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The Disparity of Maternal and Neonatal Death Modeling in Sumatra Region Using Geographically Weighted Bivariate Negative Binomial Regression

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Abstract

The Sumatra region occupies the second highest rank in terms of Maternal Mortality Rate (MMR) and Neonatal Mortality Rate (NMR) in Indonesia in 2020. Many factors are thought to have influenced these two cases, both directly and indirectly. So it is necessary to do an analysis to find out what factors influence MMR and NMR. The methods that can be used to determine these factors are Bivariate Negative Binomial Regression (BNBR) and Geographically Weighted Bivariate Negative Binomial Regression (GWBNBR). The results of the analysis show that the Deviance Information Criterion (DIC) in GWBNBR is smaller than BNBR, so GWBNBR is better than BNBR in modeling MMR and NMR in the Sumatra Region in 2020.

1. INTRODUCTION

Spatial effects include spatial dependence and heterogeneity [1]. Spatial dependence is a condition in which location observations depend on other nearby locations [2]. Meanwhile, spatial heterogeneity is a regional condition that has differences between one location and another, in terms of geography, socio-culture and other things that can lead to spatial diversity [3]. One of the impacts arising from the existence of spatial heterogeneity is that the regression parameters vary spatially [4].

Geographically Weighted Regression (GWR) is a method used to overcome spatial heterogeneity. The GWR model uses a weighting matrix whose magnitude depends on the proximity between locations and produces estimates of model parameters that are local for each location [5]. The response variable in the GWR model is estimated by predictor variables where each regression coefficient depends on the location where the data is observed [6].

If the response variable in the GWR model contains overdispersion, which is a condition where the mean value is smaller than the variance value, so that it follows a negative binomial distribution, then the development becomes Geographically Weighted Negative Binomial Regression (GWNBR) [7]. Research on GWNBR has been widely applied, for example in the health sector. [8] modeled the number of cases of Dengue Hemorrhagic Fever (DHF) in Bengkulu Province using GWNBR with Adaptive Bisquare Kernel. [9] uses GWNBR to model Corona Virus Disease 2019 (COVID-19) cases in Ciamis Regency with a Fixed Bisquare Kernel.

However, in practice GWNBR can only be applied to a single case or one response variable (univariate), so that in some cases there are two related response variables (bivariate) GWNBR cannot be applied. To deal with this problem, [10] developed the GWNBR method so that it can be applied to bivariate cases so that it becomes Geographically Weighted Bivariate Negative Binomial Regression (GWBNBR) which is applied to data on the number of PB and MB leprosy patients in East Java with an Adaptive Bisquare Kernel. [11] conducted research on GWBNBR on the number of school dropouts of compulsory education age and the number of women who married early in East Java using the Adaptive Bisquare Kernel. The GWBNBR method can be applied to other bivariate data, such as cases of maternal and neonatal deaths.

The World Health Organization (WHO) defines maternal and neonatal deaths not resulting from accidents or injuries. Efforts to improve maternal and neonatal health status including reducing the Maternal Mortality

Rate (MMR) and Neonatal Mortality Rate (NMR) are one of the priorities of the 2020-2024 National Medium-Term Development Plan (RPJMN) [12].

According to the Indonesian Ministry of Health (2021), the 2020 Indonesia Health Profile shows that MMR in Indonesia reaches 98 per 100,000 live births (KH) and NMR reaches 22 per 1000 KH, with 22% of maternal deaths and 21% of neonatal deaths occurring in the Sumatra Region. This figure illustrates that the Sumatra Region is in the second highest position after Java Island with 48% of the total maternal and neonatal deaths in Indonesia. As well as exceeding the RPJMN target which targets MMR 70 per 100,000 KH and NMR 12 per 1000 KH. Therefore, the Sumatra Region requires intervention to reduce MMR and NMR as early as possible.

The issue of disparity in maternal and infant mortality is two things that are interrelated because during this period the nutrients obtained by the fetus are channeled from the mother's body through the placenta so that the condition of the mother during pregnancy will affect the fetus and the baby that will be born. This study aims to examine and determine the factors that influence these two cases for each research unit, namely districts and cities using the GWBNBR method. The GWBNBR method will be compared with the BNBR method to obtain the best method for modeling MMR and NMR in the Sumatra Region in 2020.

1.1 Maternal Mortality Rate and Neonatal Mortality Rate

The Maternal Mortality Rate (MMR) is the ratio of women who die during pregnancy or within 42 days after pregnancy, both during pregnancy, childbirth and childbirth in every 100,000 KH. While the Neonatal Mortality Rate (NMR) is the ratio of deaths of newborns to 28 days after birth, that is, from 0-28 days or 4 weeks in every 1,000 KH.

1.2 Multicollinearity

Multicollinearity occurs when there is a perfect linear relationship between some or all of the predictors of the multiple regression model [13]. The detection of multicollinearity according to [14] is by looking at the Variance Inflation Factor (VIF) value. The VIF_j formula is generally written as follows:

$$\mathrm{VIF}_j = \frac{1}{1 - R_j^2}$$

where R_j^2 is the coefficient of determination of the j-th predictor on the other predictors. When the value of $VIF > 10$, it indicates that there is a multicollinierity among the predictors.

1.3 Overdispersion

Overdispersion occurs when the value of the variety of response variables is greater than the average value [15]. The hypothesis of over-dispersion testing on two response variables with the Index of Dispersion Test (I_B) approach is as follows [16]:

$H_0 : V(Y_k) = \left(\mu + \psi\mu^2\right)_k$ (there are significant overdispersion on both response variables)

$H_1 : V(Y_k) \neq \left(\mu + \psi\mu^2\right)_k$ (there are no significant overdispersion on either response variables)

Test statistic:

$$I_B = \frac{n\left(\bar{y}_2 S_{y_1}^2 - 2Cov_{y_1y_2}^2 + \bar{y}_1 S_{y_2}^2\right)}{\left(\bar{y}_1\bar{y}_2 Cov_{y_1y_2}^2\right)} \tag{1}$$

where

$S_y^2 = \frac{\sum_{i=1}^{n}(y-\bar{y})}{n}$ and $Cov_{y_1y_2} = \frac{\sum_{i=1}^{n}(y_{1i}-\bar{y}_1)(y_{2i}-\bar{y}_2)}{n}$

Rejection criteria:

H_0 is rejected if $|I_B| > \chi^2_{(\alpha;2n-3)}$.

1.4 Correlation

The bivariate regression model is used when a pair of data is correlated [17]. The hypothesis of testing the correlation between Y_1 and Y_2 was carried out using the Pearson's Product Moment Correlation (ρ) approach as follows [18]:

$H_0 : \hat{\rho} = 0$ (there is no significant correlation between Y_1 and Y_2)

$H_1 : \hat{\rho} \neq 0$ (there is a significant correlation between Y_1 and Y_2)

Test statistic:

$$t_{cal} = \frac{\hat{\rho}_{y_1y_2}\sqrt{n-2}}{\sqrt{1-(\hat{\rho}_{y_1y_2})^2}}$$

where $\hat{\rho}_{y_1y_2} = \frac{\sum_{i=1}^{n}(y_{1i}-\bar{y}_1)(y_{2i}-\bar{y}_2)}{\sqrt{\sum_{i=1}^{n}(y_{1i}-\bar{y}_1)^2\sum_{i=1}^{n}(y_{2i}-\bar{y}_2)^2}}$

Rejection criteria:

H_0 is rejected if $|t_{cal}| > t_{\alpha/2:n-2}$.

1.5 Bivariate Negative Binomial Regression

1.5.1 Bivariate Negative Binomial Regression Model

Bivariate Negative Binomial Regression (BNBR) is based on the Bivariate Negative Binomial (BNB) distribution. If a pair of response variables Y_1 and Y_2 each have a Negative Binomial distribution which is regressed against the predictor variables $X_1, X_2, \ldots, X_p$ then the form of the BNBR model equation can be expressed as [19]:

$$(y_1, y_2) \sim BNB(\mu_1, \mu_2, \psi_1, \psi_2, \lambda)$$
$$\mu_{ki} = \exp\left(\mathbf{x}_i^T \boldsymbol{\beta}_k\right), i = 1,2, \ldots, n; k = 1,2$$

where

$\mathbf{x}_i^T = \begin{bmatrix} 1 & x_{i1} & x_{i2} & \ldots & x_{ip} \end{bmatrix}^T$

$\boldsymbol{\beta}_k = \begin{bmatrix} \beta_{k0} & \beta_{k1} & \beta_{k2} & \ldots & \beta_{kp} \end{bmatrix}^T$

The parameter estimation of the BNBR model was carried out using the Maximum Likelihood Estimation (MLE) method with the Newton-Raphson iteration procedure.

1.5.2 BNBR Model Parameter Testing

BNBR model testing is divided into two, namely simultaneous and partial testing.
Simultaneous testing of the BNBR model parameter uses the Maximum Likelihood Ratio Test (MLRT). The hypothesis used is as follows [19]:

$H_0: \beta_{k1} = \ldots = \beta_{kj} = 0; j = 1,2, .. p; k = 1,2$

H_1: at least one $\beta_{kj} \neq 0$

Test statistic:

$$D_0 = -2\ln\left[\frac{L(\hat{\omega})}{L(\hat{\Omega})}\right]$$

where

$L(\hat{\omega})$: maximum likelihood value under H_0

$L(\hat{\Omega})$: maximum likelihood value under H_1

Rejection criteria:

H_0 is rejected if $|D_0| > \chi^2_{(\alpha;(b-a))}$.

Partial testing of the BNBR model parameter uses the Wald test with the following hypothesis [20]:

$H_0: \beta_{kj} = 0; j = 1,2, .. p; k = 1,2$

$H_1: \beta_{kj} \neq 0$

Test statistic:

$$Z_{hit} = \frac{\widehat{\beta}_{kj}}{se(\widehat{\beta}_{kj})}$$

Rejection criteria:
H_0 is rejected if $|Z_{hit}| > Z_\alpha$.

1.6 Spatial Heterogeneity

Spatial heterogeneity indicates regional diversity caused by the fact that the spatial units within an observation area are basically not homogeneous [2]. Hypothesis testing of spatial heterogeneity if there are two or more response variables is carried out using the Glejser'G approach as follows [21]:

$H_0: \sum_1 = \dots = \sum_n = \begin{bmatrix} \sigma_1^2 & \sigma_{21} \\ \sigma_{12} & \sigma_2^2 \end{bmatrix}$ (there is spatial homogeneity)

H_1: at least one $\sum_i \neq \begin{bmatrix} \sigma_1^2 & \sigma_{21} \\ \sigma_{12} & \sigma_2^2 \end{bmatrix}$ (there is spatial heterogeneity)

Test statistic:

$$G = -\left[n - p - 1 - \frac{1}{2}(k - p + 1)\right] \ln \left[\frac{|\Sigma_\Omega|}{|\Sigma_\omega|}\right] \#$$

where

$\sum_\Omega$: variance covariance matrix under H_1

$\sum_\omega$: variance covariance matrix under H_0

Rejection criteria:
H_0 is rejected if $|G| > \chi^2_{(\alpha;2p)}$.

1.7 Geographically Weighted Matrix (GWM)

1.7.1 Geographically Weighted Matrix

A geographically weighted matrix is needed because of spatial diversity. Using the wrong weights will cause the parameter estimates to be biased. While using the right weight will minimize the standard error [22].

The weighting matrix at the i-th location can be written in the following equation:

$$\boldsymbol{W}(u_i, v_i) = diag[w_1(u_i, v_i), \dots, w_n(u_i, v_i)]$$

where

u_i : latitude of the i-th location

v_i : longitude of the i-th location

Calculation of matrix elements is determined by a weighting function which contains the distance between locations and the smoothing parameter (bandwidth).

1.7.2 Haversine Distance

The Haversine formula is an equation used in navigation, which gives a circle distance between two points on the earth's surface based on longitude and latitude coordinates taking into account that the earth is not a flat plane but a plane that has degrees of curvature. [23]. Here is the Haversine formula [24]:

$$d_{ij} = 2R \arcsin\left[\sin^2\left(\frac{u_i - u_j}{2}\right) + \cos(u_i)\cos(u_j)\sin^2\left(\frac{v_i - v_j}{2}\right)\right]^{1/2}$$

where R is the unit length of the average radius of the Earth (6.371 km).

1.7.3 Bandwidth Parameters

Bandwidth is a smoothing parameter with a radius h from the center point of the location, which is used as a basis for determining the weight of each observation, so that a point that is within a circular radius is considered to still have influence. The method used to determine the optimal bandwidth is Cross Validation (CV) as follows:

$$CV(h) = \sum_{i=1}^{n} [y_i - \hat{y}_{\neq i}(h)]^2$$

where $\hat{y}_{\neq i}(h)$ is the estimator of y_i, with the observation at the i-th location point is omitted from the assessment process. The optimal bandwidth value is obtained when the CV is minimum [5].

1.7.4 Kernel Function

The kernel function has the advantage that it is flexible, has an easy mathematical form and can reach a level of convergence relatively quickly and functions to control the smoothness of the estimation curve [25]. One of the kernel functions that can be used in geographic weighting is the Adaptive Gaussian Kernel with the following equation [26]:

$$w_{ij} = \exp\left(-\frac{d_{ij}}{h_i}\right)^2$$

where

w_{ij}: weight of the i-th location to the j-th location

d_{ij}: the distance of the i-th location to the j-th location

h_i : smoothing parameter at the i-th location

1.8 Geographically Weighted Bivariate Negative Binomial Regression

1.8.1 Geographically Weighted Bivariate Negative Binomial Regression Model

The Geographically Weighted Bivariate Negative Binomial Regression Model (GWBNBR) is an extension of the BNBR model with geographic weights for parameter estimation. The form of the GWBNBR equation is as follows [10]:

$$(y_1, y_2) \sim BNB(\mu_1(u_i, v_i), \mu_2(u_i, v_i), \psi_1(u_i, v_i), \psi_2(u_i, v_i), \lambda(u_i, v_i))$$

$$\mu_{ki}(u_i, v_i) = \exp\left(\mathbf{x}_i^T \boldsymbol{\beta}_k^*\right)$$

where

$$\boldsymbol{\beta}_k^* = \boldsymbol{\beta}_k(u_i, v_i) = \left[\beta_{k0}(u_i, v_i)\ \beta_{k1}(u_i, v_i) \dots \beta_{kp}(u_i, v_i)\right]^T$$

GWBNBR model parameter estimation was carried out using the Maximum Likelihood Estimation (MLE) method with the Newton-Raphson iteration procedure.

1.8.2 GWBNBR Model Parameter Testing

GWBNBR model testing is divided into three, namely testing the similarity of the GWBNBR model with the BNBR model, simultaneous testing and partial testing.

Testing the similarity of the GWBNBR model with the BNBR model was carried out to test the significance of geographical factors in the resulting local parameters, with the following hypothesis [27]:

H_0: $\beta_{kj}^* = \beta_{kj}; j = 1,2, \dots, p; k = 1,2$ (there is no geographical influence on the model)

H_1: at least one $\beta_{kj}^* \neq \beta_{kj}$ (there is a geographical influence on the model)

Test statistic:

$$F_{hit} = \frac{D_0/df_0}{D_1/df_1}$$

where

D_0 : test statistic for the simultaneous test of the BNBR model

D_1 : test statistic for the simultaneous test of the GWBNBR model

df_0: degrees of freedom D_0 $(b-a)$
df_1: degrees of freedom D_1 $\left(2(b-a)\right)$
a : the number of parameter under H_0
b : the number of parameter under H_1

Rejection Criteria:
H_0 is rejected if $|F_{hit}| > F_{\alpha;(df_0,df_1)}$.

Simultaneous testing of the GWBNBR model parameter uses the Maximum Likelihood Ratio Test (MLRT). The hypothesis used is as follows [19]:

$H_0: \beta_{k1}^* = \ldots = \beta_{kj}^* = 0; j = 1,2,..p; k = 1,2$
H_1: at least one $\beta_{kj}^* \neq 0$

Test statistic:

$$D_1 =- 2\ln\left[\frac{L(\widehat{\omega}^*)}{L(\widehat{\Omega}^*)}\right]$$

Rejection criteria:
H_0 is rejected if $|D_1| > \chi^2_{(\alpha;2(b-a))}$.

Partial testing of the GWBNBR model parameter uses the Wald test with the following hypothesis [20]:

$H_0: \beta_{kj}^* = 0; j = 1,2,..p; k = 1,2$
$H_1: \beta_{kj}^* \neq 0$

Test statistic:

$$Z_{hit} = \frac{\widehat{\beta}_{kj}^*}{se\left(\widehat{\beta}_{kj}^*\right)}$$

Rejection criteria
H_0 is rejected if $|Z_{hit}| > Z_{\alpha}$.

1.9 Goodness-of-fit Criteria

Deviance Information Criterion (DIC) is used to measure the goodness of the Generalized Linear Model (GLM) which is equivalent to AIC and BIC. As with AIC and BIC, the best model is the model that has the smallest DIC value [28].

The formula for the DIC value of the BNBR model is as follows [29]:

$$DIC =- 2\ln\left[\frac{L(\widehat{\Omega})}{L(\widehat{\Theta})}\right]$$

where $L(\widehat{\Theta})$ is the maximum likelihood value below H_1 where the μ value in the function is replaced by the observed y value.

2. METHOD

This study uses secondary data sourced from the publication of the Health Profiles of 9 Provinces in 2020, the West Sumatra Health Office Performance Report in 2021, 10 Provincial publications in Figures and Statistics on Provincial People's Welfare in 2020 by the Indonesian Central Bureau of Statistics (BPS Indonesia). There are 154 districts/cities in the Sumatra Region as observation units with 2 response variables (Y) and 20 predictor variables (X). The methods used are Bivariate Negative Binomial Regression (BNBR) and Geographically Weighted Bivariate Negative Binomial Regression (GWBNBR).

The first step in this research is to collect and describe the data. The second step examines the presence of predictor variable multicollinearity. The third step detects the overdispersion of the two response variables. The fourth step measures the correlation between the two response variables. The fifth step is doing BNBR modeling. The sixth step tested the spatial heterogeneity in the BNBR model. The seventh step forms a geographic weighting matrix. The eighth step is doing GWBNBR modeling. Then the final step is choosing the best model between the BNBR model and the GWBNBR model.

Table 1. Research Variables

Variable	Information
X_1	Percentage of Pregnant Women Implementing K1 Program
X_2	Percentage of Pregnant Women Implementing K4 Program
X_3	Percentage of Pregnant Women Receiving Blood Supplement Tablets
X_4	Percentage of Birth Receiving Health Services
X_5	Percentage of Birth Assisted by Health Workers
X_6	Percentage of Birth Assisted by Witch Doctor
X_7	Percentage of Babies Receiving Complete Basic Immunization
X_8	Percentage of Babies Receiving Exclusive Mother's Milk
X_9	Percentage of Infants Suffering from Malnutrition
X_{10}	Percentage of Early Married Young Women
X_{11}	Percentage of Out of School Teenagers
X_{12}	Percentage of Population Following Active Family Planning Program
X_{13}	Percentage of Population Having Health Insurance
X_{14}	Percentage of Active Smoking Population
X_{15}	Percentage of Poor Population
X_{16}	Percentage of Households Having Access to Proper Sanitation
X_{17}	Percentage of Households Having Access to Clean Water
X_{18}	Population Density Ratio Per km^2
X_{19}	Ratio of Health Workers Per 100,000 Population
X_{20}	Ratio of Health Facilities Per 100,000 Population
Y_1	Maternal Mortality Rate Per 100,000 Live Births
Y_2	Neonatal Mortality Rate Per 1000 Live Births
u	District/City Latitude Coordinates
v	Regency/City Longitude Coordinates

3. RESULTS AND DISCUSSION

3.1 Descriptive Analysis

Descriptive analysis was performed to determine the characteristics of a data. Descriptive analysis consists of measures of concentration and distribution of data. The measure of the concentration of the data can use the average value, while the measure of the spread of the data can use the value of the variance. Descriptive analysis shows that the variable percentage of pregnant women implementing the K1 program is a predictor that has the highest average compared to other predictors. Rokan Hulu District is the region with the lowest percentage of pregnant women implementing the K1 program, while the regions with the highest percentage of pregnant women implementing the K1 program are found in 22 districts/cities. Meanwhile, the predictor with the most diverse spread was the percentage of infants who received complete basic immunization because it had the highest variance value. the average value of MMR was 114 cases, while NMR was 5 cases.

The minimum value of MMR and NMR is 0, meaning that there are areas in the Sumatra Region where according to the report there are no MMR or NMR cases recorded at all. However, judging from the maximum value, there are areas that have a fairly large number of cases. The highest MMR values were found in Padang Panjang City with 402 cases, while the highest NMR values were found in Kerinci Regency and Mentawai Islands Regency with 15 cases. In general, the provinces of Aceh, West Sumatra and the Riau Archipelago have relatively high MMR and NMR compared to other regions. Meanwhile, relatively low MMR and NMR were found in the Southern Sumatra region.

Data visualization is presented in the form of thematic maps to better describe the distribution conditions of each variable in each region. Presentation of thematic maps using GeoDa 1.20 software based on Geographic Information System (GIS) and Open Source. The following is a thematic map for the deployment of MMR and NMR:

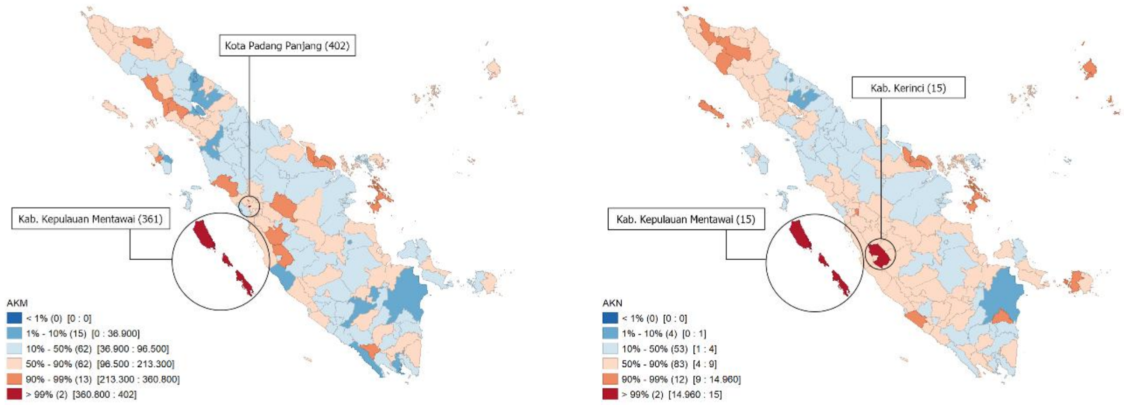

Figure 1. Thematic Map of the Distribution of MMR and NMR in the Sumatra Region

3.2 Multicollinearity Check

Multicollinearity checks are carried out by looking at the Variance Inflation Factor (VIF) value. The following is the result of calculating the VIF value for each predictor variable:

Table 2. Predictor variable VIF values

Variable	VIF	Variable	VIF
X_1	3,833	X_{11}	2,427
X_2	7,610	X_{12}	2,073
X_3	4,291	X_{13}	1,127
X_4	4,950	X_{14}	1,749
X_5	3,680	X_{15}	1,829
X_6	2,127	X_{16}	2,209
X_7	1,849	X_{17}	1,808
X_8	1,489	X_{18}	1,669
X_9	1,268	X_{19}	1,525
X_{10}	1,641	X_{20}	2,090

Based on Table 2, it is found that all predictor variables have a VIF value of less than 10, which means that there is no predictor variable as a source of multicollinearity.

3.3 Overdispersion Detection

The overdispersion detection of the two response variables was carried out by the Index of Dispersion Test (I_B). Based on the results of the analysis obtained value $I_B = 321{,}629 < \chi^2_{(0{,}05;305)} = 346{,}729$ and $p_{value} = 0{,}246 > \alpha = 0{,}05$. Thus H_0 is accepted, which means that the response variables Y_1 and Y_2 have a Bivariate Negative Binomial distribution or the two response variables are overdispersion by the property of Negative Binomial.

3.4 Correlation Measurement

Measurement of the correlation of the two response variables was carried out with Pearson's Product Moment (ρ). Based on the results of the analysis, a correlation value of 0.502 was obtained which showed that the correlation between the response variables Y_1 and Y_2 was quite strong. Furthermore, testing the hypothesis produces a value of $t_{cal} = 7{,}164 > t_{(0{,}025;152)} = 1{,}976$ and $p_{value} = 0{,}000 < \alpha = 0{,}05$. Thus the decision is to reject H0, which means that there is a significant relationship between Y_1 and Y_2.

3.5 Modeling with BNBR

Simultaneous testing of the parameters of the BNBR model was carried out to test whether the predictor variables simultaneously affect the response variable. Based on the results of the analysis, the value of $D_0 = 64098{,}3 > \chi^2_{(0{,}05;40)} = 55{,}758$ and $p_{value} = 0{,}00 < \alpha = 0{,}05$, with the decision to reject H0, which means that there is at least one predictor variable that has a significant effect on MMR and NMR in the Sumatra Region in 2020.

Furthermore, partial testing of the BNBR model parameters. Partially testing the significance of the parameters of the BNBR model was carried out to test whether each of the j-th predictor variables affected the k-th response variable. The results of the analysis for testing the parameters of the BNBR model partially are presented in Table 3. Based on Table 3 it was found that with a significant level of 5% there were 9 predictor variables for Y_1 and 5 predictor variables for Y_2 which have $Z_{cal} > Z_{0{,}05} = 1{,}645$ and $p_{value} < \alpha = 0{,}05$. So it was decided to reject H0, meaning that there are 9 predictor variables that affect MMR and 5 predictor variables that affect NMR in the Sumatra Region in 2020.

Predictor variables that have a significant effect on MMR are the percentage of pregnant women carrying out K1 (X_1), the percentage of pregnant women carrying out K4 (X_2), the percentage of deliveries assisted by health workers (X_5), the percentage of poor people (X_{15}), the percentage of households having proper sanitation (X_{16}) and clean water (X_{17}), ratio of population density per km2 (X_{18}), ratio of health workers (X_{19}) and health facilities per 100,000 inhabitants (X_{20}).

Table 3. Estimated Value of BNBR Model Parameters

β	Maternal Mortality Rate (Y_1)				Neonatal Mortality Rate (Y_2)			
	Estimate	Std. Eror	Z_{cal}	p_{value}	Estimate	Std. Eror	Z_{cal}	p_{value}
β_0	-0,9779	0,9185	-1,0647	0,1435	-1,0704	1,1634	-0,9201	0,1788
β_1	0,0221*	0,0089	2,4783	**0,0066**	-0,0242*	0,0128	-1,8868	**0,0296**
β_2	-0,0279*	0,0124	-2,2390	**0,0126**	0,0049	0,0155	0,3157	0,3761
β_3	0,0055	0,0085	0,6454	0,2593	-0,0005	0,0107	-0,0445	0,4823
β_4	-0,0063	0,0106	-0,5884	0,2781	0,0007	0,0125	0,0581	0,4768
β_5	0,0251*	0,0089	2,8106	**0,0025**	0,0212*	0,0120	1,7675	**0,0386**
β_6	0,0048	0,0144	0,3327	0,3697	0,0096	0,0166	0,5783	0,2815
β_7	0,0035	0,0032	1,0831	0,1394	0,0039	0,0039	0,9914	0,1607
β_8	0,0009	0,0035	0,2711	0,3931	0,0029	0,0043	0,6799	0,2483
β_9	0,0012	0,0056	0,2101	0,4168	0,0017	0,0068	0,2476	0,4022
β_{10}	0,0043	0,0039	1,1264	0,1300	0,0013	0,0046	0,2924	0,3850
β_{11}	0,0024	0,0138	0,1714	0,4320	-0,0120	0,0172	-0,6974	0,2428
β_{12}	0,0199	0,0165	1,2067	0,1138	-0,0016	0,0189	-0,0838	0,4666
β_{13}	-0,0005	0,0028	-0,1853	0,4265	0,0027	0,0038	0,7108	0,2386
β_{14}	-0,0045	0,0152	-0,2933	0,3846	0,0088	0,0170	0,5173	0,3025
β_{15}	0,0274*	0,0162	1,6957	**0,0450**	0,0159	0,0190	0,8372	0,2012
β_{16}	0,0099*	0,0047	2,1157	**0,0172**	0,0121*	0,0057	2,1210	**0,0170**
β_{17}	0,0086*	0,0045	1,8930	**0,0292**	0,0007	0,0056	0,1334	0,4469
β_{18}	-0,0001*	0,0000	-3,0964	**0,0010**	-0,0003*	0,0001	-3,6070	**0,0002**
β_{19}	0,0010*	0,0003	3,2468	**0,0006**	0,0013*	0,0004	2,9339	**0,0017**
β_{20}	0,0061*	0,0019	3,2226	**0,0006**	0,0029	0,0022	1,3071	0,0956

Meanwhile, predictor variables that have a significant effect on NMR are the percentage of pregnant women carrying out K1 (X_1), the percentage of births assisted by health workers (X_5), the percentage of households having proper sanitation (X_{16}), the ratio of population density per km^2 (X_{18}) and the ratio of health workers per 100,000 resident (X_{19}).

Based on Table 3, the BNBR model for MMR and NMR in the Sumatra Region in 2020 is as follows:

$$\hat{\mu}_1 = \exp(-0{,}98 + 0{,}0221X_1 - 0{,}0279X_2 + 0{,}0055X_3 - 0{,}0063X_4 + 0{,}0251X_5 + 0{,}0048X_6 + 0{,}0035X_7 + 0{,}0009X_8 + 0{,}0012X_9 + 0{,}0043X_{10} + 0{,}0024X_{11} + 0{,}0199X_{12} - 0{,}0005X_{13} - 0{,}004X_{14} + 0{,}0274X_{15} + 0{,}0099X_{16} + 0{,}009X_{17} - 0{,}0001X_{18} + 0{,}0010X_{19} + 0{,}006X_{20})$$

$$\hat{\mu}_2 = \exp(-1{,}07 - 0{,}0242X_1 + 0{,}0049X_2 - 0{,}0005X_3 + 0{,}0007X_4 + 0{,}0212X_5 + 0{,}0096X_6 + 0{,}0039X_7 + 0{,}0029X_8 + 0{,}0017X_9 + 0{,}0013X_{10} - 0{,}0120X_{11} - 0{,}0016X_{12} + 0{,}0027X_{13} + 0{,}009X_{14} + 0{,}0159X_{15} + 0{,}0121X_{16} + 0{,}001X_{17} - 0{,}0003X_{18} + 0{,}0013X_{19} + 0{,}003X_{20})$$

The first model estimates the average maternal mortality ($\hat{\mu}_1$) based on 20 explanatory variables (X_1 to X_{20}), and is expressed in the form of an exponential function. The estimation results show that several variables such as X_1, X_5, X_6, and X_{12} have positive coefficients, which means that every one unit increase in these variables will increase the exponential value of the average maternal mortality, thus potentially increasing the maternal mortality rate. Conversely, variables such as X_2, X_4, and X_{14} have negative coefficients, which indicate that an increase in these variables can reduce the maternal mortality rate.

Meanwhile, the second model estimates the mean neonatal mortality ($\hat{\mu}_2$) with a similar structure. The slightly lower intercept value (–1.07) indicates that the baseline log-mean value of neonatal mortality is slightly smaller than maternal mortality. In this model, variables such as X_5, X_6, X_{14}, and X_{15} show a positive relationship to the increase in neonatal mortality, while variables such as X_1 and X_{11} show a negative relationship. This indicates that each variable has a different impact on the two types of deaths.

3.6 Spatial Heterogeneity Testing

Spatial diversity testing in the BNBR model was carried out using the Glejser'G approach. Based on the results of the analysis, the value of $G = 70{,}806 > \chi^2_{(0{,}05;40)} = 55{,}758$ and $p_{value} = 0{,}003 < \alpha = 0{,}05$, with the conclusion of rejecting H_0 which means that there is a spatial homogeneity in the model of BNBR.

3.7 Modeling with GWBNBR

The GWBNBR model is an extension of the BNBR model, using a geographic weighting matrix, parameter estimation for each location is carried out by finding the maximum point of the likelihood function that has been multiplied by the weighting matrix.

Testing the similarity of the GWBNBR and BNBR models was carried out to test the significance of geographical factors in the resulting local parameters. Based on the results of the analysis obtained the value of $F_{cal} = 1{,}978 > F_{(0.05;40,80)} = 1{,}545$ and $p_{value} = 0{,}005 < \alpha = 0{,}05$, with the decision of accepting H_0 which means that there is a significant difference between GWBNBR and BNBR models and also there is a geographical effect on the model.

Then the simultaneous testing of GWBNBR model parameters. Simultaneous testing of the significance of the parameters of the GWBNBR model was carried out to test whether the predictor variables simultaneously affect the response variable. Based on the results of the analysis obtained value of $D_1 = 64799{,}6 > \chi^2_{(0.05;80)} = 101{,}879$ and $p_{value} = 0{,}000 < \alpha = 0{,}05$, resulting a conclusion of rejecting H_0 which is at least one predictor variable having a significant effect on MMR and NMR in the Sumatra Region in 2020.

Partially testing the significance of the parameters of the GWBNBR model was carried out to test whether each of the j-th predictor variables affects the k-th response variable. The results of the analysis for testing the parameters of the GWBNBR model partially in Bengkulu City (u_{31}, v_{31}) are presented in Table 4. Based on this table, it is found that with a significant level of 5% there are 3 predictor variables for μ_1 and 1 predictor variable for μ_2 which has a value $Z_{cal} > Z_{0.05} = 1.645$ and $p_{value} < 0.05$. So, it is concluded to reject H_0, meaning that there are 3 predictor variables that have a significant effect on MMR and 1 predictor variable that has a significant effect on NMR in Bengkulu City in 2020.

The predictor variables that significantly influence MMR are the percentage of births assisted by a health worker (X_5), the percentage of households with access to clean water (X_{17}) and the ratio of health facilities per 100,000 population (X_{20}). Meanwhile, the predictor variable that has a significant effect on NMR is the percentage of youth dropping out of school (X_{11}).

Table 4. Estimated Value of GWBNBR Model Parameters in Bengkulu City

β	Maternal Mortality Rate (Y_1)				Neonatal Mortality Rate (Y_2)			
	Estimate	Std. Eror	Z_{hitung}	p_{value}	Estimate	Std. Eror	Z_{hitung}	p_{value}
β_0	-1,0109	1,8562	-0,5446	0,2930	-1,0294	2,0807	-0,4947	0,3104
β_1	0,0102	0,0188	0,5425	0,2937	0,0020	0,0210	0,0934	0,4628
β_2	-0,0140	0,0234	-0,5996	0,2744	0,0056	0,0257	0,2170	0,4141
β_3	-0,0036	0,0156	-0,2335	0,4077	-0,0097	0,0183	-0,5322	0,2973
β_4	-0,0085	0,0184	-0,4641	0,3213	-0,0011	0,0211	-0,0544	0,4783
β_5	0,0400*	0,0156	2,5740	**0,0050**	0,0131	0,0199	0,6602	0,2546
β_6	-0,0152	0,0252	-0,6037	0,2730	-0,0192	0,0285	-0,6733	0,2504
β_7	0,0071	0,0063	1,1377	0,1276	-0,0009	0,0077	-0,1194	0,4525
β_8	-0,0017	0,0065	-0,2595	0,3976	0,0029	0,0077	0,3815	0,3514
β_9	-0,0048	0,0150	-0,3158	0,3761	0,0095	0,0203	0,4697	0,3193
β_{10}	-0,0038	0,0080	-0,4750	0,3174	-0,0020	0,0092	-0,2167	0,4142
β_{11}	0,0216	0,0236	0,9162	0,1798	0,0509*	0,0268	1,8997	**0,0287**
β_{12}	0,0259	0,0286	0,9076	0,1821	-0,0302	0,0318	-0,9488	0,1714
β_{13}	-0,0003	0,0050	-0,0544	0,4783	-0,0005	0,0060	-0,0905	0,4639
β_{14}	-0,0134	0,0286	-0,4693	0,3194	0,0068	0,0303	0,2246	0,4111
β_{15}	0,0214	0,0265	0,8076	0,2096	0,0184	0,0306	0,6009	0,2740
β_{16}	0,0056	0,0082	0,6803	0,2482	0,0058	0,0099	0,5875	0,2784
β_{17}	0,0129*	0,0074	1,7533	**0,0398**	0,0045	0,0086	0,5261	0,2994
β_{18}	0,0000	0,0000	-0,6486	0,2583	-0,0002	0,0001	-1,0920	0,1374
β_{19}	0,0003	0,0006	0,5103	0,3049	0,0007	0,0008	0,9030	0,1833
β_{20}	0,0084*	0,0035	2,3984	**0,0082**	0,0047	0,0037	1,2880	0,0989

Using the information available in Table 4, the GWBNBR model for MMR and NMR in Bengkulu City in 2020 is as follows:

$$\begin{aligned}\hat{\mu}_1 = \exp\,(&-1{,}0109 + 0{,}0102X_1 - 0{,}0140X_2 - 0{,}0036X_3 - 0{,}0085X_4 + 0{,}0400X_5 - 0{,}0152X_6 \\ &+ 0{,}0071X_7 - 0{,}0017X_8 - 0{,}0048X_9 - 0{,}0038X_{10} + 0{,}0216X_{11} + 0{,}0259X_{12} \\ &- 0{,}0003X_{13} - 0{,}0134X_{14} + 0{,}0214X_{15} + 0{,}0056X_{16} + 0{,}0129X_{17} - 0{,}0000X_{18} \\ &+ 0{,}0003X_{19} + 0{,}0084X_{20})\end{aligned}$$

$$\begin{aligned}\hat{\mu}_2 = \exp\,(&-1{,}0294 + 0{,}0020X_1 + 0{,}0056X_2 - 0{,}0097X_3 - 0{,}0011X_4 + 0{,}0131X_5 - 0{,}0192X_6 \\ &- 0{,}0009X_7 + 0{,}0029X_8 + 0{,}0095X_9 - 0{,}0020X_{10} + 0{,}0509X_{11} - 0{,}0302X_{12} \\ &- 0{,}0005X_{13} + 0{,}007X_{14} + 0{,}0184X_{15} + 0{,}0058X_{16} + 0{,}004X_{17} - 0{,}0002X_{18} \\ &+ 0{,}0007X_{19} + 0{,}005X_{20})\end{aligned}$$

After partial testing of the parameters of the GWBNBR model, then grouping areas (locations) based on significant parameter similarities.

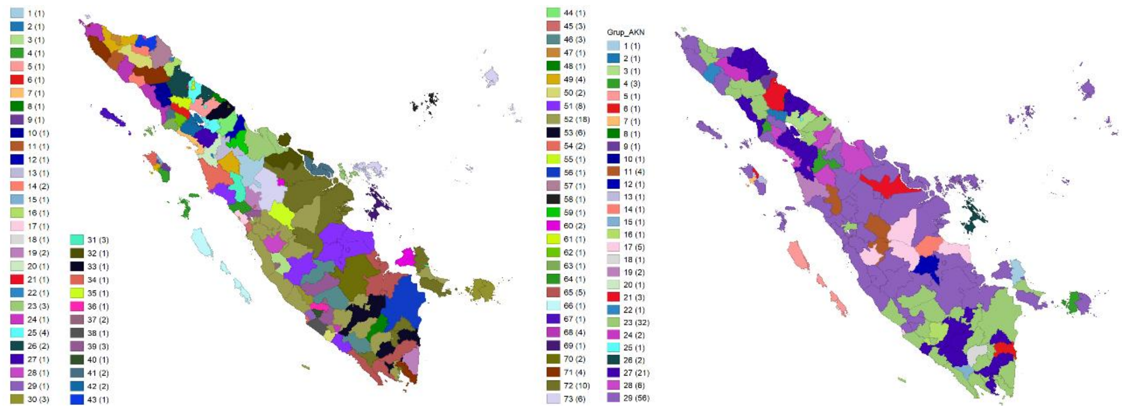

Figure 2. Thematic Map of Regional Group Distribution Based on the Significance of MMR and NMR Parameters

Table 5. Grouping of Regions Based on Significance of MMR Parameters

Group	Variables	Districts/Cities
1	X_1, X_2, X_5, X_{15}	Rokan Hulu
2	$X_1, X_2, X_5, X_{15}, X_{16}, X_{19}$	Padang Sidempuan
3	$X_1, X_2, X_5, X_{17}, X_{20}$	Kerinci
4	X_1, X_2, X_5, X_{20}	Nias Selatan
5	$X_1, X_4, X_5, X_{12}, X_{20}$	Simalungun
6	$X_1, X_4, X_5, X_{15}, X_{18}$	Dairi
7	$X_1, X_5, X_{15}, X_{18}, X_{19}$	Tapanuli Tengah
8	X_1, X_5, X_{16}, X_{19}	Batu Bara
9	X_1, X_5, X_{18}, X_{19}	Nias
10	$X_1, X_5, X_{18}, X_{19}, X_{20}$	Aceh Tenggara
11	X_1, X_5, X_{18}, X_{20}	Aceh Barat
12	X_1, X_5, X_{19}, X_{20}	Labuhanbatu
13	X_1, X_{16}, X_{20}	Padang Lawas Utara
14	X_1, X_{18}, X_{19}	Aceh Barat Daya, Bener Meriah
15	$X_1, X_{18}, X_{19}, X_{20}$	Gunungsitoli
16	X_1, X_{20}	Aceh Tamiang
17	X_2, X_5	Padang Pariaman
18	X_2, X_5, X_{15}	Padang Panjang
19	X_2, X_5, X_{17}, X_{20}	Lampung Timur, Lima Puluh Kota
20	X_2, X_5, X_{19}, X_{20}	Tapanuli Selatan
21	$X_4, X_5, X_6, X_8, X_{10}, X_{15}, X_{18}$	Binjai
22	$X_4, X_{18}, X_{19}, X_{20}$	Langsa
23	X_5	Karimun, Dumai, Rokan Hilir
24	X_5, X_7, X_{20}	Pagar Alam
25	$X_5, X_{10}, X_{15}, X_{16}$	Deli Serdang, Pematang Siantar, Tebing Tinggi, Toba Samosir
26	$X_5, X_{10}, X_{15}, X_{16}, X_{18}, X_{19}$	Langkat, Serdang Bedagai
27	$X_5, X_{10}, X_{15}, X_{16}, X_{19}$	Tapanuli Utara
28	$X_5, X_{11}, X_{15}, X_{16}, X_{20}$	Solok Selatan
29	X_5, X_{12}, X_{20}	Bengkulu Tengah
30	X_5, X_{15}	Belitung, Belitung Timur, Lebong
31	X_5, X_{15}, X_{16}	Pangkalpinang, Bukittinggi, Pasaman
32	$X_5, X_{15}, X_{16}, X_{18}$	Bengkalis
33	$X_5, X_{15}, X_{16}, X_{18}, X_{19}$	Asahan
34	$X_5, X_{15}, X_{16}, X_{19}, X_{20}$	Nias Utara
35	$X_5, X_{15}, X_{16}, X_{20}$	Kuantan Singingi

Group	Variables	Districts/Cities
36	$X_5, X_{15}, X_{17}, X_{18}, X_{20}$	Rejang Lebong
37	$X_5, X_{15}, X_{17}, X_{20}$	Sungai Penuh, Lubuklinggau
38	X_5, X_{15}, X_{18}	Seluma
39	$X_5, X_{15}, X_{18}, X_{20}$	Tanah Datar, Empat Lawang, Musi Rawas Utara
40	X_5, X_{15}, X_{20}	Kepahiang
41	X_5, X_{16}	Subulussalam, Kepulauan Meranti
42	$X_5, X_{16}, X_{18}, X_{19}$	Humbang Hasundutan, Samosir
43	$X_5, X_{16}, X_{18}, X_{19}, X_{20}$	Aceh Utara
44	X_5, X_{16}, X_{19}	Labuhanbatu Utara
45	X_5, X_{16}, X_{20}	Kota Solok, Padang, Payakumbuh
46	$X_5, X_{17}, X_{18}, X_{20}$	Sarolangun, Musi Rawas, Ogan Komering Ulu Selatan
47	X_5, X_{17}, X_{19}	Pidie Jaya
48	$X_5, X_{17}, X_{19}, X_{20}$	Ogan Komering Ulu Timur
49	X_5, X_{18}, X_{19}	Bireuen, Pidie, Nias Barat, Padang Lawas
50	$X_5, X_{18}, X_{19}, X_{20}$	Aceh Tengah, Bengkulu Selatan
51	X_5, X_{18}, X_{20}	Kaur, Batanghari, Jambi, Merangin, Muaro Jambi, Tanjung Jabung Barat, Tanjung Jabung Timur, Pasaman Barat
52	X_5, X_{20}	Bangka Tengah, Bengkulu Utara, Mukomuko, Bungo, Pesawaran, Way Kanan, Indragiri Hulu, Dharmasraya, Pariaman, Pesisir Selatan, Sawahlunto, Sijunjung, Solok, Lahat, Ogan Ilir, Ogan Komering Ulu, Penukal Abab Lematang Ilir, Prabumulih, Sibolga
53	X_5, X_{17}, X_{20}	Bengkulu, Lampung Utara, Metro, Pringsewu, Tulang Bawang, Muara Enim
54	X_5, X_{19}, X_{20}	Mandailing Natal
55	X_{10}, X_{15}, X_{19}	Medan
56	X_{12}, X_{17}, X_{20}	Ogan Komering Ilir
57	$X_{14}, X_{18}, X_{19}, X_{20}$	Aceh Timur
58	X_{15}	Kepulauan Anambas
59	X_{15}, X_{18}, X_{19}	Labuhanbatu Selatan
60	X_{15}, X_{20}	Bangka Barat, Pekanbaru
61	X_{16}, X_{18}, X_{19}	Karo
62	X_{16}, X_{19}	Pakpak Bharat
63	X_{16}, X_{20}	Aceh Singkil
64	X_{17}, X_{19}, X_{20}	Agam
65	X_{17}, X_{20}	Lampung Barat, Lampung Tengah, Tanggamus, Banyuasin, Palembang
66	X_{18}	Kepulauan Mentawai
67	X_{18}, X_{19}	Simeulue
68	X_{18}, X_{19}, X_{20}	Aceh Besar, Aceh Selatan, Lhokseumawe, Nagan Raya
69	X_{18}, X_{20}	Lingga
70	X_{19}	Musi Banyuasin, Tanjungbalai
71	X_{19}, X_{20}	Aceh Jaya, Banda Aceh, Gayo Lues, Lampung Selatan
72	X_{20}	Bangka, Bangka Selatan, Tebo, Bandar Lampung, Mesuji, Pesisir Barat, Tulang Bawang Barat, Indragiri Hilir, Pelalawan, Siak
73	-	Sabang, Batam, Bintan, Natuna, Tanjungpinang, Kampar

Based on the information obtained from Table 5, there are 73 regional groups according to parameter significance, with the largest significant number being 18 districts/cities in the 52nd group. The most dominating variable in cases of maternal death is the percentage of deliveries assisted by health personnel (X_5), which is significant in 103 regions. While the areas where there are no significant variables are 6 districts/cities in the 73rd group.

Based on Table 6, 29 regional groups were obtained according to the significance of the parameters, with the largest significant number being 32 districts/cities in the 23rd group. The most dominating variable in neonatal mortality cases is the ratio of population density per km^2 (X_{18}) which is significant in 65 regions. While the areas where there are no significant variables are 56 districts/cities in the 29th group.

Table 6. Grouping of Regions Based on Significance of PTNMR Parameters

Group	Variables	Districts/Cities
1	X_1	Bangka
2	X_1, X_2, X_{19}	Karo
3	X_1, X_{19}	Simalungun
4	X_2	Subulussalam, Belitung, Padang Lawas Utara
5	X_2, X_{11}	Kepulauan Mentawai
6	X_2, X_{11}, X_{18}	Tulang Bawang
7	X_2, X_{15}	Nias Barat
8	X_2, X_{18}, X_{19}	Binjai
9	X_4, X_5, X_{19}	Aceh Tamiang
10	X_4, X_5, X_{18}, X_{19}	Tebing Tinggi
11	X_5	Kuantan Singingi, Dharmasraya, Kota Solok, Pasaman
12	X_5, X_6	Batanghari
13	X_5, X_{18}, X_{19}	Nias
14	X_6	Tanjung Jabung Barat
15	X_9, X_{18}	Pesisir Barat
16	X_9, X_{18}, X_{19}	Lahat
17	X_{11}	Bengkulu, Tanjung Jabung Timur, Tebo, Indragiri Hulu, Solok Selatan
18	X_{11}, X_{18}	Way Kanan
19	X_{14}	Labuhanbatu, Mandailing Natal
20	X_{14}, X_{18}	Sabang
21	X_{14}, X_{19}	Siak, Gunungsitoli, Langkat
22	X_{15}, X_{18}	Aceh Barat
23	X_{18}	Aceh Barat Daya, Aceh Tenggara, Banda Aceh, Gayo Lues, Pidie, Pidie Jaya, Bangka Tengah, Bengkulu Utara, Kaur, Seluma, BandarLampung, Lampung Barat, Lampung Selatan, Lampung Timur, Lampung Utara, Pringsewu, Tanggamus, Tulang Bawang Barat, Tanah Datar, Empat Lawang, Musi Rawas, Musi Rawas Utara, Ogan Ilir, OKI, OKU Timur, Pagar Alam, Palembang, PALI, Prabumulih, Asahan, Sibolga, Toba
24	X_{18}, X_{19}, X_{20}	Aceh Tengah, Batu Bara
25	X_{19}, X_{20}	Pematang Siantar
26	X_{20}	Lingga
27	X_{18}, X_{19}	Aceh Selatan, Aceh Timur, Aceh Utara, Bener Meriah, Langsa, Lhokseumawe, Bengkulu Selatan, Lampung Tengah, Mesuji, Metro, Pesawaran, Muara Enim, OKU, OKU Selatan, Deli Serdang, Humbang Hasundutan, Medan, Samosir, Serdang Bedagai, Tanjungbalai, Tapanuli Selatan, Tapanuli Utara
28	X_{19}	Rokan Hilir, Labuhanbatu Utara, Padang Lawas, Padang Sidempuan, Pakpak Bharat, Tapanuli Tengah
29	-	Aceh Besar, Aceh Jaya, Aceh Singkil, Bireuen, Nagan Raya, Simeulue, Bangka Barat, Bangka Selatan, Belitung Timur, Pangkalpinang, Bengkulu Tengah, Kepahiang, Lebong, Mukomuko, Rejang Lebong, Bungo, Jambi, Kerinci, Merangin, Muaro Jambi, Sarolangun, Sungai Penuh, Batam, Bintan, Karimun, Kep. Anambas, Natuna, Tanjung-pinang, Bengkalis, Dumai, Indragiri Hilir, Kampar, Kep. Meranti, Pekanbaru, Pelalawan, Rokan Hulu, Agam, Bukittinggi, Lima Puluh Kota, Padang, Padang Panjang, Padang Pariaman, Pariaman, Pasaman Barat, Payakumbuh, Pesisir Selatan, Sawahlunto, Sijunjung, Solok, Banyuasin, Lubuklinggau, Musi Banyuasin, Dairi, Labuhanbatu Selatan, Nias Selatan, Nias Utara

3.8 Best Model Selection

Selection of the best model between the BNBR model and the GWBNBR model can take into account the DIC value. Based on the results of the analysis, the DIC values for each model are presented in the following table:

Table 7. DIC values

Model	DIC
BNBR	274,855
GWBNBR	225,048

Based on Table 7, the DIC value for the GWBNBR model produces a smaller value than the BNBR model. It can be concluded that the GWBNBR model is better at modeling MMR and NMR in the Sumatra Region in 2020.

4. CONCLUSION

Based on the results of the analysis and discussion that have been carried out, the following conclusions can be drawn modeling the maternal and neonatal mortality rates in the Sumatra Region for 2020 using the Ordinary Least Square (OLS) approach has experienced overdispersion problems. This is evidenced by the mean value of the two responses which is smaller than the value of the variance and the significant Index of Dispersion Test, so that a model based on the Bivariate Negative Binomial distribution is suitable for use in this case. However, the results of the homogeneity test show that there is a problem of spatial heterogeneity in the BNBR model, so it is believed that the local model is better used for modeling maternal and neonatal deaths in the Sumatra Region in 2020.

GWBNBR parameter estimation is carried out by maximizing the n-function likelihood of the BNBR model for each weighted location. The solution to get the parameter estimator is done by Newton-Raphson iteration. The results of the model similarity test show that the GWBNBR model is significantly different from the BNBR model, which means that there is an influence of geographical factors on the BNBR model, so that the GWBNBR model is good enough to be used in this study.

The DIC value obtained for the GWBNBR model is smaller than the BNBR model, so it can be concluded that the GWBNBR model is better than the BNBR model in modeling MMR and NMR in the Sumatra Region in 2020.

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