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Spatial Modeling of Factors Determining Active Family Planning Participation in East Java: A Geographically Weighted Regression and Elastic Net Approach

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ABSTRACT

Abstract— This research identifies regional variations and determinants of active family planning (KB) participation in East Java using spatial modeling. The study utilizes data from the 2024 Family Information System (SIGA) of BKKBN East Java. To address multicollinearity and high-dimensional data, the Elastic Net method—combining Ridge and Lasso penalties—was employed for variable selection, retaining 6 out of 10 initial variables. Global modeling through Ordinary Least Squares (OLS) showed an Adjusted of 0.668. However, a Moran's I test on the residuals revealed significant spatial autocorrelation (Z-score = 2.5677, p = 0.0102), justifying the use of Geographically Weighted Regression (GWR). The GWR model, using a Fixed Gaussian kernel with a bandwidth of 103.63, improved performance with an Adjusted of 0.7348. The results demonstrate spatial heterogeneity, where factors such as unmet need, households with children, and welfare levels have varying impacts across different districts. This spatial visualization helps identify priority areas for strategic resource allocation to enhance KB program efficiency.

Keywords: Elastic Net Geographically Weighted Regression, Family Planning, Spatial Heterogeneity, East Java

I. INTRODUCTION

The Family Planning (KB) program is a strategic pillar in managing population growth and improving family welfare in Indonesia, particularly in the Province of East Java. The Mobilization and Community Participation (PERMAS) team at the BKKBN Representative Office in East Java plays a crucial role in driving community participation and conducting advocacy and education for the "Bangga Kencana" program [1]. However, the effectiveness of these programs often faces challenges due to non-uniform achievement variations across regions [2]. A deep understanding of the determinant factors of active KB participation is essential to ensure that policies are accurately targeted. Recent research emphasizes that the integration of demographic and population health data is key to mapping primary service needs at the local level [3].

In the analysis of public health data, researchers often encounter high-dimensional datasets with many interdependent independent variables. This condition, known as multicollinearity, can lead to model instability and significantly reduce predictive accuracy [4]. To address these issues, regularization techniques such as Elastic Net are employed, as they combine the penalties of Ridge (L2) and Lasso (L1) regression [5]. This method is particularly effective for simultaneous variable selection and handling data where variables are highly redundant [6]. Recent research in data analytics has also highlighted the importance of robust feature selection and object detection in complex, high-

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dimensional environments [7].

Beyond data dimensionality, the spatial distribution of active KB participants is a critical factor that conventional statistical models often fail to capture [8]. Spatial autocorrelation tests, such as Moran's I, often reveal that observations are not independent, indicating that the relationship between variables varies depending on geographic location [9]. To account for this spatial heterogeneity, the Geographically Weighted Regression (GWR) model is utilized to estimate local regression coefficients for each district, addressing multicollinearity through spatial regularization [10]. Previous studies have shown that localized modeling is essential for the accuracy of public health descriptions in East Java [11].

This study aims to perform a comprehensive spatial analysis of the factors determining active KB program participation in East Java by integrating Elastic Net regularization with GWR. By utilizing 2024 Family Information System (SIGA) data, this research identifies unique regional characteristics and priority intervention zones [12]. The findings provide strategic recommendations for policymakers to allocate resources more efficiently, particularly concerning the selection of long-acting contraceptive methods across administrative units [13].

II. PROCEDURE AND METHODOLOGY

A. Data Source and Preprocessing

his study utilizes secondary data from the 2024 Family Information System (SIGA) provided by BKKBN East Java. The dataset covers 38 districts/cities in East Java, focusing on family planning service indicators. Pre-processing involves data cleaning to handle missing values and the formation of ratio variables using the number of Couples of Childbearing Age (PUS) as the denominator to ensure comparability across regions

B. Feature Selection via Elastic Net

To address high dimensionality and multicollinearity among the 10 initial independent variables, the Elastic Net method is applied,. Elastic Net combines the penalties of Ridge (L2) and Lasso (L1) regression into a single objective function

$$\frac{1}{2N}||y-\beta_0-\boldsymbol{X}\beta||^2+\lambda\left(\frac{1-\alpha}{2}||\beta||_2^2+\alpha||\beta||_1\right)$$

Where $\lambda \geq 0$ is the regularization parameter and $\alpha \in$ balances the L1 and L2 penalties,. This approach allows for simultaneous variable selection and stabilization of coefficient estimates.

C. Spatial Autocorrelation Analysis

Before performing local modeling, the residuals of the global Ordinary Least Squares (OLS) model are tested for spatial autocorrelation using the Moran's I statistic,. Moran's I measures the degree of linkage between variable values based on geographic proximity.

$$I=\frac{n}{\sum\sum w_{ijj}}\frac{\sum\sum w_{ijj}\,(x_i-\bar{x})(x_j-\bar{x})}{\sum(x_i-\bar{x})}$$

A significant p-value (< 0.05) indicates the presence of spatial dependence, justifying the transition from a global to a local regression model.

D. Geographically Weighted Regression (GWR)

The GWR model is an extension of linear regression designed to capture spatial heterogeneity by allowing coefficients to vary locally. The model is formulated as follows:

$$y_i = \beta_0(u_i, v_i) + \sum \beta_0(u_i, v_i)x_{ik} + \epsilon_i$$

Where (u_i, v_i) represents the geographic coordinates of location i. The optimal bandwidth and kernel function—specifically the Fixed Gaussian kernel—are selected based on the minimum Corrected Akaike Information Criterion (AICc) to ensure the best model fit.

E. The Corrected Akaike Information Criterion (AICc)

AICc is a statistical measure used for model selection and performance evaluation by balancing the goodness-of-fit against the complexity of the model. A model configuration with the lowest AICc value is considered the most efficient, as it minimizes information loss while avoiding overfitting caused by including excessive parameters.

$$AIC = 2k - 2\ln(L)$$

Where k represents the number of estimated parameters and L is the maximum likelihood of the model.

III. RESULT AND DISCUSSION

A. Variable Selection and Multicollinearity Analysis

The initial dataset contained 10 variables, which were subjected to Elastic Net regularization to ensure model stability and address potential redundancy. The process successfully identified 6 primary determinants, eliminating 4 variables that were found to be weak or highly redundant. To verify the stability of these selected variables before spatial modelling, a Variance Inflation Factor (VIF) test was conducted. As shown in Table I, all variables yielded VIF values significantly below the threshold of 10, indicating the absence of serious multicollinearity.

TABLE I. MULTICOLINEARITY DIAGNOSTIC (VIF)

Variable	VIF
Ratio of Unmet Need	1,55
Ratio of Families with ≥ 3 Children	1,78
Ratio of Prosperous Families	2,30
Ratio of Unsafe Water	2,62
Contraceptive Discontinuation Rate	1,02
Ratio of BPJS-Collaborated KB Services	1,08

B. Feature Selection and Global Baseline

The feature selection process using Elastic Net successfully reduced the initial 10 independent variables to 6 primary determinants of active family planning (KB) participation in East Java,. The method combined Ridge and Lasso penalties to eliminate redundant variables, retaining factors such as the ratio of unmet need, prosperous families, and families with children. The coefficients for the selected variables are detailed in Table II.

TABLE II. ELASTIC NET FEATURE SELECTION RESULT

Variable	Coefficient
Ratio of Unmet Need	-26,92
Ratio of Families with ≥ 3 Children	-14,75
Ratio of Prosperous Families	-7,68
Ratio of Unsafe Water	-5,85
Contraceptive Discontinuation Rate	2,52

Ratio of BPJS-Collaborated KB Services	-1,89

The global Ordinary Least Squares (OLS) model provided an Adjusted of 0.668, with an F-statistic of 13.40 ($p < 0.001$), confirming the collective significance of the predictors. Further diagnostic tests on the residuals showed a Jarque-Bera value of 1.311 ($p = 0.519$) and a Shapiro-Wilk p-value of 0.3818, indicating that the residuals follow a normal distribution. Additionally, a Durbin-Watson score of 1.60 suggested no serious global autocorrelation issues. However, these global metrics do not account for geographic variations, necessitating spatial dependency tests.

However, to ensure the residuals were not influenced by geographic location, a Moran's I test was performed. The diagnostic results in Table III show significant spatial autocorrelation (p-value < 0.05), justifying the transition to a local modelling approach.

TABLE III. SPATIAL AUTOCORRELATION TEST ON OLS RESIDUAL

Metric	Value
Moran's L	0,20
Expected	-0,03
Z-Score	2,57
P-value	0,01
Decision	Reject H0

C. GWR Model performance and Comparison

The Geographically Weighted Regression (GWR) model was configured using a Fixed Gaussian kernel with an optimal bandwidth of 103.63, selected based on the minimum AICc value,. The GWR model significantly improved the predictive accuracy and reduced errors compared to the global OLS model,. The comparison of performance metrics between the two models is summarized in Table III.

TABLE IV. PERFORMANCE COMPARISON : GLOBAL OLS VS. LOCAL GWR

Metric	Global (OLS)	Local Model (GWR)
Adjusted R2	0,67	**0,73**
Residual Sum of Squares (RSS)	50.631,57	**37.041,26**
AICc	**395,24**	395,98
BIC	406,70	**404,27**

The results in Table IV demonstrate that by incorporating spatial weights, the GWR model provides a better fit for the East Java dataset, with a higher Adjusted and a substantially lower RSS. The decrease in the BIC value further confirms that the GWR model is more efficient in explaining the spatial heterogeneity of KB participation factors across the 38 districts and cities.

D. Spatial Distribution of Model Fit and Priority Areas

The spatial distribution of the Local values provides insight into the varying performance of the GWR model across East Java. The analysis identified several "Priority Areas" where the model fit is less than optimal (Local), suggesting that in these regions, family planning participation is likely influenced by additional contextual factors—such as local cultural norms or specific service access issues, that are not captured in the current dataset. The summary of the spatial model fit is presented in Table V.

TABLE V. SUMMARY OF SPATIAL MODEL FIT AND PRIORITY AREAS

Category	Criterion (Local R2)	No. of Districts	General Regions
High Fit	≥0.795	28	Northern & Western East Java
Priority Area	< 0,795	10	Southern & "Tapal Kuda"

E. Local Beta Analysis and Policy Implications

The GWR results confirm significant spatial heterogeneity in the influence of determinants across the province. A notable example is the Ratio of Prosperous Families (x3), which exhibits a directional shift in its relationship with active KB participation depending on the location,. While the relationship is positive in the majority of East Java, three specific districts in the southern region show a negative correlation, highlighting the need for localized policy interventions rather than a uniform provincial strategy,,. The classification of these local influences is summarized in Table VI.

TABLE VI. LOCAL BETA CLASSIFICATION FOR PROSPEROUS FAMILIES RATIO

Influence Class	No. of Districts	Beta Mean	Min – Max Beta	Sample Districts
Positive (Increases Y)	35	6,58	6.31 – 8.2	Either Pacitan, Trenggalek Ponorogo
Negative (Decreases Y)	3	-17,84	-17,8 – -17,83	Pacitan, Trenggalek, Ponorogo

The findings in Table V demonstrate that in districts like Pacitan, Trenggalek, and Ponorogo, an increase in the prosperity ratio is associated with a decrease in active KB participation. This unique characteristic necessitates a specialized approach by BKKBN, such as strengthening socio-cultural advocacy in these specific southern districts to align family welfare with program participation.

CONCLUSION

This study successfully implemented a spatial modelling framework by integrating Elastic Net regularization and Geographically Weighted Regression (GWR) to analyze active family planning (KB) participation in East Java. The use of Elastic Net proved effective in addressing multicollinearity and high-dimensional data, refining 10 initial variables into 6 most relevant determinants—including unmet need, family prosperity, and the number of children. This methodological combination provided a more robust and interpretable model compared to conventional global regression.

The empirical results demonstrate that family planning participation in East Java is not spatially homogeneous. The GWR model significantly outperformed the global OLS model, achieving a higher Adjusted of 0.7348 and a substantial reduction in the Residual Sum of Squares (RSS). The analysis confirms the existence of spatial heterogeneity, where the influence of factors such as the ratio of prosperous families and the number of children (≥ 3) varies in direction and magnitude across the 38 districts,. Specifically, regions like Pacitan, Trenggalek, and Ponorogo exhibited unique local characteristics that differ from the provincial average.

In terms of policy implications, these findings underscore the necessity for region-specific strategies rather than a uniform "one-size-fits-all" approach. BKKBN and relevant stakeholders should prioritize interventions in identified "priority areas", primarily in the southern and "tapal kuda" regions, where the model fit indicates the presence of additional local contextual factors such as cultural norms or specific access barriers,

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