International Journal of Public Health Science (IJPHS)
Vol. 15, No. 2, June 2026, pp. 297~312
ISSN: 2252-8806, DOI: 10.11591/ijphs.v15i2.26883

Interregional stunting prevalence determinants from a regional perspective in Indonesia: multivariate and spatial analysis approaches

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Article Info

Article history:

Received Oct 28, 2025
Revised Feb 25, 2026
Accepted Apr 25, 2026

Keywords:

Geographic information system
Inequality human capital
Principal component analysis
Spatial aspect
Stunting

ABSTRACT

Stunting continues to be a significant public health issue globally, impacting millions of children and hindering long-term human capital development. Prior studies on stunting have predominantly focused on individual factors, neglecting the influence of regional characteristics. The majority of analyses depend on global regression models that presume consistent correlations across areas inclined to using many variables. This research applied Geographically Weighted Spatial Regression to analyze stunting risk factors across 514 districts in Indonesia. By identifying spatially variable determinants, this study supports more targeted and effective stunting reduction strategies. The research results using geographic information systems (GIS) and multivariate analysis show that stunting is highest in eastern Indonesia, where poor sanitation is the dominant factor causing stunting. The policy implemented by the local government is to enhance collaboration with various parties, including academics, government, private sector, and communities, in addressing stunting.

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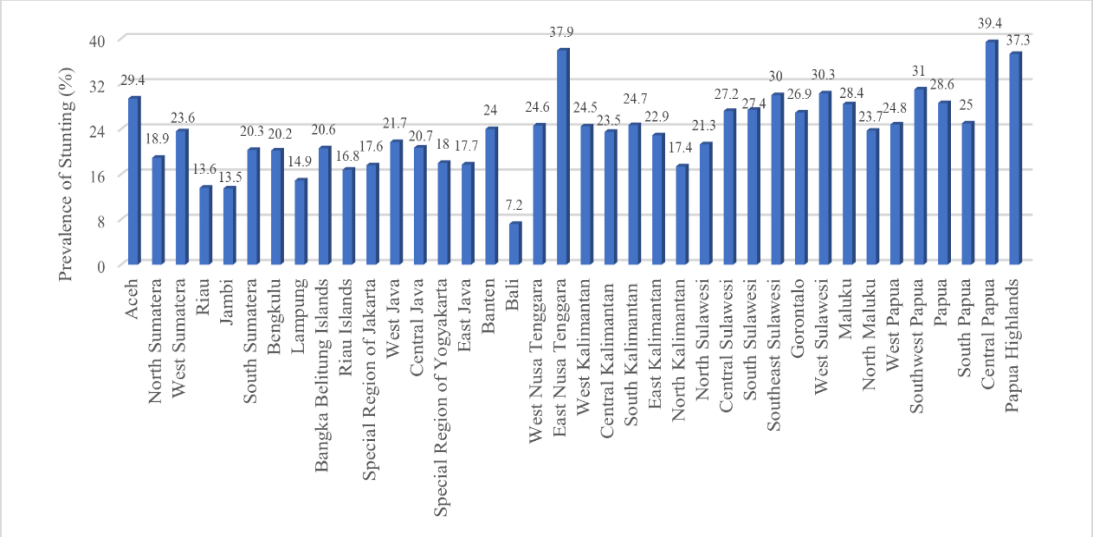
1. INTRODUCTION

Stunting remains one of the most pressing public health challenges worldwide, affecting millions of children [1]-[5] and undermining long-term human capital development [6]. Over the long term, it can reduce an individual's productivity level, potentially lowering the gross domestic product (GDP) by 1 to 2 percent annually [7]. According to WHO data from 2022, the global prevalence of stunting is 22.3%; this rate is considered high and is predominantly driven by countries in Africa and Southeast Asia. The prevalence rate of stunting in African countries is 31%, while in Southeast Asia, it is 30.10%, both significantly above the global average. Indonesia's stunting prevalence rate is 31%, far exceeding the government's target of 14%. This situation underscores the importance of addressing stunting as a primary goal within the Sustainable Development Goals (SDGs). The global prevalence rate of stunting is 46%, with Asian and African countries each contributing 25% [8]. The prevalence of stunting varies by region, exhibiting a clustering pattern across different areas. In Indonesia, prevalence remains high despite national targets for reduction. Although Indonesia targets a stunting prevalence rate below 14%, many regions, particularly those outside of Java

Island, still report very high rates. Figure 1 illustrates the distribution of stunting prevalence across various areas of Indonesia.



Source: Statistics Indonesia, Indonesia Health Survey (2024)

Figure 1. Distribution of stunting prevalence in Indonesia

Figure 1 shows that stunting prevalence remains high across regions in Indonesia. The lowest prevalence is in Bali, at 7.2%, while the highest is in Central Papua Province, at 37.3%. The national target for stunting prevalence in Indonesia is set at 14%; however, most regions exceed this threshold. Only 2.6% of regions equivalent to one province have stunting prevalence below the national target, while the remaining 97.37%, or 37 provinces, exceed it. Data in Figure 1 also indicate that regions in eastern Indonesia, such as Central Papua, Papua Mountains, Southwest Papua, and East Nusa Tenggara Province, exhibit particularly high stunting prevalence.

Previous studies have established that nutritional deficiencies, poor sanitation, and limited access to healthcare are major determinants of stunting, with interventions such as maternal supplementation and immunization shown to reduce the prevalence of stunting. Prior studies have shown that sanitation, maternal nutrition, and immunization are critical factors [9]-[11]. States that poor sanitation is one of the causes of the increase in stunting cases [8], [12], [13]. Daga and Ballon-Salcedo [14] stated that maternal nutrition is one of the important factors in the prevalence of stunting in children. Low levels of maternal nutrition will affect the decrease in stunting incidence. Immunization is also a factor that reduces stunting rates [13].

These studies provide valuable insights into the determinants of stunting. Previous research on stunting has focused more on the individual factors influencing it and neglected the existence of regional characteristics. Without understanding local variation, interventions risk being ineffective or misdirected. However, the majority of analyses depend on global regression models that presume consistent correlations across areas. Additionally, the conventional approach using general regression is prone to using many variables. This gap motivates our use of spatial modeling to capture regional differences and multivariate analysis to capture phenomena related to the causes of stunting without losing information from those variables. We applied Geographically Weighted Spatial Regression to analyze stunting risk factors across 514 districts in Indonesia. By identifying spatially variable determinants, this study supports more targeted and effective stunting reduction strategies. It also demonstrates the value of spatial approaches for public health research in diverse settings. This approach enables the estimation of localized parameters, revealing district-specific relationships that are often obscured in global models. The use of multivariate analysis, principal component analysis (PCA), and cluster analysis (CA) to complement spatial regression involves grouping areas based on the many variables that cause stunting without losing information from each variable. By uncovering these spatially variable associations, our research provides evidence for more targeted, region-specific interventions, supporting policymakers in designing effective strategies to accelerate stunting reduction and achieve national health targets.

As an archipelagic nation, Indonesia comprises a diverse array of administrative regions, including 38 provinces and approximately 514 regencies and cities. This diversity complicates the effective management of

stunting, as regional characteristics vary significantly. Data from the Central Statistics Agency and the Ministry of Health of Indonesia indicate that areas on Java Island generally exhibit lower stunting prevalence compared to regions outside Java. Additionally, areas with similar conditions tend to have stunting prevalence rates that do not differ significantly, highlighting the influence of spatial factors on stunting prevalence in Indonesia, suggesting that spatial factors significantly impact stunting prevalence in a region [12], [15]-[17]. The research objectives are: i) To examine the clustering patterns of stunting prevalence among regions in Indonesia; ii) To analyze how spatial aspects influence stunting prevalence across these regions; and iii) To identify determinants affecting stunting prevalence rates in different areas of Indonesia.

2. METHOD

2.1. Data and data sources

This study uses quantitative data from secondary sources accessed from Statistics Indonesia and the Ministry of Health Indonesia. Data accessed from the Ministry of Health include the prevalence rate of stunting in districts and cities in Indonesia, the coverage of children under five who receive complete basic immunization, the percentage of infants who receive exclusive breastfeeding, mothers who give birth with the assistance of healthcare professionals, and infants who receive complementary feeding. Data accessed from the Central Bureau of Statistics include the percentage of fertile couples using modern contraception, school-age children accessing early childhood education (ECE), access to safe drinking water, access to proper sanitation, families receiving social assistance, households with health insurance, and per capita income in districts and cities in Indonesia.

2.2. Multivariate analysis: principal component analysis and cluster analysis

This study employed multivariate analysis tools, including CA and PCA, to analyze the clustering patterns of regions in Indonesia based on stunting prevalence. Additionally, spatial regression analysis was utilized to assess the influence of spatial factors and determinants affecting stunting prevalence across these regions. CA is a multivariate method primarily aimed at grouping objects based on their characteristics [18]. It is commonly used as a classification tool based on a set of clustering variables. The resulting clusters exhibit high internal homogeneity and external heterogeneity, meaning that objects with similar characteristics tend to group together, while those with differing characteristics are separated.

PCA is a widely used multivariate analysis tool in statistics and data science, typically employed to describe regional clustering patterns [18]. High-dimensional data can benefit from PCA, which simplifies the correlation between variables without sacrificing information. PCA reduces the dimensions of high-dimensional data to lower dimensions while retaining the information in the variables. It transforms the data into new coordinates, namely principal component 1 (PC1) and PC 2. The first coordinate represents the first PC derived from the largest eigenvalue, while the second coordinate represents the second PC derived from the second-largest eigenvalue.

Cluster analysis is used to ascertain the membership of certain groups. Cluster analysis is a multivariate analysis technique to identify and classify objects with similarities into specific groups. Objects in one group have the same similarity level based on the selection criteria set [18]. The first clustering process determines how object groupings are formed. The method used is to measure the Euclidian distance between objects to determine the similarity of grouping between objects.

$$d_{ij} = \sqrt{\sum_{k-1}^{p}(X_{ik} - X_{jk})^2} \quad (1)$$

Where X_{ik} is the ith object, and X_{jk} is the jth object. After that, determine the clustering algorithm. Grouping algorithms can be done in two ways—hierarchical and non-hierarchical. In a hierarchical algorithm, the number of groups formed depends on the object's characteristics based on the variable used (centroid). In non-hierarchical grouping, the user determines the number of groups to be formed (k-means clustering).

2.3. Geographically weighted spatial regression

Spatial regression analysis extends traditional regression analysis by considering spatial aspects. Incorporating spatial factors into regression models can reveal effects such as the influence of location on the relationships between observations and differences in modeling approaches [19], [20]. Spatial dependence refers to the correlation of a variable with itself across space, defined by the similarity of objects within a given space, such as distance, time, or region. A positive spatial dependence value indicates that nearby objects exhibit similar values and tend to cluster, while a negative value suggests that objects are dispersed and differ from one another. Generally, there are 3 spatial regression models: the spatial autoregressive model (SAR), the spatial error model (SEM), and the spatial autoregressive moving average (SARMA). The

model selection was performed using the Lagrange multiplier (LM) test. If there is a correlation between spatial lag and the dependent variable, then the SAR model is more suitable for use. The SEM model is used if there is a correlation between the dependent variable and its spatial lag error in the LM test. If both the spatial lag and the error lag are correlated with the dependent variable, then the SARMA model is the most suitable for use. In general, the SAR, SEM, and SARMA models are shown in (2) to (4) [19]:

$$\text{Model SAR: } Y = \alpha 1_N + \lambda WY + X\beta + u \quad (2)$$

$$\text{Model SEM: } Y = \alpha 1_N + X\beta + \lambda Wu + \varepsilon \quad (3)$$

$$\text{Model SARMA: } Y = \alpha 1_N + \lambda WY + X\beta + \lambda Wu + \varepsilon \quad (4)$$

where Y is the independent variable, X is the $n \times k$ matrix of dependent variables, λ is the spatial autoregressive coefficient, λWY is the spatial lag dependent weighting matrix, λWu is the spatial weight matrix, β is the coefficient of the influence of variable X on variable Y, and ε is the error term. The research model based on spatial regression analysis constructed in this study is (5):

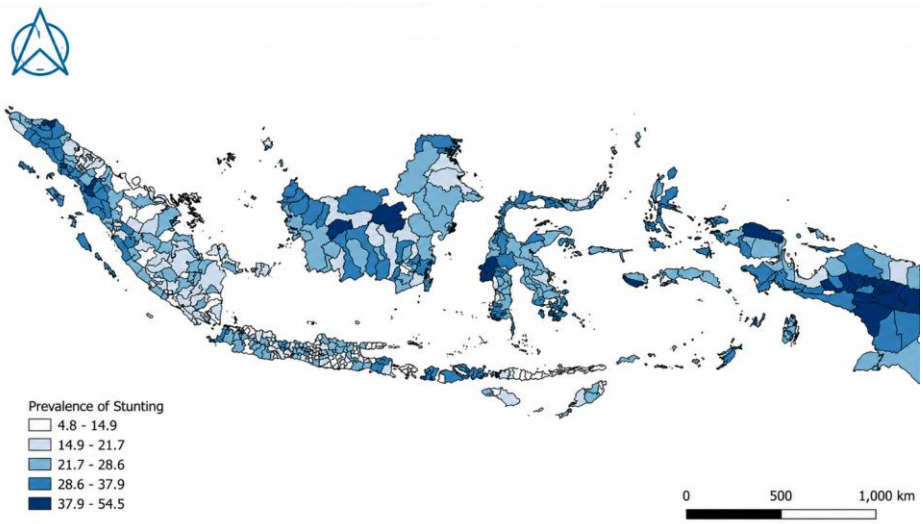
$$\begin{aligned} \mathrm{PS}_{it} = {} & \beta_0 + \lambda WY_{it} + \beta_1 \mathrm{IM}_{\mathrm{it}} + \beta_2 \mathrm{BA}_{\mathrm{it}} + \beta_3 \mathrm{FP}_{\mathrm{it}} + \beta_4 \mathrm{BF}_{\mathrm{it}} + \beta_5 \mathrm{FA}_{\mathrm{it}} + \beta_6 \mathrm{Water}_{\mathrm{it}} + \beta_7 \mathrm{SAN}_{\mathrm{it}} + \\ & \beta_8 \mathrm{PS}_{\mathrm{it}} + \beta_9 \mathrm{HI}_{\mathrm{it}} + \beta_{10} \mathrm{SP}_{\mathrm{it}} + \beta_{11} \mathrm{Income}_{\mathrm{it}} + \lambda Wu + \varepsilon_{\mathrm{it}} \end{aligned} \quad (5)$$

where PS: prevalence of stunting, BF: breastfeeding, IM: immunization, FA: food attendant, BA: birth attendant, water: access to clean and safe drinking water, FP: family planning, SAN: access to adequate sanitation, PS: pre-school, HI: health insurance, SP: social protection, income: per capita income, and λ: spatial weight matrix.

3. RESULT AND DISCUSSION

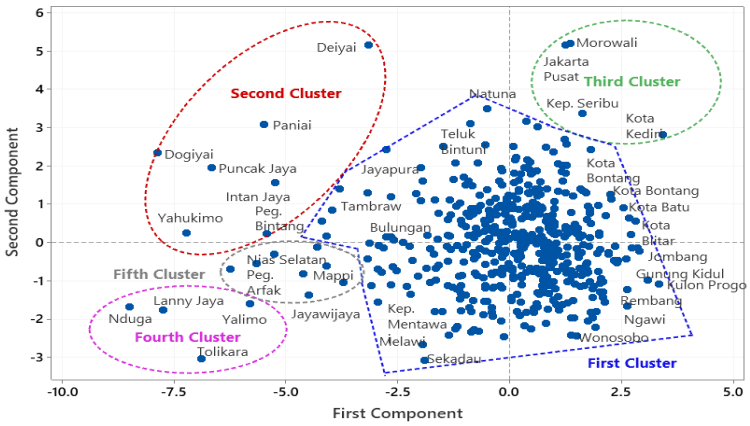
3.1. Mapping the prevalence of stunting across regions in Indonesia

Based on the QGIS version 3.16.8 result, the distribution pattern of stunting prevalence across regions in Indonesia reveals significant disparities. Overall, the national stunting prevalence remains notably high at 21.6% in 2022. However, when examined at smaller regional levels, several areas continue to report high stunting prevalence. Based on the output, QGIS shows the distribution of stunting prevalence across 514 districts and cities in Indonesia. The QGIS output shows a color gradient from lightest to darkest. Light colors indicate areas with low prevalence density, while dark colors represent areas with high stunting density. Figure 2 illustrates the distribution of stunting prevalence across Indonesian regions. Figure 3 shows a map of hotspot and coldspot areas for the distribution of stunting prevalence.



Source: Data processed by the author using QGIS 3.16.8 software (2025)

Figure 2. Mapping the distribution of stunting prevalence in regional Indonesia



Source: Data processed by the author (2025)

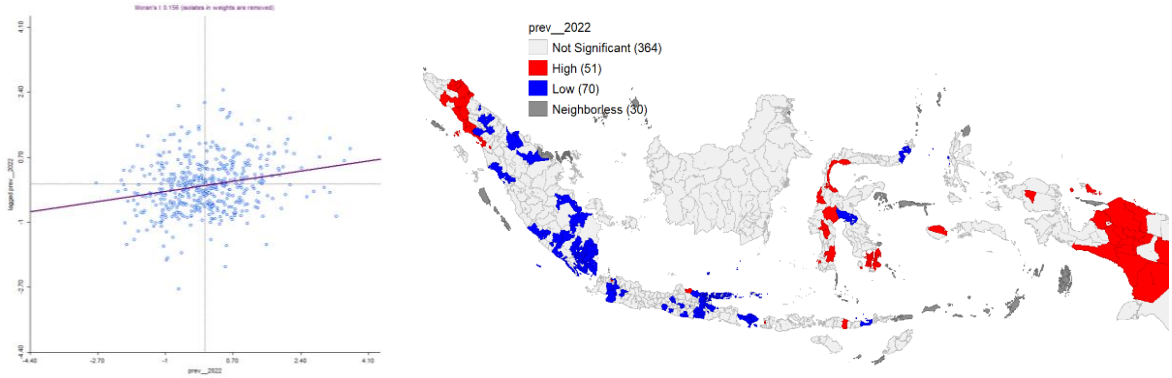
Figure 3. Clustering pattern of stunting prevalence based on PCA

Figure 2 indicates the prevalence of stunting across regions in Indonesia for 2022. The overall stunting rate remains alarmingly high at 21.6% [21], exceeding the government's target of 14%. Based on data from the 2024 SSGI, it shows that Surabaya City has the lowest stunting prevalence at 4.80%, while Asmat Regency records the highest at 54.50%. Areas in Papua Island dominate regions with high stunting rates in Indonesia. The stunting rate in the districts of Central Papua Province reaches over 35%. These areas include Nduga, Jayawijaya, Lanny Jaya, Tolikara, Central Memberamo, Yalimo, Yahukimo, and Pegunungan Bintang districts. Based on the output from Geoda using the local indicator of spatial association (LISA), information was obtained regarding the spatial patterns of hotspot and coldspot areas for stunting prevalence in Indonesia. Hotspot areas are areas with high density marked in red, and cold spot areas are areas with low density marked in blue, as shown in Figure 4.

Based on the analysis using the LISA in Figure 4, it shows that hotspot areas or regions with high stunting prevalence are more dominant in eastern Indonesia, particularly in East Nusa Tenggara, Papua, and several areas on Sulawesi Island. However, the high stunting rates are also indicated to be concentrated in areas of Aceh Province such as East Aceh Regency, Southwest Aceh, Aceh Singkil, South Aceh, Benar Meriah, and Pidie Jaya. Papua has the highest rates of stunting. Meanwhile, western Indonesia has a higher concentration of coldspot areas, or areas with low stunting rates. The regencies and cities in the provinces of Bali, Lampung, and East Java are the areas with the most coldspots. Districts and cities in Papua Province exhibit the highest stunting rates among all Indonesian regions, indicating ongoing challenges in effective stunting management. Some factors contributing to the high stunting rates in eastern Indonesia include difficult access and geography, sanitation, mothers' education levels, access to healthcare services, low nutritional intake, and a high prevalence of infectious diseases [22]-[25]. Another factor causing stunting in eastern Indonesia is low household food security [26] and household per capita income [25].

Asmat Regency, one of the areas with the most severe malnutrition in Indonesia, has not prioritized food aid policies, as evidenced by the low number of households receiving food assistance. Access to social assistance in the form of food is a policy priority in the Papua region in general, especially for areas with difficult geographical access. The distribution of food aid to the most remote areas can involve community organizations or government agencies, such as the Yayasan Inspirasi Indonesia Membangun (YIIM), which actively organizes social services to distribute food aid to the people of Papua. In addition, collaboration between government agencies is also important in expanding access to food aid for the people of Papua, such as the Indonesian National Army (TNI), the Logistics Affairs Agency (BULOG), the National Zakat Agency (BAZNAS), and the National Food Agency (Bapanas).

A high stunting rate in an area is closely linked to the poverty rate. Children experiencing stunting largely come from poor families. Poor households tend to have low incomes, making it difficult to allocate quality nutrition for family members. Based on data from Statistics Indonesia in 2022, regions in Papua are among the areas with high poverty rates in Indonesia, especially in Central Papua and Mountainous Papua provinces, where poverty rates are above 37%. According to Ragnar Nurske's theory of the vicious cycle of poverty, poor household conditions limit a person's access to education and healthcare [27]. In the long term, stunting will reduce the quality of human resources, leading to low productivity and impacting the contribution to the economy. In a regional context, the continuous decline in individual productivity will potentially lower economic growth, which will affect the multidimensional aspects of regional development.



(a) (b)

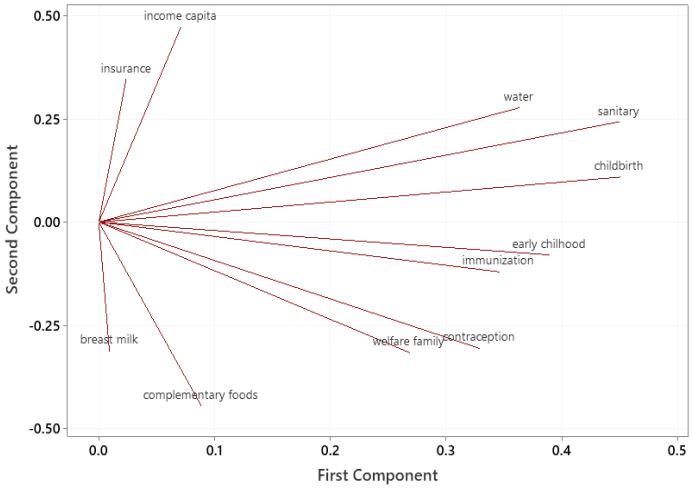
Source: Data processed by Geoda Software Output (2025)

Figure 4. LISA prevalence of stunting in Indonesia: (a) Indeks Moran's prevalensi stunting and (b) local indicator spatial analysis prevalence of stunting

3.2. Regional grouping based on principal component analysis and cluster analysis

Indonesia is one of the countries with a significant number of administrative regions, totaling 514 regencies and cities. Grouping regions based on the indicator causing stunting is important to accelerate the target of reducing stunting in Indonesia. Regional grouping can be done using PCA and CA on stunting prevalence indicators; we identified patterns in how regencies and cities in Indonesia are grouped, as shown in Figure 3.

Figure 3 illustrates the grouping of regions based on stunting prevalence across Indonesia based on PCA, consisting of five groups: the first cluster, the second cluster, the third cluster, the fourth cluster, and the fifth cluster. Analysis using PCA will group regions in Indonesia based on specific characteristics. Regions with similar characteristics will be in the same cluster, while those with different characteristics will be in different clusters. Most regions fall into the first cluster, which is considered to have excellent performance in addressing stunting. The other clusters demonstrate lower performance compared to the first cluster, with the fifth cluster being the lowest. Although the clustering pattern of stunting management in Indonesia shows promising results, some areas remain in clusters with low achievements, particularly in Papua, where most regions belong to the fourth and fifth cluster areas with the highest stunting prevalence in the country. The dominant indicator influencing the clustering, based on stunting prevalence, is identified in the loading plot by the longest wavelength in the PCA. The PCA loading plot, based on these indicators, is displayed in Figure 5.



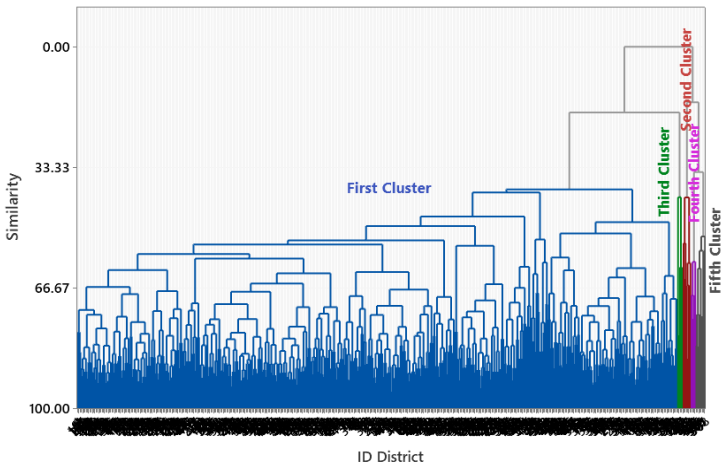
Source: Data processed by the author (2025)

Figure 5. Principal component analysis loading plot

Figure 5 presents the loading plot of the determinants of stunting prevalence indicators, where longer wavelengths indicate that the indicator is more dominant in regional groupings. The indicator with the longest wavelength is considered the main one, while the indicator with the shortest wavelength has the least influence on regional clustering. Based on the loading plot results, it is known that the sanitation indicator has the longest wavelength, followed by births assisted by healthcare professionals and access to safe drinking water. Meanwhile, the breastfeeding indicator and health insurance coverage have the shortest wavelengths. The results of the loading plot show that sanitation indicators, assisted childbirth by healthcare professionals, and access to safe drinking water are the primary factors driving the clustering based on the PCA of 514 regions in Indonesia with respect to stunting prevalence. The regions in the fourth and fifth clusters, predominantly located in Papua, belong to this group and have lower access to proper sanitation, assisted childbirth by health professionals, and clean drinking water compared to other regions.

Figure 6 illustrates the clustering results obtained through CA. The first cluster consists of 491 regions, the second cluster has 7 regions, the third cluster has 4 regions, the fourth cluster has 4 regions, and the fifth cluster has 8 regions. The regions in the second cluster are predominantly regencies and cities in Papua, including Deiyai Regency, Paniai, Dogiyai, Puncak Jaya, Yahukimo, Intan Jaya, and Pegunungan Bintang. The third cluster includes the Central Jakarta area, Thousand Islands Regency, Morowali Regency, and the City of Kediri. The fourth cluster comprises Nduga Regency, Lanny Jaya, Yalimo, and Tolikara. Members of the fifth cluster include South Nias Regency, Arfak Mountains, Mappi, Central Memberamo, South Sorong, Jayawijaya, Wondama Bay, and the Aru Islands. Meanwhile, the first cluster includes the City of Bontang, the City of Madiun, the City of Batu, the City of Blitar, Jombang, Gunung Kidul, and Kulon Progo.

The use of CA allows us to identify the strengths and weaknesses of each group based on the indicators by examining the values of the cluster centroids. A high centroid value for an indicator signifies superior performance, while a low cluster centroid value indicates weaknesses in that indicator's performance [18]. The cluster centroid values are shown in Table 1.



Source: Data processed by the author (2025)

Figure 6. Clustering results based on cluster analysis

Table 1. Cluster centroid values of stunting prevalence indicators in Indonesia

Variable	First cluster	Second cluster	Third cluster	Fourth cluster	Fifth cluster
Immunization	0.0546	-1.9545	0.0749	-2.2777	-0.5413
Childbirth assisted by healthcare workers	0.0785	-1.8540	0.3478	-2.0472	-2.3478
The use of modern contraceptives	0.1074	-2.7090	0.2623	-2.8966	-2.9048
Breastfeeding	-0.0028	-0.5457	-1.2985	0.4560	1.0707
Complementary food for breast milk	0.0147	-2.9995	-0.2122	1.8775	0.8871
Access to safe drinking water	0.0688	-0.1187	-0.4541	0.0854	-3.9322
Access to adequate sanitation	0.1281	-2.9814	-0.2345	-2.6929	-3.7926
Access to early childhood education	0.0723	-2.1922	1.0566	-1.7428	-2.1769
Health insurance	-0.0459	0.5227	0.9728	0.8422	1.4515
Food aid	0.0563	-1.5583	-0.2994	-1.8164	-1.0331
Income per capita	-0.0338	-0.6286	6.9431	-0.5099	-0.5896
Average cluster centroid	0.0453	-1.5472	0.6508	-0.97476	-1.26445

Source: Data processed by the author (2025)

Table 1 shows the cluster centroid values for each indicator in each cluster. Based on the cluster centroid values, it is known that cluster 3 is the group of regions with the best performance in the stunting rate indicator, as indicated by an average cluster centroid value of 0.6508, which is the highest compared to other clusters. Cluster 1 falls into the medium cluster group with a cluster centroid value of 0.0453, where most regencies and cities in Indonesia are included in this cluster. Clusters 2, 4, and 5 are categorized as regions with low performance on the stunting rate indicator, indicated by a negative average cluster centroid value. Among the lowest clusters, clusters 2 and 5 have the highest negative cluster centroid values. This condition indicates that the handling of stunts in the two clusters is still far from the government's target. Based on the data in Table 1, the strengths and weaknesses of the indicators used to assess the determinants of stunting prevalence across regions in Indonesia have been identified. CA enables the mapping of the primary problems faced by each cluster group. This information can assist both central and local governments in formulating policies targeted at the main issues encountered by each cluster. The cluster centroid values in Table 1 summarize the problems faced by each cluster, as detailed in Table 2.

Table 2 highlights the strengths and weaknesses of stunting prevalence indicators across regions in Indonesia. Local governments can utilize these results to formulate targeted policies aimed at reducing stunting rates. Such policies will be more effective if they prioritize indicators with low achievement and high contributions to stunting prevalence in each region. Most clusters exhibit lagging indicators in food aid and access to proper sanitation. Based on data from Statistics Indonesia, access to proper sanitation shows that most regencies and cities in Indonesia, particularly areas in eastern Indonesia, tend to still be low. This suggests that many households in Indonesia have low per capita income, affecting their access to nutritious food and adequate sanitation. Limited access to nutritious food is a primary factor contributing to high stunting prevalence in an area [28], [29]. Therefore, the government's food assistance policy must be well-targeted to ensure support reaches households in need, particularly in underdeveloped areas struggling to meet basic food requirements. Furthermore, the government should increase its budget for food assistance, expanding beyond rice aid to include protein provision for children, thereby supporting programs aimed at improving child nutrition.

Access to proper sanitation remains a critical issue in areas with high stunting prevalence. Insufficient sanitation increases the risk of stunting by 6.6 times [30]. Additionally, children exposed to unsanitary environments are at greater risk of infectious diseases, leading to higher morbidity rates. Children with elevated morbidity are more likely to be underweight and experience stunting [31]. Poor sanitation also increases contamination by pathogenic bacteria that cause diseases such as cholera and dysentery, which contribute to rising stunting prevalence in children [1]. Dysentery in children reduces nutrient absorption, thereby increasing the likelihood of a child experiencing stunting prevalence. The government's policy to expand the coverage of proper sanitation can be focused on clusters 2, 4, and 5, where the indicators are still very low. Efforts that can be made by local governments include increasing education and literacy among the public about healthy lifestyles and the importance of proper sanitation through health departments, community health centers (*Puskesmas*), and integrated health posts (*Posyandu*), cadres, schools, or community groups. In addition, the policy regarding proper sanitation includes a special budget allocation from village funds used to build sanitation infrastructure such as communal toilets, especially in areas with very high stunting rates, such as regencies and cities in East Nusa Tenggara and Papua.

Additionally, inadequate access to proper sanitation remains a major issue in Papua, which has the lowest sanitation coverage in Indonesia. The extremely difficult geographical conditions in Papua make the construction of sanitation infrastructure expensive. Additionally, the low human resource conditions in Papua also result in low literacy regarding healthy lifestyles and clean sanitation. Based on data from Statistics Indonesia for 2022, the average level of education for the population of Papua is one of the lowest because many people do not complete primary school. Collaboration with several community organizations in providing adequate sanitation is an effort to reduce stunting, including with UNICEF, the corporate social responsibility (CSR) program of companies focused on disadvantaged, outermost, and foremost areas (3T), and Danone-Aqua with the water access, sanitation, hygiene (WASH) program.

3.3. The influence of spatial aspects on the prevalence of stunting across regions in Indonesia

The high prevalence of stunting in Indonesia has long-term effects on individual productivity, which, in turn, impacts the country's economic growth. These conditions motivate further research into the determinants affecting the high stunting rates in Indonesia and the potential influence of spatial factors across different regions. Spatial regression analysis provides an overview of the factors influencing stunting prevalence, including nutritional, social, economic, and spatial aspects. The choice of the right spatial model depends on the values of the spatial weight matrix for the stunting prevalence variable and its error term. If the value of the spatial weight matrix for the stunting prevalence variable is statistically significant, then the SAR model is more suitable. However, if the spatial weight matrix for the error term is statistically significant, then the SEM model is more suitable. If the spatial weight matrix for both the stunting prevalence

variable and the error term is statistically significant, then the SARMA model is the best. A comparison between SAR, SEM, and SARMA is presented in Table 3.

Table 2. Weaknesses and strengths of the cluster

Cluster	Superior indicator	Lagging indicator
First cluster	1. Access to adequate sanitation 2. Percentage of couples using modern contraceptives	1. Exclusive breastfeeding 2. Percentage of the population with health insurance 3. Income per capita
Second cluster	1. Percentage of the population with health insurance	1. Complementary food for breastfeeding 2. Access to adequate sanitation 3. Couples who use modern contraception 4. Immunization 5. Birth assisted by healthcare personnel
Third cluster	1. Income per capita 2. Access to early childhood education 3. Percentage of the population with health insurance ownership 4. Birth assisted by healthcare personnel 5. Couples who use modern contraception	1. Exclusive breastfeeding 2. Access to safe drinking water 3. Access to adequate sanitation 4. Food assistance
Fourth cluster	1. Complementary food for breastfeeding 2. Percentage of the population with health insurance	1. Couples who use modern contraception 2. Access to adequate sanitation 3. Access to early childhood education 4. Immunization 5. Birth assisted by healthcare personnel 6. Food assistance 7. Income per capita
Fifth cluster	1. Exclusive breastfeeding 2. Percentage of the population with health insurance	1. Access to safe drinking water 2. Access to adequate sanitation 3. Couples who use modern contraception 4. Birth assisted by healthcare personnel 5. Access to early childhood education

Source: Data processed by the author (2025)

Table 3 shows that based on the values of the LM, the lag and error are known to be 6.5211 and 9.1980, respectively, which are statistically significant at a 5% significance level, making the SARMA model the most suitable to use. Based on the results of Moran's I index, it is known to be 3.2176 and significant at 5% alpha. This condition indicates a spatial relationship between regions, where adjacent regions tend to share similar characteristics. Table 3 compares the spatial regression analysis results obtained from SAR, SEM, and SARMA. Based on the results of the LM test for lag and error at a 95% significance level, it is known that the LM test for lag and error is significant at $\alpha = 5\%$, so the suitable spatial model is SARMA. Overall, spatial regression results indicate that the key factors influencing stunting in a given area include the percentage of immunized children, deliveries attended by health professionals, exclusive breastfeeding during the first six months, providing complementary foods, access to clean drinking water, proper sanitation, health insurance coverage, and per capita income. Factors that do not have a significant impact include the use of modern contraception, saving drinking water, early childhood education, and food assistance for families in need. The equations for SARMA models are as (6).

$$\begin{aligned}\text{Prevalence of Stunting} = {} & 0.3153 + 0.0906\, W\text{Prevalence of Stunting}_{it} - \\ & 0.0539\ \text{Immunization}^{***} - 0.0983\ \text{Birth Attendance}^{***} + 0.0203 \\ & \text{Family Planning} + 0.0382\ \text{Breastfeeding}^{***} + 0.945\ \text{Food Attendant}^{***} \\ & - 0.0170\ \text{Water}^{**} - 0.1091\ \text{Sanitation}^{***} - 0.001\ \text{Pre-School} + 0.0850 \\ & \text{Health Insurance}^{***} - 0.0028\ \text{Social Protection} - 1.20\text{x}10^{-7}\ \text{Income}^{**} + 0.13561\ \text{Wu}_{it}^{**}\end{aligned} \quad (6)$$

Based on the spatial SARMA model with a 95% significance level, immunization, childbirth with the assistance of health workers, access to proper sanitation, and per capita income significantly reduce the prevalence rate of stunting across regions in Indonesia. These factors indicate an important contribution to improving child health and nutritional conditions. Meanwhile, the use of breastfeeding, complementary feeding, and health insurance positively influences the prevalence rate of stunting.

Childbirth assisted by healthcare professionals significantly negatively affects the prevalence rate of stunting. Health literacy among women impacts child-rearing practices from the womb. Childbirth assisted by healthcare professionals ensures monitoring of newborn conditions, including the risk of stunting. Healthcare workers also educate parents, particularly women, regarding child-rearing practices, nutritious feeding, and

healthy lifestyles. They assist mothers giving birth and educate them on the importance of breastfeeding as the primary source of nutrition for newborns [32]. Show that providing breast milk nutrition early in an infant's life significantly reduces the risk of stunting. This finding aligns with research by [33], which indicates that health worker interventions for pregnant women improve health literacy, behaviors, and practices related to nutrition and reproductive health. Central Java Province implements a notable policy for reducing stunting prevalence in Indonesia, known as "Jateng Gayeng Nginceng Wong Meteng." This policy has significantly reduced stunting prevalence in regencies and cities in Central Java from approximately 30.8% in 2018 to 21.6% in 2022, placing the province below the national average. The policy optimizes the roles of healthcare workers and community empowerment cadres in monitoring pregnant women to ensure regular check-ups at integrated health posts and puskesmas (community health centers). It also promotes child-rearing practices related to breastfeeding, immunization, child growth and development checks, and providing supplementary food for infants.

Immunization significantly negatively affects the prevalence rate of stunting in Indonesia. Stunting is a condition where a child experiences growth failure due to malnutrition and recurrent infections. The probability of recurrent infections can be reduced through complete and timely immunization. Children with incomplete immunization are more likely to experience stunting [33]-[35]. Found that children who do not receive complete immunization have a 1.2 times higher risk of stunting compared to those who receive complete immunization [36]. The provision of basic immunization for children is a government program offered free of charge to all children in Indonesia. Access to complete immunization is available at all community health centers, thus expanding public access and reducing the risk of stunting. Gianyar Regency, known for its low stunting prevalence, boasts a relatively high immunization coverage rate of 98.7%. In contrast, areas in Papua, such as Puncak Jaya and Yahukimo, which have the lowest vaccination rates in Indonesia, exhibit the highest stunting prevalence in the country. This situation indicates a lack of government involvement in providing healthcare infrastructure to improve community access to immunization facilities. Health issues also persist as significant challenges throughout much of Papua, where immunization rates are considerably lower than in other regions. In some areas, such as Asmat, Puncak, Yahukimo, Puncak Jaya, and Pegunungan Arfak, portions of the population have never received immunizations. Stating that incomplete immunization increases the probability of a child suffering from stunting by 6 times [37]. Policies to improve public access to healthcare can collaborate with several community groups concerned about Papua, such as the Papua Without Borders Medical Community, which can reach geographically difficult areas in Papua to provide free medical services. Increasing immunization access in Papua can be achieved through collaboration between the Yayasan Gapai Harapan Papua, which is already partnered with the health department, and the United Nations Children's Fund (UNICEF) Indonesia, which is very active in improving immunization access for the people of Papua.

Policies to strengthen immunization coverage in high-prevalence areas can be implemented by, among other things, intensifying the implementation of the national immunization program (National Immunization Month), especially for children under two years of age throughout Indonesia, with the addition of routine vaccine types from the initial 11 to 14 types of vaccines. This policy has proven capable of reducing the prevalence of stunting cases by less than 20% by 2024 compared to the previous year. Additionally, the integrated immunization catch-up policy can also be one way to improve access to complete basic immunization for children who have missed their routine immunization schedule by collaborating with community health centers, village health posts, or by going door-to-door to administer routine immunization schedules in schools (School Children's Immunization Month). In addition, to expand the coverage of immunization in high-prevalence areas, partnerships with various global health alliance organizations, both public and private, such as GAVI, which collaborates with the Ministry of Health in equalizing immunization coverage in Indonesia, are crucial. Community and stakeholder involvement play a crucial role in the effectiveness of increasing immunization access across a wider geographical area and simultaneously serve as health promotion to enhance public trust in vaccines and immunization [38]. Interventions to provide immunization as early as possible with broad coverage have been proven to reduce the probability of a community group experiencing a fatal outcome from a disease [39].

Access to proper sanitation negatively affects the prevalence rate of stunting in Indonesia. Poor sanitation and hygiene increase the risk of stunting, a chronic health condition caused by malnutrition and nutrient deficiencies. Poor sanitation also raises the risk of spreading infectious diseases, which affects nutrient absorption in toddlers, thereby increasing the risk of stunting [40]. Indirectly state that malnutrition arises from food insecurity, limited healthcare access, and poor sanitation [41]. Poor sanitation increases bacterial contamination in the environment, most commonly affecting household drinking water. The most common bacterial contamination is *E. coli*, which is the primary cause of decreased drinking water quality in households. Contaminated drinking water, if consumed by children, can cause health and developmental problems [42]. Policies to increase literacy in managing defecation can be one strategy in reducing the probability of children experiencing stunting through preventive efforts [43], [44]. Stunting prevalence is influenced not only by inadequate nutrition and diet in children but also by limited access to proper sanitation. Ensuring adequate

sanitation in households is crucial for reducing the incidence of infectious diseases that contribute to stunting. Empirical evidence from Indonesia indicates that regions with good access to proper sanitation tend to have lower stunting prevalence rates. For instance, the City of Surabaya and Gianyar District in Bali have nearly universal access to proper sanitation, with stunting prevalence rates among the lowest in Indonesia, at only 4.8% and 6.3%, respectively. Government policy interventions to improve community access to proper sanitation, especially in the Papua region cluster, are important to implement, such as increasing literacy on clean and healthy sanitation behaviors, allocating special funds for the construction of healthy sanitation infrastructure, optimizing the use of special autonomy funds in the health sector, and enhancing partnership collaboration with various parties, including local governments, indigenous groups, the private sector, academics, and international organizations like UNICEF in the "Papua Sanitation Improvement Program (BISA)/*Papua Benahi Sanitasi (BISA)*" program. In addition, to improve adequate sanitation in Papua, local governments are involved in formulating policies related to the provision of standardized housing with excellent sanitation. This issue is important because findings from the health department in various regions of Papua indicate that many homes still lack adequate sanitation.

The provision of exclusive breastfeeding, complementary foods, access to safe drinking water, and health guarantees positively and significantly impacts the prevalence of stunting across regions in Indonesia. A study by [45] stated that failure to practice exclusive breastfeeding is a cause of the increasing number of stunting cases, especially due to the lack of optimal nutrition and immune protection provided by breast milk. Habits and cultures passed down from generation to generation lead to ignorance about exclusive breastfeeding. [46] stated that stunting is more likely to occur in families with low socioeconomic status, which is related to the mother's low level of education, resulting in exclusive breastfeeding practices that often do not meet WHO standards, which is breastfeeding for at least 6 months without any additional food. This finding is consistent with the study of [47], which states that mothers with low levels of education increase the incidence of stunting in children by 50%. Also highlighted that stunting is not solely caused by exclusive breastfeeding but also by the provision of good nutrition after 6 months of age [47]. Additionally, prevailing public perceptions and traditional cultural practices, such as pre-breast milk feeding and complementary feeding, were identified as influential factors, particularly for families with low socioeconomic status. States that the coverage of exclusive breastfeeding in Indonesia is still very low, at 14.6% [48]. Ceasing breastfeeding before six months increases the likelihood of stunting in infants. This finding is consistent with research by [49], which states that stopping breastfeeding before six months increases the incidence of stunting in Pakistan. Highlights that stunting is not solely due to exclusive breastfeeding but also to good nutrition after the child is 6 months old. States that as the mother's education level increases, the stunting rate will be higher [25]. This is because higher education allows mothers to make a greater contribution to the family economy by working outside the home. This condition causes women to spend less time on domestic chores and caring for family members, thus shortening the schedule for exclusive breastfeeding. Childcare and feeding are provided by low-educated domestic helpers, so the child does not receive sufficient nutrition, leading to an increase in stunting.

Access to clean water plays an important role in reducing stunting. Access to clean water reduces the likelihood of vulnerable family members contracting diseases. Access to clean water decreases stunting, as the water consumed by communities must meet health standards and avoid pollution. Currently, only about 20% of households in Indonesia have access to safe drinking water. Although the percentage of households with access to safe water is already high at 80%, only 11% of households have access to drinking water free from bacterial contamination. This finding is consistent with [50], [51], which states that most households in Indonesia access drinking water sources that are unsafe from bacterial contamination.

States that low-income families tend to have limited access to healthcare services and facilities [46]. One healthcare service that people are reluctant to access is health insurance because it will increase family expenses. Health insurance positively and significantly impacts the prevalence of stunting. The Indonesian government implements health insurance for the community through the Health Insurance Administration Agency. Stunting cases are considered a health issue, and their management is covered by the Health Insurance Administration Agency. However, many individuals are either not registered for health insurance or remain inactive despite having insurance coverage. Often, people only reactivate their insurance membership when they become ill and require medical treatment. Report that more than 50% of stunted children do not have insurance coverage [52]. Additionally, low health literacy among women results in over 70% of stunted children not utilizing health insurance for their nutritional care [52]. States that having health insurance accelerates the reduction of stunting because health complaints related to stunting are addressed more quickly [53].

The lack of information on how to effectively utilize health insurance has led to its limited impact on reducing stunting rates. Although several regions in Indonesia have seen an increase in health insurance ownership, stunting rates remain high. For instance, Yahukimo and Asmat Districts have high health insurance coverage but also report the highest stunting prevalence in Indonesia, at 54.50%. This situation indicates that the utilization of health insurance for stunting reduction is not yet optimal, primarily due to limited community awareness of its coverage. The government must intensify efforts to disseminate information about health

insurance usage and the diseases it covers. Public access to online media and social media can facilitate this dissemination. Additionally, it is essential to inform prospective mothers about the benefits of accessing health insurance. This study uses regional data from 514 districts and cities in Indonesia for the 2024 period and does not analyze individual data. Therefore, the possibility of latent variables influencing individual aspects is not included in this study's analysis.

Table 3. Comparison of spatial analysis between SAR, SEM, and SARMA models

Variables	Spatial autoregressive model (SAR)	Spatial error model (SEM)	Spatial autoregressive moving average (SARMA)
Constanta	0.0906***	0.3110***	0.3153***
	(0.0381)	(0.0286)	(0.0289)
Immunization (IM)	0.2935**	-0.0496**	-0.0539**
	(0.0299)	(0.0167)	(0.0168)
Childbirth with the assistance of health workers (BA)	-0.1028***	-0.0908***	-0.0983***
	(0.0242)	(0.0241)	(0.0245)
Modern contraception (FP)	-0.0216	-0.0208	0.0203
	(0.0255)	(0.0259)	(0.0260)
Breastfeeding (BF)	0.0371**	0.0382**	0.0382***
	(0.0159)	(0.0159)	(0.0163)
Food attendant for breastfeeding (FA)	0.0972***	0.1002***	0.0945***
	(0.0250)	(0.0252)	(0.0255)
Safe drinking water (WATER)	-0.0117	-0.0114	-0.0170
	(0.0266)	(0.0266)	(0.0271)
Proper sanitary (SAN)	-0.1072***	-0.1149***	-0.1091***
	(0.0253)	(0.0258)	(0.0258)
Early childhood education programs (PS)	-0.0021	-0.0022	-0.001
	(0.0274)	(0.0279)	(0.0280)
Health insurance (HI)	0.0819***	0.0776***	0.0850***
	(0.0193)	(0.0195)	(0.0197)
Welfare family assistance (SP)	0.0013	-0.0033	0.0028
	(0.0234)	(0.0236)	(0.0239)
Per capita income (INCOME)	-1.1929x10-7**	-1.2278x10-7**	-1.20x10-7**
	(4.1847x10-7)	(4.1998x10-8)	(4.2612x10-8)
Lagrange multiplier (lag)	0.0906**		6.5211
	(0.0381)		(0.0106)
Lagrange multiplier (error)		0.1356**	9.1980**
		(0.0592)	(0.0024)
Lagrange multiplier (SARMA)			9.8755
			(0.0072)
R-squared	0.3166	0.3191	0.3074
F-statistic probability			20.2973
			(0.0000)
Moran's I			3.2176
			(0.0013)

Significant at *** α= 1%; ** α= 5%; * α= 10%

Source: Data processed by the author (2025)

4. CONCLUSION

The mapping results using LISA based on stunting indicators across regions in Indonesia show that hotspot areas or areas with high stunting rates are more dominated by regions in eastern Indonesia, such as East Nusa Tenggara, Papua, and parts of Sulawesi Island. Coldspot areas or areas with low stunting rates are more prevalent in western Indonesia. Based on multivariate analysis using PCA and CA, it is known that regencies and cities in Indonesia are divided into 5 clusters, where cluster 3 has the best performance, cluster 1 has the largest number of members, and clusters 2, 4, and 5 have the lowest performance. Poor sanitation in many areas is a major cause of stunting in Indonesia. Efforts that can be made by local governments include increasing education and literacy among the public about healthy lifestyles and the importance of proper sanitation through health departments, community health centers, *Posyandu* cadres, schools, or community groups. In addition, the policy regarding proper sanitation includes a special budget allocation from village funds used to build sanitation infrastructure such as communal toilets, especially in areas with very high stunting rates, such as regencies and cities in East Nusa Tenggara and Papua.

Spatial aspects influence the stunting rate among regions in Indonesia, as indicated by a positive and significant Moran's Index value. Policies addressing stunting across regions in Indonesia must be focused on the specific characteristics of the existing problems to ensure targeted and effective interventions. For instance, areas with high stunting rates are often linked to poor access to sanitation. Therefore, appropriate policies for

addressing stunting should focus on improving community access to better sanitation, particularly in remote areas. Local governments can implement education on good sanitation practices by enhancing the role of health workers at the grassroots level, such as those in community health centers and integrated health posts. Furthermore, the government should provide adequate sanitation facilities, especially for low-income families. Improved access to sanitation will reduce the likelihood of children contracting diseases that hinder nutrient absorption, thereby decreasing the risk of stunting. Stunting management will be more effective if focused on the problems in the characteristics of each cluster. Stunting management policies must be integrated and collaborative with various parties, including the government, the private sector, and community organizations. Stunting management policies focus on expanding community access to health facilities, such as immunization, with the optimization of national immunization months in collaboration with community organizations like Doctors Without Borders Papua Community, and Yayasan Gapai Harapan Papua, which have partnered with the health department and the United Nations Children's Fund (UNICEF) Indonesia, which is very active in increasing access to immunization for the people of Papua. Government policy interventions to improve community access to proper sanitation, especially in the Papua region cluster, are important to implement, such as increasing literacy on clean and healthy sanitation behavior, allocating special funds for the construction of healthy sanitation infrastructure, optimizing the use of special autonomy funds in the health sector, and increasing partnership collaboration with various parties, including local governments, indigenous groups, the private sector, academics, and international organizations like UNICEF in the "Papua Benahi Sanitasi (BISA)" programme.

ACKNOWLEDGMENT

We extend our gratitude to the Research and Community Service Institute of Jenderal Soedirman University for funding this research grant under the Unsoed Basic Research scheme (RDU), contract number 14.338/UN23.34/PT.01/V/2025.

FUNDING INFORMATION

Research funding was obtained from the Jenderal Soedirman University Basic Research scheme as part of the university's funding, and there was no funding from outside the institution.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
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R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known financial, personal, professional, or non-financial competing interests that could have influenced the work presented in this paper. There are no external funding sources, affiliations, or relationships that could be perceived as a conflict of interest. Furthermore, the authors affirm that there are no political, religious, ideological, academic, or intellectual interests that could have affected the objectivity or integrity of the research. The research was conducted independently, without any bias or external influence, ensuring fair and objective decision-making throughout the study.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The data in this paper do not use humans or animals as experimental subjects. All data used in this study can be accessed through the data providers Statistics Indonesia and the Ministry of Health Indonesia.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [KW], upon reasonable request.

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