried out according to the flow that has been explained, both related to data collection and drawing conclusions according to the flowchart or flow diagram as in figure 1.

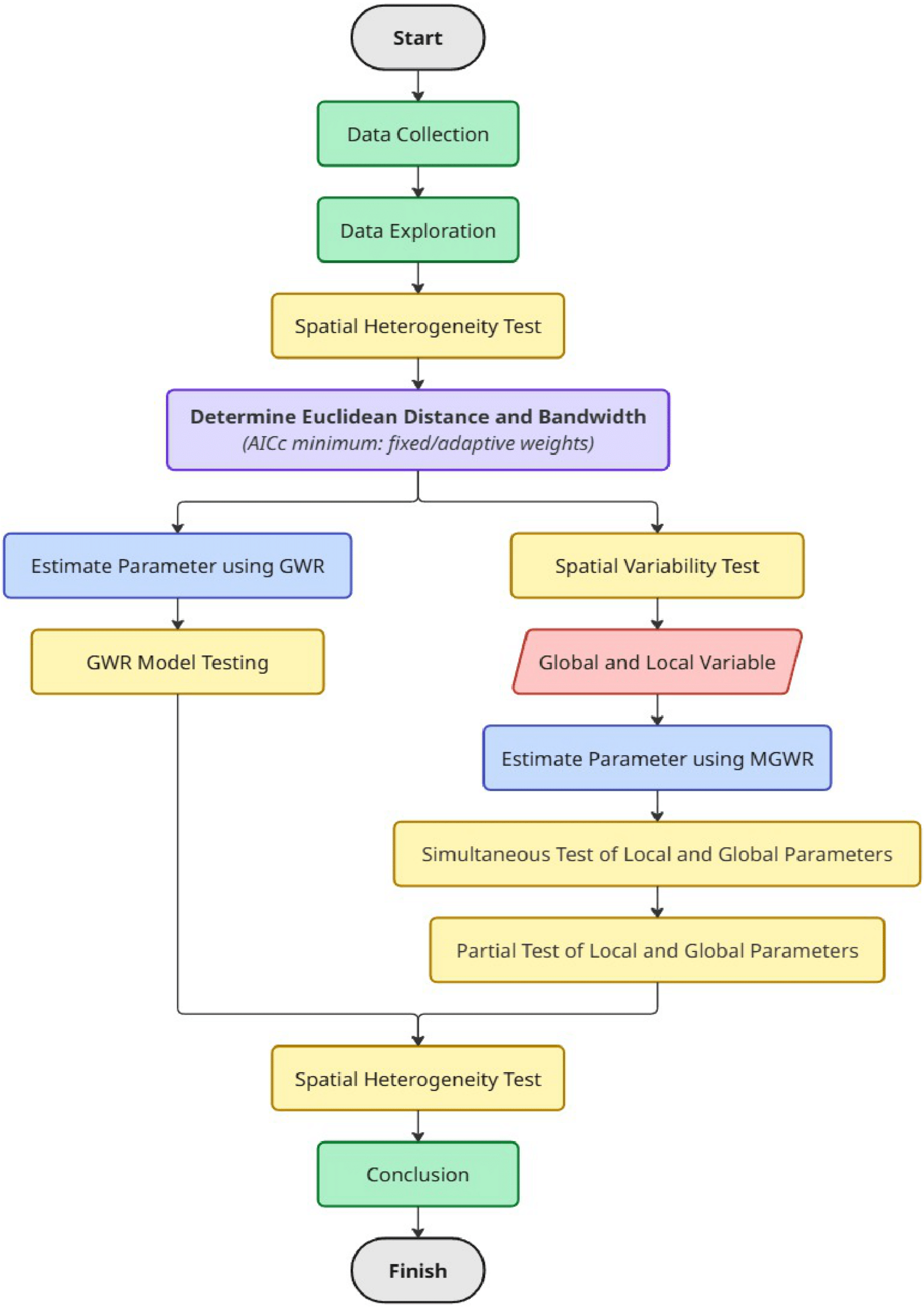

Figure 1. Research Flow Chart

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RESULTS AND DISCUSSION

Exploratory Data Analysis

Descriptive statistics in this research include mean values, variance, and minimum and maximum values, which are given in table 3.

Table 3. Descriptive Statistics Summary

Variable	Mean	Varians	Min.	Max.
Y	3,897	6,031	-6,7	8,3
X_1	10,382	18,264	3,79	21,61
X_2	74	2 237 886	65,44	83,38
X_3	2 502 930	6 458 741	1 922 123	4 375 479
X_4	2017	5 509 706	414	8595
X_5	577,5	727 969	156,3	5314,7
X_6	890,2	83 589,44	367,6	1607,5
X^7	0,026	0,001	0,003	0,247
X_8	5,273	3,152	1,36	8,8

Based on the results in table 3, it shows significant regional disparities in socioeconomic and demographic indicators across Regencies and Cities in East Java. The average GRDP per capita growth rate is 3,897 %, with considerable variation, ranging from economic contraction (-6,7 %) to strong growth (8,3 %). Overall, the data suggests that regional economic growth is influenced by a complex interplay of human development, income levels, urbanization, and labor dynamics, making spatial and policy-targeted approaches essential for balanced development. Then, visually descriptive statistics for independent variables in each region are given in the form of a thematic map in figure 2 to figure 10.

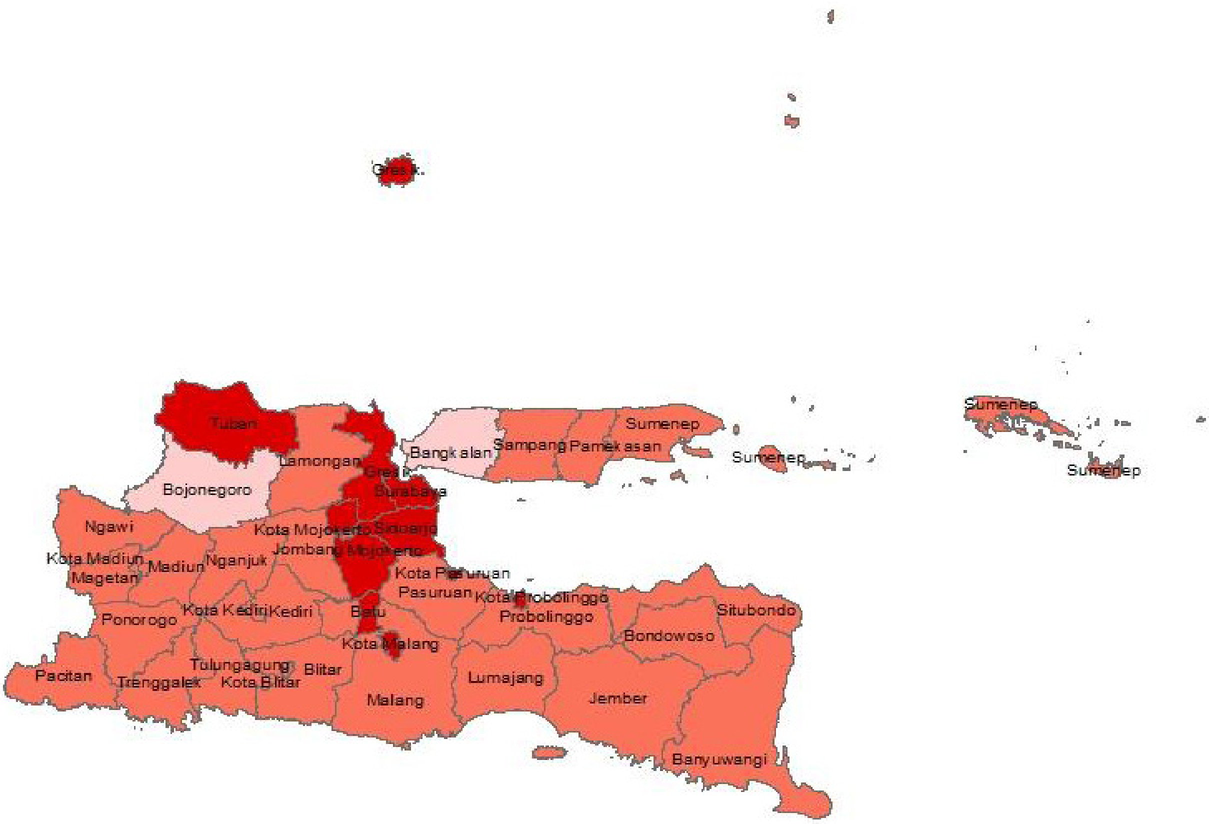

Figure 2. GRDP Growth Rate in East Java

Based on the results of the thematic map in figure 2, it shows that the brighter the color of the region on the map, the smaller the GRDP growth rate will be. It is known that the Bojonegoro and Bangkalan regions have the lowest GRDP growth rates, which are -6,7 and -2,48 respectively, which are indicated by the brightness of the color of the region on the map. A negative value in the GRDP growth rate may occur because there has been a decline in national oil and gas production, where Bojonegoro is known as an oil and gas producer with an estimated 25 % of oil reserves located in the Bojonegoro region, so this factor can affect the economic conditions of Bojonegoro in addition to the COVID-19 pandemic.

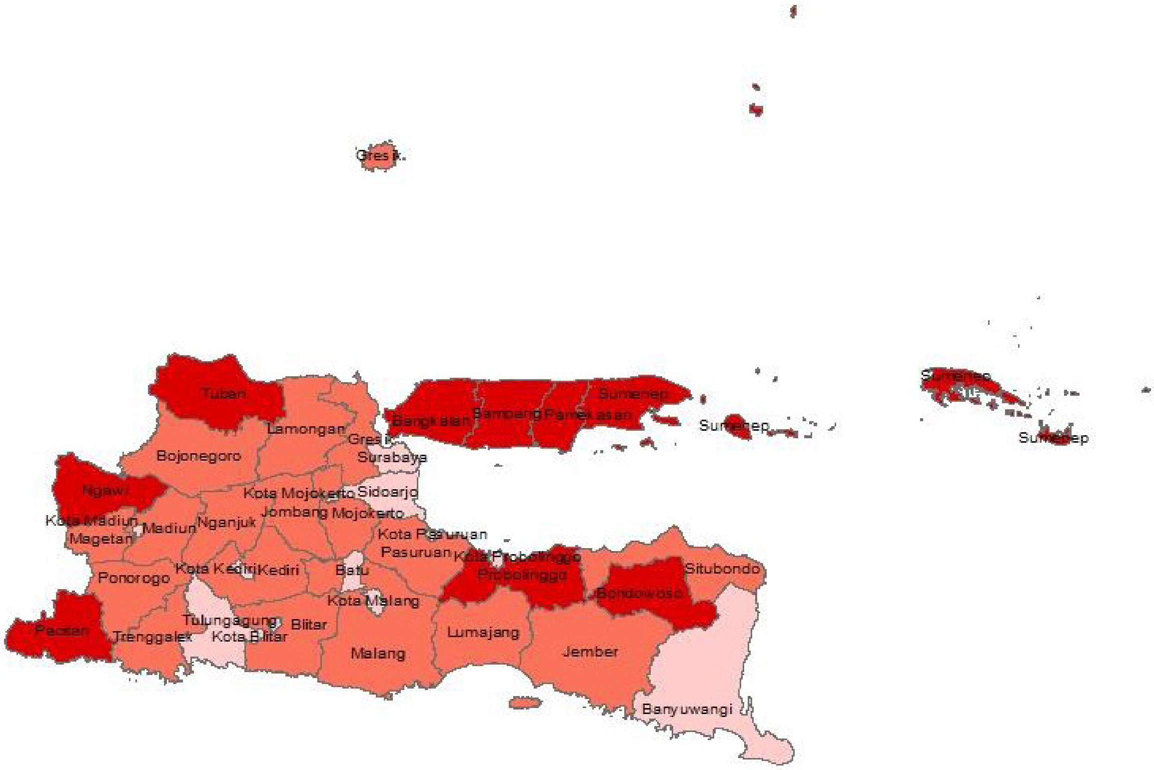

Figure 3. Percentage of Poor Population in East Java

Based on the results of the thematic map in figure 3, it shows that the brighter the color of the area on the map, the smaller the Percentage of Poor People. It is known that the Sampang area is the area with the highest Percentage of Poor People in East Java, which is also indicated by the dark red color in the Sampang area.

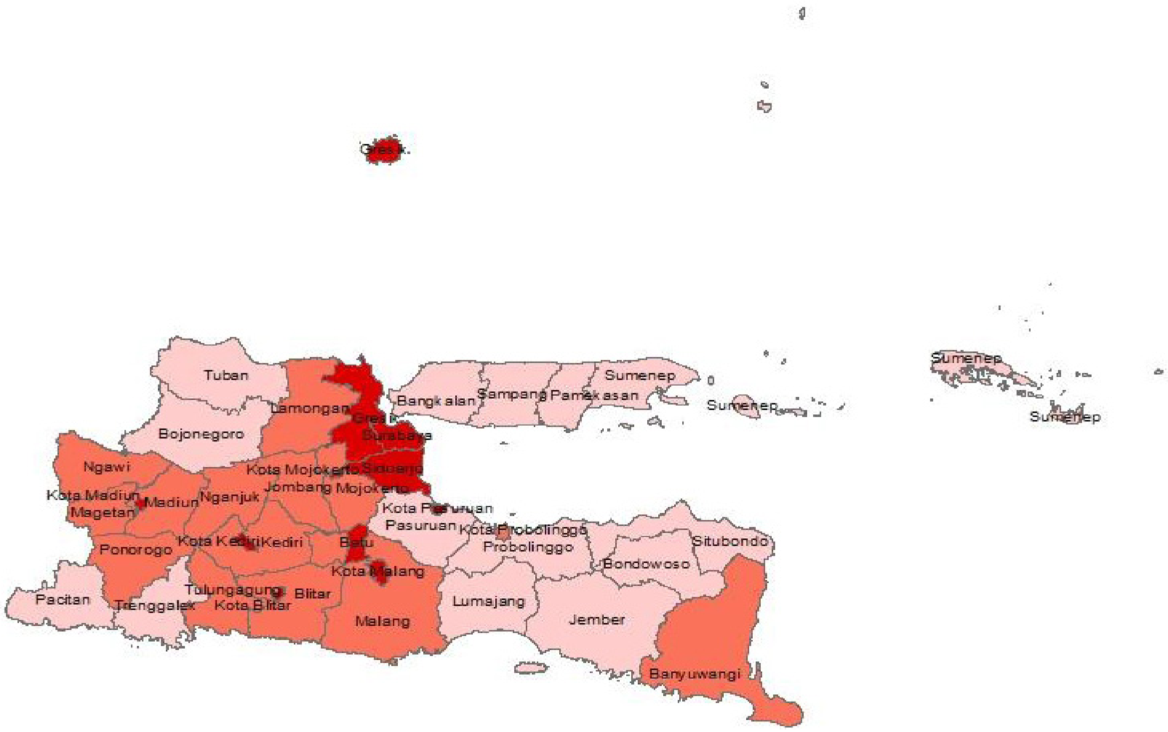

Figure 4. Human Development Index in East Java

Based on the results of the thematic map in figure 4, it shows that the brighter the color of the area on the map, the smaller the Human Development Index value will be. It is known that the Sampang area is the area with the lowest Human Development Index value in East Java, which is also indicated by the bright red color in the Sampang area.

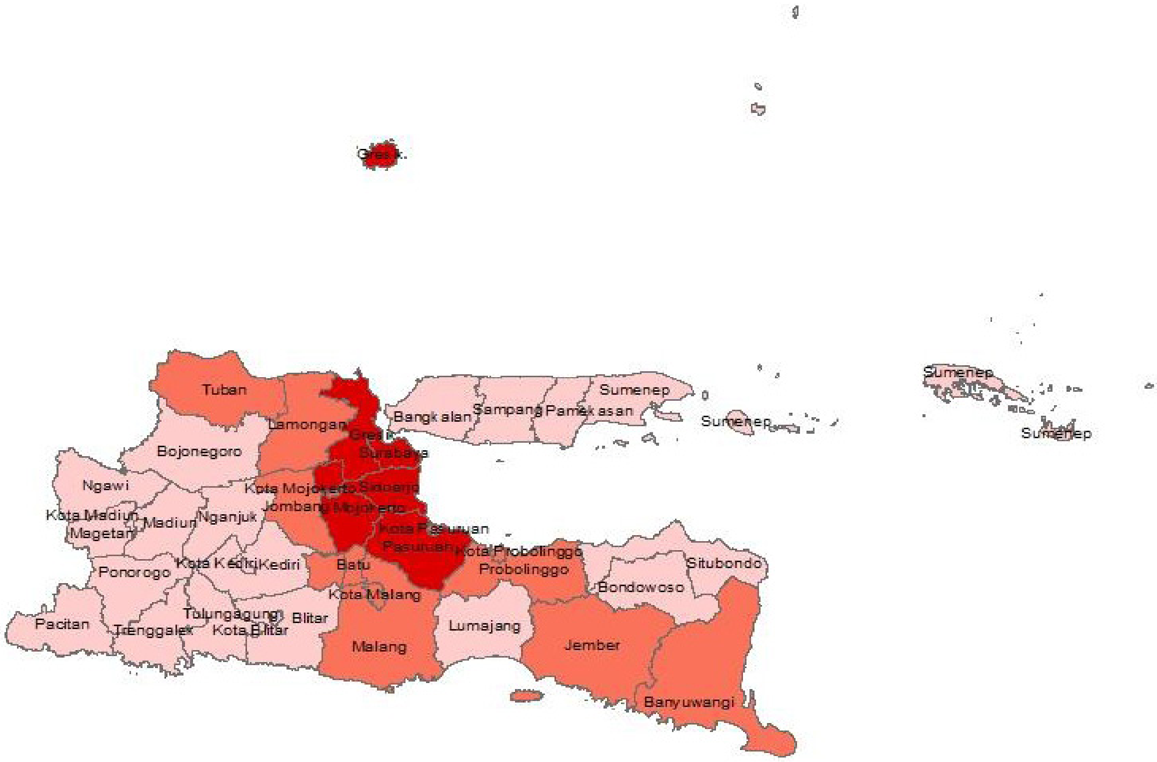

Figure 5. Regional Minimum Wage in East Java

Based on the results of the thematic map in figure 5, it shows that the brighter the color of the area on the map, the smaller the Regional Minimum Wage will be. It is known that the Sampang area is the area with the lowest Average Minimum Wage in East Java, which is also indicated by the lighter red color in the Sampang area.

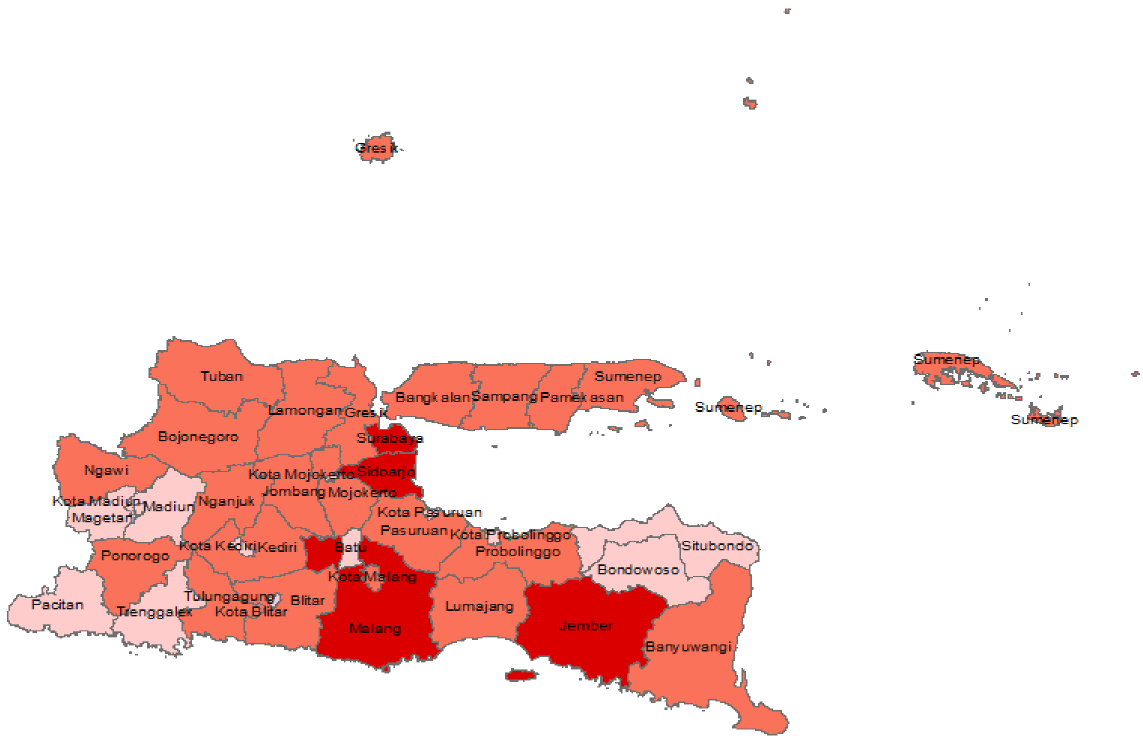

Figure 6. Population Density in East Java

Based on the results of the thematic map in figure 6, it shows that the brighter the color of the area on the map, the smaller the Population Density value will be. It is known that the Pacitan area is the area with the lowest Population Density in East Java, while Surabaya is the area with the highest population density in East Java.

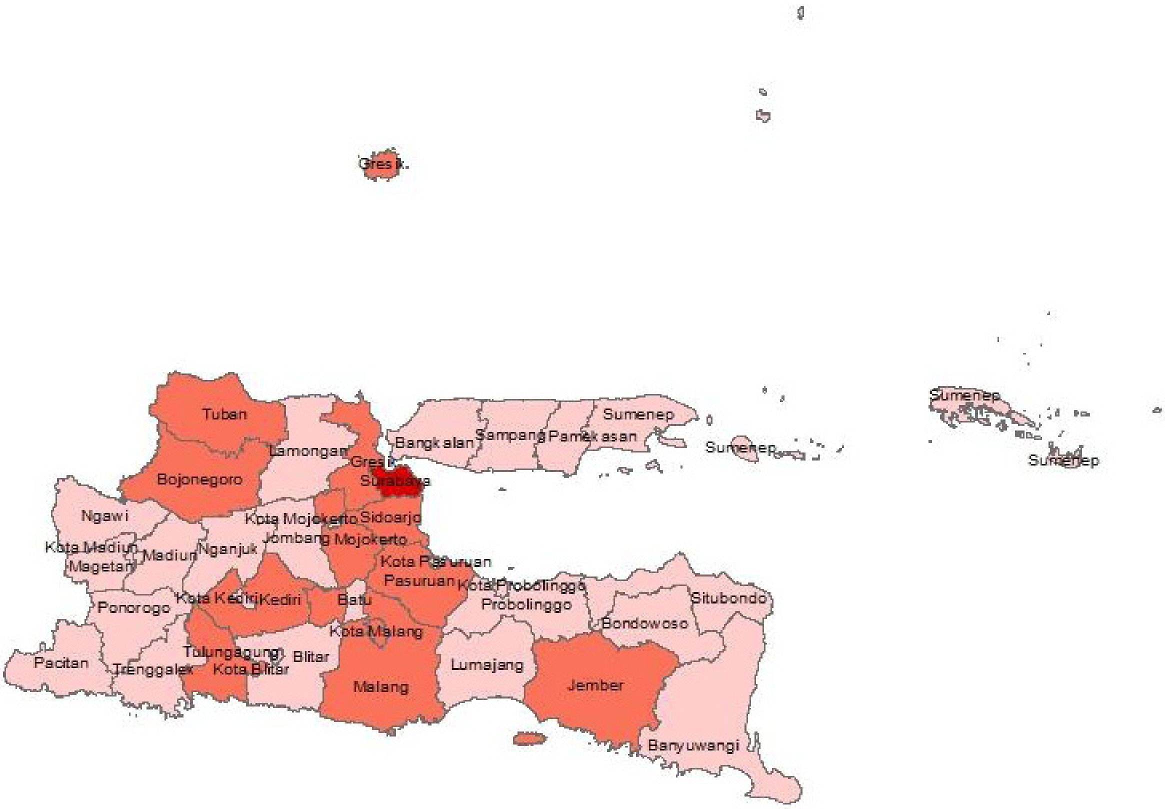

Figure 7. Local Original Income in East Java

Based on the results of the thematic map in figure 7, it shows that the brighter the color of the area on the map, the smaller the Local Original Income value will be. It is known that the Blitar City area is the area with the lowest Local Original Income in East Java, which is also indicated by the lighter red color in the Blitar area.

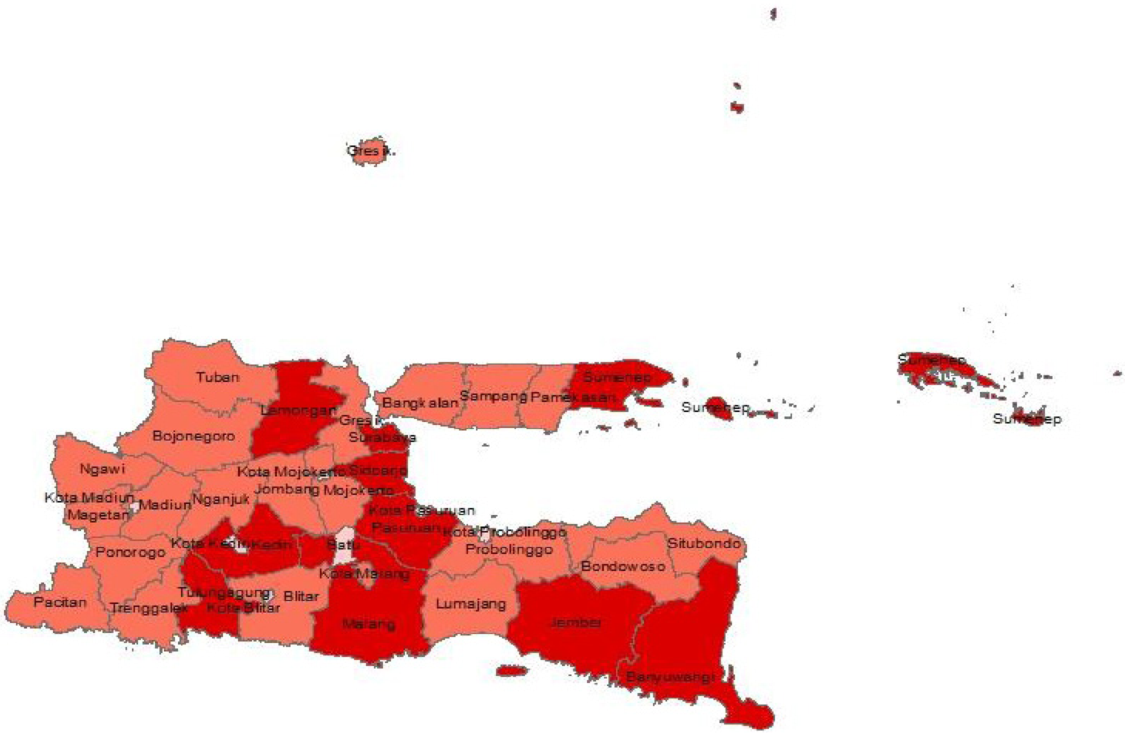

Figure 8. General Allocation Fund in East Java

Based on the results of the thematic map in figure 8, it shows that the brighter the color of the area on the map, the smaller the General Allocation Fund value will be. It is known that the Mojokerto City area is the area with the lowest General Allocation Fund amount in East Java, which is also indicated by the lighter red color in the Mojokerto City area.

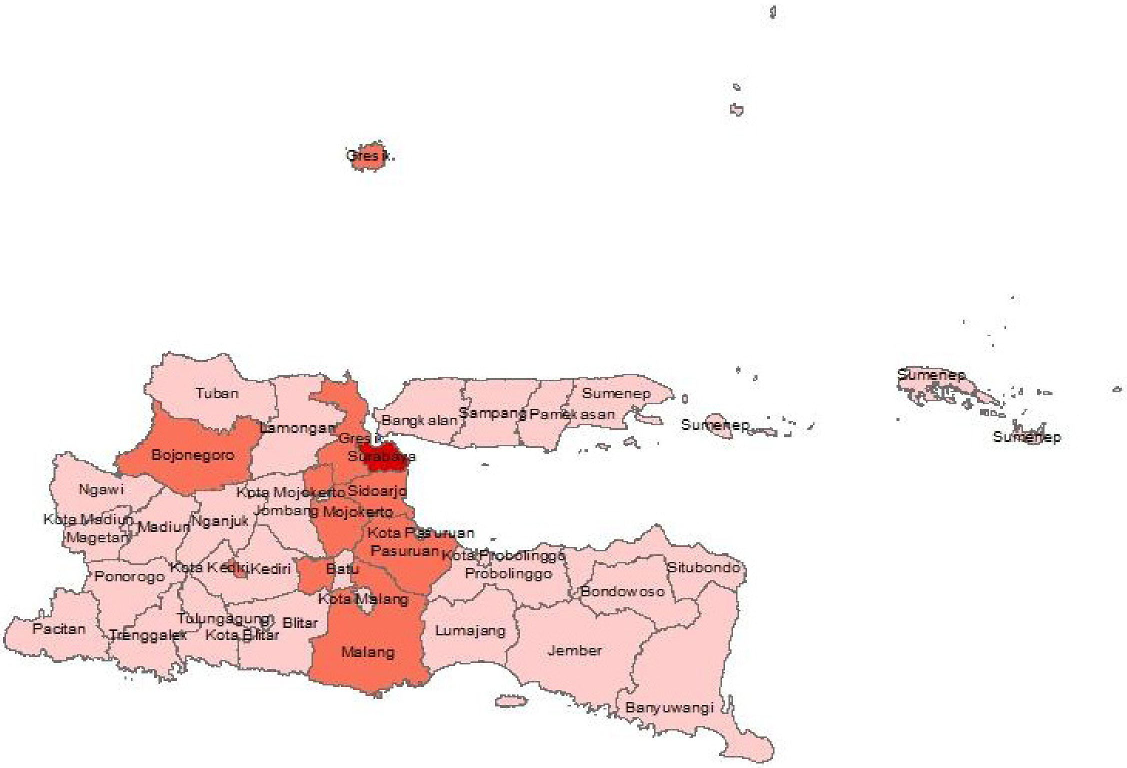

Figure 9. Production Agglomeration in East Java

Based on the results of the thematic map in figure 9, it shows that the brighter the color of the area on the map, the smaller the production agglomeration value will be. It is known that the Blitar City area is the area with the lowest production agglomeration value in East Java, which is also indicated by the lighter red color in the Blitar area.

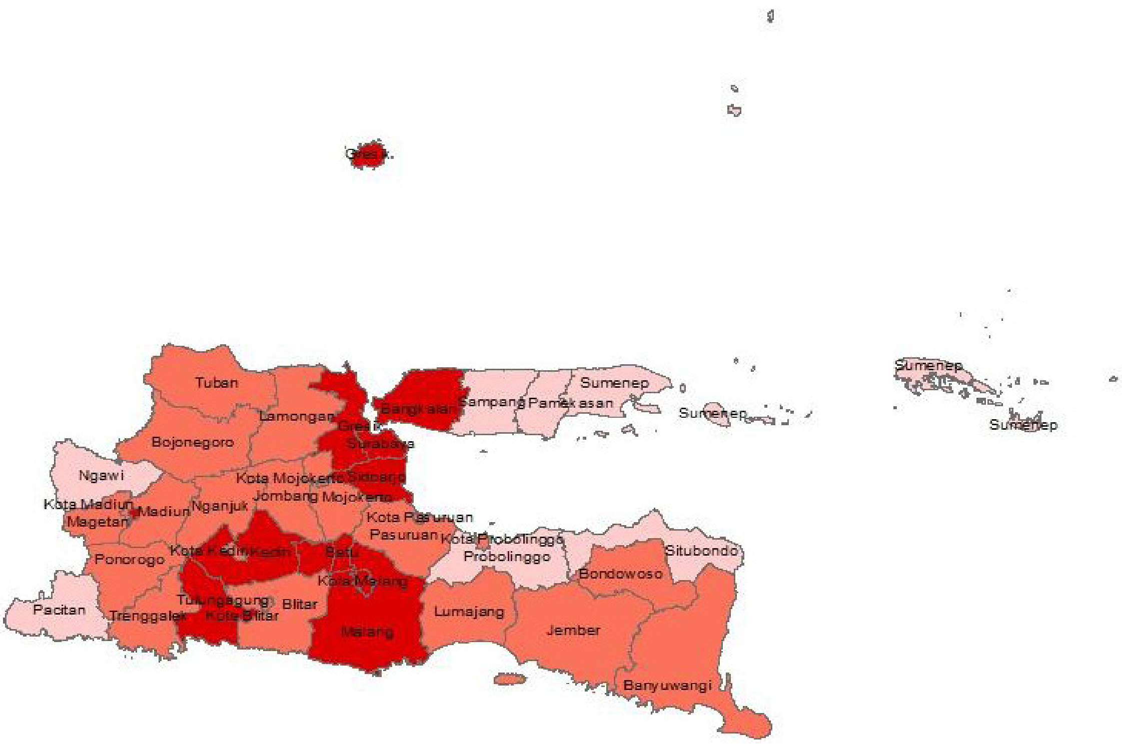

Figure 10. Open Unemployment Rate in East Java

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Based on the results of the thematic map in figure 10, it shows that the darker the color of the area on the map, the higher the Open Unemployment Rate value will be. It is known that the Sidoarjo Regency area is the area with the highest number of the Open Unemployment Rate in East Java, which is also indicated by the increasingly dense red color in the Sidoarjo Regency area.

Spatial Heterogeneity Test

Furthermore, spatial heterogeneity testing was carried out using the Breusch-pagan test method. This method is used to determine spatial heterogeneity in the research dataset. Using a significance level of α = 5 %, the following are the Breusch-pagan test hypotheses:

- H_0: variance between locations is the same (homogeneous).
- H_1: variance between locations is different (heterogeneous).

Based on the results of the Breusch-pagan test using the R Studio software, the p- value = $7,22110^{-5}$ < significance level α = 5 % and the BPtest value = 84,119 $>_{7}^{2}$= 15,5, it can be concluded that H_0 is rejected or the variance between locations is different (heterogeneous).

Spatial Weighting

In conducting spatial data analysis, spatial weighting is a very important factor in determining the weighting matrix (W_{ij}) that represents the location between research locations. The calculation of the weighting matrix is done by substituting the Euclidean distance value with the optimum bandwidth obtained into the kernel function used. The calculation results of each kernel can be seen in table 4 kernel selection based on the smallest AICc value.

Table 4. Kernel Exploration Results

Criteria		**AICc**
Fixed	Bisquare	142,315
	Tricube	140,697
	Gaussian	136,646
Adaptive	Bisquare	150,641
	Tricube	148,965
	Gaussian	137,786

Based on the results of the specified selection criteria score (AICc) in table 4, the kernel function that will be used in this research is Fixed Gaussian. The optimum bandwidth (h) used for this observation is 3,339 with a minimum Cross Validation (CV) score of 82,193.

GWR Analysis

After the assumption of spatial heterogeneity is met, the next step is to conduct a Geographically Weighted Regression (GWR) analysis, in this research R software was used.

Parameter Estimation Result

The calculation of the estimated parameter values of the GWR model using the Fixed Gaussian weighting is shown in table 5.

Table 5. Estimated Parameter Values of the GWR Model

Regency/City	β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8
Bangkalan	-5,040	-0,143	0,115	0,026	-0,162	0,303	0,431	-39,571	-0,233
Banyuwangi	-5,151	-0,139	0,113	0,027	-0,196	0,302	0,477	-39,324	-0,225
Blitar	-5,252	-0,141	0,116	0,026	-0,182	0,307	0,465	-39,823	-0,227
Bojonegoro	-5,344	-0,140	0,117	0,026	-0,190	0,308	0,479	-39,975	-0,225
Bondowoso	-5,199	-0,143	0,117	0,026	-0,164	0,307	0,440	-39,979	-0,231
Gresik	-5,102	-0,140	0,114	0,027	-0,186	0,302	0,462	-39,354	-0,228
Jember	-5,105	-0,143	0,116	0,026	-0,164	0,305	0,436	-39,715	-0,232
Jombang	-5,199	-0,139	0,114	0,027	-0,193	0,304	0,476	-39,492	-0,226
Kediri	-5,219	-0,142	0,116	0,026	-0,174	0,307	0,453	-39,869	-0,229

Lamongan	-5,296	-0,141	0,117	0,026	-0,181	0,308	0,466	-39,977	-0,227
Lumajang	-5,343	-0,140	0,117	0,026	-0,189	0,309	0,477	-39,994	-0,225
Madiun	-5,302	-0,141	0,117	0,026	-0,181	0,308	0,465	-40,002	-0,227
Magetan	-5,302	-0,142	0,118	0,026	-0,174	0,309	0,456	-40,139	-0,228
Malang	-5,271	-0,140	0,116	0,026	-0,186	0,307	0,471	-39,810	-0,227
Mojokerto	-5,186	-0,142	0,116	0,026	-0,172	0,306	0,450	-39,798	-0,230
Nganjuk	-5,172	-0,141	0,115	0,026	-0,178	0,305	0,457	-39,664	-0,229
Ngawi	-5,164	-0,141	0,115	0,027	-0,181	0,304	0,461	-39,582	-0,228
Pacitan	-5,127	-0,143	0,116	0,026	-0,163	0,305	0,436	-39,793	-0,232
Pamekasan	-5,245	-0,140	0,115	0,027	-0,191	0,305	0,476	-39,658	-0,226
Pasuruan	-5,292	-0,142	0,117	0,026	-0,174	0,309	0,456	-40,097	-0,228
Ponorogo	-5,323	-0,142	0,118	0,026	-0,174	0,310	0,457	-40,206	-0,228
Probolinggo	-5,300	-0,140	0,116	0,026	-0,190	0,307	0,478	-39,831	-0,226
Sampang	-5,197	-0,142	0,116	0,026	-0,174	0,306	0,453	-39,794	-0,229
Sidoarjo	-5,261	-0,142	0,117	0,026	-0,174	0,308	0,455	-39,991	-0,229
Situbondo	-5,276	-0,142	0,118	0,026	-0,167	0,309	0,447	-40,172	-0,229
Sumenep	-5,432	-0,140	0,118	0,026	-0,186	0,312	0,477	-40,355	-0,224
Trenggalek	-4,975	-0,143	0,114	0,026	-0,163	0,301	0,430	-39,385	-0,233
Tuban	-5,201	-0,141	0,116	0,026	-0,180	0,305	0,461	-39,705	-0,228
Tulungagung	-5,368	-0,141	0,118	0,026	-0,182	0,310	0,469	-40,203	-0,226
Batu	-5,168	-0,141	0,115	0,027	-0,184	0,304	0,464	-39,556	-0,228
Blitar City	-5,003	-0,143	0,114	0,026	-0,163	0,302	0,431	-39,464	-0,233
Kediri City	-5,154	-0,142	0,116	0,026	-0,172	0,305	0,449	-39,706	-0,230
Madiun City	-5,057	-0,141	0,113	0,027	-0,182	0,301	0,455	-39,299	-0,229
Malang City	-4,916	-0,143	0,113	0,027	-0,161	0,300	0,425	-39,272	-0,234
Mojokerto City	-5,113	-0,142	0,115	0,026	-0,168	0,304	0,441	-39,673	-0,231
Pasuruan City	-5,405	-0,140	0,118	0,026	-0,189	0,311	0,480	-40,199	-0,225
Probolinggo City	-5,127	-0,143	0,117	0,026	-0,157	0,306	0,428	-39,904	-0,233
Surabaya	-5,373	-0,140	0,117	0,026	-0,188	0,310	0,478	-40,097	-0,225

Based on the results in table 5 shows that the negative intercepts across regions suggest an overall baseline reduction in GRDP growth without the influence of independent variables. Most coefficients exhibit consistent signs and similar magnitudes across regions, indicating relatively stable relationships, such as a positive impact of human development index and regional income, and a negative influence of unemployment rate and population density. The significant negative coefficients for agglomeration (X_7) across all regions imply a strong inverse relationship with GRDP growth, highlighting the potential challenges of over-concentration in economic activity.

Parameter Significance Test

GWR model parameter testing was conducted to determine the parameters of the predictor variables that have a significant influence on each observation location, using a significance level of α = 5 %, the following is the test hypothesis in the parameter test:

- H_0: $\beta_k (u_i, v_i) = 0$; the predictor variable (β_k) has no influence on the response variable; for k=1,2,…,8; i=1,2,…,38
- H_1: $\beta_k (u_i, v_i) \neq 0$; the predictor variable (β_k) has an influence on the response variable; for k = 1,2,…,8; i = 1,2,…,38

The table of parameter significance test results is shown in table 6.

Based on the results on table 6 show the significance levels of each parameter across all regencies and cities in East Java, indicating how strongly each independent variable influences the GRDP growth rate per capita. Generally, all intercepts and coefficients (β_1 to β_8) show relatively low p-values (mostly below 0,05), suggesting that the explanatory variables such as human development index (X_2), average minimum wage (X_3), population density (X_4), and others are statistically significant in explaining regional economic growth. Notably,

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variables like X_3 (average minimum wage) consistently exhibit the lowest p-values across regions, indicating a particularly strong and consistent relationship with GRDP growth. This suggests that regional economic policies focusing on wage regulation and employment (as reflected in X_3 and X_8) may have a critical role in influencing economic development across East Java.

Table 6. Parameter Significance Test of the GWR Model

Regency/City	β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8
Bangkalan	0,344	0,127	0,008	0,693	0,1	0,016	0,063	0,143	0,344
Banyuwangi	0,408	0,117	0,007	0,71	0,094	0,017	0,064	0,163	0,408
Blitar	0,339	0,131	0,007	0,627	0,091	0,014	0,056	0,153	0,339
Bojonegoro	0,332	0,135	0,007	0,596	0,088	0,012	0,053	0,157	0,332
Bondowoso	0,311	0,141	0,008	0,615	0,094	0,013	0,056	0,146	0,311
Gresik	0,392	0,118	0,007	0,714	0,096	0,017	0,065	0,156	0,392
Jember	0,333	0,131	0,008	0,662	0,097	0,015	0,06	0,144	0,333
Jombang	0,385	0,12	0,007	0,679	0,092	0,015	0,061	0,16	0,385
Kediri	0,328	0,135	0,008	0,626	0,093	0,014	0,056	0,149	0,328
Lamongan	0,324	0,137	0,007	0,602	0,09	0,013	0,054	0,153	0,324
Lumajang	0,329	0,136	0,007	0,594	0,088	0,012	0,053	0,156	0,329
Madiun	0,322	0,138	0,007	0,598	0,09	0,013	0,053	0,153	0,322
Magetan	0,305	0,145	0,008	0,583	0,091	0,012	0,052	0,151	0,305
Malang	0,345	0,130	0,007	0,626	0,09	0,013	0,056	0,155	0,345
Mojokerto	0,333	0,132	0,008	0,64	0,094	0,014	0,058	0,148	0,333
Nganjuk	0,351	0,127	0,008	0,66	0,094	0,015	0,059	0,151	0,351
Ngawi	0,362	0,124	0,007	0,672	0,094	0,015	0,061	0,153	0,362
Pacitan	0,325	0,134	0,008	0,649	0,096	0,015	0,059	0,144	0,325
Pamekasan	0,364	0,125	0,007	0,650	0,090	0,014	0,058	0,157	0,364
Pasuruan	0,309	0,143	0,008	0,589	0,091	0,012	0,053	0,151	0,309
Ponorogo	0,300	0,148	0,008	0,573	0,090	0,012	0,051	0,152	0,300
Probolinggo	0,346	0,130	0,007	0,619	0,089	0,013	0,055	0,157	0,346
Sampang	0,335	0,132	0,008	0,639	0,093	0,014	0,058	0,149	0,335
Sidoarjo	0,318	0,139	0,008	0,605	0,091	0,013	0,054	0,15	0,318
Situbondo	0,298	0,148	0,008	0,582	0,092	0,012	0,052	0,149	0,298
Sumenep	0,298	0,151	0,007	0,544	0,087	0,011	0,048	0,158	0,298
Trenggalek	0,364	0,122	0,008	0,731	0,103	0,018	0,067	0,144	0,364
Tuban	0,349	0,128	0,007	0,65	0,093	0,014	0,058	0,152	0,349
Tulungagung	0,306	0,146	0,007	0,568	0,088	0,012	0,05	0,155	0,306
Batu	0,368	0,123	0,007	0,675	0,094	0,015	0,061	0,154	0,368
Blitar City	0,355	0,124	0,008	0,714	0,102	0,017	0,065	0,144	0,355
Kediri City	0,341	0,129	0,008	0,657	0,095	0,015	0,059	0,148	0,341
Madiun City	0,394	0,117	0,008	0,73	0,099	0,017	0,066	0,155	0,394
Malang City	0,374	0,119	0,008	0,758	0,106	0,019	0,07	0,144	0,374
Mojokerto City	0,34	0,129	0,008	0,667	0,097	0,015	0,06	0,146	0,34
Pasuruan City	0,312	0,144	0,007	0,563	0,087	0,011	0,05	0,158	0,312
Probolinggo City	0,310	0,140	0,008	0,634	0,097	0,014	0,058	0,142	0,310
Surabaya	0,320	0,140	0,007	0,578	0,087	0,012	0,051	0,157	0,320

Based on the results of the model parameter test on the GWR model using the help of R Studio software, $\alpha = 5\%$, and the following fixed Gaussian weighting in table 7 presents the grouping of research locations based on the similarity of significant variables at that location.

Table 7. Grouping of Research Locations Based on the Similarity of the GWR Model

Group	Regency/City	Significant Variables
1	Magetan, Pacitan, Ponorogo, Tulungagung	X_3, X_6, X_7
2	Bangkalan, Banyuwangi, Blitar, Bojonegoro, Bondowoso, Gresik, Jember, Jombang, Kediri, Lamongan, Lumajang, Madiun, Malang, Mojokerto, Nganjuk, Ngawi, Pamekasan, Pasuruan, Probolinggo, Sampang, Sidoarjo, Situbondo, Sumenep, Trenggalek, Tuban, Batu, Blitar City, Kediri City, Madiun City, Malang City, Mojokerto City, Pasuruan City, Probolinggo City, Surabaya.	X_3, X_6

Based on the significance results of the partially tested predictor variables for each observation location in table 7, two groups were formed. The first group consists of areas where the percentage of GRDP growth rate is influenced by the predictor variables UMR (X_3), General Allocation Fund (X_6), and Production Agglomeration (X_7). While the second group consists of areas where the percentage of GRDP growth rate is influenced by the predictor variables UMR (X_3) and General Allocation Fund (X_6). Figure 11 is the result of mapping the predictor variables that are significant to the GRDP Growth Rate variable at each observation location using the GWR model.

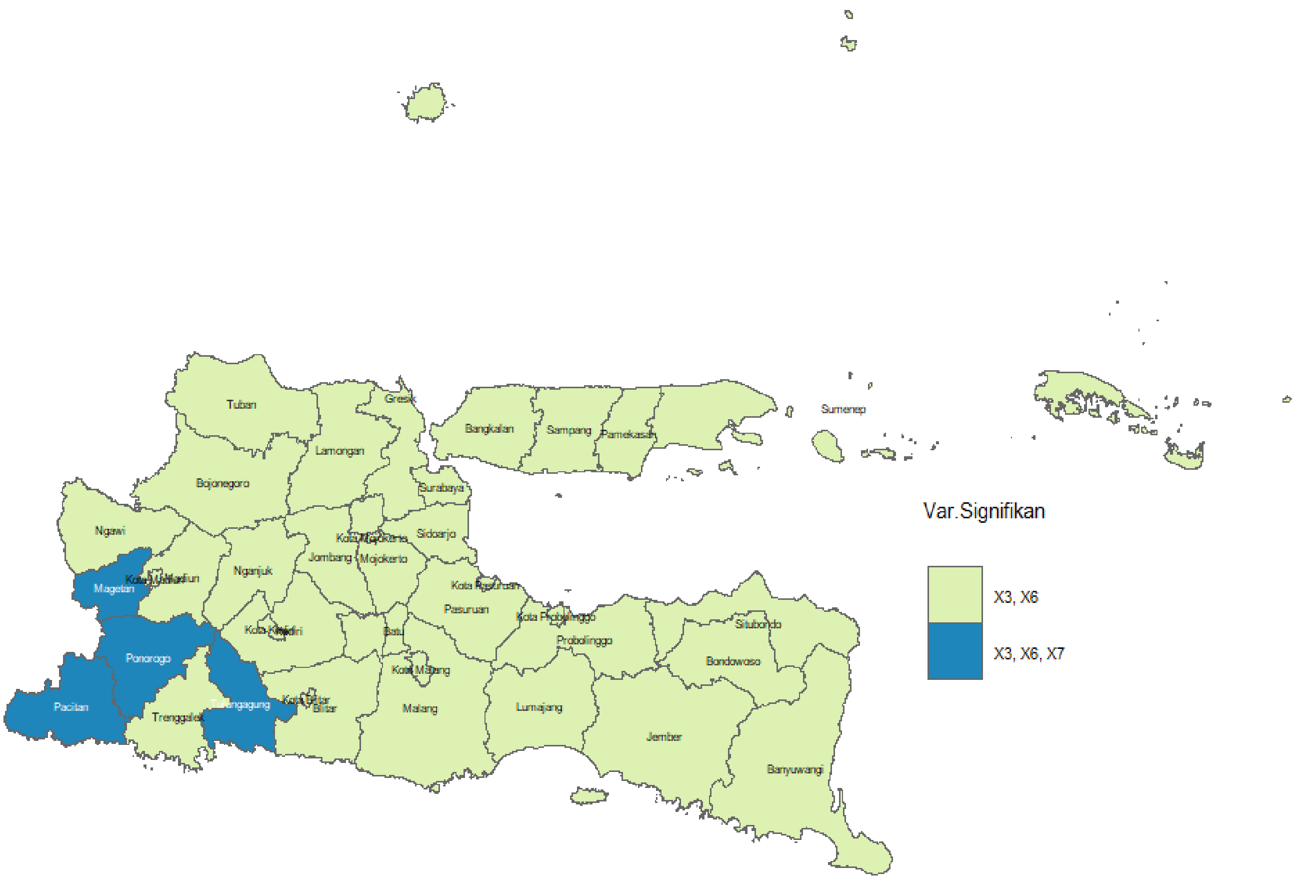

Figure 11. Thematic Map of Significant Variables of the GWR Model

The visualization results of the thematic map of GWR modeling using fixed Gaussian weighting as in figure 11 show that there are two groups of significant variables. There is an area in blue that has a concentration point in the southwest of East Java Province, based on this there is a possibility of similarities related to economic factors or there is a significant interaction of economic activities in the region. In addition, in the Magetan, Ponorogo, Pacitan, and Tulungagung regions there are many companies in the agricultural sector, processing industry, and local tourism that can adapt faster than other regions. Meanwhile, other regions have a more diversified economic sector or are more dependent on industries that are more severely affected by the COVID-19 pandemic, so the adaptation process takes longer. By using the GWR model, it can be seen that variables X_3 and X_6 are significant predictor variables for the Malang City area, so it can be modeled in equation (16).

$$\hat{Y}_{gwr\ malang\ city} = -4{,}916 + 0{,}0265X_3 + 0{,}424X_6 \quad (16)$$

Based on the results of the GWR model in Malang City in equation (16), it is obtained information that if there is an increase of one million rupiah in the Average Minimum Wage variable (X_3) in Malang City, it will affect the increase in the growth rate of Malang City's GRDP by 0,0265. Furthermore, if there is an increase of one billion rupiah in the General Allocation Fund variable (X_6) in Malang City, it will affect the increase in the growth rate of Malang City's GRDP by 0,424.

Spatial Variability Testing

Spatial variability testing is needed before conducting analysis with the MGWR model so that it can be known which variables significantly affect each observation location locally or globally. Using a significance level of α = 5 %, the following is the hypothesis of the spatial variability test:

- H_0: $\beta_k (u_1, v_1)=\beta_k (u_2, v_2)=\cdots=\beta_k (u_n, v_n)$; for k=1,2,…,8
- H_1: there is at least one $\beta_k (u_i, v_i)\neq \beta_k (u_j, v_j)$; for i ,j= 1,2,… ,n; k = 1,2,…,8

The table of spatial variability testing results is shown in table 8.

Table 8. Spatial Variability Testing

Variable	F	F_{table}	P-value	Decision	Conclusion
X_1	2,55279	2,048	0,014	Reject H_0	Significant
X_2	1,2902	2,071	0,279	Failed to reject H_0	Not significant
X_3	2,83135	2,069	0,010	Reject H_0	Significant
X_4	1,11744	2,361	0,390	Failed to reject H_0	Not significant
X_5	2,66412	2,054	0,013	Reject H_0	Significant
X_6	0,45271	2,073	0,761	Failed to reject H_0	Not significant
X_7	3,08799	2,407	0,001	Reject H_0	Significant
X_8	0,7131	2,099	0,406	Failed to reject H_0	Not significant

The test results in table 8 show that the variables Percentage of Poor Population (X_1), Regional Minimum Wage (X_3), Local Original Income (X_5), and Production Agglomeration (X_7) are significant variables or can be interpreted that these variables can have different effects depending on the location of observation. The variables Percentage of Human Development Index (X_2), Population Density (X_4), and General Allocation Fund (X_6), and Open Unemployment Rate (X_8) are not significant, which means that these variables do not have a significant difference in influence between observation locations.

MGWR Analysis

Parameter Estimation Result

Parameter Estimation Result in MGWR analysis displays the locally estimated coefficients (intercept and β_1 to β_8) for each regency and city. These coefficients represent the spatially varying relationships between the dependent variable and each independent variable, allowing for location-specific modeling in the MGWR framework. The parameter estimation result is shown in table 9.

Table 9. Parameter Estimation Results of the MGWR Model

Regency/City	β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7	β_8
Bangkalan	-4,918	-0,184	0,053	0,028	-0,206	0,336	0,375	-40,054	-0,241
Banyuwangi	-5,150	-0,193	0,053	0,029	-0,206	0,329	0,375	-40,166	-0,241
Blitar	-5,646	-0,183	0,053	0,028	-0,206	0,340	0,375	-40,867	-0,241
Bojonegoro	-5,784	-0,185	0,053	0,028	-0,206	0,355	0,375	-42,556	-0,241
Bondowoso	-5,255	-0,185	0,053	0,027	-0,206	0,376	0,375	-44,115	-0,241
Gresik	-5,081	-0,190	0,053	0,028	-0,206	0,323	0,375	-39,315	-0,241
Jember	-5,109	-0,183	0,053	0,027	-0,206	0,344	0,375	-40,899	-0,241
Jombang	-5,245	-0,188	0,053	0,028	-0,206	0,324	0,375	-39,603	-0,241
Kediri	-5,399	-0,183	0,053	0,027	-0,206	0,350	0,375	-41,723	-0,241
Lamongan	-5,554	-0,185	0,053	0,027	-0,206	0,359	0,375	-42,769	-0,241
Lumajang	-5,735	-0,185	0,053	0,028	-0,206	0,358	0,375	-42,815	-0,241

Madiun	-5,539	-0,185	0,053	0,027	-0,206	0,363	0,375	-43,145	-0,241
Magetan	-5,387	-0,187	0,053	0,027	-0,206	0,392	0,375	-45,918	-0,241
Malang	-5,809	-0,184	0,053	0,028	-0,206	0,337	0,375	-40,710	-0,241
Mojokerto	-5,344	-0,183	0,053	0,027	-0,206	0,344	0,375	-41,028	-0,241
Nganjuk	-5,317	-0,183	0,053	0,028	-0,206	0,329	0,375	-39,690	-0,241
Ngawi	-5,227	-0,184	0,053	0,028	-0,206	0,324	0,375	-39,275	-0,241
Pacitan	-5,155	-0,183	0,053	0,027	-0,206	0,353	0,375	-41,787	-0,241
Pamekasan	-5,469	-0,185	0,053	0,028	-0,206	0,327	0,375	-39,797	-0,241
Pasuruan	-5,396	-0,186	0,053	0,027	-0,206	0,384	0,375	-45,136	-0,241
Ponorogo	-5,384	-0,189	0,053	0,028	-0,206	0,404	0,375	-47,138	-0,241
Probolinggo	-5,904	-0,184	0,053	0,028	-0,206	0,339	0,375	-40,951	-0,241
Sampang	-5,399	-0,183	0,053	0,027	-0,206	0,342	0,375	-40,859	-0,241
Sidoarjo	-5,410	-0,185	0,053	0,027	-0,206	0,366	0,375	-43,357	-0,241
Situbondo	-5,314	-0,188	0,053	0,027	-0,206	0,405	0,375	-47,125	-0,241
Sumenep	-5,498	-0,192	0,053	0,028	-0,206	0,422	0,375	-49,190	-0,241
Trenggalek	-4,864	-0,187	0,053	0,028	-0,206	0,330	0,375	-39,479	-0,241
Tuban	-5,458	-0,183	0,053	0,028	-0,206	0,331	0,375	-39,910	-0,241
Tulungagung	-5,491	-0,189	0,053	0,028	-0,206	0,396	0,375	-46,491	-0,241
Batu	-5,223	-0,185	0,053	0,028	-0,206	0,323	0,375	-39,231	-0,241
Blitar City	-4,877	-0,186	0,053	0,028	-0,206	0,331	0,375	-39,610	-0,241
Kediri City	-5,280	-0,183	0,053	0,027	-0,206	0,335	0,375	-40,187	-0,241
Madiun City	-5,026	-0,191	0,053	0,028	-0,206	0,324	0,375	-39,321	-0,241
Malang City	-4,838	-0,190	0,053	0,028	-0,206	0,332	0,375	-39,727	-0,241
Mojokerto City	-5,129	-0,183	0,053	0,027	-0,206	0,337	0,375	-40,226	-0,241
Pasuruan City	-5,600	-0,189	0,053	0,028	-0,206	0,391	0,375	-46,115	-0,241
Probolinggo City	-5,137	-0,185	0,053	0,027	-0,206	0,376	0,375	-44,000	-0,241
Surabaya	-5,652	-0,187	0,053	0,028	-0,206	0,373	0,375	-44,364	-0,241

The results in table 9 shows the parameter estimation results of the MGWR model, showing how each coefficient varies across regencies and cities. The intercepts and several coefficients such as $β_1$, $β_3$, $β_5$, and $β_7$ display spatial variation, indicating that the relationship between the predictors and the response variable differs by location. Meanwhile, some coefficients such as $β_2$, $β_4$, $β_6$, and $β_8$ remain relatively constant, suggesting globally stable effects. The variation in local parameter estimates highlights the advantage of MGWR in capturing spatial heterogeneity, allowing for more region-specific insights compared to global regression models.

Parameter Significance Test

After conducting the spatial variability test, local and global variables have been obtained that will be used in conducting MGWR modeling, while the dependent variables used for local variables are variables X_1, X_3, X_5, and X_7 and global predictor variables X_2, X_4, X_6, and X_8. Furthermore, simultaneous and partial significance tests are carried out for all variables in the MGWR model.

Simultaneous Testing of Global Parameters of MGWR Model

Simultaneous testing on the global variables of the MGWR model is carried out to determine whether the global predictor variables will affect the response variables together, using a value at a significance level of α = 5 %. The following is the hypothesis of the simultaneous test of the global MGWR variables:

- H_0: $β_2 (u_i, v_i) = β_4 (u_i, v_i) = β_6 (u_i, v_i) = β_8 (u_i, v_i) = 0$; for i = 1,2,… ,38
- H_1: there is at least one $β_k (u_i, v_i) \neq 0$; for k=2,4,6,8; i = 1,2,…,38

Based on the results of the simultaneous test of the global MGWR variable using the R Studio software, the P-value = 9,757〚10〛^(-5) < α = 5 % and the F_{test} = 4,094> F_{table} = 1,8577 can be concluded to reject H_0 or the global variables used in the research simultaneously have a significant influence.

Simultaneous Testing of Local Parameters of MGWR Model

Simultaneous testing on the global variables of the MGWR model is carried out to determine whether the global predictor variables will affect the response variables together, using a significance level of α = 5 %. The following is the hypothesis of the simultaneous test of the global MGWR variables:

- H_0: $\beta_1 (u_i, v_i) = \beta_3 (u_i, v_i) = \beta_5 (u_i, v_i) = \beta_7 (u_i, v_i) = 0$; for i = 1,2,…,38
- H_1: There is at least one $\beta_k (u_i, v_i) \neq 0$; for k=1,3,5,7; i = 1,2,…,38

Based on the results of the simultaneous test of local MGWR variables using the help of R Studio software, the P-value = 3,224⟦10⟧^(-5) <α = 5 % and the F_{test} = 4,657> F_{table} = 1,872 can be concluded to reject H_0 or the local variables used in the study simultaneously have a significant influence.

Partial Testing of Global Parameters of the MGWR Model

Partial tests on the global variables of the MGWR model are carried out to determine which global predictor variables have an effect on the response variable, using a significance level of α = 5 %. The following are partial test hypotheses for the MGWR global variables.

- H_0: β_k=0 or the global variable X_k at the i-th location does not have a significant effect; for k=2,4,6,8; i = 1,2,… ,38
- H_1: $\beta_k \neq 0$ or the global variable X_k at the i-th location has a significant effect; for k=2,4,6,8; i = 1,2,… ,38

The partial test of global predictors variable is shown in table 10.

Table 10. Results of Partial Test of Global Predictor Variables

Variable	T_{test}	P-Value	Decision	Conclusion
X_2	2,575	0,992867	Failed to reject H_0	Not significant
X_4	-0,395	0,347284	Failed to reject H_0	Not significant
X_6	-1,786	0,04228	Reject H_0	Significant
X_8	-1,786	0,03441	Reject H_0	Significant

Based on table 10 which is the result of partial test of global variables in the MGWR model using the R Studio software, it is known that the predictor variables Human Development Index (X_2) and Population Density (X_4) do not have a significant effect on the response variable (GRDP growth rate) because they have a p-value > α = 5 %.

The population density factor does not have a significant influence in this research, this could be due to the COVID-19 pandemic and in 2022 is the new normal era, where population density depends on several factors such as non-formal economic activities and individual income. The Human Development Index factor does not have a significant influence in this research, this could also be due to the COVID-19 pandemic and in 2022 is the new normal era, because the COVID-19 pandemic has an influence on the Human Development Index indicators.

Partial Testing of Local Parameters of the MGWR Model

Partial tests on local variables of the MGWR model are carried out to determine which local predictor variables have an effect on the response variable at each observation location, using a significance level of α = 5 %. The following are partial test hypotheses for local MGWR variables

- H_0: $\beta_k (u_i, v_i)=0$ or local variables X_k at the i-th location do not have a significant effect; for k=1,3,5,7; i = 1,2,… ,38
- H_1: $\beta_k (u_i, v_i) \neq 0$ or local variables X_k at the i-th location have a significant effect; for k=1,3,5,7; i = 1,2,… ,38

The partial test of global predictors variable is shown in table 11.

Table 11. Results of Partial Test of Local Predictor Variables

Regency/City	X_1	X_3	X_5	X_7
Bangkalan	0,0000893	0,092	0,083	0,024
Banyuwangi	0,0000613	0,119	0,118	0,029
Blitar	0,0000948	0,074	0,067	0,022
Bojonegoro	0,0000872	0,060	0,059	0,019
Bondowoso	0,0000946	0,057	0,061	0,016

Gresik	0,0000711	0,112	0,107	0,029
Jember	0,0000951	0,080	0,074	0,022
Jombang	0,0000741	0,102	0,094	0,027
Kediri	0,0000966	0,069	0,065	0,020
Lamongan	0,0000921	0,060	0,059	0,018
Lumajang	0,0000875	0,058	0,058	0,018
Madiun	0,0000914	0,058	0,058	0,018
Magetan	0,0000908	0,046	0,054	0,014
Malang	0,0000925	0,075	0,068	0,023
Mojokerto	0,0000973	0,075	0,069	0,022
Nganjuk	0,0000946	0,088	0,077	0,025
Ngawi	0,0000894	0,095	0,083	0,027
Pacitan	0,0000956	0,073	0,069	0,020
Pamekasan	0,0000858	0,088	0,078	0,025
Pasuruan	0,0000912	0,049	0,056	0,015
Ponorogo	0,0000906	0,042	0,053	0,013
Probolinggo	0,0000894	0,073	0,066	0,022
Sampang	0,0000972	0,076	0,069	0,022
Sidoarjo	0,0000937	0,058	0,059	0,017
Situbondo	0,0000934	0,044	0,054	0,013
Sumenep	0,0000862	0,035	0,049	0,012
Trenggalek	0,0000778	0,104	0,098	0,027
Tuban	0,0000948	0,085	0,074	0,025
Tulungagung	0,0000861	0,043	0,052	0,014
Batu	0,0000865	0,097	0,086	0,027
Blitar City	0,0000832	0,100	0,092	0,026
Kediri City	0,0000965	0,084	0,074	0,024
Madiun City	0,0000693	0,115	0,113	0,029
Malang City	0,0000693	0,109	0,109	0,027
Mojokerto City	0,0000952	0,086	0,076	0,024
Pasuruan City	0,0000819	0,043	0,050	0,014
Probolinggo City	0,0000938	0,061	0,064	0,016
Surabaya	0,0000845	0,050	0,054	0,016

Based on table 11 above, which is the result of partial testing of local variables in the MGWR model using the assistance of R Studio software and a significance level of α = 5 %, the following are the results of grouping observation areas based on the similarity of significance of local variables presented in table 12.

Table 12. Regional Groups Based on Significant Local Predictor Variables of the MGWR Model

Group	Regency/City	Significant Variables
1	Pacitan and Trenggalek	X_1, X_3, X_5, X_7
2	Madiun Kota, Madiun, Magetan, Ngawi, Ponorogo, Tulungagung	X_1, X_3, X_7
3	Bangkalan, Banyuwangi, Bondowoso Bojonegoro, Blitar, Jember, Jombang, Kediri, Lamongan, Lumajang, Malang, Nganjuk, Pamekasan, Pasuruan, Probolinggo, Sampang, Situbondo, Sumenep, Trenggalek, Tuban, Batu, Pasuruan City, Probolinggo City, Blitar City, Kediri City, Madiun City, Malang City, Mojokerto Kota.	X_1, X_7

Figure 12 is the result of mapping the significant predictor variables on the GRDP Growth Rate variable at each observation location using the GWR model.

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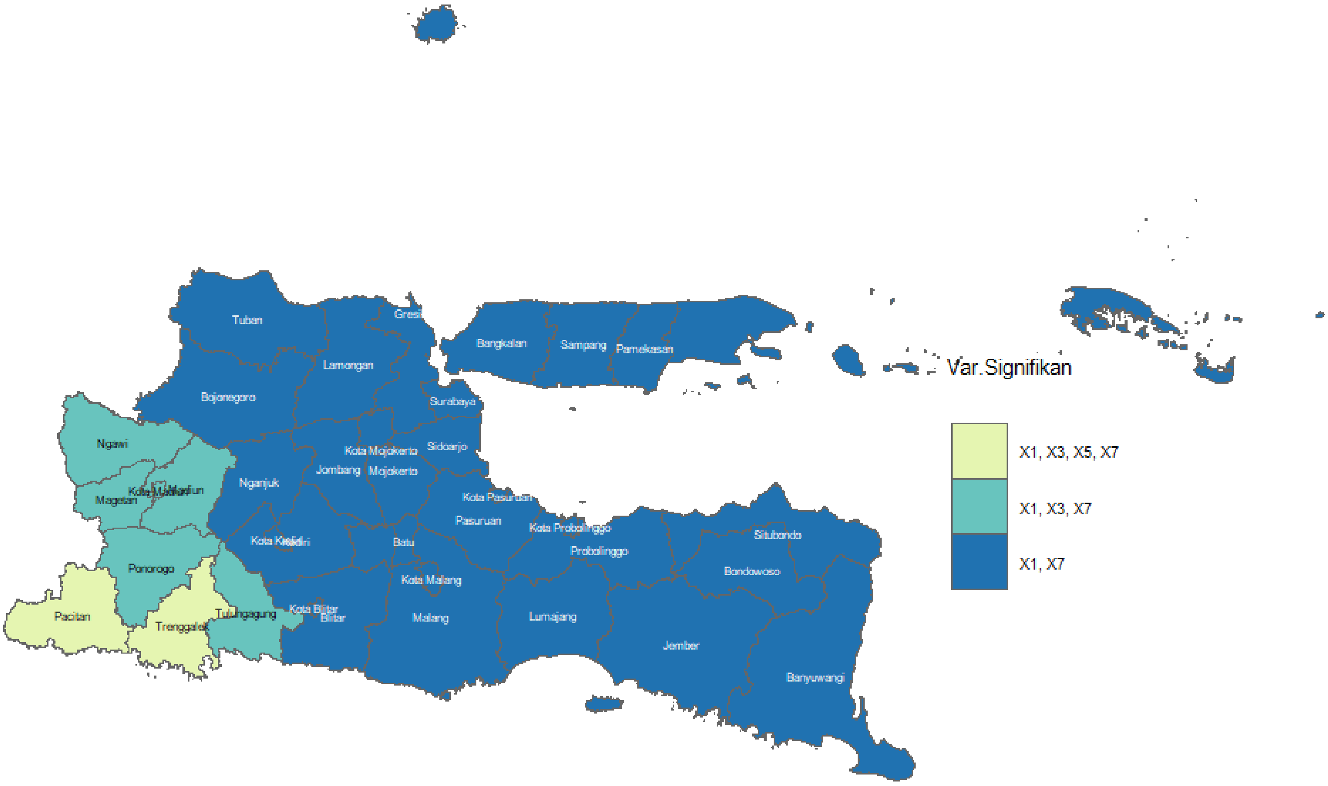

Figure 12. Thematic Map of Significant Variables of the MGWR Model

Figure 12 is the result of the visualization of thematic maps of significant local variable modeling using the MGWR model. The visualization results also show a concentration in the southwest of East Java Province like the previous GWR model results, but the visualization with the MGWR model has a more detailed grouping. Based on the results of the analysis and visualization of thematic maps of significant local variables, it is known that the Average Minimum Wage (X_3) and Regional Original Income (X_5) variables have a significant effect on the southwest region of East Java, this is thought to occur because there is a relationship and similarity in economic activity as indicated by the amount of Regional Minimum Wage which is not much different between these regions.

By using the results of the MGWR modeling, it can be seen that local and global variables X_1, X_6, X_7, and X_8 are significant predictor variables for the Malang City area, so they can be modeled in equation (17).

$$\hat{Y}_{mgwr\ malang\ city} = -4{,}838 - 0{,}1902X_1 + 0{,}375X_6 - 39{,}726X_7 - 0{,}241X_8 \quad (17)$$

Based on the results of the MGWR model in Malang City in equation (17), it is obtained that if there is an increase of one percent in the variable Percentage of Poor Population (X_1) in Malang City, it will affect the decrease in the growth rate of Malang City's GRDP by 0,190. Furthermore, if there is an increase of one billion rupiah in the General Allocation Fund variable (X_6) in Malang City, it will affect the increase in the growth rate of Malang City's GRDP by 0,375. Then, if there is an increase of one percent in the Production Agglomeration variable (X_7) in Malang City, it will affect the decrease in the growth rate of Malang City's GRDP by 39,726. If there is an increase of one percent in the Percentage of Open Unemployment Rate variable (X_8) in Malang City, it will affect the decrease in the growth rate of Malang City's GRDP by 0,241.

Model Selection

The best model between the GWR and MGWR models is determined by using the smallest AICc measurement parameters using the help of R Studio software. The following is a comparison of the measurement parameters of the GWR and MGWR models. The best model result shown in table 13.

Based on the results in table 13, it is known that using the MGWR model obtained the smallest AICc value of 134,318, so it is concluded that modeling using the MGWR method on the data used in the research is better than using the GWR model.

Based on the results in table 13, the MGWR model produced the smallest AICc value of 134,318, indicating that MGWR provides a better fit than the GWR model for the data used in this research. This finding is consistent with previous research, such as Fotheringham et al.[21], which demonstrated that MGWR often outperforms GWR in capturing spatial heterogeneity by allowing each predictor to operate at its own spatial scale. The improved model fit suggests that the spatial processes influencing GRDP growth in East Java vary across predictors and locations, which MGWR can accommodate more effectively than GWR. This supports the growing body of literature emphasizing the advantage of MGWR in regional economic modeling, particularly in complex, heterogeneous regions like East Java.[22] Thus, the application of MGWR contributes to more nuanced spatial interpretations and reinforces the importance of selecting flexible modeling techniques in spatial econometric studies.

Table 13. Best Model Assessment Parameter Values

Model	AICc
GWR	136,646
MGWR	134,318

CONCLUSIONS

In this research, the GWR model with a fixed Gaussian weighting kernel identified Average Minimum Wage (X_3), General Allocation Fund (X_6), and Production Agglomeration (X_7) as significant predictors of GRDP growth rate in East Java. Other variables—Percentage of Poor Population (X_1), Human Development Index (X_2), Population Density (X_4), Regional Original Income (X_5), and Percentage of Open Unemployment (X_8) did not show significant effects in any region under the GWR model.

Using the MGWR model, it was found that X_2 (Human Development Index) and X_4 (Population Density) remain insignificant both locally and globally. The COVID-19 pandemic is presumed to have caused substantial shifts in variables previously found significant in other studies, due to widespread economic disruption—such as supply chain issues, rising unemployment, declining demand, and health sector strain—impacting GRDP growth nationally and globally.

Additionally, Sampang, Sumenep, and Pamekasan show high poverty rates, low average wages, and low HDI, yet also low open unemployment. This may be due to the dominant agricultural sector, informal employment, and government programs absorbing the labor force. However, low-income levels from such jobs do little to alleviate poverty or improve HDI.

In the MGWR model, General Allocation Fund (X_6) and Open Unemployment Rate (X_8) have global significance, while X_1 (Poverty Rate), X_3 (Wages), X_5 (Local Income), and X_7 (Agglomeration) are locally significant. Thematic map comparisons show interaction patterns in southwest East Java and reveal MGWR provides more detailed spatial insight. MGWR also outperforms GWR with a lower AICc value (134,3184), confirming it as the best model for this dataset.

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