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Geographic Weighted Regression Models for Contraceptive Use in West Sumatera

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Abstract

Spatial heterogeneity in family planning is a critical issue that reflects significant variations in contraceptive use and related indicators across regions, highlighting the need for targeted interventions to enhance family planning services. The Geographically Weighted Regression (GWR) model, a spatial analytical approach, incorporates geographic weights at each observation site to estimate localized regression parameters. This study aims to identify the GWR model and determine the factors influencing the Contraceptive Prevalence Rate (CPR) in 19 districts and cities in West Sumatera Province in 2023. The Adaptive Kernel Bisquare Function is employed to assign spatial weighting, while Cross-Validation (CV) is used to optimize the bandwidth, ensuring robust and localized model estimation. Using secondary data from the West Sumatera Central Bureau of Statistics, the study reveals substantial spatial variability in the factors influencing CPR. Key determinants include the number of family planning clinics, the number of village family planning service posts, the proportion of poor households, and the proportion of women of reproductive age using contraceptives. The GWR model achieves a high coefficient of determination (R^2) of 86.98%, indicating strong model performance in explaining CPR variation. These findings underscore the methodological importance of Adaptive Kernel Bisquare weighting and cross-validation in capturing spatial heterogeneity and provide actionable insights for localized family planning strategies.

Keywords Contraceptive Use, Geographic Weighted Regression, Spatial Heterogeneity.

INTRODUCTION

Population growth is a global issue that seriously threatens people's quality of life, especially in countries that are developing or underdeveloped [1]. In Indonesia, population growth has an impact on public health. The maternal and newborn mortality rates remain high. In 2020, the maternal death rate was over 189 per 100,000 live births, while the infant mortality rate was roughly 18 per 1,000 live births [2]. This rate was higher than in other ASEAN nations. Family planning plays a crucial role in government efforts to effectively manage population growth, enhance maternal and child health, improve education and quality of life, advancing economic and social development [3]–[6].

Contraceptive Prevalence Rate (CPR) in Indonesia is still dominated by provinces with low categories. West Sumatra is one of the provinces that has a low CPR category. Disparities in contraceptive use between urban and rural areas, with lower prevalence in urban areas, socioeconomic and demographic factors such as age, education level, employment status, and number of living children also influence contraceptive use [7], [8].

Spatial modeling has emerged as a critical tool in public health for analyzing geographical patterns of health outcomes and their determinants. However, traditional methods like Ordinary Least Squares (OLS) and global spatial regression often fail to capture local variations, as they assume uniform relationships across regions. Recent studies, such as those on the spatial distribution of COVID-19 and stunting risk factors, demonstrate the limitations of global models in addressing spatial heterogeneity and emphasize the need for localized approaches [9]–[12].

Spatial heterogeneity in family planning highlights significant local variation in contraceptive use and related indicators, reflecting how the impact of explanatory variables may differ in different locations within a study area. These variations are critical for designing targeted and region-specific interventions to address disparities in family planning outcomes [13]–[17]. This variability is common in studies of contraceptive prevalence, where factors such as access to family planning services, socio-economic conditions, and cultural norms vary significantly across regions. In reality, geographic, socio-cultural, and other localized characteristics can cause substantial differences in the relationships observed in one area compared to another. To address this complexity, Geographically Weighted Regression (GWR) provides a robust framework by allowing regression parameters to vary spatially, enabling localized analysis. This method incorporates geographic information (spatial coordinates) into a normal regression model and applies the spatial covariance model to each regression model estimate to express the spatial variability derived from the regression model [14].

This study was conducted to form a GWR model, the factors that affect the percentage of CPR in each district and city in West Sumatra province and then compare the coefficient of determination R^2 and Sum square Error (SSE) between the GWR model and the global regression model so that the best model is obtained.

MATERIALS AND METHODS

Data

The research conducted is applied research. The data used is secondary data taken from the official website and publication book of West Sumatra in figures by the Central Bureau of Statistics (BPS) of West Sumatra Province in 2023. The object that is the topic of this research is the Contraceptive Prevalence Rate in West Sumatra Province in 2023 which is set as the dependent variable (Y), and the data set as the independent variable, namely the number of family planning service clinics (X_1), Village Family Planning Service Post (X_2), life expectancy (X_3), Proportion of productive-age women with a junior high school education or below (X_4), proportion of poor population (X_5), Proportion of women of reproductive age using contraceptives (X_6), Proportion of women over the age of 15 who are employed (X_7). The selection of variables in this study was based on geo-demographic, socio-economic data available from the Central Bureau of Statistics (BPS) and their relevance to contraceptive use as evidenced by prior research and their significance in the context of West Sumatera Province [18]–[20]. The analysis in this study was conducted using R-Studio, leveraging several specialized packages to implement the Geographically Weighted Regression (GWR) model effectively.

Global Regression.

The first step of this research is to conduct simultaneous and partial tests on the global regression model and determine the best global linear regression based on significant independent variables. Next, test the normality assumption, non-multicollinearity assumption and homoscedasticity assumption on the best global regression model.

Data exploration is done to see spatial patterns in the data. At this point, symptoms of spatial heteroscedasticity are sought using the Breush-Pagan test with Equation 1.

$$BP = \left(\frac{1}{2}\right) f^T Z(Z^T ZP)^{-1} Z^T f \sim \chi^2_{(p)} \tag{1}$$

Geographically Weighted Regression

The next step in the GWR model is spatial weighting, where the amount of weight assigned to each observation site is determined using a kernel function. The GWR model's kernel function is a weighting function that is employed to estimate model parameters. Greater weight will be assigned to data at the regression point than to data farther away [21], [22]. Equations 2 and 3 provide the generic form of the Adaptive Kernel Bisquare and adaptive kernel Gaussian weighting functions used in this study.

Adaptive Kernel Gaussian

$$w_{ij} = \exp\left(-\frac{1}{2}\left(\frac{d_{ij}}{h_{i(p)}}\right)^2\right)^2 \tag{2}$$

Adaptive Kernel Bisquare

$$w_{ij} = \begin{cases} \left(1 - \left(\frac{d_{ij}}{h}\right)^2\right)^2 & , for\ d_{ij} \le h_{i(p)} \\ 0 & , for\ d_{ij} \ge h_{i(p)} \end{cases} \tag{3}$$

Next, the cross validation (CV) value of the weighting function is examined to determine the optimum bandwidth, CV is defined in equation 4.

$$CV = \sum_{i=1}^{n} \left(y_i - \hat{y}_{\neq 1}(h)\right)^2 \tag{4}$$

The next step is to form a GWR model where for n observations with p independent variables, GWR can be written as equation 5.

$$y_i = \beta_0(u_i, v_i) + \sum_{k=1}^{p} \beta_k(u_i, v_i)\, x_{ik} + \varepsilon_{ik} \tag{5}$$

This GWR model was built to get a model that represents the percentage of CPR in West Sumatra Province and find out the factors that affect the percentage of CPR in each districts and city in West Sumatra Province. Additionally, the generated GWR model is subjected to the F and t-tests. The t-test is used to determine the explanatory variables that substantially influence the GWR model, whereas the F test is used to determine the significance between the GWR model and the global regression model. The t test is used to find explanatory variables that have a substantial impact on the model parameters.

RESULTS AND DISCUSSION

The percentage of CPR in West Sumatra Province varies across districts and cities due to differing regional conditions and influencing factors. The following table provides a summary of the descriptive statistics for the variables examined in this study.

Table 1 Descriptive Statistics of CPR and Influencing Variables

Variables	Min	Max	Mean
Y	51.78	74.34	64.9
X_1	14.00	269.00	101.95
X_2	13.00	467.00	95.68
X_3	65.10	75.13	70.78
X_4	29.65	70.14	52.02
X_5	2.27	13.72	5.90
X_6	30.17	68.81	49.80
X_7	49.10	70.86	62.17

Table 1 shows that the highest CPR percentage in West Sumatra Province in 2023 was 74.34% in Sawahlunto City, while the lowest was 51.77% in Mentawai Islands Regency.

.Global Linear Regression Model of CPR in West Sumatra Province

To get the best global regression model, first test the significance of the parameters both simultaneously and partially as follows.

Simultaneous Test

With hypothesis $H_0 : \beta_0 = \beta_1 = \cdots = \beta_7 = 0$ (no independent variable has a significant effect on the model) and H_1: at least one $\beta_j \neq 0$ (there is at least one independent variable that has a significant effect on the model) obtained the P-value 0.00 which is smaller than $\alpha = 5\%$, it can be concluded that H_0 is rejected, which means that at least one independent variable has a significant effect on the model.

Partial Test

$H_0 : \beta_k = 0$ (independent variable k has no effect on the model) and $H_1 : \beta_k \neq 0$ (independent variable k has an effect on the model). The analysis results produce t test statistics as follows.

Table 2 Parameter Estimation of Global Regression Model

Variables	Estimation	T value	Pr(>|t|)	
Intercept	10.23434	2.93	0.01371	Significant
X_1	0.042296	3.73	0.00330	Significant
X_2	0.028768	-3.65	0.00384	Significant
X_3	-0.578406	-1.31	0.21605	Not significant
X_4	0.061775	0.50	0.62579	Not significant
X_5	-2.243746	-5.99	8.94e-05	Significant

X_6	0.186472	2.61	0.02419	Significant
X_7	0.043144	0.37	0.71995	Not significant

Table 2 shows that the partial test at the 5% significance level obtained the variable number of family planning service clinics (X_1), Village Family Planning Service Post (X_2), Proportion of poor people (X_5) and the proportion of productive age women using contraceptives (X_6) has a significant effect on the percentage of CPR in West Sumatera province.

Based on the results of significance testing, the best global regression model is obtained:

$$\hat{Y} = 0.042X_1 + 0.029X_2 - 2.243X_5 + 0.186X_6$$

The global regression model produced an R^2 of 85.1% and an SSE value of 165.445.

Furthermore, global regression assumption testing is carried out to determine whether the model obtained has accuracy in estimation, is unbiased and consistent. In the assumption test, it can be concluded that the residuals are normally distributed, there is no linear relationship between explanatory variables, and the variance of the residuals is not constant. The results of the assumption test analysis can be seen in the following table:

Table 3 Normality, Multicolinearity,Heteroscedasticity Test

Normality Test			
Shapiro-Wilk			
Statistic	0.98		
P-value	0.97		
Multicolinearity Test			
Var	VIF	Var	VIF
X_1	2.81	X_5	2.41
X_2	2.2	X_6	1.64
X_3	4.07	X_7	1.57
X_4	5.95		
Heteroscedasticity test			
Breusch-Pagan Test			
BP	59.79		
Df	7		
p-value	0.0421		

Based on Table 3, given that the p-value is higher than 0.05, the residuals are thought to be normally distributed. Additionally, all explanatory variables have VIF values less than 10, indicating that multicollinearity among the explanatory variables is not an issue. The Breusch-Pagan test shows a p-value of less than 0.05, indicating that the global regression model exhibits heteroscedasticity, likely due to spatial heteroscedasticity. Therefore, the Geographically Weighted Regression (GWR) method was used in this study due to the violation of the non-heteroscedasticity assumption in the global regression model.

Geographically Weighted Regression Modeling

The first step to start the GWR analysis is to determine the optimum bandwidth using the minimum CV method. Selection of the optimum bandwidth by checking the Cross validation (CV) score of the weighting function. The results of the weighting function with the Kernel function can be seen in Table 4.

Table 4 Bandwith and CV score

Weight function	Gaussian	Bisquare
Band-with	19	19
CV score	667.14	523.64

Based on Table 4, the minimum CV value of Adaptive Gaussian Kernel is greater than the minimum CV value of Adaptive Bisquare Kernel. Therefore, the Adaptive Bisquare Kernel weighting function with an optimal bandwidth of 19 is used in this study, which means that points within a radius of 19 are considered optimally influential in shaping the location model parameters, which means that points within a radius of 19 are considered optimally influential in shaping the location model parameters. The bandwidth generated by the Bisquare Kernel function is not the same for each location, this is because the Adaptive Bisquare weighting function bases its calculations on points at the observation location. The GWR model will be created using the weighting matrices collected at each observation location, so that each district and city in West Sumatra Province has a unique model.

The results of the GWR model parameter estimation are presented in Table 5.

Table 5 Parameter Coefficient Estimation

Variables	Parameter coefficient		
	Min.	Median	Max.
Intercept	1.51e+01	2.49e+01	36.4782
X_1	-2.53e-02	-8.74e-03	0.01778
X_2	-3.22e-01	2.55e-01	0.3889
X_5	3.58e-02	5.54e-02	0.451
X_6	3.71e-01	5.11e-01	0.6035

With the weights used in the model, the parameter estimates apply locally, causing different parameter values for each district and city. From Table 5, the parameter value of the number of family planning clinics (X_1) ranges from -0.0253 to 0.01778, which means that the variable number of family planning clinics can affect the CPR in West Sumatra province with a range of estimated values between -0.0253 to 0.01778. The GWR parameter estimation model produces R^2 of 86.98% and SSE value of 114.3657.

GWR Model Fit Testing.

GWR model fit testing was conducted to determine model fit between the global regression model and the GWR model using the ANOVA test with the formulation of the hypothesis:

H_0 : $\beta_k(u_i, v_i) = \beta_k$, for each k = 0,1,2, ... , p and i = 1,2, ... , n (Between the global linear regression model and the GWR model, there are not any significant differences).

H_1 : at least one $\beta_k(u_i, v_i) \neq \beta_k$, for k = 0,1,2, ... , p (The global linear regression model and the GWR model differ significantly).

The p-value obtained is 0.498, it can be concluded that H_0 is not rejected, which means there is no significant difference between the global linear regression model and the GWR model. This can be seen from the independent variables that are significant between the global regression model and the GWR model are the same, namely the number of family planning service clinics (X_1), Village Family Planning Service post (X_2), and the Proportion of poor people (X_5) and the Proportion of productive age women using contraceptives (X_6).

Test of the significance of GWR parameters partially can be done using the t test with the following hypothesis test.

H_0 : $\beta_k(u_i, v_i)$ = 0, for each k = 0,1,2, ... , p and i = 1,2, ... , n (There is no significant effect of the predictor variable xk between locations).
H_1 : There is at least one $\beta_k(u_i, v_i) \neq 0$, for k = 0,1,2, ... , p (There is a significant effect of the predictor variable xk between one location and another).

With a significance level of 5%, the variables that significantly affect each district and city are presented in Table 6.

Table 6 Grouping of Districts and Cities Based on Significant Variables

No	Significant Variables	Kab/Kota
1	X_1, X_2, X_5, X_6	Kab. Kepulauan mentawai
2	X_1, X_2, X_6	Kota Payakumbuh
3	X_2, X_6	Kab. Padang Pariaman, Kab. Agam, Kab. Lima Puluh Kota, Kab. Pasaman, Kab. Pasaman Barat, Kota Padang Panjang, Kota Bukittinggi, Kota Pariaman.
4	X_5, X_6	Kab. Pesisir Selatan, Kab. Solok Selatan
5	X_6	Kab. Solok, Kab. Sijunjung , Kab. Dharmasraya, Kab. Tanah Datar, Kota Padang , Kota Solok, Kota Sawahlunto

Table 6 shows the factors influencing the percentage of CPR (Contraceptive Prevalence Rate) in each district and city in West Sumatra. The dominant factors affecting CPR in West Sumatra Province include the number of family planning clinic services and the proportion of women of reproductive age using contraceptives. Additionally, some districts and cities share similar factors influencing the CPR percentage. The following figures show the distribution of variables that significantly affect the percentage of CPR in West Sumatra Province.

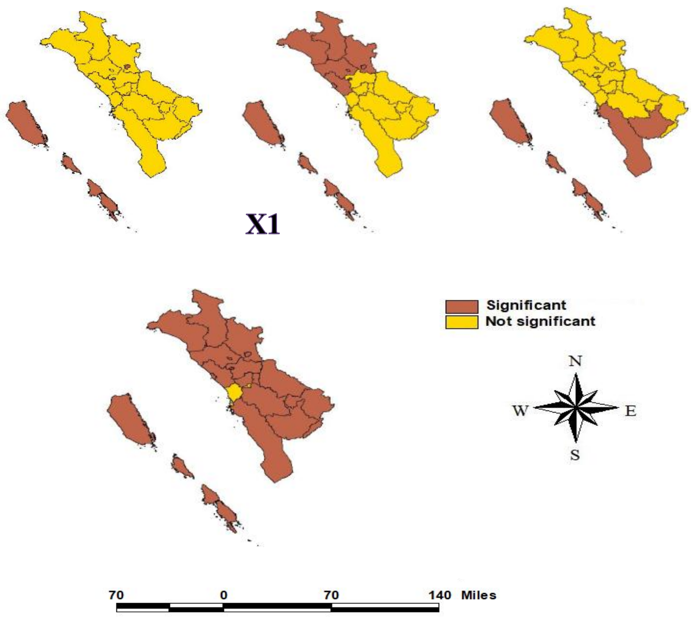

Figure 1 The distribution of variables that significantly affect the percentage of CPR in West Sumatra Province

A study of contraceptive use in West Sumatra reveals significant variations across different geo-demographic and socioeconomic characteristics of each district or city. Geo-demographically, areas with a high concentration of women of childbearing age, especially in urban areas such as Padang City and Bukittinggi, tend to have a higher prevalence of contraceptive use. This phenomenon is influenced by the accessibility of health facilities and the availability of information about family planning. Conversely, rural regions such as the Mentawai Islands District, Pasaman District, and West Pasaman District often encounter obstacles including limited access to health services, inadequate infrastructure, and lower educational levels, which can result in lower levels of contraceptive use [23][24].

In terms of socioeconomics, districts with low poverty rates and high levels of education tend to have better contraceptive prevalence [25]. This factor is supported by a more complete understanding of the benefits of family planning and the economic ability to access contraceptive services. In contrast, areas with a higher proportion of impoverished residents, such as some districts, demonstrate challenges in accessing contraceptive services due to financial limitations and socio-cultural constraints.
The analysis shows that the percentage of CPR in Mentawai Islands District is significantly influenced by several variables including the number of family planning clinics, the number of village family planning clinics, the proportion of poor people and the proportion of productive age women who use contraceptives. This can be understood with the unique local characteristics, being in the outermost region of West Sumatra Province with an archipelago-shaped area causes the process of implementing the family planning program to be constrained [20]. Villages on the islands are still very difficult to reach due to the lack of sea transport. The distance between islands also hampers the smooth socialization of the family planning program. To reach each area requires time and large operational costs. This condition is also pertinent to the high poverty rate in the Mentawai district. According to the most recent data, the percentage of impoverished individuals in this region reached 14.35%, which is higher than the average poverty percentage of West Sumatra province (6.28%) and the national average (9.78%)[26]. The following is a thematic map of the grouping of districts and cities in West Sumatera based on the independent variables affecting CPR in the local model**.**

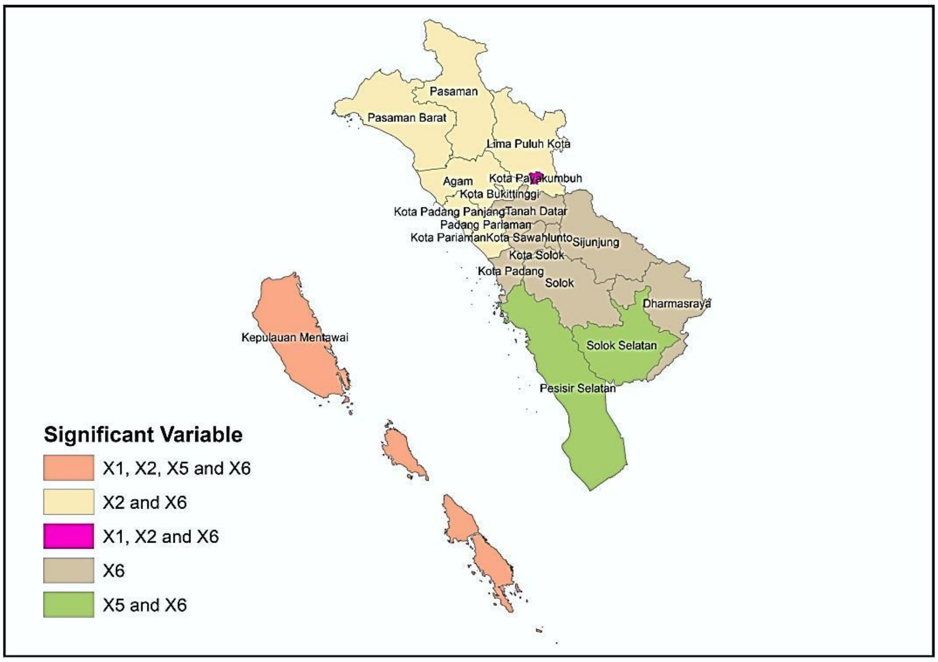

Fig. 2. Thematic Map of District / City Grouping of West Sumatra Province Based on Significant Variables

After analyzing the GWR model, 19 district and city local models were obtained based on the independent variables that influence each region. The Mentawai Islands District was used as one of the examples of districts/cities in West Sumatra Province that produced the GWR model using the Adaptive Bisquare weighting function as follows:

$$y_1 = 19.21 + 0.0177x_1 + 0.243x_2 + 0.047x_5 + 0.521x_6$$

Comparison of Global Linear Regression Model and GWR Model

To determine whether the model is more effective in simulating CPR in West Sumatra Province, the global linear regression model and GWR model are compared. Based on the R^2 value of each model presented in Table 7.

Table 7 Comparison of Global Linear Regression Model and GWR Model

	R^2(%)
Global Regression	85.10%
GWR	89.98%

Based on Table 7, it can be seen that the coefficient of determination (R^2 score) for the GWR model is 89.98%, which is higher compared to the R^2 score of the global regression model, which is 85.10%. The GWR model is considered superior to the global regression model because a higher R^2 value indicates a better model. Therefore, this comparison suggests that the GWR model provides a better explanation of the CPR rate in districts and cities in West Sumatra Province. The findings from geographically weighted regression (GWR) models demonstrate local variation in factors affecting contraceptive use prevalence (CPR). These findings provide strategic guidance for local governments in designing evidence-based policies. The government can use the results of this study's analysis to design strategies including:

The government can use the results of this study's analysis to design strategies including:

1. Tailoring Interventions Based on Local Needs: The government can prioritize interventions in areas with low CPR, such as the Mentawai Islands, by considering local factors such as poverty levels, accessibility of health services, and socio-cultural influences.
2. More Efficient Resource Allocation: The results of this study's analysis can help determine areas that require greater investment, such as family planning facilities or health worker training, to achieve significant impact.

CONCLUSION

The GWR model produced in this study using the Adaptive Bisquare kernel function is different for each districts and city in West Sumatra Province. Although the global linear regression model and the GWR model identify the same significant variables, the GWR model is more effective at explaining the factors affecting CPR in West Sumatra Province. Specifically, the coefficient of determination for the GWR model is higher than that for the global linear regression model. Both models identify several significant variables, including the number of family planning clinics, the number of village family planning service posts, the proportion of poor people, and the proportion of productive-age women using contraceptives. The findings from geographically weighted regression (GWR) models demonstrate local variation in factors affecting contraceptive use prevalence (CPR). These findings provide strategic guidance for local governments in designing evidence-based policies: tailoring interventions based on local needs, more efficient resource allocation.

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