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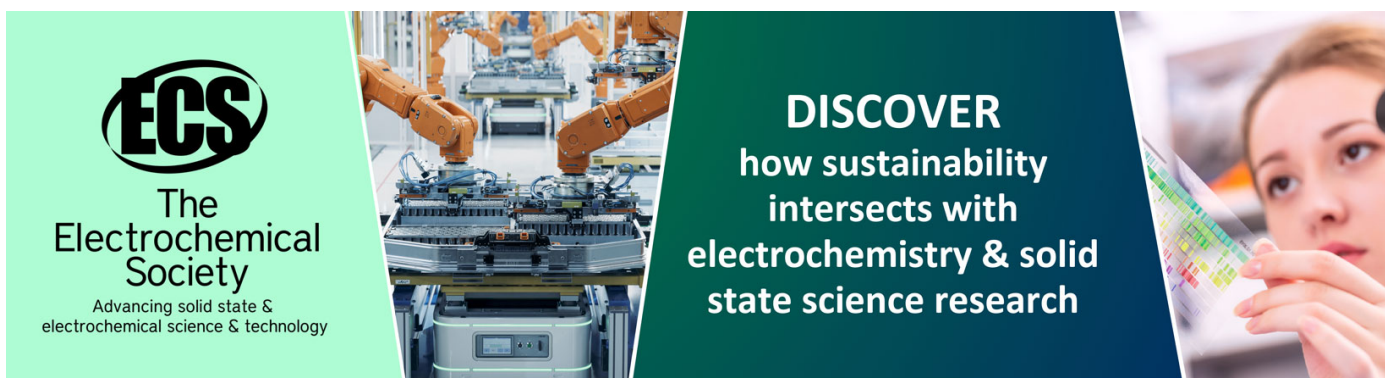
Geographically Weighted Bivariate Gamma Regression in The Analysis of Maternal Mortality Rate and Infant Mortality Rate in North Sumatra Province 2017

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Geographically Weighted Bivariate Gamma Regression in The Analysis of Maternal Mortality Rate and Infant Mortality Rate in North Sumatra Province 2017

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Abstract. In this study, Geographically Weighted Bivariate Gamma Regression (GWBGR) model is proposed. This GWBGR model is a developer of the Bivariate Gamma Regression (BGR) model which all of the regression parameters depend on the geographical location, i.e latitude, and longitude. In these models, the response variables are correlated and follow the gamma distribution. We applied the GWBGR model to analyze Maternal Mortality Rate (MMR) and Infant Mortality Rate (IMR) in North Sumatra Province 2017. The result shows that the test of heterogeneity spatial is significant, it means MMR and IMR in North Sumatra Province depend on the geographical location. Modelling with BGR produced 6 groups based on significant variable similarities to MMR and 3 groups based on significant similarity of variables towards IMR. Based on AICc, GWBGR model is smallest than BGR model. Finally, we conclude that the GWBGR model was better than the BGR Model (global model).

Keywords: Bivariate Gamma Regression, Geographically Weighted Bivariate Gamma Regression, IMR, MMR, AICc

1. Introduction

Maternal Mortality Rate (MMR) and Infant Mortality Rate (IMR) are measures of progress in the health status of a country, especially those related to maternal and child health problems. One of the keys to the success of health development in an area can be seen from the size of MMR and IMR. Evidence of a large amount of government attention in improving public health is by including MMR and IMR as one of Sustainable Development Goals (SDGs) targets. SDG targets in 2030 MMR to 70/100,000 live births and IMR to 14/1000 live births [1].

Infant mortality can be divided into two, namely endogenous and exogenous. Endogenous infant deaths are infant deaths that occur in the first month after birth and are mostly caused by factors brought by children from birth obtained from their parents at conception or obtained during the month of pregnancy. Exogenous death is infant mortality that occurs after the age of one month until the age of one year due to factors related to the outside environment. So that infant mortality is closely related to maternal death.

Based on the results of the SP2010, MMR in North Sumatra Province amounted to 328/100,000 live births, but the figure is still quite high when compared to the national figures for the SP2010 which amounted to 259/100,000 live births. The health profile report of the Province of North Sumatra states that MMR in North Sumatra Province has not experienced a significant decline until 2016. This is confirmed by the results of a survey conducted by the North Sumatra Provincial Health Office with



FKM USU which stated that MMR in North Sumatra Province was 268/100,000 live births, so that MMR in North Sumatra Province is far from the SDGs target. As for the IMR in North Sumatra Province based on the latest SP results, there was a very significant decrease. IMR in North Sumatra SP 2000 results amounted to 44/1000 live births then dropped to 26/1000 live births in the SP 2010 results. Various factors that led to a decrease in IMR in North Sumatra Province included improved distribution of health services and better handling of diseases, increased knowledge, awareness healthy community life and access to maternal and child health [4].

Research on MMR and IMR has been carried out. In 1992, James McCarthy and Deborah Maine in their journal entitled "A Framework for Analyzing the Determinants of Maternal Mortality" discussed the framework of factors that influence maternal mortality and infant mortality. Frameworks in this journal are divided into 3 determinants, namely contextual, intermediate, and proxy [5]. In addition, other studies include estimating parameters and testing hypotheses on the number of infant deaths and the number of maternal deaths in East Java Province in 2013 using Bivariate Generalized Poisson Regression using the MLE method and Newton Raphson optimization [6]. In the following year this research was continued by adding spatial effects, namely using Geographically Weighted Bivariate Generalized Poisson Regression using the same estimation method and optimization method [7]. This modelling of MMR and IMR was also carried out by using Mixed Geographically Weighted Bivariate Weibull Regression in the MMR and IMR data in East Java Province in 2016 using the MLE method and Berndt-Hall-Hall-Hausman (BHHH) optimization [8].

Based on the formulation of the problem above, this study aims to obtain the factors that influence MMR and IMR in the Province of North Sumatra in 2017 using the GWBGR model.

2. Theoretical Review

2.1. Bivariate Gamma Regression (BGR)

Bivariate gamma regression (BGR) is one form of regression that can describe the relationship between two response variables (Y_1 and Y_2), each of which is gamma distribution with a set of predictor variables (X). The model of BGR is: [9]

$$\mu_{1i} = E(Y_1) = \exp(\mathbf{x}_i^T \boldsymbol{\beta}_1) \text{ and } \mu_{2i} = E(Y_2) = \exp(\mathbf{x}_i^T \boldsymbol{\beta}_2) \quad (1)$$

so the form of the BGR pdf model is:

$$f(y_{1i}, y_{2i}) = \begin{cases} C_i (y_{1i} \cdot y_{2i})^{\tau-1} \left(\frac{y_{1i}}{\exp(\mathbf{x}_i^T \boldsymbol{\beta}_1)} + \frac{y_{2i}}{\exp(\mathbf{x}_i^T \boldsymbol{\beta}_2)} \right)^{\alpha-2\tau} A_i & \\ 0 & , \text{ for } y_{1i}, y_{2i} \text{ others} \end{cases} \quad (2)$$

where $y_{1i} > 0, y_{2i} > 0, \alpha > 0, \tau > 0; i = 1, 2, \dots, n$

$$C_i = \left((\exp(\mathbf{x}_i^T \boldsymbol{\beta}_1) \exp(\mathbf{x}_i^T \boldsymbol{\beta}_2))^{\tau} \Gamma(\tau) \Gamma(\alpha) \right)^{-1} \quad A_i = \Gamma \left(2\tau - \alpha, \frac{y_{1i}}{\exp(\mathbf{x}_i^T \boldsymbol{\beta}_1)} + \frac{y_{2i}}{\exp(\mathbf{x}_i^T \boldsymbol{\beta}_2)} \right)$$

2.2. Geographically Weighted Bivariate Gamma Regression (GWBGR)

GWBGR is a development from BGR which is given a spatial weight in the form of latitude and longitude coordinates. The GWBGR density function is: [10]

$$f(y_{1i}, y_{2i}) = \begin{cases} E_i (y_{1i} \cdot y_{2i})^{\tau-1} D_i M_i & \text{for } y_{1i} > 0, y_{2i} > 0, \alpha > 0, \tau > 0 \\ 0 & , \text{ for others} \end{cases} \quad (3)$$

where $i = 1, 2, \dots, n$

$$E_i = \left((\exp(\mathbf{x}_i^T \boldsymbol{\beta}_1(u_i, v_i)) \exp(\mathbf{x}_i^T \boldsymbol{\beta}_2(u_i, v_i)))^{\tau} \Gamma(\tau) \Gamma(\alpha) \right)^{-1} \\ D_i = \left(\frac{y_{1i}}{\exp(\mathbf{x}_i^T \boldsymbol{\beta}_1(u_i, v_i))} + \frac{y_{2i}}{\exp(\mathbf{x}_i^T \boldsymbol{\beta}_2(u_i, v_i))} \right)^{\alpha-2\tau} \text{ and } M_i = \Gamma \left(2\tau - \alpha, \frac{y_{1i}}{\exp(\mathbf{x}_i^T \boldsymbol{\beta}_1(u_i, v_i))} + \frac{y_{2i}}{\exp(\mathbf{x}_i^T \boldsymbol{\beta}_2(u_i, v_i))} \right)$$

2.3. Spatial Heterogeneity

The existence of diversity in regional relations within an observation area is described by spatial heterogeneity. The method for testing spatial heterogeneity is the Glejser test. The hypothesis of the glejser test $H_0 : \beta_{j_1} = \beta_{j_2} = \dots = \beta_{j_k} = 0$ against $H_1 : \text{at least one } \beta_{j_l} \neq 0 ; l=1,2,\dots,k ; j=1,2$. The glejser test is: [12]

$$G = \left[n - k - 1 - \frac{1}{2}(j - k + 1) \right] \ln \left(\frac{|\hat{\Sigma}_\Omega|}{|\hat{\Sigma}_\omega|} \right) \quad (4)$$

where $\hat{\Sigma}_\omega$ is matrix Varian covariance under H_0 and $\hat{\Sigma}_\Omega$ is matrix Varian covariance under-population. Reject H_0 if $|G| > \chi^2_{\alpha, jk}$

2.4. Spatial Weighting

Some of the spatial weight that can be used is the kernel function as follows [13]:

1. Fixed Gaussian Kernel : $w_{ij^*} = \exp \left[-\frac{1}{2} \left(\frac{d_{ij^*}}{h} \right)^2 \right]$
2. Fixed Bisquare Kernel : $w_{ij^*} = \begin{cases} \left(1 - \left(\frac{d_{ij^*}}{h} \right)^2 \right)^2 & ; \text{for } d_{ij^*} \leq h \\ 0 & ; \text{for } d_{ij^*} > h \end{cases}$
3. Adaptive Gaussian Kernel: $w_{ij^*} = \exp \left[-\frac{1}{2} \left(\frac{d_{ij^*}}{h_i} \right)^2 \right]$
4. Adaptive Bisquare Kernel : $w_{ij^*} = \begin{cases} \left(1 - \left(\frac{d_{ij^*}}{h_i} \right)^2 \right)^2 & ; \text{for } d_{ij^*} \leq h_i \\ 0 & ; \text{for } d_{ij^*} > h_i \end{cases}$

where d_{ij^*} is the euclidian distance from the location (u_i, v_i) to (u_{i^*}, v_{i^*}) , w_{ij^*} is geographical weight i^* -th location for the coefficient estimate at i -th location and h is bandwidth.

2.5. Model Goodness Criteria

The Akaike Information Criterion Corrected (AICc) criteria are used as the purpose of regression modelling for factors that influence the model. The formula of AICc is: [14]

$$AICc = -2 \ln(L(\hat{\alpha}, \hat{\tau}, \hat{\beta}_1, \hat{\beta}_2)) + 2p + \frac{2p(p+1)}{n-p-1} \quad (5)$$

where n = sum of observations, and p = sum of parameters in the model. The smaller the AICc value indicates a better model.

2.6. Maternal Mortality Rate and Infant Mortality Rate

According to WHO, maternal death (maternal death) is death during pregnancy or in a period of 42 days after the end of pregnancy due to pregnancy or treatment but not due to accident or injury. The calculation formula for MMR is as follows [2]:

$$MMR = \frac{\text{number of maternal deaths in a given year}}{\text{number of live births in a given year}} \times 100000 \quad (6)$$

Infant mortality is a death that occurs shortly after the baby is born until the baby is not less than one year old. The formula for calculating IMR is as follows [2]:

$$IMR = \frac{\text{the number of infant deaths under 1 year in a given year}}{\text{number of live births in a given year}} \times 1000 \quad (7)$$

2.7. Model Conceptual for Analyzing the Determinant of Maternal and Infant Mortality

Factors suspected of influencing MMR and IMR in North Sumatra Province based on the modified Conceptual Model of McCarthy and Maine (1992) are as follows [5]:

1. Determinants of Proxies / Outcomes are complications of high-risk pregnancy.
2. Intermediate determinants are an administration of FE3 tablets to pregnant women, the age of first marriage under 17 years, health facilities, birth attendants by health workers, visits to K4 pregnant women, and PHBS household.
3. Distant determinants namely mother's education and household income.

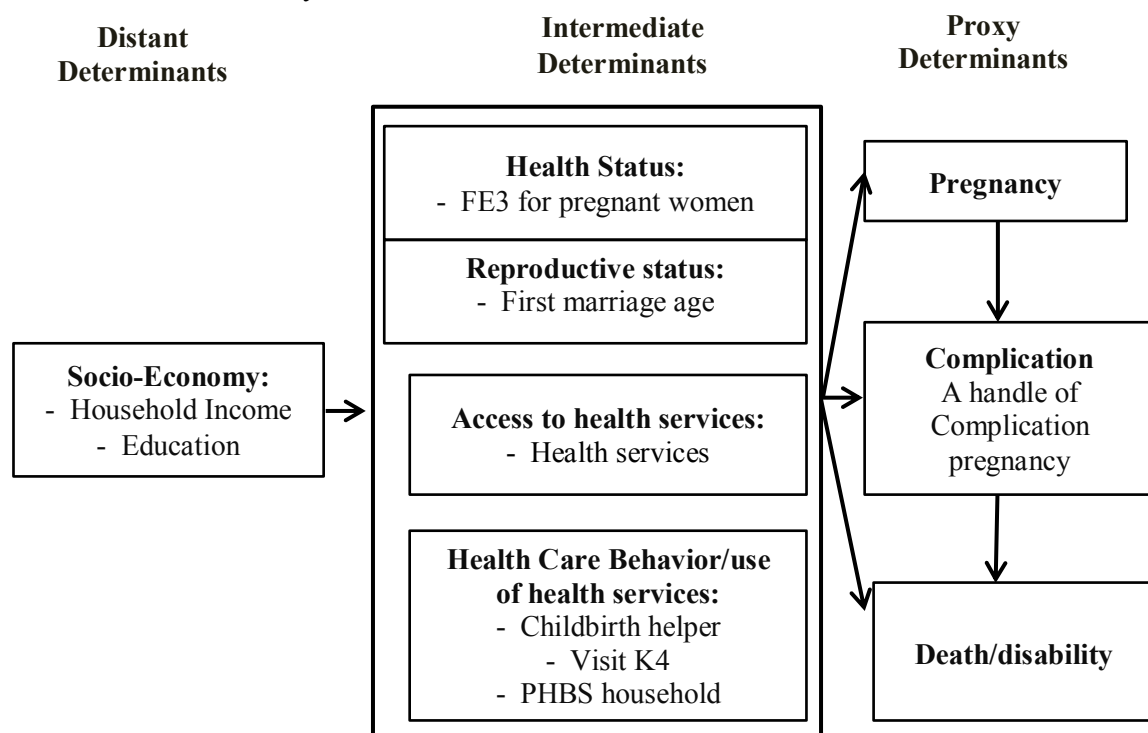


Figure 1. Modification of the Conceptual Model of McCarthy and Maine (1992) on Factors that Influence Maternal Mortality and Infant Mortality in North Sumatra in 2017

3. Methodology

This study uses secondary data obtained from the Profile of North Sumatra Province in 2017, North Sumatra in Figures 2018 and People's Welfare Indicators in North Sumatra Province in 2017. The observation unit is 25 districts and 8 Cities in North Sumatra Province.

The variables used consisted of two response variables namely maternal mortality and infant mortality. While the predictor variables used are 6, namely Percentage of delivery by health workers (X_1), Percentage of obstetric complications handled (X_2), Percentage of married women under 17 years (X_3), Percentage of poor people (X_4), Percentage of pregnant women who get FE3 (X_5) and Percentage of use of health facilities for childbirth (X_6).

1. Procedure to get the factors that influence the MMR and IMR as follows:
2. Make a descriptive analysis of the factors that affect MMR and IMR in the Province of North Sumatra in 2017.
3. Conducting gamma distribution testing on the MMR and IMR response variables.

4. Test the closeness of the relationship between the MMR and IMR response variables using the correlation test.
5. Perform multicollinearity checks between independent variables/predictors using VIF values.
6. Analyzing data using the Bivariate Gamma Regression Regression (BGR) model and determining the deviance value of the model.
7. Test spatial heterogeneity in the data to examine the existence of spatial aspects.
8. Determine spatial weighting functions using 4 types of weighting kernel functions, namely fixed gaussian, adaptive gaussian, fixed bisquare and adaptive bisquare. The selected weight is the weighting which produces the smallest AICc value.
9. Get a model for GWBGR in modelling MMR and IMR in the Province of North Sumatra in 2017.
10. Interpret the best model obtained by looking at the smallest AICc value.
11. Make conclusions from the analysis of the GWBGR model

4. Result and Discussion

4.1. Statistics Descriptive

The following is a description of the response variable and the predictor variable. Based on table 1, it is known that the average percentage of deliveries by health workers in each Regency / City in North Sumatra, which is 90.73%, means that almost all the last deliveries of women aged 15-49 have been assisted by health workers who have midwifery competencies (SpOG doctor, general practitioner, and midwife). This figure has reached the target of the 2017 RPJMD of 89%. The average percentage of complications of labour handled in North Sumatra Province is 61.39%, which means that out of 100 cases of labour complications, only 61 cases were handled. This is still below the RPJMD target of 79%. The statistic descriptive of predictor variables are presented below:

Table 1. Statistics Descriptive of Predictor Variables

Variable	Min	Max	Mean	St. Dev
X_1	52.41	100	90.73	12.53
X_2	2.44	100	61.39	30.02
X_3	1.12	12.04	5.65	2.99
X_4	4.62	29.06	12.49	5.24
X_5	24.85	96.51	67.67	20.34
X_6	21.76	90.96	56.94	21.55

The statistic descriptive of response variables are presented below:

Table 2. Statistic Deskriptif of Response Variables

Variable	Min	Max	Median	St. Dev
Y_1	7.15	396.8	91.3	77.1
Y_2	0.41	18.46	4.49	3.96

Based on Table 2, it can be seen that the median MMR and IMR in North Sumatra Province in 2017 amounted to 91.3 and 4.49. The meaning that half of the City Districts in North Sumatra have MMR above 91.3 and have IMR above 4.49. This condition is still quite far compared to the SDGs target in 2030, which is 70 / 100,000 live births. The highest MMR is Padang Sidempuan districts while the lowest is in Medan City at 0.41. A map of the spread of MMR and IMR in North Sumatra Province as follows:

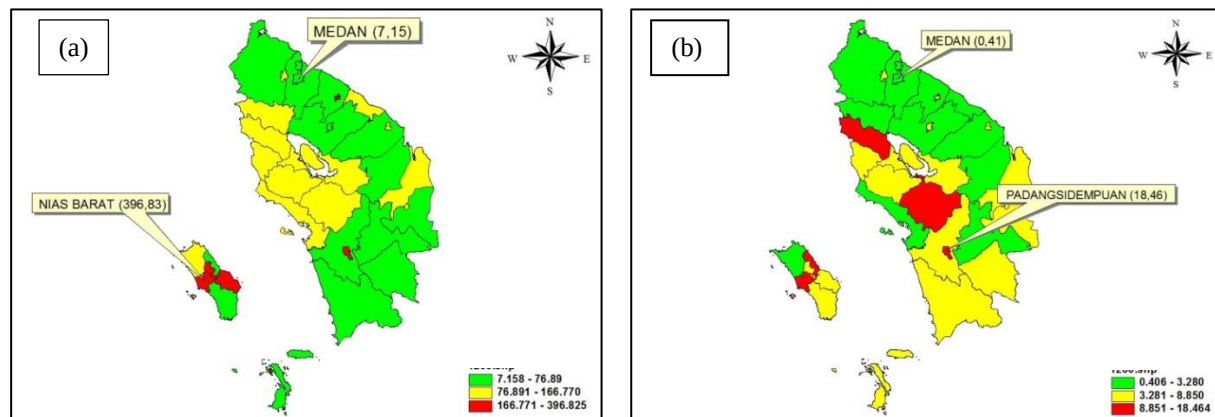


Figure 2. The spread of MMR ^{a)} and IMR ^{b)} by Regency / City in North Sumatra Province in 2017

The BGR model assumes that the response variable is correlated with each other and has a gamma distribution. Based on table 3, it is known that the P-value of MMR and IMR variables in North Sumatra Province in 2017 is greater than α , so failing to reject H_0 means that MMR and IMR are gamma distributed. Furthermore, the results of calculating the correlation between the response variables are 0.499 with t_count of 3.2059 so that it rejects H_0 which means that there is a relationship between MMR and IMR in North Sumatra Province in 2017.

Table 3. The goodness of Fit Test for Response Variables

Distribution	MMR		IMR	
	Statistic	P_value	Statistic	P_value
Normal	1.111	0.006	1.504	0.005
Exponential	1.719	0.017	1.901	0.011
Weibull	0.242	>0.25	0.511	0.199
Gamma	0.159	>0.25	0.389	>0.25

Before including the predictor variables into the model, we check the multicollinearity assumption. From Table 4, there is no predictor variable that has VIF value equal to or more than 10 indicates that there is no multicollinearity problem.

Table 4. Variance Inflation Factor (VIF) of Predictor Variables

Variable	X_1	X_2	X_3	X_4	X_5	X_6
VIF	2.16	2.30	1.30	2.17	1.57	1.54

4.2. Modelling MMR and IMR using Bivariate Gamma Regression (BGR) Model

Modelling using BGR produces the same parameters for each location, analysis of factors that affect MMR and IMR in the Province of North Sumatra in 2017 is considered the same for each Regency/City. Based on the results of simultaneous testing with a significance level of $\alpha = 5\%$, obtained a G^2 value of 527.26 and a value chiquare is 5.23. The G^2 result is greater than that resulting in an H_0 reject decision which means there is at least one variable that requires in the model.

Based on table 5, the MMR and IMR models in North Sumatra Province are obtained as follows:

$$\hat{\mu}_{1i} = \exp(4.1718 - 0.0171x_{1i} - 0.0046x_{2i} - 0.0441x_{3i} - 0.0212x_{4i} + 0.0288x_{5i} + 0.0101x_{6i})$$

$$\hat{\mu}_{2i} = \exp(2.9034 + 0.0025x_{1i} - 0.0022x_{2i} - 0.0748x_{3i} + 0.059x_{4i} - 0.0119x_{5i} - 0.0068x_{6i})$$

with variables that significantly influence MMR and IMR in North Sumatra Province, namely the are the percentage of births by health workers, percentage of labor complications handled, namely percentage of married women under 17 years, percentage of poor population, percentage of pregnant

women who get FE3 and percentage use of facilities Health for childbirth. The estimate of MMR and IMR variables is presented in table 6.

Table 5. Estimated Value of Parameter BGR Model

Parameter	Estimate	SE	Z	P-Value	Parameter	Estimate	SE	Z	P-Value
$\beta_{1.0}$	4.1718	0.0000	107125.390	0.000	$\beta_{2.0}$	2.9034	0.000	12067.632	0.000
$\beta_{1.1}$	-0.0171	0.0008	-22.462	0.000	$\beta_{2.1}$	0.0025	0.001	3.994	0.000
$\beta_{1.2}$	-0.0046	0.0016	-2.833	0.005	$\beta_{2.2}$	-0.0022	0.001	-2.531	0.011
$\beta_{1.3}$	-0.0441	0.0002	-182.121	0.000	$\beta_{2.3}$	-0.0748	0.002	-50.882	0.000
$\beta_{1.4}$	-0.0212	0.0023	-9.314	0.000	$\beta_{2.4}$	0.0591	0.003	18.646	0.000
$\beta_{1.5}$	0.0288	0.0014	20.036	0.000	$\beta_{2.5}$	-0.0119	0.001	-14.674	0.000
$\beta_{1.6}$	0.0101	0.0014	7.074	0.000	$\beta_{2.6}$	-0.0068	0.001	-12.359	0.000

Table 6. The estimate of MMR and IMR variables

Districts	MMR	IMR
Nias	100.4017	8.9937
Mandailing	47.8636	7.4004
Tapanuli	40.6051	10.9718
Tapanuli	104.1566	7.7032
Tapanuli Utara	148.6295	9.8210

MMR and IMR modelling in North Sumatra Province with the BGR model resulted in AICc of 1801.9460 and MSE for MMR of 9487.887 and MSE for IMR of 88.4656.

Before the analysis continued to GWBGR, it must be tested for the presence or absence of spatial heterogeneity in MMR and IMR. Based on the results of processing, the glejser test statistic value of 239.31 is greater than the value of 5.226 so that the reject decision is obtained. This means that MMR and IMR in the Province of North Sumatra in 2017 have spatial heterogeneity between regions so that modelling with GWBGR can be done.

4.3. Modelling MMR and IMR using Geographically Weighted Bivariate Gamma Regression (GWBGR) Model

Modelling using GWBGR produces different parameter estimators for each Regency / City. This is the effect of the addition of geographical weighting, namely the latitude and longitude coordinates at each observation location. So that the determination of the right weight is very important. The following is the comparison of the AICc for the four kernel functions.

Table 7. AICc GWBGR based on Kernel function

Kernel Function	AICc
Fixed Gaussian	513.950
Adaptive Gaussian	644.710
Fixed Bisquare	430.720
Adaptive Bisquare	502.490

Based on the AICc value in table 7, it is known that the GWBGR modelling with weighted fixed bisquare kernel functions produces the smallest AICc value so it can be concluded that the use of fixed

kernel bisquare function produces more representative weighting in describing the spatial heterogeneity of MMR and IMR between regencies/cities in Province of North Sumatra in 2017.

Next is to test the similarity of the model to determine the significance of geographical factors. At the significance level of $\alpha = 5\%$, obtained the value of $F_{\text{count}} = 9.8772$ greater than the value of $F_{0,05;12;396} = 1.669$ so that the decision is to reject H_0 which means there are significant differences between the parameters of the BGR model with the GWBGR model.

Furthermore, simultaneous tests were conducted to find out whether at least one predictor variable had an effect on MMR and IMR in North Sumatra Province in 2017. The results of simultaneous test analysis showed that the deviance value of the fixed bisquare GWBGR model of 1761.6 was greater than the value H_0 , which means that there is at least one predictor variable that influences the model.

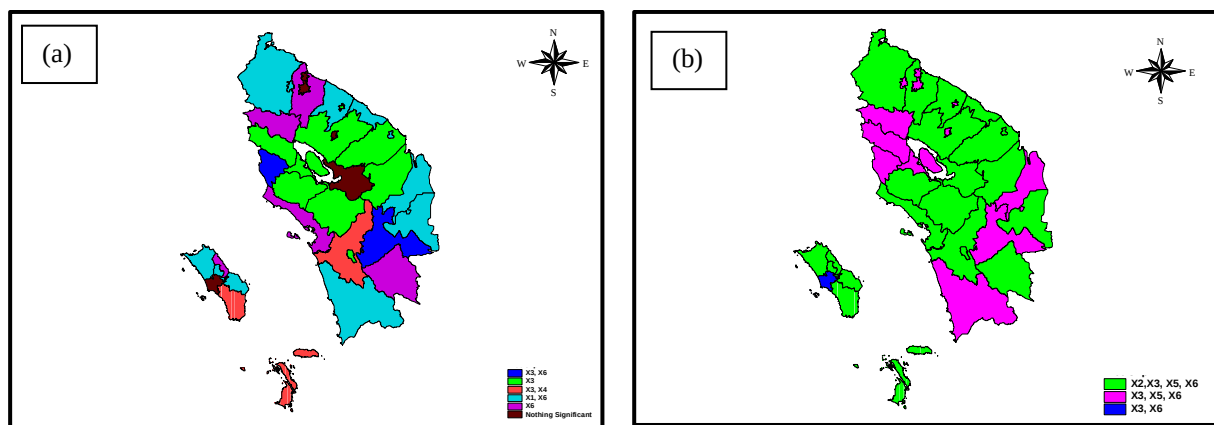


Figure 3. The Regency Grouping in based on Significant Variables Influencing MMR^{a)} and IMR^{b)}

The next, to find out which variables influence the model, a partial test is conducted and a significant grouping of variables is carried out on MMR and IMR in each Regency / City. Based on Figures 3, there are 6 District / City groups based on the similarity of variables that have a significant effect on MMR and there are 3 District / City groups based on the similarity of variables that have a significant effect on IMR. It is seen that the percentage variable of married women under 17 years has an effect on IMR in all districts/cities.

Tabel 8. Estimated Value of Parameter GWBGR Model in Nias Regency

Parameter	Estimate	SE	Z	P-Value	Parameter	Estimate	SE	Z	P-Value
$\beta_{1.0}$	4.2043	0.000	31171.7	0.000	$\beta_{2.0}$	2.9907	0.001	2135.2	0.000
$\beta_{1.1}$	0.0025	0.008	0.317	0.751	$\beta_{2.1}$	-0.0006	0.004	-0.1607	0.872
$\beta_{1.2}$	-0.0044	0.006	-0.719	0.472	$\beta_{2.2}$	-0.0080	0.003	-3.1699	0.002
$\beta_{1.3}$	-0.0325	0.002	-14.343	0.000	$\beta_{2.3}$	-0.0447	0.010	-4.4384	0.000
$\beta_{1.4}$	-0.0148	0.016	-0.943	0.346	$\beta_{2.4}$	-0.0086	0.009	-0.9644	0.335
$\beta_{1.5}$	0.0026	0.007	0.389	0.698	$\beta_{2.5}$	-0.0118	0.003	-4.0218	0.000
$\beta_{1.6}$	0.0111	0.006	2.027	0.043	$\beta_{2.6}$	0.0117	0.002	5.7879	0.000

The GWBGR model produces different parameter values for each observation location. In this study, an example of partial testing in this study was conducted in Nias Regency. Based on table 8, it can be concluded that the variables that significantly affect MMR and IMR in Nias Regency in 2017 are the percentage of married women under 17 years and percentage use of facilities Health for childbirth. The GWBGR model for MMR and IMR in Nias Regency in 2017, namely:

$$\hat{\mu}_{1,1} = \exp(4.2043 + 0.0025x_{1,1} - 0.0044x_{2,1} - 0.0325x_{3,1} - 0.0148x_{4,1} + 0.0026x_{5,1} + 0.0111x_{6,1})$$

$$\hat{\mu}_{2,1} = \exp(2.9907 - 0.0006x_{1,1} - 0.0080x_{2,1} - 0.0447x_{3,1} - 0.0086x_{4,1} - 0.0118x_{5,1} + 0.0117x_{6,1})$$

The estimate of MMR and IMR variables with GWBGR model is presented in table 9.

Table 9. The estimate of MMR and IMR variables

Districts	MMR	IMR
Nias	68.777	6.653
Mandailing Natal	83.957	6.026
Tapanuli Selatan	65.142	5.181
Tapanuli Tengah	81.464	4.333
Tapanuli Utara	137.108	9.839

Modelling MMR and IMR in North Sumatra Province with the GWBGR fixed bisquare model produces AICc of 430.72 and MSE for MMR of 7663.4 and MSE for IMR of 23.399.

4.4. Interpretation The Best Model

Interpretation of the GWBGR model for each i-location is done using the average value ratio μ_{ji} .

Table 10. AICc and MSE of MMR and IMR model

Model	AICc	MSE MMR	MSE IMR
BGR	1801.946	9487.890	88.466
GWBGR with <i>fixed bisquare</i>	430.720	7663.400	23.399

Based on table 10, the GWBGR model with fixed weight bisquare produces AICc and MSE values that are smaller than the BGR model so it is concluded that the GWBGR model with fixed bisquare is better than BGR to model MMR and IMR in North Sumatra Province 2017 So that it continues with the best interpretation of the model, namely GWBGR fixed bisquare.

Table 11. Value of Ratio GWBGR Model in Nias regency

Variable	MMR		IMR	
	$\hat{R}_{1,1}(x_{1,1})$	Resiko (%)	$\hat{R}_{1,1}(x_{1,1})$	Resiko (%)
X_1	1.0025 ^{*)}	0.2475	0.9994 ^{*)}	0.0568
X_1	0.9956 ^{*)}	0.4372	0.9921	0.7926
X_3	0.9680	3.1995	0.9563	4.3749
X_4	0.9853 ^{*)}	1.4716	0.9915 ^{*)}	0.8521
X_5	1.0026 ^{*)}	0.2593	0.9883	1.1696
X_6	1.0112	1.1182	1.0118	1.1789

^{*)}stated that these variables did not significantly influence MMR and IMR with the GWBGR model in Nias Regency.

Based on the ratio calculation results in Table 11, the interpretation of the ratio of the GWBGR model in Nias Regency is as follows:

1. Variables The percentage of married women under 17 years of age (X_3) gives a ratio of MMR of 0.968 and in IMR of 0.9563. This means that the percentage of married women under 17 years is increase 1%, then the risk of MMR and IMR value in Nias Regency will increase by 3.1995% and by 4.3749% assuming the value of other predictor variables remains.

2. Variables Percentage of use of health facilities for childbirth (X_6) gives a ratio of MMR of 1.0112 and in IMR of 1.0118. This means that the percentage of use of health facilities for childbirth is increase 1%, then the risk of MMR and IMR value in Nias Regency will decrease by 1.1182% and by 1.1789% assuming the value of other predictor variables remains.

5. Conclusion

Modelling with BGR produces significant variables on MMR and IMR in North Sumatra Province: Percentage of Labor by Health Personnel, Percentage of Delivery Complications Treated, Percentage of Married Women Under 17 Years, Percentage of Poor Population, Percentage of Pregnant Women Receiving FE3 and Percentage of Use Health Facilities for Childbirth. The fixed bisquare weighting function produces the smallest AICc value among the four kernel weighting functions. Modelling with GWBGR fixed bisquare was obtained by 6 groups based on significant variable similarities to MMR and 3 groups based on significant variable similarity to IMR with variables Percentage of married women under 17 years influencing IMR in all districts/cities. The AICc and MSE values of the GWBGR fixed bisquare model are smaller than the AICc and MSE BGR models. This means that the GWBGR model is better for modelling MMR and IMR in North Sumatra Province compared to BGR models

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