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Bayesian Geoadditive Modelling of Poverty Distribution: A Spatial Analysis of Indonesia

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Abstract

Zakat, as an instrument of financial redistribution in the Islamic economy, has significant potential for poverty alleviation; however, the spatial distribution patterns of its impact in Indonesia have not yet been extensively analyzed using spatial modelling. In this paper, we measure the spatial pattern of the impact of zakat on poverty and identify zakat clusters in Indonesia using the Bayesian geoadditive model approach. In this study, we collected data from the Indonesian Central Statistics Agency and the National Amil Zakat Agency (BAZNAS) in 2024, respectively, to analyse the socio-economic and spatial relationship between zakat and poverty in Indonesia. We found strong evidence that zakat has a significant effect on poverty, with a posterior mean of 21,042.1 (SD = 28,142.4; 95% PCI: 12,665.3–30,185.0), where the entirely positive credible interval indicates a consistent spatial association between the distribution of zakat and the concentration of the poor. Furthermore, the structured spatial effects reveal regional heterogeneity with a significant East–West divide: the Papua region exhibits the highest positive spatial effect (up to +317.67), indicating a poverty burden far exceeding the model's predictions, whilst Java and parts of Kalimantan show a negative effect (up to −517.67), reflecting the greater effectiveness of zakat distribution. The model identifies distinct regional clusters, demonstrating significant spatial heterogeneity across regions in Indonesia. The Bayesian geoadditive approach proved superior to conventional models in capturing these non-linear patterns and spatial inequalities. The resulting maps provide policymakers with a practical basis for designing more targeted zakat collection and distribution strategies to support national poverty alleviation.

1. Introduction

Indonesia, the most populous country in ASEAN, had a population of 270.20 million according to the 2020 Population Census. The country is currently experiencing a demographic bonus, in which the productive-age population outnumbers the dependent-age population, providing considerable potential for economic growth (Cicih & Nugroho, 2021). This demographic bonus is expected to have an impact on *zakat* receipts in Indonesia (Bilqis & Zaki, 2020; Setiyowati, 2017). Reducing poverty disparities should be able to encourage the growth of *zakat* in Indonesia (Harahap et al., 2023), in line with the increase in population demographics, which is expected to encourage an increase in *zakat* receipts. An important issue in this context is how significant the influence of *zakat* is in reducing poverty in Indonesia. A good distribution of *zakat* is the goal of meeting the demand in the community to reduce the disparity in people's prosperity. On a broader scale, enhancing economic growth and development, along with ensuring fair income distribution, are crucial factors in alleviating poverty in Indonesia. On a small scale, the resources accessible to households grant them income and impact the extent of poverty experienced (Karim et al., 2020; Karim et al., 2017).

The utilization of zakat as an alternative tool to reduce poverty rates should be maximized.(Pratama & Purba, 2021; Pratama, 2015). Hence, exploring the capacity of zakat in Indonesia is crucial (Karim et al., 2020). Conducted research on zakat and poverty in Indonesia, employing the local indicator spatial association (LISA) method. The findings of the LISA analysis reveal a noteworthy and affirmative impact of zakat potential on poverty in Indonesia, demonstrating interdependence among adjacent areas in terms of both zakat potential and poverty levels. Differences in conditions owned by each district/city, such as differences in the number of poor people and economic growth, can cause variations in the growth of *zakat* receipts in each region. Differences in regional characteristics that have implications for *zakat* receipts vary. The increase in regional connectivity and or proximity, as well as the same characteristics between regions, is strongly suspected of having a spillover effect.

Spatial data includes information about location and spatial distribution in a geographical area. When the response variable contains spatial information, spatial Bayesian models often capture spatial dependence or correlation between neighboring locations (Krapu et al., 2023). In spatial Bayesian modelling, the prior distribution is combined with the likelihood function to produce a posterior distribution that reflects prior knowledge and observed data (Geyer et al., 2021; Omre & Rimstad, 2021). Spatial Bayesian models generally use Gaussian or Markov random distributions to account for spatial autocorrelation (Wang, 2022). Spatial Bayesian modelling is preferred over classical linear regression because spatial data tend to violate assumptions such as independence in the data (Kang et al., 2024; Louzada et al., 2021; Zhao & Xu, 2023). Classical linear regression assumes that residuals are uncorrelated and homoscedastic, which often does not hold in a spatial context where neighboring observations in one region tend to have similar characteristics in another region (Chen, 2016; Dumelle et al., 2023; Karim et al., 2020). Spatial Bayesian models have the advantage of flexibility because they allow for spatial heterogeneity (Ling & Le Gallo, 2023).

The implications for regional planning from spatial Bayesian methods lie in their ability to identify priority areas and spatial spillover effects in the effectiveness of poverty interventions. Previous research utilized the Spatial Durbin model to detect the direct and indirect effects of sectoral government expenditure on poverty at the district/municipal level, confirming the existence of spatial dependence in poverty dynamics (Zhou & Liu, 2022). Fiscal decentralization in Indonesia creates opportunities for local governments to design poverty alleviation strategies responsive to local spatial contexts. Yet, their effectiveness depends on the availability of precise spatial empirical evidence (Digdowiseiso et al., 2020). Bayesian geoadditive models enable policymakers to distinguish between global effects (mean parameters) and local effects (spatial variation), allowing interventions to be tailored to the unique characteristics of each region (Fahrmeir & Lang, 2001).

From a regional planning perspective, fiscal decentralization and regional autonomy present both opportunities and challenges in efforts to alleviate poverty in a spatially-based and locally-contextualized manner. Previous studies using spatial panel data analysis on districts in Indonesia found significant spatial autocorrelation in poverty and positive spillover effects from government spending in the education, health, and social protection sectors on poverty reduction in surrounding areas (Novitasari & Iskandar, 2022). These findings imply that spatial inequality in poverty in Indonesia cannot be resolved through a universal approach, but rather requires regional development strategies that are sensitive to local characteristics and spatial dynamics between regions.

The involvement of local institutions, including the provincial-level zakat management organization (Baznas), in regional development planning strategies is becoming increasingly important to ensure the optimal allocation of Islamic philanthropic resources in line with the specific needs of the region. Previous studies on the relationship between zakat and poverty indicate that zakat has significant potential to reduce extreme poverty as a complement to government social protection programmers; however, its effectiveness depends on coordination across levels of government within a holistic regional development strategy (Nurzaman & Khanifa Kurniaeny, 2019). Bayesian spatial analysis in the regional development planning process enables local governments to identify areas with high-priority needs and appropriate interventions.

This study has two main objectives: first, to measure the spatial patterns of the impact of zakat on poverty across Indonesia; and second, to identify significant zakat clusters using a Bayesian geoadditive model. This approach was chosen due to its superior ability to capture non-linear effects, structured spatial effects via Markov Random Field priors, and smooth covariates simultaneously within a single integrated estimation framework. The main novelty of this study lies in three aspects: (1) the use of a Bayesian geoadditive model for zakat-poverty analysis, which is the first of its kind in Indonesia at the national level; (2) the visualization of spatial effect maps that can be directly utilized as a basis for policy targeting; and (3) the empirical demonstration of an East–West spatial dichotomy in the relationship between zakat and poverty, which has not previously been documented quantitatively.

This study highlights the significant benefit of employing flexible modelling techniques to capture region-specific effects, which surpass the limitations of traditional parametric and frequentist methods. For instance, while frequentist modelling leads to redundant parameters for single variables, Bayesian geoadditive models offer the unique advantage of incorporating spatial, nonlinear, and temporal variations of covariates alongside linear effects through appropriate adjustment of smoothness. Moreover, the novelty of this analytical approach holds promise for informing policy formulation, allowing governments to focus on strategies concerning zakat policy. Increasing zakat awareness from provinces to districts and cities may be imperative.

2. Data and Methods

2.1. Data

A primary repository of extensive national data concerning zakat and the economy lies within the National Amil Zakat Agency (Baznas) and the Central Statistics Agency of the Republic of Indonesia (BPS). Baznas functions as a non-structural governmental entity with a key role in overseeing zakat, infaq, and sadaqah management, among other responsibilities. The data used in this study are secondary data from the National Amil Zakat Agency (Baznas) and the Central Statistics Agency (BPS) in 2024. This study was conducted in Indonesia, the world's largest archipelago, which is astronomically situated between 6°N and 11°S and 95°E and 141°E. Indonesia stretches over 5,100 km from west to east and comprises more than 17,000 islands with a total land area of approximately 1.91 million km², spread across five main island groups: Sumatra, Java, Kalimantan, Sulawesi, as well as Nusa Tenggara, Maluku and Papua. This research is the development of a study on the potential of zakat conducted by Karim et al. (2020) which uses the spatial association methodology with the global Moran's and local Moran's methods. The difference is that analysis development is carried out in the form of modelling and clustering using the Bayesian Geoadditive Model.

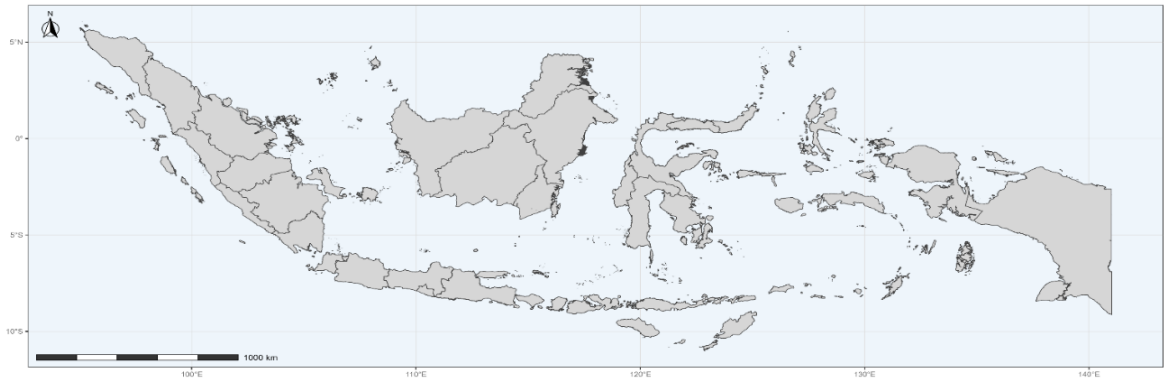

Figure 1. Map of the Study Area

Demographically, Indonesia is the world's fourth most populous country, with a population of over 270 million according to the 2020 Population Census; however, the distribution is highly uneven more than 56 per cent of the population is concentrated on the island of Java, which accounts for only around 7 per cent of the total national land area (BPS, 2021). This disparity in population distribution reflects a broader structural heterogeneity in socio-economic conditions across Indonesia's regions. Poverty rates vary significantly between

provinces, ranging from the lowest figures of under 4 per cent in some provinces on the islands of Java and Kalimantan, to exceeding 25 per cent in provinces in Papua (BPS, 2023). This substantial spatial variation makes Indonesia a highly relevant context for spatial modelling analysis, whilst also serving as the primary justification for the use of a Bayesian geoadditive model approach, which is capable of explicitly accommodating spatial dependency structures.

The spatial unit used in this analysis is the province, with each province treated as a single observation unit (Figure 1). The choice of the provincial level as the unit of analysis is based on two considerations. Firstly, the zakat distribution data compiled by the National Zakat Agency (BAZNAS) and the poverty rate data published by the Central Statistics Agency (BPS) are available at the provincial level. Secondly, within the framework of fiscal decentralization in Indonesia, the authority for managing zakat and implementing poverty alleviation programs largely resides at the provincial government level.

2.2. Bayesian Geoadditive Model

This section discusses a Bayesian geoadditive approach that aims to estimate fixed effect parameters, unknown smooth functions of metric covariates, and spatial effects of geographic location (Balekelayi & Tesfamariam, 2019).An overview of the analytical workflow is provided in Figure 2, outlining the sequence from data collection and preliminary analysis to Bayesian geoadditive modelling, MCMC estimation, convergence diagnostics, and the visualization of spatial and nonparametric effects across the four geographic units. This approach is based on fully Bayesian inference using the Markov Chain Monte Carlo (MCMC) technique.

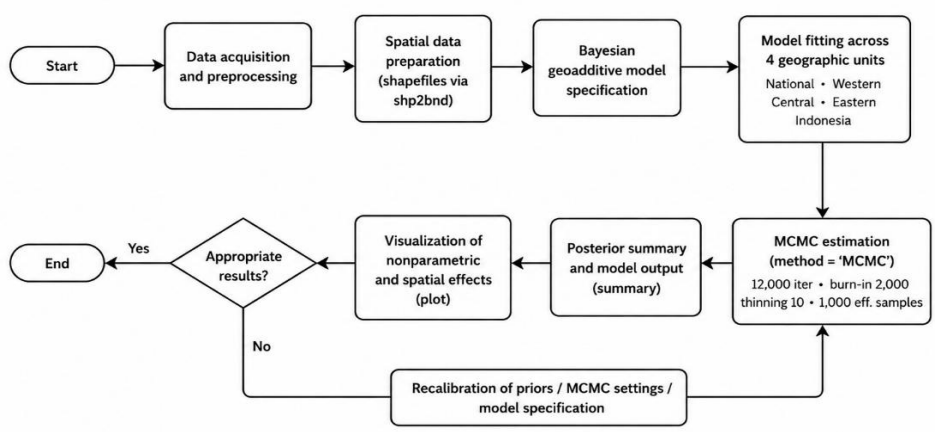

Figure 2. Research Flowchart

The Bayesian method is used to overcome limitations in modelling, such as complex models and unrealistic assumptions. Equation 1 presents the Bayesian modelling; the parameter θ is treated as a random variable with a certain distribution. The basis of Bayesian modelling is the posterior model, which combines prior information with observed data through the likelihood function. The estimator in the Bayesian approach is the mean or mode of the posterior distribution. Before making an observation, the parameter θ is assumed to have a prior distribution. After observing data, the likelihood function incorporates the observed information to form the posterior distribution.

$$f(\theta|x) = \frac{f(x|\theta)f(\theta)}{f(x)} \propto f(x|\theta)f(\theta) \ldots\ldots\ldots\ldots \textit{(Equation 1)}$$

with $f(\theta \mid x)$ defined as the posterior distribution, $f(x \mid \theta)$ a likelihood function, $f(\theta)$ as the prior distribution, x as the data and θ as the parameter (Gelman et al., 2013).

Furthermore, in multiple linear regression models cannot accommodate the non-linear influence of independent variables and require strict assumptions about the distribution of data. One method that can be used to overcome these problems is the additive model (Hastie & Tibshirani, 1990). Suppose we have a set of data

$\{y_i, x_{i1}, x_{i2}, \ldots, x_{ip}\}_{i=1}^{n}$, where n is the number of observations. Then the additive model can be written in Equation 2:

$$Y_i = f_0 + \sum_{j=1}^{p} f_j(X_{ij}) + \varepsilon_j \quad \ldots\ldots\ldots \textit{(Equation 2)}$$

where fj(.) is a single function that belongs to each predictor, p is the number of independent variables, E(ε) has the value 0 and Var(ε) is σ^2.

Additive models (AM) are one of the development methods of linear regression, which replaces linear functions with additive functions. AM is used in order to define the relationship between the dependent variable and several independent variables that have non-linear characteristics (Jamilatuzzahro et al., 2018). The Generalized Additive Model is a development of linear models and the Generalized Linear Model (GLM), which assumes that the independent variables follow the characteristics of an exponential distribution (Wood, 2017). Nonlinear impacts stemming from continuous covariates can manifest within regression models, even when dealing with binary or other non-normally distributed response variables. Echoing the additive models discussed earlier, prioritizing the incorporation of adaptable nonparametric effects for continuous covariates is typically preferred over imposing rigid parametric structures. Techniques for flexible and data-informed estimation of nonlinear effects assume heightened significance in scenarios involving non-normally distributed responses, given that visual aids like scatter plots may not always be viable for grasping the relationship between the response variable and covariates (Karim et al., 2025).

Generalized Additive Models are an extension of linear regression by substituting the linear function $\sum_{j=1}^{p} \beta_j X_j$ with an additive function $\sum_{j=1}^{p} f_j(X_j)$. This makes the GAM model more flexible than GLM or Additive Models (AM). GAM can be formulated in Equation 3:

$$g(\mu) = s_0 + \sum_{j=1}^{p} s_j(X_j) + \varepsilon \quad \ldots\ldots\ldots \textit{(Equation 3)}$$

The response variable is assumed to be exponentially distributed, and s is a smooth function. GAM and GLM models can be applied in similar situations, but they provide different analytics. GLM focuses more on estimation and inference for model parameters, while GAM focuses on nonparametric data exploration.

The Bayesian geoadditive model decomposes the linear predictor into a nonparametric smooth function of the covariate and a spatially structured random effect. For province *i*, the model is specified in Equation 4:

$$\text{Poverty}_i = \beta_0 + f(\text{Zakat}_i) + f\_spat(s_i) + \varepsilon_i \quad \ldots\ldots\ldots \textit{(Equation 4)}$$

where β_0 is the overall intercept, $f(Zakat_i)$ is a nonparametric smooth function of zakat, estimated using a penalized spline (P-spline) smoother via the *sx()* function, $f\_spat(s_i)$ is the structured spatial effect for province s_i, modeled with a Geokriging (GK) basis function that accounts for spatial autocorrelation through the provincial adjacency structure, $\varepsilon_i \sim N(0, \sigma^2)$ and is the Gaussian error term.

Table 1. MCMC Estimation Settings

MCMC Setting	Value	Description
Total iterations	12,000	Total number of MCMC sweeps
Burn-in	2,000	Initial samples discarded for chain convergence
Thinning interval	10	Every 10th sample retained to reduce autocorrelation
Effective posterior samples	1,000	Used for posterior inference: (12,000 − 2,000) / 10
Sampler algorithm	Mixed MCMC	IWLS for regression coefficients; slice/Gibbs for variance components
Posterior summary	Mean, SD, 95% CI	Posterior mean as point estimate; 95% credible interval for uncertainty

This study employs a Bayesian geoadditive approach to examine the relationship between zakat and poverty rates across provinces in Indonesia. The analytical framework integrates nonparametric smoothing of covariate effects with spatial dependency modelling through a geokriging (GK) spatial effect, estimated within a

fully Bayesian MCMC framework. Analysis was conducted at four geographic levels: the provinces level and three regional island groupings (Western Indonesia, Central Indonesia, and Eastern Indonesia), allowing both aggregate and disaggregated spatial inference. All analyses were performed using the R programming language with the following packages: BayesX, and R2BayesX. All models were estimated using Markov Chain Monte Carlo (MCMC (see Table 1).

3. Result and Discussion

A confidence interval refers to a span between two points within which the sample mean is precisely positioned at the midpoint. Hypothesis testing on the parameters is carried out using the 95% Probability Confidence Interval approach for each parameter. The 95% Probability Confidence Interval is calculated with the lower limit being the 50% quintile and the upper limit being the 97.5% quintile. The parameter is declared significant if the 95% Probability Confidence Interval parameter does not contain a zero value.

Table 2. Parameter Estimation Results

Variable	Mean	Standard Deviation	95% PCI	Significant
Constant	2,804.49	2,661.89	3,335	-
Zakat	210,421	281,424	(12665.3,30185.0)	Yes

Table 2 shows the results of fixed effect parameters (non-spatial) in Indonesia. From the table above, it can be seen that the zakat variable has a value of 0 at the 95% Probability Confidence Interval. This shows that the zakat variable has a positive influence on the variable of the poor population in Indonesia, with an average of 210421. It can be interpreted that the higher the value of zakat in an area will have a positive effect on reducing poverty levels in Indonesia, with an average of 210421.

This indicates that globally, zakat provides benefits for the poor in Indonesia. This study follows the research that states the importance of increasing zakat receipts and encouraging people's productivity. Currently, it can be seen that individual and corporate productivity will be able to increase zakat receipts. The higher the potential level of zakat, both for individuals and corporations, the stronger it is suspected that zakat receipts will increase, so that it will be able to reduce the level of poverty in Indonesia.

3.1. Analysis of Spatial Effects on Poverty

Territories are, in most cases, not a set of unconnected administrative units. Numerous connections exist among localities, leading to interactions that generate a spillover impact (Czyżewski et al., 2020; Kim et al., 2021). Among these effects, we can calculate the association for each region. Thus, when provinces have interacted with each other, the expansion of public goods and services offered by a specific province stimulates economic growth not only within its own political and administrative borders but also throughout the surrounding geographic region it's connected to. This interconnectedness fosters a ripple effect, spreading economic benefits beyond the province's immediate boundaries (Asmawi et al., 2017; Chai et al., 2021).

In Bayesian inference, Probability Confidence Interval (PCI) is the posterior probability interval used for interval estimation, while in the classical approach, the Probability Confidence Interval is obtained from sample data. To find out the specific spatial effects in Indonesia, Figures 2, 3, 4, and 5 show the importance of the observed spatial effects in the form of a posterior probability map. As research conducted by Kandala (2006), the level of significance corresponds to the Probability Confidence Interval. The value of Probability Confidence Interval 0 to 317.67 (colored red) shows a significant positive effect, the value of Probability Confidence Interval 0 (colored white) shows an insignificant effect, and the value of Probability Confidence Interval -317.67 to 0 (colored blue) shows a significant negative effect.

Spatial data is data related to location, based on geography, consisting of latitude, longitude, and area. Spatial data analysis cannot be done globally. This means that each location has its own characteristics. Most of the analytical approaches are exploratory data presented in the form of thematic maps. Thematic maps are also known as statistical maps or special-purpose maps, which produce an overview of the use of space in a particular place according to the desired theme.

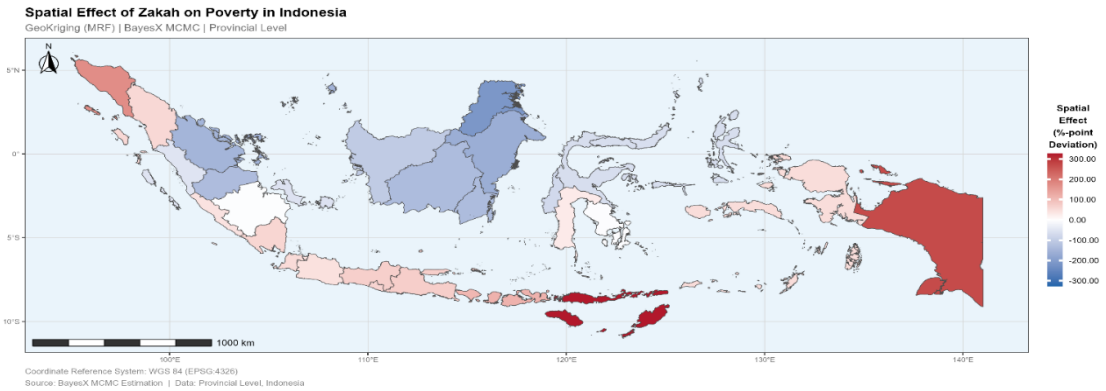

Figure 3. Spatial Effects on Zakat in Indonesia

To compare the spatial effects, it is presented in Figures 3, 4, 5, and 6 present a map showing the effects of the provinces in Indonesia. Figure 4 is Island one (1). The region includes Aceh, North Sumatra, West Sumatra, Riau, Jambi, South Sumatra, Bengkulu, Lampung, the Bangka Belitung Islands, and the Riau Islands. Figure 5 is Island two (2) consisting of DKI Jakarta, Banten, West Java, Central Java, DI Yogyakarta, East Java, West Kalimantan Province, Central Kalimantan, South Kalimantan, East Kalimantan, North Kalimantan, Bali Province, West Nusa Tenggara, and East Nusa Tenggara. Figure 6 shows island three (3) consisting of North Sulawesi, Central Sulawesi, South Sulawesi, Southeast Sulawesi, West Sulawesi, Gorontalo, Maluku, North Maluku, West Papua, and Papua Provinces.

Several important findings emerged, among which many of these structured spatial effects were significant as shown by the probability maps (Figures 3, 4, 5, and 6). The mapping results show a map of the posterior probability of zakat at 95% credible intervals. Provinces in blue show a significant negative spatial effect, while provinces in red show a significant positive spatial effect. Other provinces (in gray) have no significant effect.

The spatial effects of zakat on regions indicate that many variations in the pattern of these relationships still need to be explained in more detail. The model assigns these spatial effects to structured effects depicted in Figures 3, 4, 5, and 6. This is because the pattern for each province tends to cluster or show spatial dependencies.

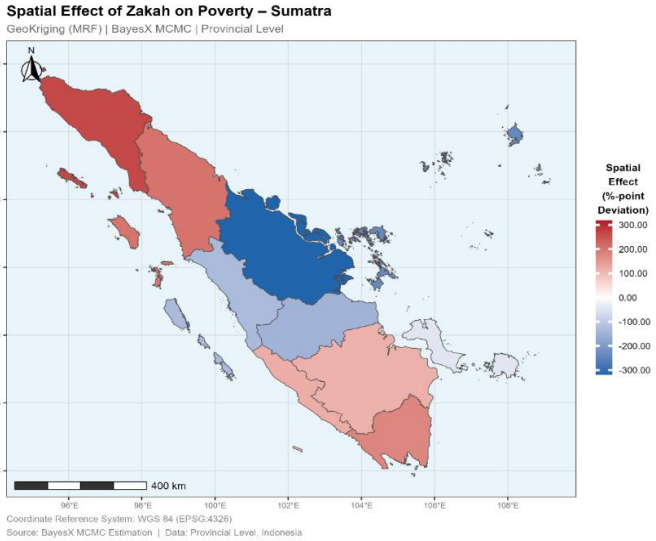

Figure 4. Spatial Effect Island 1

Figure 4 shows the provinces on Island one (1), which are divided into several classifications, for example, Aceh, North Sumatra, Lampung, South Sumatra, and Bengkulu, which are in the positive significant category, indicating the effect of zakat on the poverty population of these provinces is influenced by adjacent areas that have relatively high zakat receipts. This condition causes the poverty in the area to be affected by zakat from

adjacent areas. Furthermore, Riau, Jambi, and West Sumatra are in the significant negative category, indicating that the effect of zakat on poverty in these areas is not influenced by adjacent provinces which have relatively higher zakat receipts

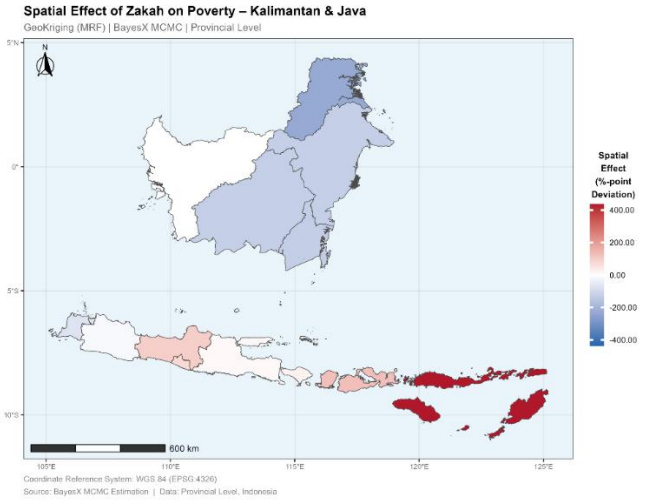

Figure 5. Spatial Effect Island 2

Figure 5 shows the provinces on Island 2, which are classified into several categories. East Nusa Tenggara belongs to the significant positive category, indicating a positive spatial association between zakat and poverty with neighboring provinces that also have relatively high zakat receipts. Meanwhile, North Kalimantan, East Kalimantan, Central Kalimantan, and South Kalimantan fall into the significant negative category, indicating a negative spatial association with neighboring provinces. The remaining provinces on Java, Bali, and West Kalimantan do not exhibit significant spatial association in the relationship between zakat and poverty. Figure 5 also shows the provinces on Island 3, which are classified into several categories. Papua belongs to the significant positive category, indicating a positive spatial association between zakat and poverty with neighboring provinces that have relatively high zakat receipts. No province falls into the significant negative category. Meanwhile, the provinces on Sulawesi, Maluku, and West Papua do not exhibit significant spatial association in the relationship between zakat and poverty.

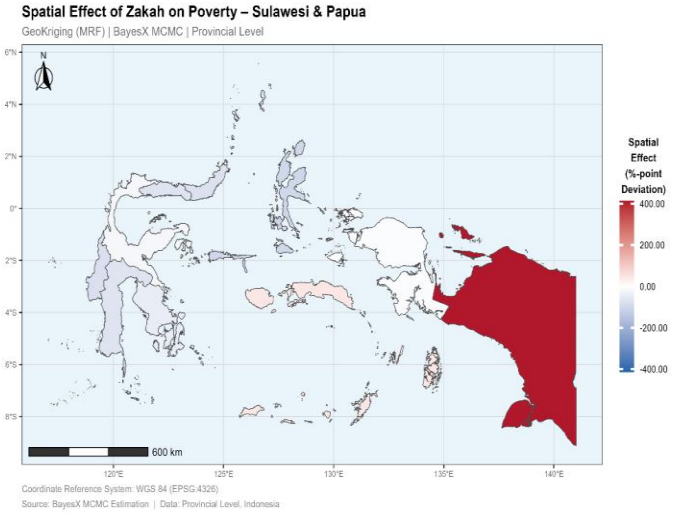

Figure 6. Spatial Effect Island 3

Based on Figures 3, 4, 5, and 6, the classification of regional (spatial) influences on poverty in Indonesia using the Bayesian Geoadditive Regression Models method produces three categories (see Table 3). Based on the Table 3, we can know which areas have spatial dependencies. Regions or provinces that are in the significant

positive category indicate that these areas influence each other positively. It means that if the poverty rate in an area is high, the surrounding area will have a high poverty rate as well. However, provinces that are in the significant negative category indicate that these areas influence each other negatively. It means that if the poverty rate in an area is high, the surrounding area will have a low poverty rate. As for the insignificant category, the area does not have spatial dependencies.

Table 3 Classification of the Spatial Effect on Poverty

Categories	Islands	Provinces
Significant Positive	Island 1	Aceh, North Sumatra, Lampung, and South Sumatra and Bengkulu
Not significant		Bangka Belitung
Significant Negative		Riau, Jambi, and West Sumatera
Significant Positive	Island 2	East Nusa Tenggara
Not significant		West Kalimantan, Banten, DKI Jakarta, West Java, Central Java, East Java, Bali and West Nusa Tenggara
Significant Negative		North Kalimantan, East Kalimantan, Central Kalimantan and South Kalimantan
Significant Positive	Island 3	Papua
Not significant		North Sulawesi, Gorontalo, Central Sulawesi, West Sulawesi, South Sulawesi, Southeast Sulawesi, Maluku, North Maluku and West Papua
Significant Negative		-

Source: Analysis, 2025

3.2. Discussion

Poverty, in the simplest terms, can be defined as the lack of basic needs such as food, clothing, and shelter (Bogaevskaya, 2019; Islam, 2024; Satpathy et al., 2023). In other words, the lack of means and money to meet these needs. More than that, the current condition is very worrying, where poverty is rampant in Muslim countries. Poverty among Muslims should be able to be suppressed because Islam strongly recommends helping others and encouraging mutual assistance in terms of goodness, especially reducing poverty (Sulaiman, 2025; Hunjra et al., 2024; Thalgi, 2024). Many countries in the Muslim world are rich in resources, but poverty is beyond normal limits. Somalia and Yemen are examples of how poverty destroys the social fabric. In the past, these two countries were the main exporters of food and livestock in the Region. In addition, Iraq and Libya are two rich countries that have natural resources, and many people still suffer from poverty (Abdi Ali et al., 2025; Alnashwan et al., 2021; Samatar, 2025).

The third pillar of Islam is Zakat, which is mandatory for eligible Muslims (*muzakki*) to purify their wealth by allocating a portion to those entitled to receive it (*mustahik*). On a broader scale, Zakat serves not only to cleanse the wealth of the giver but also to address the basic economic needs of the recipients, potentially contributing to poverty alleviation. The Republic of Indonesia, as a unitary state, exhibits diverse characteristics across its provinces (Shaifudin & Muhlas, 2020). Modernization leads to a contemporary societal setting where individuals exhibit high levels of openness. Muslim communities residing in diverse locales must adopt an inclusive approach, treating one another as siblings in faith, while acknowledging differences in economic status, population demographics, and geographical location. This underscores the necessity for ongoing cooperation among fellow Muslims to alleviate poverty.

Zakat holds significance in reducing poverty, but its effectiveness depends on the efficiency of zakat institutions in collecting and distributing funds. These institutions require a robust governance framework and effective management practices, including transparent decision-making, implementation, skilled personnel, adaptability for innovation, and cost-effective operations. To achieve optimal results, the tasks of fundraising and distributing funds should be distinctly separated. This research confirms that poverty is not only seen globally, but solving its problems requires a multidimensional approach. One part of this research is to examine the role of zakat on poverty. The results of the macro analysis in Indonesia show that poverty cannot be eliminated without using zakat effectively because it plays an important role in reducing poverty.

The findings of this study indicate that zakat has a significant positive effect on the concentration of poverty, with a posterior mean of 21,042.1 (SD = 28,142.4; 95% PCI: 12,665.3–30,185.0). This entirely positive credible interval confirms the existence of a consistent spatial association between the distribution of zakat and the concentration of the poor in Indonesia. These results are consistent with the findings of Choiriyah et al. (2020), who used provincial panel data analysis and found that a higher Baznas Welfare Index (Indeks Kesejahteraan Baznas) was significantly correlated with a reduction in the absolute poverty ratio (P0). Furthermore, the study by Ayuniyyah et al. (2018) in West Java also confirmed that zakat distribution programs are significantly effective in reducing poverty and income inequality amongst beneficiaries. However, our study goes beyond both of these studies by demonstrating that the impact of zakat is not spatially homogeneous, but rather varies considerably depending on the geographical context and institutional capacity in each region.

This study indicates that zakat can effectively reduce poverty when supported by sound macroeconomic policies that promote economic growth and equitable income distribution. Poverty alleviation is further enhanced when a larger share of zakat is allocated to productive activities through efficient collection and distribution. Strengthening policy support and institutional capacity, particularly for amil zakat institutions, is essential to integrate zakat into broader development agendas. As government-managed zakat collection remains limited in many regions, centralizing collection and distribution through public institutions could improve efficiency, transparency, public trust, and the overall effectiveness of zakat in reducing poverty.

The structured spatial effects identified in this study reveal a sharp dichotomy between eastern and western Indonesia. The Papua region recorded the highest positive spatial effect (up to +317.67), indicating a poverty burden far exceeding the model's predictions, whilst Java and parts of Kalimantan showed negative effects (down to -517.67), reflecting the greater effectiveness of zakat distribution. These findings are consistent with patterns of spatial inequality previously documented by a number of researchers. In the context of multidimensional poverty in East Java, Putri et al. (2022) have shown that poverty in Indonesia is highly spatially uneven, with pockets of poverty concentrated in specific regions far from economic centers. At the national level, the mapping of zakat potential carried out by the Zaenal et al. (2022) revealed that DKI Jakarta, East Java and West Java dominate national zakat potential, whilst eastern Indonesia has a significantly lower collection capacity despite facing a heavier burden of poverty. This disparity explains why the positive spatial effect (where the burden of poverty exceeds predictions) is concentrated in Papua and the eastern regions: the limited distribution of zakat in these areas is unable to meet the scale of existing social needs.

The findings from the analysis highlight the circumstances wherein zakat can effectively contribute to reducing poverty. Specifically, the findings reveal two main policy considerations concerning the utilization of zakat for poverty alleviation. The first pertains to incorporating zakat into the comprehensive development plan of each region. In contrast, the second aspect concerns establishing institutions to enhance the utilization of zakat in poverty alleviation efforts.

The main advantage of Bayesian Geoadditive modelling is its ability to capture spatial heterogeneity beyond conventional linear regression, providing valuable insights for zakat-based regional planning. The estimated Markov Random Field (MRF) GeoKriging spatial effects reveal substantial interprovincial variation, with Papua exhibiting the highest positive effect (up to +300 points), while several provinces in Kalimantan and Sulawesi show pronounced negative effects (up to −300 points). These findings indicate that the effectiveness of zakat varies across regions depending on local structural conditions and institutional capacity. Accordingly, provinces with strong positive spatial effects, such as Papua and East Nusa Tenggara, require strengthened National Zakat Agency (BAZNAS) institutions, whereas negative-effect regions in Kalimantan and Central Sulawesi warrant further investigation of spatial spillover effects to support more equitable zakat distribution. These findings are consistent with previous studies showing that zakat distribution reduces poverty and income inequality (Ayuniyyah et al., 2022) and that productive zakat programs improve beneficiaries' welfare (Mawardi et al., 2023). The large standard deviation of the zakat coefficient (281.424) further suggests substantial differences in institutional capacity across provinces, which may moderate the effectiveness of zakat in reducing poverty.

Compared with previous empirical studies, the Bayesian Geoadditive Model demonstrates methodological advantages over conventional spatial regression models. Previous studies using the Spatial Autoregressive Model (SAR), Spatial Error Model (SEM), and Spatial Durbin Model (SDM) on district/city-level panel data in Indonesia found strong spatial dependence in poverty distribution, indicating that ignoring spatial effects produces biased and inefficient estimates. Similarly, Hamrullah et al. (2026) showed that regional economic conditions in Eastern Indonesia are spatially interconnected through labor mobility, capital flows, infrastructure networks, and market access, making spatial effects essential in regional analysis. Compared to these approaches, the Bayesian Geoadditive Model offers two advantages. First, non-parametric estimation using Markov Random Fields (MRF) captures complex, non-linear spatial patterns without relying on predefined weighting matrix assumptions (queen or rook contiguity) used in SAR and SEM. Second, probabilistic inference through the Posterior Credible Interval (PCI) provides a more robust measure of uncertainty than frequentist confidence intervals, particularly for imbalanced and hierarchically structured inter-provincial data.

Since the majority of macroeconomic policies fall under governmental jurisdiction, the influence of zakat in fostering growth through such policies will be restricted. Nevertheless, Amil Zakat institutions can significantly impact redistribution initiatives. Their primary objective is to equitably distribute income to aid the impoverished within a society. Zakat's potential contributions to macroeconomic endeavors lie in enhancing human capital and implementing targeted initiatives for the disadvantaged. These initiatives may encompass educational provisions, healthcare services, and social welfare programs aimed at enhancing the well-being of the less fortunate.

Based on the findings above, the policy implications that can be made are as follows: first, poverty in Indonesia has a significant spatial dependence, which indicates that the provincial government should be strengthened from a broader perspective by involving targeted local amil zakat agencies. The implementation of regional economic policies must be based on cooperation with the surrounding area. In particular, the territory of Indonesia, which consists of islands, must be considered as the main area, and it is necessary to accelerate income distribution as a driver of regional economic growth. In addition, the distribution of zakat should not always mean that all zakat is distributed entirely or allocated at 1 USD/day for the reduction of poverty families; the distribution of zakat is intended to empower the poverty. Empowerment is an effort to help those who are vulnerable and powerless so that they can achieve prosperity in their social life.

It is advised that crafting a focused zakat collection plan should take into account local conditions indicated by the clustering analysis. Clustering serves not only to assess zakat potential but also to tailor collection strategies for each area. Building on these findings, promoting the National Amil Zakat Agency's initiatives through online platforms, government bodies, and private institutions can effectively reach communities and facilitate zakat payments via digital platforms such as e-commerce and banks. Leveraging online media also helps address challenges posed by diverse economic structures, demographics, and geography. Therefore, strengthening collaboration between provincial BAZNAS and digital platforms is crucial to raising public awareness of zakat obligations.

BAZNAS should continue focusing its outreach efforts on fostering societal transformation, particularly by addressing social and humanitarian issues related to poverty. To improve the distribution of zakat funds across provinces, socialization activities should promote values such as mutual cooperation, solidarity, and other positive social principles. These efforts are expected to strengthen public awareness and encourage greater participation in poverty alleviation.

4. Conclusion

The Bayesian geoadditive model applied in this study distinguishes the influence of geographic location on the relationship between zakat and poverty across Indonesian provinces. Using structured additive predictors estimated through Markov Chain Monte Carlo (MCMC) simulation, the model incorporates correlated random effects to represent unobserved contextual factors, spline functions for continuous covariates, and geographic random effects to capture spatial variation. Based on these findings, zakat collection should be managed through

regional amil zakat institutions rather than distributed directly to *mustahik*, ensuring that assistance includes empowerment and capacity-building alongside financial support. Strengthening collaboration between amil zakat institutions and local governments is essential to optimize zakat collection and utilization, thereby enhancing poverty alleviation and complementing government expenditure on poverty reduction programs.

The spatial effect map reveals that Indonesia is characterized by substantial regional variation in the effectiveness of zakat distribution, reflecting differences in institutional capacity, economic connectivity, and structural conditions. The marked contrast between Papua, which exhibits the highest positive spatial effect, and several provinces in Kalimantan and Central Sulawesi with significant negative effects indicates a mismatch between current zakat distribution patterns and regional needs. These findings suggest that zakat policies should be integrated into regional spatial plans as spatially targeted fiscal instruments rather than implemented through a uniform national approach. Moreover, the observed spatial spillover effects in Kalimantan and Central Sulawesi indicate that the impact of zakat extends beyond administrative boundaries, highlighting the need for inter-regional planning and stronger coordination among regional BAZNAS offices. Overall, the proposed spatial mapping approach provides a practical decision-support tool for policymakers to improve zakat-based poverty alleviation in Indonesia.

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