Parameter: Journal of Statistics
Available at https://bestjournal.untad.ac.id/index.php/parameter
Vol. 4 No. 2 2024, 93 - 102
DOI: *https://doi.org/10.22487/27765660.2024.v4.i2.17267*
eISSN: 2776-5660

GEOGRAPHICALLY WEIGHTED PANEL REGRESSION MODELING ON LIFE EXPECTANCY RATE IN SOUTH SULAWESI

Nabila Miftakhurriza[1], Jelita Zalzabila[2], Siswanto Siswanto[3*], Annisa Kalondeng[4], Andi Isna Yunita[5], Samsir Aditya Ania[6]

[1,2,3,4,5,6] Department of Statistics, Faculty of Mathematics and Natural Sciences, Hasanuddin University

***e-mail**: *siswanto@unhas.ac.id*

ABSTRACT

Geographically Weighted Panel Regression (GWPR) is one of the panel data regression approaches used in spatial data analysis. This study uses the global Fixed Effect Model (FEM) panel regression model and the local GWPR model to examine Life Expectancy Rate (LER) at the district/city level in South Sulawesi Province in 2019-2021. LER is an important indicator that reflects the health and welfare of the community. This research aims to develop a GWPR model that can explain variations in LER and identify factors that affect that variable, so that it can help stakeholders in allocating resources and designing effective intervention programs. Parameter estimation in the GWPR model is carried out in each observation area using the Weighted Least Square (WLS) method. The calculation of spatial weights in the GWPR model used weighting functions such as fixed bi-square, fixed gaussian, fixed exponential, adaptive bi-square, adaptive gaussian, and adaptive exponential. The results showed that the use of a fixed exponential weighting function gave optimal results with the lowest cross-validation (CV) value of 44,614. Parameter analysis of the GWPR model shows that the factors that affect LER are local and not the same in each district/city in South Sulawesi Province. Factors that have a significant influence include the number of health facilities and households that have access to proper sanitation. This GWPR model has a coefficient of determination of 97,7%. The FEM model has a coefficient of determination of 58,4%. Therefore, GWPR performs LER modelling more effectively than FEM.

Keywords: *Life Expectancy Rate, Fixed Exponential, Fixed Effect Model, Geographically Weighted Panel Regression*

Cite: Miftakhurriza, N., Zalzabila, J., Siswanto, S., Kalondeng, A., Yunita, A. I., & Ania, S. A. (2024). *Geographically Weighted Panel Regression Modeling on Life Expectancy Rate in South Sulawesi. Parameter: Journal of Statistics, 4(2), 93-102*. https://doi.org/10.22487/27765660.2024.v4.i2.17267.

*Received: Jul 2024; Reviewed: Jul 2024; Published: Dec 2024

INTRODUCTION

Life Expectancy Rate (LER) is an indicator that measures the results of government work in improving the overall welfare of society and the level of health in particular (Faturahman, 2019). Regions with low LER levels need to carry out programs such as health development, nutritional adequacy, environmental health, and poverty eradication (Felangi & Yasa, 2021). Badan Pusat Statistik (BPS) noted that the prevalence of LER in Indonesia has increased every year, from 70,01 years in 2011 to 71,47 years in 2020. That indicates that the Indonesian population's average age of natality before 2020 was 71 to 72 years. This demonstrates an improvement in the quality of health and socioeconomic conditions. Indonesia's LER varies in each province. South Sulawesi is one of the provinces that sees an increase in LER every year. According to BPS, the LER in South Sulawesi increased from 70,43 in 2019 to 70,57 in 2020, or 0,14 years (Alwi et al., 2023).

A regression analysis examines the relationship between the dependent variable and the independent variable. Spatial regression analysis is a type of analysis that is used for modeling data related to location. Spatial data usually shows the relationship between one area and the surrounding area (Tamara et al., 2016). Panel data spatial regression is a commonly used analysis in data modeling that establishes a relationship between place and time (Amil et al., 2023).

LER data, due to its diverse influence on each location, is commonly referred to as spatial panel data. Geographically Weighted Panel Regression (GWPR) is a statistical method that is useful in handling spatial effects, especially spatial heterogeneity in panel data (Meutuah et al., 2017). GWPR is a method that combines panel data regression and Geographically Weighted Regression (GWR) (Rahman et al., 2023). The GWPR method has the advantage of considering aspects of location and time in order to provide good estimator results (Pratama et al., 2021).

Previous research about the GWPR method was conducted by Wati and Utami (2020), which compared GWPR with linear regression for the Human Development Index (HDI) in East Java Province. The result of the research is that GWPR is more optimal for modeling HDI compared to linear regression. The factors that affect LER have been explained in previous studies. Research by Bangun (2019), which analysed the factors that have an influence on LER with multiple linear regression analysis methods. The study resulted in the health facility variable having a positive impact on LER. In addition, research by Nisa, Sugito, and Hakim (2022), which analysed the factors that affect LER with Mixed Geographically Weighted Regression. The results showed that the percentage of poor people and households that have proper sanitation have a significant effect on LER.

Based on the description above, research was conducted to apply GWPR modelling that is able to explain variations in LER in South Sulawesi by considering spatial and temporal effects. Through the GWPR model, it is expected to identify significant factors that affect LER in each district/city. The results of this research are expected to provide useful information for the government in designing appropriate policies to increase LER effectively and evenly throughout South Sulawesi.

MATERIALS AND METHODS

The data in the following study is secondary data obtained from BPS South Sulawesi Province, with observation units per district/city in South Sulawesi. The following research utilises panel data in the form of LER, the number of health facilities, households that have access to proper sanitation, and the number of poor people in 24 districts/cities in South Sulawesi Province with a period from 2019 to 2021, as shown in Table 1.

Table 1. Research Variable

Code	Variable Name	Unit
Y	Life Expectancy Rate	Year
X_1	Number of Health Facilities Households that have	Unit
X_2	Access to Proper Sanitation	Percentage (%)
	Number of Poor People	
X_3		Thousand People

This research uses the help of R software. The following are the stages of data analysis:

1. Analysing data descriptively.
2. Conducting assumptions test, namely residual normality, non-autocorrelation, heteroscedasticity, and non-multicollinearity test. Detecting multicollinearity in the data can be done by looking at the Variance Inflation Factor (VIF) value using equation (1) (Ananda et al., 2023).

$$VIF_k = \frac{1}{1 - R_k^2} \tag{1}$$

where R_k^2 is the coefficient of determination of the regression model of the independent variable X_k on the other independent variables.

3. Performing panel data regression modeling with Common Effect Model (CEM), Fixed Effect Model (FEM), and Random Effect Model (REM).
4. Determining the best panel data model using the Chow test and Hausman test. The Chow test is utilized to choose between CEM and FEM by considering behavioral differences across cross-sectional units. Meanwhile, the Hausman test is applied to compare FEM and REM, focusing on degrees of freedom trade-offs and error assumption compliance. The Chow statistical test is as represented in equation (2) (Wati & Utami, 2020).

$$Chow = \frac{\frac{RSS_1 - RSS_2}{N - 1}}{\frac{RSS_2}{NJ - N - K}} \tag{2}$$

where,
RSS_1 : Residual sum of squares of CEM estimation results,
RSS_2 : The residual sum of squares of FEM estimation results,
N : Number of observations (cross-section),
J : Total observation time (time series),
K : Number of independent variables.

where the test hypothesis is as follows,
H_0 : $Chow < F$ distribution (CEM is appropriate)
H_1 : $Chow > F$ distribution (FEM is appropriate)

5. Testing the significance of panel data model parameters simultaneously with the F test and partially with the T test. The F test is carried out using equation (3) (Sari, 2021).

$$F_{test} = \frac{\left(\sum_{i=1}^{N}\sum_{j=1}^{J}\left(\hat{y}_{ij} - \bar{y}_i\right)^2\right)/K}{\left(\sum_{i=1}^{N}\sum_{j=1}^{J}\left(\hat{y}_{ij} - \bar{y}_i\right)^2\right)/(NJ - K - 1)} \tag{3}$$

where,
$\hat{y}_{ij}$: Forecast value of the i-th individual unit and j-th time of the dependent variable,
$\bar{y}_i$: The mean value of the dependent variable at the i-th individual unit,
K : Number of parameters in the model.

Then, the T test is performed using equation (4).

$$t_{test} = \frac{\hat{\beta}_k}{SE(\hat{\beta}_k)} \tag{4}$$

where,
$\hat{\beta}_k$: Estimated value of the regression coefficient on the k-th independent variable,
$SE(\hat{\beta}_k)$: Standard error of regression coefficient on the k-th independent variable.

6. Testing panel data heteroscedasticity with Breusch-Pagan test (Alfiani & Arum, 2022). If there is heteroscedasticity, then the test can be continued in the GWPR model.
7. Testing spatial autocorrelation using Moran's I.
8. Selecting the optimum bandwidth by minimizing Cross Validation (CV) as shown in equation (5) (Bara et al., 2023).

$$\text{CV} = \sum_{i=1}^{n}\left(y_i - \hat{y}_{\neq 1}(b)\right)^2 \tag{5}$$

where,
n : Number of observation units,
$\hat{y}_{\neq 1}(b)$: Predicted value of y_i with observation location (u_i, v_i) removed from the prediction process.

9. Calculating the weight matrix with kernel weight function. This study tested several weighting functions namely Fixed Bisquare, Fixed Gaussian, Fixed Exponential, Adaptive Gaussian, Adaptive Bisquare, and Adaptive Exponential. The weighting function is selected based on the largest R^2 value and the smallest AIC.
10. Performing GWPR modeling. The general form of GWPR is shown in the equation (6) below (Wati & Utami, 2020).

$$y_{ij} = \beta_0(u_i, v_i) + \sum_{k=1}^{p} \beta_k(u_i, v_i) x_{kij} + \varepsilon_{ij} \tag{6}$$

where,
$\bar{y}_i$: The mean value of the dependent variable at the i-th location,
$\bar{x}_{kij}$: The mean value of the k-th independent variable at the i-th location,
ε_{ij} : Random errors that are assumed to be independent, identical and follow a normal distribution with zero mean and constant variance.

Then the transformation is done within estimator by subtracting the FEM regression model equation from the average equation as shown in equation (7).

$$\tilde{y}_{ij} = \beta_0(u_i, v_i) + \sum_{k=1}^{p} \beta_k(u_i, v_i) \tilde{x}_{kij} + \tilde{\varepsilon}_{ij}\ ; i = 1,2, \dots, I; j = 1,2 \dots, J \tag{7}$$

11. Testing the suitability of the GWPR model. Test is conducted using equation (8) (Rahman et al., 2023)

$$F = \frac{\frac{RSS(H_1)}{df_1}}{\frac{RSS(H_0)}{df_2}} \tag{8}$$

where the test hypothesis is as follows,
$H_0 : \beta_k(u_{it}, v_{it}) = \beta_k$ (there is no significant difference in the linear regression model and GWPR model)
H_1 : there is at least one $\beta_k(u_{it}, v_{it}) \neq \beta_k$ (there is a significant difference in the linear regression model and GWPR model)

12. Partially test the significance of the GWPR model parameters with the T test as shown in equation (9) (Wati & Utami, 2020).

$$T_{test} = \frac{\hat{\beta}_k(u_{ij}, v_{ij})}{\bar{\sigma}\sqrt{C_{kk}}} \tag{9}$$

where,
$\bar{\sigma}$: $\sqrt{\frac{RSS_{GWPR}}{\delta_1}}$,
$\boldsymbol{C}_{kk}$: The k-th diagonal element of the matrix $\boldsymbol{C}_{ij}\boldsymbol{C}_{ij}^T$ where $\boldsymbol{C}_{ij} = [\widetilde{\boldsymbol{X}}^T \boldsymbol{W}(u_{ij}, v_{ij}) \widetilde{\boldsymbol{X}}]^{-1} \widetilde{\boldsymbol{X}}^T \boldsymbol{W}(u_{ij}, v_{ij})$.

13. Measuring the goodness of the FEM and GWPR models with R^2 using equation (10) (Sari, 2021).

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\sum_{j=1}^{J}\left(y_{ij} - \hat{y}_{ij}\right)^2}{\sum_{i=1}^{N}\sum_{j=1}^{J}\left(y_{ij} - \bar{y}_{ij}\right)^2} \tag{10}$$

where,
y_{ij} : The value of the dependent variable at the i-th location and j-th time,
$\hat{y}_{ij}$: The forecast value of the dependent variable at the i-th location and the j-th time,
$\bar{y}_{ij}$: The average value of the dependent variable at the i-th location and the j-th time.

RESULTS AND DISCUSSION

The LER value varies in value from one region to another. It depends on the quality of life of the population in the region. The increase in LER is caused by many aspects, from social to economic, such as government policies, environmental conditions, community economy, food availability, and education.

Table 2. Descriptive Statistics of Research Variables

Variable	Mean	Variance	Minimum	Maximum
Y	69,469	3,845	66,240	73,410
X_1	106,847	2995,850	45,000	302,000
X_2	85,781	110,811	45,780	98,520
X_3	32,356	332,023	7,620	81,330

Table 2 shows that the LER in 24 districts/cities in South Sulawesi in 2019-2021 has an average of 69,469 years with a variance of 3,845. The highest LER is in North Toraja Regency, which is 73,41 years. This is due to the way the North Toraja Regency government works regarding efforts to improve the basic quality of life of the community, which is carried out through a program of development activities in the health sector (Regional Government of North Toraja Regency, 2021). Meanwhile, the lowest LER value is in Jeneponto Regency, which is 66,24 years. This is due to the low standard of living. Based on BPS data in 2021, the poverty rate in Jeneponto Regency was 14,28%, making it one of the least developed regions in South Sulawesi. The low standard of living has a significant impact on public health. The main factor is limited access to basic health services (Ameliah et al., 2023).

Multicollinearity is a term to describe the linear relationship among the independent variables in the model. One way of detecting multicollinearity is through Variance Inflation Factors (VIF) testing. If VIF > 10, then there is multicollinearity (Meutuah et al., 2017). Table 3 indicates that all independent variables have a VIF value less than 10, indicating the absence of multicollinearity.

Table 3. VIF Value

Variable	VIF
$\mathbf{X_1}$	2,692
$\mathbf{X_2}$	1,064
$\mathbf{X_3}$	2,590

Panel data regression can be modeled using three methods, namely CEM, FEM, and REM. CEM is a method for analyzing combined cross section and time series data. CEM is a method that does not pay attention to time and subject differences between individuals (Wati & Utami, 2020). The CEM estimation results with R software are shown in the equation (11).

$$\hat{y}_{it} = 69{,}186 + 0{,}017x_{it1} + 0{,}005x_{it2} - 0{,}061x_{it3} \tag{11}$$

FEM is a method that can also be used in analyzing combined cross section and time series data. FEM has the assumption that the intercept between subjects is different and the slope between subjects is the same (Wati & Utami, 2020). The FEM estimation results with R software are shown in equation (12).

$$\hat{y}_{it} = 0{,}006x_{it1} + 0{,}009x_{it2} + 0{,}012x_{it3} \tag{12}$$

Next, REM is carried out. This model is a panel data regression model that considers random individual effects and has no correlation with the observed independent variables (Sutro et al., 2020). The REM estimation results with R software are shown in equation (13).

$$\hat{y}_{it} = 67{,}893 + 0{,}006x_{it1} + 0{,}009x_{it2} + 0{,}003x_{it3} \tag{13}$$

After obtaining the CEM, FEM, and REM panel regression models, testing is carried out in determining the best panel regression model. The Chow test is applied in selecting the best model between CEM or FEM (Rahman et al., 2023). H_0 in the Chow test states CEM and H_1 states FEM. H_0 is rejected if the *p-value* < 0,05, then the FEM model will be used. The Chow test results are shown in Table 4.

Table 4. Chow Test

Chow Test	
F	1383,800
p-value	0,000

Table 4 shows that *p-value* = 0,000 and less than 0,05, meaning reject H_0. Therefore, the model used is FEM.

The Hausman test is applied in selecting the best model between FEM or REM. H_0 in the Hausman test indicates REM and H_1 states FEM. H_0 is rejected if the *p-value* < 0,05, which means the model to be used is FEM. The Hausman test results are shown in Table 5.

Table 5. Hausman Test

Hausman Test	
χ^2	13,643
p-value	0,003

Based on Table 5, *p-value* = 0,003 and less than 0,05 which means reject H_0. This means that the model used is FEM.

Then test the significance of the FEM parameters. The following test aims to see the independent variables that have an impact on the LER variable are significant. The results of testing the significance of the FEM parameters are presented in Table 6.

Table 6. FEM Parameter Estimation Result

Variable	Coefficient	*p-value*	Description
X_1	0,006	0,003	Significant
X_2	0,009	0,000	Significant
X_3	0,012	0,283	Insignificant
	R^2	0,584	

Based on Table 6, *p-value* < 0,05, which means that the independent variable has no significant effect. This indicates that from 2019 to 2021, the number of poor people (X_3) has no significant impact on LER (Y) in South Sulawesi. Therefore, the number of poor people (X_3) is not included in further testing.

Next, heteroscedasticity testing was conducted. If heteroscedasticity occurs, then the research can be continued with GWPR modeling. This test was conducted using the Breusch-Pagan test. H_0 means no spatial heterogeneity and H_1 means spatial heterogeneity. H_0 is rejected if *p-value* < 0,05, means spatial heterogeneity occurs.

Table 7. *Breusch-Pagan* Test of FEM

χ^2	***p-value***
71,658	0,000

Table 7 shows that p-value is less than 0,05, which means H_0 is rejected. In other words, there is spatial heterogeneity. Therefore, GWPR modelling is continued (Mar'ah & Sifriyani, 2023).

The first step in GWPR modelling is to determine the optimum bandwidth by minimising CV (Rahayu, 2017). After the calculation, the bandwidth value is 0,112 with a CV value of 44,614. Next, the best kernel weighting function is selected for the GWPR model by looking at the largest R^2 value and the smallest AIC.

Table 8. R^2 and AIC Value of Kernel Weighting Function

Weighting Function	R^2	AIC
Adaptive Bisquare	0,671	231,898
Adaptive Gaussian	0,506	255,771
Adaptive Exponential	0,541	251,650
Fixed Bisquare	0,611	243,319

Fixed Gaussian	0,900	160,441
Fixed Exponential	0,977	63,786

Table 8 shows that the fixed exponential kernel weighting function has the largest R^2 value, which is 97,77%. In addition, the fixed exponential kernel weighting function has the smallest AIC value, which is 63,786. This means that the fixed exponential weighting function is the best weighting function.

After obtaining the best weighting function, GWPR modelling is performed. Each observation location has a different GWPR model. This research produces 24 GWPR models according to the number of observation units. The GWPR model at Jeneponto location is shown in equation (14).

$$\hat{y}_{4t} = -1953{,}760 + 0{,}014x_{4t1} + 0{,}045x_{4t2} \tag{14}$$

According to equation (14), if the variables are the number of health facilities and the percentage of households with proper sanitation, the LER variable will be -1953,760. Every time the number of health facilities increases by 1 unit, LER will increase by 0,014. Then, for every 1% of households with proper sanitation, LER will increase by 0,045.

The GWPR model obtained was then tested for fit. The goodness of fit test is useful to see the existence of differences in the FEM model (global regression model) and GWPR (Sari, 2021). H_0 in this test means that there is no significant difference between the FEM and the GWPR model, while H_1 means that there is a significant difference between the FEM and GWPR models. H_0 is rejected if the $F_{count} > F_{table}$.

Table 9. Goodness of Fit Test of GWPR

$\boldsymbol{F_{count}}$	$\boldsymbol{F_{table}}$
650,354	3,130

Based on Table 9, the value of $F_{count} > F_{table}$. Therefore, H_0 is rejected. This means that the FEM and GWPR models have significant differences.

Then, the GWPR model parameters are tested partially with the aim of identifying variables that significantly impact the dependent variable (Trisnawati, 2022). This test is done by checking the *p-value*. H_0 in this test means that the independent variable has no significant effect on LER, while H_1 means that the independent variable has a significant effect on LER. H_0 is rejected if the *p-value* is less than 0,05.

Table 10. Partial Testing of GWPR Model in Jeneponto

Parameter	***p-value***
β_1	0,003
β_2	0,036

Table 10 shows that the p-value of all parameters is < 0.05. Therefore, it can be concluded that the variables of the number of health facilities and the percentage of households with proper sanitation have a significant impact on Jeneponto's LER. Table 11 displays the groupings based on the significant variables.

Table 11. Grouping of Significant Variables in Each District/City

Group	**District/City**	**Significant Variables**
1.	Selayar Islands, Sinjai, Bone, East Luwu	None
2.	Bulukumba, Bantaeng, Takalar, Gowa, Maros, Barru, Soppeng, Wajo, Pinrang, Luwu, Tana Toraja, North Luwu, North Toraja, Makassar City	X_1
3.	Enrekang	X_2
4.	Jeneponto, Pangkajene and Islands, Sidenreng Rappang, Parepare City, Palopo City	X_1 and X_2

Table 11 shows the grouping of variables that significantly influence LER in each district/city in South Sulawesi based on two significant variables, namely the number of health facilities (X_1) and households with proper sanitation (X_2). The test yielded four groups. Figure 1 presents the grouping results with a distribution map.

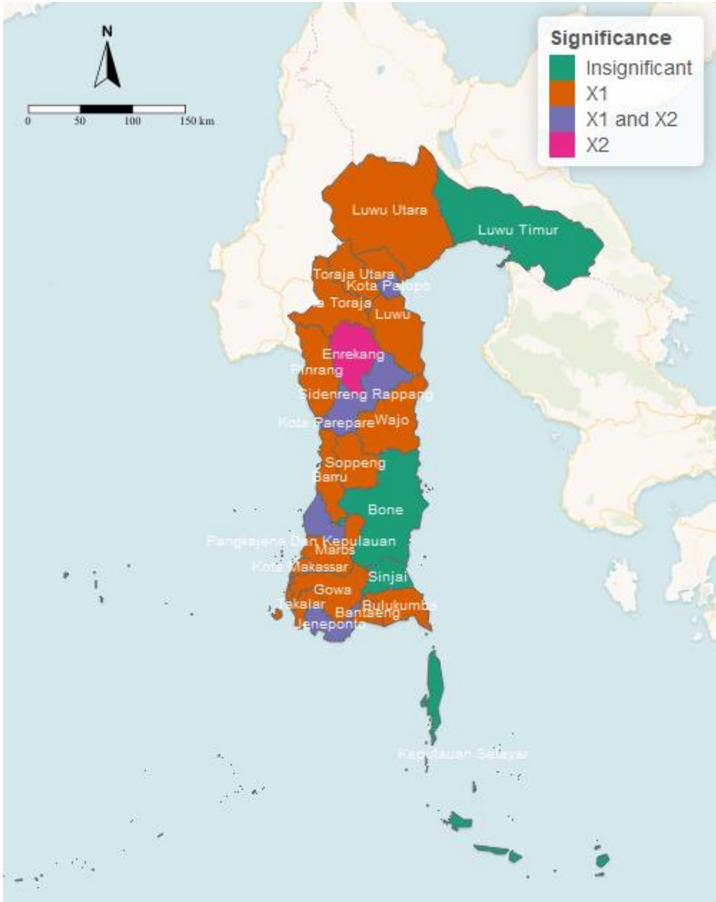

Figure 1. Grouping Map of Significant Variables for Each Regency/City

Figure 1 shows the grouping map of significant variables in each district/city. Each district/city has different significant variables so that four groups with different colours are formed. Next, we measured the goodness of the FEM and GWPR models with the R^2 value. The R^2 value or coefficient of determination is presented in Table 12.

Table 12. Measures of Goodness for FEM and GWPR Models

Model	R^2
FEM	0,584
GWPR	0,977

Table 12 shows the cofficient of determination (R^2) for the FEM and the GWPR model. The results show that the GWPR model has a higher R^2 value than the FEM. This suggests that the GWPR model is more effective than the FEM model to analyze LER in South Sulawesi, by emphasizing local spatial and temporal factors, in contrast to previous studies that did not consider spatial factors.

CONCLUSION

Based on the research conducted, it is concluded that the variables that influence LER in each district/city in South Sulawesi in 2019-2021 are different. The diversity in the influential variables resulted in the formation of four groups based on significant variables in each district/city. The GWPR model has a coefficient of determination of 97,7%. Thus, it is better at modelling LER districts/cities in South Sulawesi compared to the FEM. Therefore, the government should consider these factors when designing health policies and programs targeted at effectively increasing LER across regions.

REFERENCES

Alfiani, S., & Arum, P. R. (2022). Pemodelan Pertumbuhan Ekonomi di Jawa Barat Menggunakan Metode Geographically Weighted Panel Regression. *Jurnal Statistika*, *15*(2), 219–227. www.unipasby.ac.id

Alwi, W., Sauddin, A., & M., N. I. (2023). Faktor-Faktor Yang Mempengaruhi Angka Harapan Hidup di Sulawesi Selatan Menggunakan Analisis Regresi. *Jurnal Matematika Dan Statistika Serta Aplikasinya*, *11*(1), 72–80.

Ameliah, W. R., Razak, A., & Rusydi, A. R. (2023). Pengaruh Kualitas Pelayanan Kesehatan Terhadap Kepuasan Pasien Rawat Jalan di Puskesmas Barana Kabupaten Jeneponto Tahun 2022. *Journal of Muslim Community Health (JMCH)*, *4*(4), 226–237. https://doi.org/10.52103/jmch.v4i4.1431

Ananda, N. M. S., Suyitno, S., & Siringoringo, M. (2023). Geographically Weighted Panel Regression Modelling of Human Development Index Data in East Kalimantan Province in 2017-2020. *Jurnal Matematika, Statistika Dan Komputasi*, *19*(2), 323–341. https://doi.org/10.20956/j.v19i2.23775

Faturahman. (2019). Angka Harapan Hidup sebagai Intervening Anggaran Kesehatan Masyarakat dan Sumber Daya Manusia Kesehatan terhadap Kemiskinan di Kota Jambi. *Iltizam Journal of Shariah Economic Research*, *3*(1), 24–40.

Felangi, R. P., & Yasa, I. G. W. M. (2021). Analisis Beberapa Variabel yang Berpengaruh Terhadap Angka Harapan Hidup di Kabupaten/Kota Provinsi Bali. *E-Jurnal EP Unud*, *10*(4), 1447–1477.

Mar'ah, Z., & Sifriyani, S. (2023). Geographically Weighted Panel Regression (GWPR) for COVID-19 Case in Indonesia. *Barekeng: Jurnal Ilmu Matematika Dan Terapan*, *17*(2), 0879–0886. https://doi.org/10.30598/barekengvol17iss2pp0879-0886

Meutuah, S. M., Yasin, H., & Maruddani, D. A. I. (2017). Pemodelan Fixed Effect Geographically Weighted Panel Regression untuk Indeks Pembangunan Manusia di Jawa Tengah. *Jurnal Gaussian*, *6*(2), 241–250. http://ejournal-s1.undip.ac.id/index.php/gaussian

Pratama, A., Suyitno, & Purnamasari, I. (2021). Pemodelan Persentase Penduduk Miskin di Provinsi Kalimantan Timur Menggunakan Model Geographically Weighted Panel Regression. *Jurnal Matematika Dan Statistika Serta Aplikasinya*, *9*(2), 1–11.

Rahayu, N. S. (2017). *Geographically Weighted Panel Regression untuk Pemodelan Persentase Penduduk Miskin di Provinsi Jawa Tengah*. Institut Teknologi Sepuluh Nopember.

Rahman, A. F., Syafriandi, Amalita, N., & Zilrahmi. (2023). Geographically Weighted Panel Regression Modeling on Human Development Index in West Sumatra. *UNP Journal of Statistics and Data Science*, *1*(3), 231–239. https://doi.org/10.24036/ujsds/vol1-iss3/63

Regional Government of North Toraja Regency. (2021, February 27). *Kabupaten Toraja Utara Capai Angka Harapan Hidup Tertinggi Se-Sulsel, Bupati Kalatiku Paembonan Dianugerahi Public Health Achievement Award*.

Sari, M. S. S. N. (2021). *Model Geographically Weighted Panel Regression dengan Fixed Effect Model pada Penyebaran Kemiskinan di Jawa Tengah*. Universitas Islam Negeri Maulana Malik Ibrahim.

Sutro, S., Yundari, Y., & Martha, S. (2020). Pemodelan Fixed Effect Geographically Weighted Panel Regression untuk Indeks Pembangunan Manusia di Kalimantan Barat. *Buletin Ilmiah Math. Stat. Dan Terapannya (Bimaster)*, *9*(3), 413–422.

Tamara, I., Ispriyanti, D., & Prahutama, A. (2016). Pembentukan Model Spasial Data Fixed Effect Menggunakan Gui Matlab (Studi Kasus : Kemiskinan di Jawa Tengah). *JURNAL GAUSSIAN*, *5*(3), 417–426. http://ejournal-s1.undip.ac.id/index.php/gaussian

Trisnawati, T. (2022). *Model Geographically Weighted Panel Regression (GWPR) Pada Kejadian Tanah Longsor di Provinsi Jawa Tengah*. Universitas Islam Negeri Sunan Ampel.

Wati, D. C., & Utami, H. (2020). Model Geographically Weighted Panel Regression (GWPR) dengan Fungsi Kernel Fixed Gaussian pada Indeks Pembangunan Manusia di Jawa Timur. *Jurnal Matematika Thales (JMT)*, *2*(1), 78–97.