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Article

Analysis of the spatial distribution patterns of education infrastructure development (A case study of 33 regencies/city in North Sumatra Province)

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Abstract: This study explores the spatial distribution pattern of educational infrastructure development across districts and cities in North Sumatra, identifying significant disparities between urban and rural areas. The study aims to: (1) determine the distribution of educational development across districts and cities, (2) analyze global spatial autocorrelation, and (3) identify priority locations for educational development policies in North Sumatra Province. The methodology includes quantile analysis, Moran's Global Index, and Local Indicators of Spatial Autocorrelation (LISA) using GeoDa software to address spatial autocorrelation. The results indicate that there are nine areas with a low School Participation Rate Index (SPRI), eleven areas with a low School Facilities and Infrastructure Index (SFII), and eleven areas with a low Regional Education Index (REI). Spatial autocorrelation analysis reveals that SFII shows positive spatial autocorrelation, while SPRI and REI exhibit negative spatial autocorrelation, indicating a high level of inequality between regions. Labuhan Batu Selatan and Labuhan Batu are identified as priorities for the provincial government in overseeing educational development policies.

Keywords: spatial distribution; educational development; global spatial autocorrelation; priority locations; North Sumatra

1. Introduction

Educational development in the districts/cities of North Sumatra still shows significant disparities between regions. Urban areas such as Medan and Pematang Siantar have better access to educational facilities compared to rural areas like Nias and Mandailing Natal. According to Bahari et al. (2020) and Harahap and Daud (2020), this disparity is caused by uneven budget allocation, which is more concentrated in areas with larger populations. Similar findings were reported by Darnawaty and Purnasari (2019) and Putri and Kurnia (2022), who stated that regions with higher economic growth tend to receive more investment in educational infrastructure. Research by Al-Samarrai et al. (2019) also emphasizes that the uneven distribution of educational resources in Indonesia significantly affects educational outcomes in remote areas.

The provision of school infrastructure by the government involves not only developing schools but also includes other services. These services involve the development of transportation networks such as roads, adequate classroom space, sufficient numbers of teachers, and effective planning strategies (Galiani et al., 2008; Hameed, 2016). A study by Majhi et al. (2019) explains that the development of educational infrastructure significantly impacts school enrollment numbers. Improved educational facilities, including better access to transportation and infrastructure upgrades, substantially increase enrollment rates, particularly among girls, who are more likely to attend school when the learning environment is safer and more comfortable (Filmer and Pritchett, 1999).

Studies by Febriaty (2018), Siregar and Tanjung (2020) and Bloom et al. (2014) show that in areas with good educational access, school participation rates are higher and dropout rates are lower, which directly contributes to increased income and reduced poverty levels in those areas. Research by Wicaksono and Aliem (2022) also supports that investment in education in rural areas can significantly reduce economic disparities. Additionally, research by Glewwe and Muralidharan (2015), Walker et al. (2019), Liu et al. (2021), Postiglione (2015), Burde et al. (2015), Kromdyas (2017), and Shaeffer (2019) shows that investment in educational infrastructure can improve access to quality education, which in turn accelerates poverty reduction and social inequality.

Research by Ghosh (2010), Ajilore (2011), and Millimet and Rangaprasad (2007) has shown that spatial dependence among public schools in the United States has been extensively studied. This dependence is due to strategic interactions and competition among schools for resources and students. A spatial approach in educational development analysis is crucial for identifying areas that require further intervention (Malczewski and Jackson, 2000). The use of Geographic Information Systems (GIS) enables more accurate and efficient mapping for allocating educational resources (Anselin et al., 2006). According to Sa'adah et al. (2022), the implementation of GIS can assist local governments in planning new school developments, improving existing infrastructure, and ensuring a more even distribution of teachers, which is expected to enhance overall educational quality and reduce regional disparities (Gertler et al., 2012).

Spatial analysis uses approaches that highlight the presence of space. From a geographical perspective, space can be analyzed through spatial structure, spatial patterns, and spatial processes (Rahman and Partono, 2018). In spatial data, observations at one location are often influenced by observations at nearby locations (Karim and Alfiyah, 2014). The lack of spatial consideration in planning leads to issues in facility utilization. Some regions lack facilities, while others have underutilized facilities (Asmanto et al., 2009).

The indicators selected for this study, namely SFII (School Facilities and Infrastructure Index), SPRI (School Participation Rate Index), and REI (Regional Education Index), were specifically designed to address the limitations identified in previous research. For example, the method developed by Oliya and Arkana (2021) to measure educational development in Indonesia was limited in terms of the diversity and scope of indicators. Their approach included only three variables and six indicators: student quality (repeat rates, graduation rates, and dropout rates), teacher quality (percentage of qualified teachers and student-teacher ratio), and school facility quality (good and adequate classrooms). These indicators provided a limited and less comprehensive perspective in assessing educational development across a broader area.

Similarly, the Regional Education Excellence Index study by Nugroho and Desriani (2022) focused solely on educational dimensions using 12 indicators divided into three variables. However, their study did not sufficiently consider infrastructure and school participation factors, which play a crucial role in the success of education at the regional level. To address these shortcomings, this study selected more comprehensive and relevant indicators and developed SFII, SPRI, and REI. SFII includes data on educational personnel, student data, teacher data, school data, and classroom data to depict the overall quality of educational infrastructure. SPRI utilizes the Gross Enrollment Index (GEI) and Net Enrollment Index (NEI) to provide a more complete picture of school participation. Meanwhile, REI includes Expected Years of Schooling (EYS) and Mean Years of Schooling (MYS), which reflect educational expectations and achievements, thus providing a deeper and more comprehensive understanding of educational development in each region.

By selecting these indicators to expand the scope and deepen the analysis, this study aims to conduct a more in-depth analysis to: First, determine the distribution of educational development in districts/cities. Second, analyze the global spatial autocorrelation of educational development in districts/cities. Third, identify priority locations for monitoring educational development policies for the North Sumatra provincial government.

2. Literature review

2.1. Educational development

Effective educational development encompasses more than just the construction of school facilities. According to Hameed (2016) and Galiani et al. (2008), crucial components of effective educational development include the establishment of robust transportation networks, adequate classroom space, and a sufficient number of qualified teachers. These elements are essential for enhancing student engagement and overall educational quality. Hameed (2016) emphasizes that well-developed transportation systems ensure students can reliably attend school, while Galiani et al. (2008) highlight that adequate classroom facilities and teacher availability are critical for creating conducive learning environments. These factors collectively support higher levels of student participation and improve educational outcomes.

Further supporting these findings, research by Majhi et al. (2019) indicates that enhancements in educational infrastructure—when coupled with good transportation access and a safe learning environment—substantially influence student participation rates. This aligns with Filmer and Pritchett's (1999) research, which demonstrates that improved access to education and better learning conditions significantly increase the likelihood of school enrollment and attendance. These studies underscore the importance of a comprehensive approach to educational development that addresses not only the physical aspects of infrastructure but also the accessibility and quality of the educational environment.

The integration of these components into educational development strategies is essential for creating an effective and inclusive educational system. By addressing both infrastructure and accessibility, policymakers can ensure that educational resources are utilized efficiently and equitably. This comprehensive approach aligns with the research goal of identifying priority locations for educational development and monitoring policies. The research emphasizes that effective educational development requires a multifaceted approach that considers various elements, including transportation, classroom facilities, and teacher availability, to create a supportive and high-quality educational environment.

By understanding and applying these findings, stakeholders can better target their efforts to improve educational infrastructure and access, ultimately enhancing educational outcomes across different regions. This aligns with the broader objective of ensuring that educational development policies are effectively implemented and monitored in priority areas.

2.2. Spatial distribution of educational infrastructure development

Research has consistently highlighted the significant spatial patterns in the distribution of educational infrastructure. Areas with better access to educational resources tend to exhibit higher school participation rates and lower dropout rates. This observation is supported by Febriaty (2018), who found that enhanced infrastructure correlates with increased student enrollment and retention, suggesting that the distribution of educational facilities is a key factor in educational development. Similarly, Siregar and Tanjung (2020) demonstrate that regions with well-developed educational facilities show better student outcomes. This evidence aligns with the goal of determining the distribution of educational development, as it underscores the direct impact of educational infrastructure on educational engagement and effectiveness across different districts and cities.

The importance of targeted investments in educational infrastructure, especially in rural areas, is underscored by Wicaksono and Aliem (2022). Their study highlights that investing in underserved regions is crucial for addressing economic disparities and fostering equal educational opportunities. This finding supports the research goal by indicating that equitable distribution of educational resources is essential for bridging gaps between urban and rural areas, thus ensuring that educational development is well-distributed across districts and cities.

Furthermore, Glewwe and Muralidharan (2015) emphasize that investments in educational infrastructure play a crucial role in accelerating poverty reduction and addressing social inequality. Their research shows that improving educational facilities not only enhances learning outcomes but also contributes to broader socio-economic benefits. This reinforces the goal of determining the distribution of educational development, as it highlights the broader socio-economic impact of educational infrastructure and the need for strategic distribution to maximize these benefits. By aligning these insights with the research goal, it becomes clear that understanding and mapping the distribution of educational development across districts and cities is essential for addressing disparities, improving educational outcomes, and achieving long-term socio-economic improvements.

2.3. Spatial autocorrelation

The concept of spatial autocorrelation plays a significant role in understanding educational dynamics. Ghosh (2010), Ajilore (2011), and Millimet and Rangaprasad (2007) discuss how spatial dependence among public schools can arise from strategic interactions and competition for resources and students. Their research highlights that schools in proximity often exhibit similar patterns of resource allocation and performance due to their interdependent nature. This spatial interaction can affect various aspects of educational outcomes, including resource distribution and student enrollment rates. This finding supports the research goal of analyzing global spatial autocorrelation by illustrating how spatial dependence patterns can influence educational development across different districts and cities.

Malczewski and Jackson (2000) emphasize the importance of integrating a spatial approach in educational development analysis. They argue that spatial methods are crucial for identifying regions that require targeted interventions. By examining spatial patterns, policymakers can better understand the geographic distribution of educational resources and determine where additional support is needed. This approach allows for a more nuanced analysis of educational development, helping to address disparities and allocate resources more effectively. This aligns with the research goal of analyzing global spatial autocorrelation by showing how spatial approaches can enhance understanding and planning of educational development.

Anselin et al. (2006) demonstrate the advantages of using Geographic Information Systems (GIS) to improve the accuracy and efficiency of educational resource allocation. GIS technology facilitates the visualization and analysis of spatial data, enabling more informed decision-making regarding resource distribution. With GIS, spatial analysis can be conducted more effectively, identifying patterns of dependence and distribution that might not be immediately apparent. This finding supports the research goal by showing how GIS can be used to understand and analyze spatial autocorrelation in educational development.

Sa’adah et al. (2022) further highlight the benefits of GIS in educational planning, particularly in the development of new schools and the equitable distribution of teachers. Their study shows that GIS can enhance the planning process by providing accurate data and visualization that aid in decision-making. This ensures that educational infrastructure meets the needs of all regions and supports fair access to quality education. Integrating GIS into spatial autocorrelation analysis allows researchers to identify distribution patterns and determine areas requiring further attention.

2.4. Priority locations

Identifying priority locations for educational development is crucial for ensuring the equitable and effective distribution of educational resources. Rahman and Partono (2018) demonstrate that spatial analysis is an invaluable tool for pinpointing areas that require additional focus and intervention. Their research highlights how spatial techniques can reveal regions with significant spatial dependence on educational facilities and services, allowing policymakers to target their efforts more precisely. By leveraging spatial data, decision-makers can prioritize areas where educational development is most needed, leading to a more efficient allocation of resources. This aligns with the research goal by emphasizing the role of spatial analysis in identifying key locations for monitoring and intervention.

Asmanto et al. (2009) emphasize the importance of incorporating spatial considerations into educational planning to prevent imbalances in the utilization of educational facilities. Their research indicates that some regions may experience a shortage of facilities, while others may have underutilized resources. Such imbalances can result in inefficient use of available infrastructure and unequal access to educational opportunities. Effective spatial analysis helps to identify these discrepancies, ensuring that educational resources are distributed more equitably across different regions. This supports the research goal by demonstrating how spatial analysis can reveal priority locations that require focused attention to address disparities in educational resources.

Furthermore, integrating spatial analysis into educational planning not only addresses facility imbalances but also enhances overall planning strategies. By identifying priority locations, stakeholders can develop targeted policies and interventions that address specific needs within different communities. This approach helps in optimizing resource use and improving educational outcomes. The insights gained from spatial analysis enable more informed decision-making, leading to a more balanced and equitable educational development strategy. Fotheringham and Wong (1991) also highlight the importance of spatial analysis in designing more effective policies by utilizing spatial techniques to identify needs and optimize resource allocation.

3. Methodology

3.1. Overview of research location

The spatial analysis data on educational development used in this study is secondary data sourced from the Central Bureau of Statistics, the Department of Education of North Sumatra Province, and the Ministry of Education and Culture for the period 2019–2022. This research was conducted from December 2023 to February 2024 in North Sumatra Province. Currently, North Sumatra Province consists of 33 regencies/cities, comprising 25 regencies and 8 cities. Before the 1998 reform, the number of regencies/cities in North Sumatra Province was only 16 regions. The administrative map of regencies/cities is attached in **Figure 1**.

To understand the geographical context of this research, **Figure 1** shows the administrative areas in North Sumatra Province that are the focus of the study. This map provides a clear overview of the geographical distribution of the regencies and cities analyzed in the research. North Sumatra can be divided into three main zones based on geographical, economic, and cultural characteristics. The Eastern Coast Region includes the regencies of Langkat, Deli Serdang, Serdang Bedagai, Batubara, Asahan, Labuhanbatu, Labuhanbatu Utara, and Labuhanbatu Selatan, as well as the cities of Medan, Binjai, Tanjungbalai, and Tebing Tinggi. This region serves as the economic and trade center of the province, with Medan acting as the provincial capital and primary commercial hub. Its strategic location near the Malacca Strait supports industries, palm oil plantations, and fisheries (Government of North Sumatra Province, 2024).

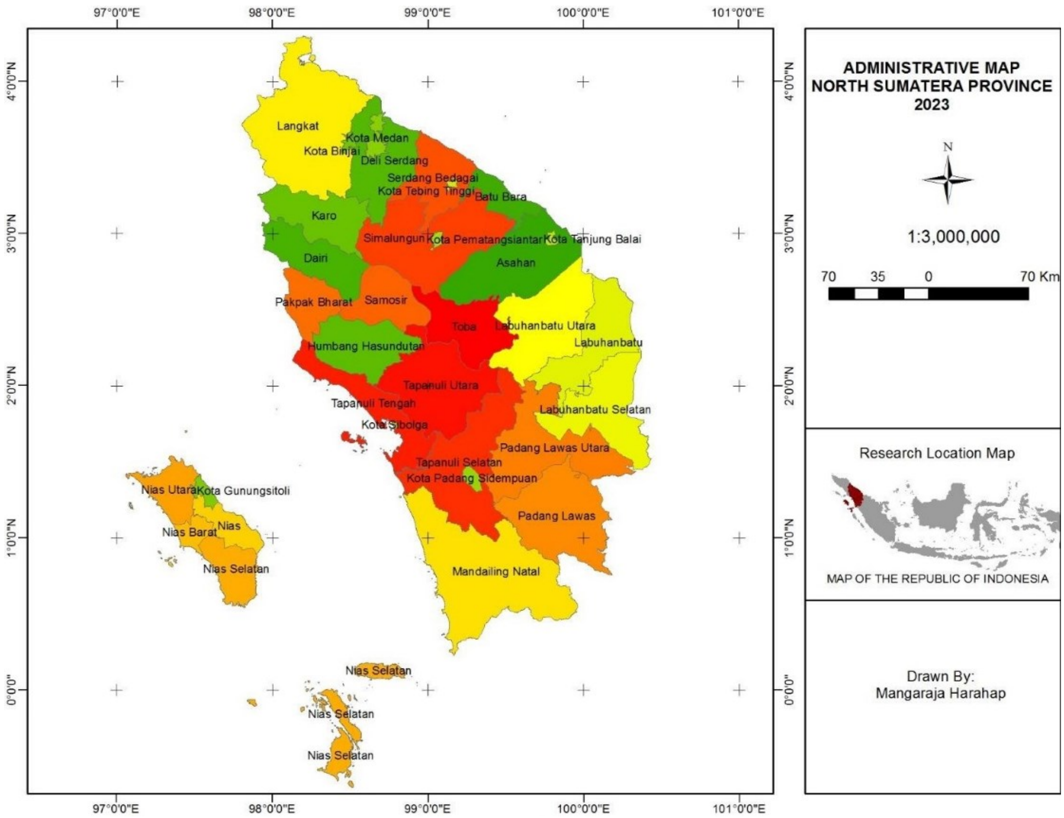

Figure 1. Administrative map of North Sumatra Province 2023, showing the areas where the research was conducted.

The Bukit Barisan Mountains Region encompasses the regencies of Karo, Dairi, Pakpak Bharat, North Tapanuli, South Tapanuli, Central Tapanuli, Humbang Hasundutan, Samosir, Simalungun, Toba Samosir, Padang Lawas, and Padang Lawas Utara, as well as the cities of Pematang Siantar and Padang Sidempuan. This area is characterized by its mountainous and highland topography, which supports agricultural activities such as horticulture, coffee cultivation, and livestock farming. Additionally, it is a center of Batak culture and a major tourist destination, featuring attractions such as Lake Toba (Tourism and Culture Office of North Sumatra, 2023).

The Islands and Western Coast Region includes the regencies of Nias, South Nias, Norths Nias, West Nias, and Mandailing Natal, along with the cities of Gunungsitoli and Sibolga. This zone comprises coastal and island areas facing the Indian Ocean, known for their unique cultural heritage, particularly in the Nias Archipelago. Economic activities in this region are dominated by fisheries, agriculture, and tourism. Mandailing Natal, with its appropriate topography, is also part of this zone (Central Statistics Agency of North Sumatra, 2023).

3.2. Method of analysis

Three educational development variables are analyzed: the School Facilities and Infrastructure Index (SFII), the School Participation Rate Index (SPRI), and the Regional Education Index (REI). Before the analysis, the composite index is calculated by taking the arithmetic mean of each indicator of the normalized and weighted variables. The respective formulae for SFII, SPRI, and REI are:

$$SFII_i = \frac{\sum_{k=1}^{n_k}(x_{ik*} w_k)}{\sum_{k=1}^{n_k} w_k}, SPRI_i = \frac{\sum_{k=1}^{n_k}(x_{ik*} w_k)}{\sum_{k=1}^{n_k} w_k}, REI_i = \frac{\sum_{k=1}^{n_k}(x_{ik*} w_k)}{\sum_{k=1}^{n_k} w_k}$$

where $SFII_i$, $SPRI_i$, and REI_i are the values of SFII, SPRI, and REI for district/city i, x_{ik} is the value of indicator k for district/city i, and w_K is the weight of indicator k.

The first objective is to determine the distribution of educational development using the quantile method, categorized into three levels: low, medium, and high. This method is supported by the research of McLafferty (2003) and Anselin (1995), which shows how dividing data into quantiles aids in the interpretation and mapping of spatial data. The respective formulae for SFII, SPRI, and REI are:

$$Q_k = SFII_{\left(\left\lceil \frac{k.n}{q} \right\rceil\right)},\ Q_k = SPRI_{\left(\left\lceil \frac{k.n}{q} \right\rceil\right)},\ Q_k = REI_{\left(\left\lceil \frac{k.n}{q} \right\rceil\right)}$$

where k is the quantile number (from 1 to q), n is the total number of values, and $\lceil\cdot\rceil$ is the ceiling function. The values of SFII, SPRI, and REI are ordered from smallest to largest with the quantile boundaries for the k-th category at the q-th quantile.

The second objective is to analyze the spatial distribution of educational development to measure the extent to which values at a particular location correlate with values in neighboring locations using the global Moran's I index. This is similar to the study by Pravitasari et al. (2021), which analyzed the spatial distribution and relationships between educational variables at the local level. The formula for SFII, SPRI, and REI is:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(SFII_i - \overline{SFII})\,(SFII_j - \overline{SFII})}{\sum_{i=1}^{n}(SFII_i - SFII)^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}}$$

where $SFII_i$ is the SFII value for district/city i, $\overline{SFII}$ is the mean SFII value, w_{ij} is the spatial weight between districts/cities i and j, and n is the number of districts/cities. A Moran's I value close to 1 indicates a strong positive correlation, while a value close to -1 indicates a strong negative correlation, and a value close to 0 indicates a random distribution of values. The same method is applied to the SPRI and REI variables.

The third objective is to identify priority areas for monitoring the educational development policies of the North Sumatra Provincial Government by measuring the extent to which values at a particular location correlate with values in neighboring locations using the Local Indicator of Spatial Autocorrelation (LISA) method. For the SFII variable, LISA is calculated with the formula:

$$LISA_i = \frac{(SFII_i - \overline{SFII})\sum_j w_{ij}\left(SFII_j - \overline{SFII}\right)}{\sum_i (SFII_i - \overline{SFII})^2}$$

where $SFII_i$ is the SFII value for district/city i, $\overline{SFII}$ is the mean SFII value, w_{ij} is the spatial weight between districts/cities i and j, and n is the number of districts/cities. The same LISA formula applies to the SPRI and REI variables.

4. Result

4.1. Spatial distribution patterns of educational development in districts/cities in North Sumatra

Figure 2 presents the distribution pattern of the School Facilities and Infrastructure Index (SFII). The components of the SFII development consist of educational personnel data, student data, teacher data, school data, and class data, which are divided into three quantiles. The first quantile, with an index ranging from 17,820 to 89,040, includes 11 districts/cities such as Asahan, Deli Serdang, and Medan, which have the best educational facilities. The second quantile, with an index ranging from 10,270 to 16,610, also includes 11 districts/cities, including Batu Bara, Dairi, and Humbang Hasundutan. The third quantile, with an index ranging from 1690 to 9850, includes 11 districts/cities such as Gunungsitoli, Padang Sidempuan, and Sibolga.

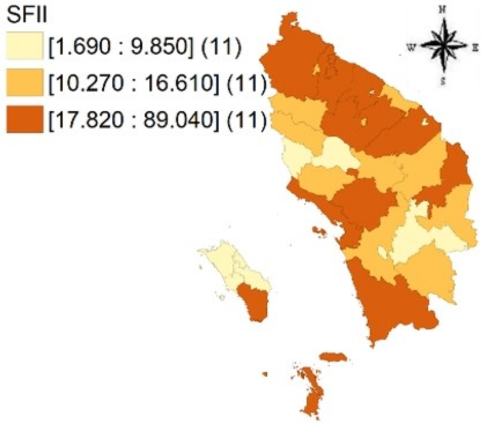

Figure 2. Distribution of SFII.

This distribution analysis shows that regions in the first quantile have adequate school facilities, which greatly contribute to better educational quality. Conversely, regions in the third quantile face limitations in providing school infrastructure facilities. Research by Sebayang (2023) explains that better educational infrastructure is associated with improved educational quality. Consistent with these findings, Nkamnebe (2023) also emphasizes the importance of educational infrastructure in determining the quality of education in an area, indicating that better facilities are crucial.

Figure 3 presents the pattern of development of the School Participation Rate Index (SPRI), which consists of the Gross Enrollment Index (GEI) and the Net Enrollment Index (NEI) divided into three quantiles. The first quantile, with an index between 46.450 and 46.560, includes 11 districts/cities with the highest SPRI, such as Binjai, Gunungsitoli, and Toba. The second quantile, with an index from 46.180 to 46.420, includes 13 districts/cities such as Medan, Padang Sidempuan, and Nias. Meanwhile, the third quantile, with an index from 45.940 to 46.150, includes 9 districts/cities including Asahan, Deli Serdang, and Labuhanbatu. This distribution analysis indicates that areas in the first quantile likely have better school participation rates, while areas in the third quantile might face lower school participation rates.

Figure 4 presents the pattern of development of the Regional Education Index (REI), which is divided into three quantiles. The first quantile, with an index ranging from 4.455 to 5.108, includes 11 districts/cities with the highest REI, such as Medan, Binjai, and Padang Sidempuan. The second quantile, with an index between 4.120 and 4.450, includes 10 districts/cities such as Toba, Deli Serdang, and Nias. Meanwhile, the third quantile, with an index from 3.741 to 4.100, includes 12 districts/cities including Asahan, Labuhanbatu Selatan, and Nias Selatan. The distribution analysis shows that areas in the first quantile generally have better education indicators.

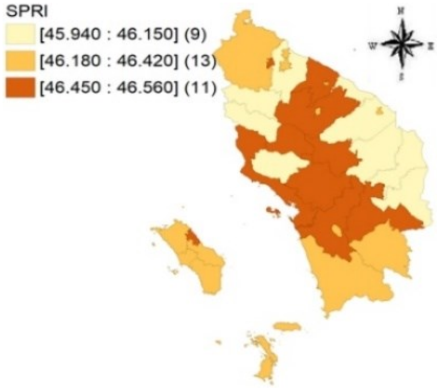

Figure 3. Distribution of SPRI.

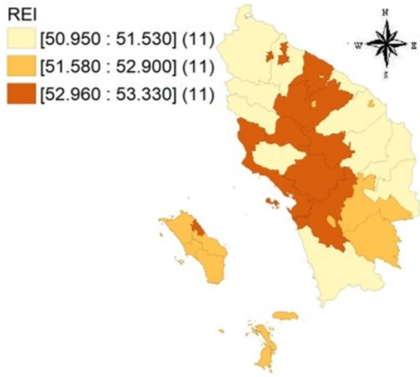

Figure 4. Distribution of REI.

The results of the data analysis on the spatial distribution of education development in North Sumatra can be understood more deeply by relating them to the division into three zones in the province: the Eastern Coastal Region, the Bukit Barisan Mountains Region, and the Archipelago and Western Coastal Region. This data analysis provides insights into how each zone may differ in terms of accessibility and quality of education. Firstly, the Eastern Coastal Region includes districts and cities such as Medan, Deli Serdang, Asahan, and Tanjungbalai, which are in the first quantile of the School Facilities and Infrastructure Index (SFII), indicating that these areas have the best educational facilities in North Sumatra. The presence of Medan as the main economic and administrative center provides a strong impetus for education development, supported by effective education policies and the availability of resources. Medan and Deli Serdang also rank in the first quantile for the School Participation Rate Index (SPRI) and the Regional Education Index (REI), reflecting high levels of school participation and educational achievements in this region. This suggests that the Eastern Coastal Region has excellent access to education, driven by urbanization and more developed infrastructure compared to other zones.

Secondly, the Bukit Barisan Mountains Region encompasses areas such as Dairi, Humbang Hasundutan, and Padang Sidempuan, showing variations in educational achievement. For example, Padang Sidempuan is in the second quantile for SPRI and REI, while Dairi is in the third quantile for SFII and REI. This indicates progress in education efforts, but significant challenges remain, particularly in terms of accessibility and quality of educational facilities. The Bukit Barisan Mountains Region is geographically more isolated, with areas spread across mountainous terrain that can hinder the distribution of educational facilities and school participation. Therefore, despite some progress, certain districts in this zone may require further attention to improve infrastructure and educational access.

Thirdly, the Archipelago and Western Coastal Region includes districts and cities such as Gunungsitoli, Sibolga, and Mandailing Natal showing varied patterns in education development. For instance, Gunungsitoli is in the first quantile for SPRI and REI, indicating good school participation and educational achievements. However, Gunungsitoli is in the third quantile for SFII, suggesting that the quality of educational facilities may still be lagging in some areas. The geographic characteristics of the archipelago and coastal areas, with more limited access, can be a barrier to developing adequate educational infrastructure. Thus, while there is potential for educational advancement in this region, more focused policies are needed to address geographic challenges and improve overall educational quality.

4.2. Spatial autocorrelation of education development in districts/cities of North Sumatra

Figure 5 presents the spatial autocorrelation of the School Facilities and Infrastructure Index (SFII) using the global Moran's I index. The results show that SFII has a positive spatial autocorrelation (Moran's I 315 = 0.75, *p*-value < 0.01), indicating that high and low SFII values tend to cluster together. This finding is consistent with the study by Wijayanti et al. (2022), which found that educational infrastructure is often concentrated in certain areas.

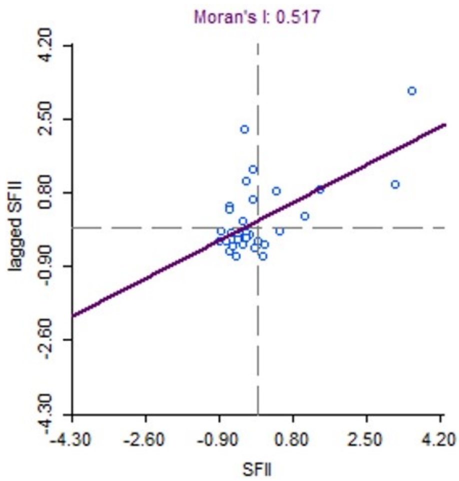

Figure 5. Spatial autocorrelation of SFII.

Figure 6 shows the spatial autocorrelation of the School Participation Rate Index (SPRI), using the global Moran's index. The results indicate a positive spatial autocorrelation (Moran's I = 0.72, *p*-value < 0.01), suggesting that high and low SPRI values are spatially clustered. This finding is supported by the research of Adi and Wahyuni (2021), which found similar clustering patterns in school participation rates. **Figure 7** illustrates the spatial autocorrelation of the Regional Education Index

(REI) using the global Moran's I index. The results show a positive spatial autocorrelation (Moran's I = 0.69, *p*-value < 0.01), meaning that high and low REI values also tend to cluster together. This finding aligns with the research by Pratama et al. (2020), which indicates that regions with higher education indices tend to be grouped together. When the results of this spatial autocorrelation analysis are linked to the three regional zones in North Sumatra—Eastern Coastal observations can be made.

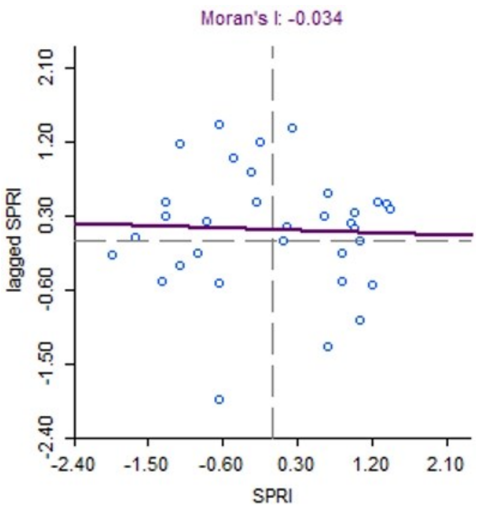

Figure 6. Spatial autocorrelation of SPRI.

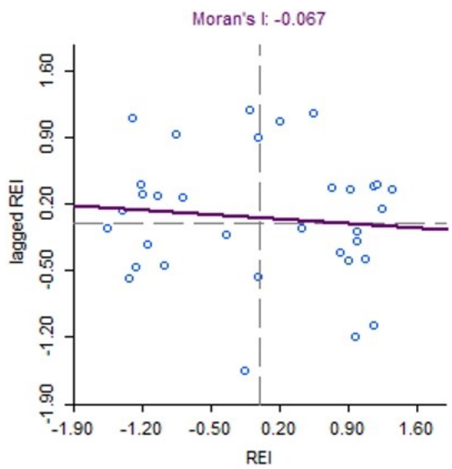

Figure 7. Spatial autocorrelation of REI.

In the Eastern Coastal Region, the significant clustering of School Facilities and Infrastructure Index (SFII) with a positive autocorrelation value of 0.5169 suggests that areas with better educational facilities tend to be close to other areas with similar facilities. However, despite these adequate facilities, the School Participation Rate Index (SPRI) and the Regional Education Index (REI) in this region show a random distribution with negative autocorrelation values of −0.0335 and −0.0671, respectively. This indicates that even though educational infrastructure is available, it is not always reflected in uniform school participation rates or educational outcomes across the region. Varying local factors, such as poverty levels and accessibility, may influence these results. In the Bukit Barisan Mountains Region, the significant clustering pattern of SFII (Moran's I 338 = 0.5169) indicates that areas with good educational infrastructure tend to cluster together. However, SPRI and REI in this region show a random distribution with negative autocorrelation, suggesting that there are challenges in access to and participation in education, likely due to difficult geographical conditions and limited accessibility.

In the Archipelago and Western Coastal Region, although SFII shows positive clustering (Moran's I = 0.5169), SPRI and REI also display random distribution patterns with negative autocorrelation values. This suggests that geographical challenges, such as remoteness and difficult access, may be major factors influencing school participation and educational outcomes in this region. From this analysis, it can be concluded that while good educational infrastructure tends to cluster in certain regions of North Sumatra, factors such as poverty, accessibility, and geographical conditions play a crucial role in determining school participation and educational outcomes in these areas. Therefore, more focused educational policies and appropriate interventions are needed to address these disparities, especially in regions facing significant geographical and accessibility challenges.

4.3. Priority locations for education development policies in districts/cities of North Sumatra

Figure 8 shows the results of the Local Indicators of Spatial Association (LISA) analysis for primary school development indicators (i.e., SFII). The map reveals that there are 22 districts/cities where no significant correlation is found between SFII development and poverty.

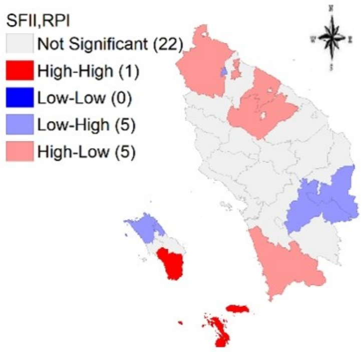

Figure 8. LISA cluster of SFII.

Only one district, Nias Selatan, falls into the high-high category. This indicates that Nias Selatan has a high level of SFII development and is surrounded by areas with similarly high SFII development, consistent with the findings of Wang et al. (2024), which state that high-high clustering indicates a strong concentration of the studied variable. No districts/cities fall into the low-low category, meaning there are no areas with consistently low SFII development and low poverty. The low-high category includes five districts/cities—Binjai, Gunung Sitoli, Labuhanbatu Selatan, Nias Utara, and Padang Lawas Utara—where the districts have low SFII development but are surrounded by areas with high SFII development. Conversely, five districts/cities—Medan, Langkat, Mandailing Natal, Serdang Bedagai, and Simalungun—fall into the high-low category, where SFII development is high but surrounded by areas with low

SFII development. These findings are consistent with the spatial patterns discussed by Tipayalai and Subchavaroj (2024) regarding regional disparities in SFI development.

Figure 9 shows that the LISA analysis for School Participation Rate Index (SPRI) reveals that 22 districts/cities do not exhibit significant correlation with poverty. However, two districts—Nias Selatan and Padang Lawas Utara—are categorized as high-high, meaning both have high levels of SPRI development and are surrounded by areas with high SPRI levels as well. No districts/cities fall into the low-low category. The low-high category includes two districts—Labuhanbatu and Labuhanbatu Selatan—with low SPRI development but surrounded by areas with high SPR levels. Conversely, the high-low category includes seven districts/cities—Medan, Padang Sidempuan, Pakpak Bharat, Samosir, Serdang Bedagai, Simalungun, and Tapanuli Tengah—where SPRI development is high but surrounded by areas with low SPR development. These findings align with Jogani's (2021) research, which shows that high-low patterns often experience disparities in education development.

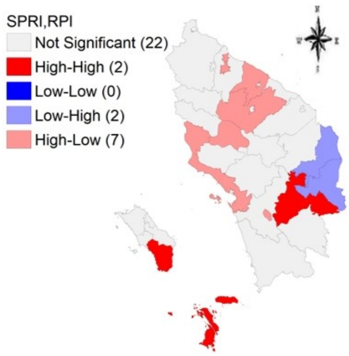

Figure 9. LISA cluster of SPRI.

Figure 10 indicates that 21 districts/cities do not show significant correlation in regional education development relative to poverty. Only one district, Padang Lawas Utara, is categorized as high-high, showing that this area has high education development and is surrounded by similarly high areas. No districts/cities fall into the low-low category. Three districts—Labuhanbatu, Labuhanbatu Selatan, and Nias Selatan—fall into the low-high category, where education development is low but surrounded by areas with high education development. The high-low category includes eight districts/cities—Medan, Padang Sidempuan, Siantar, Pakpak Bharat, Samosir, Serdang Bedagai, Simalungun, and Tapanuli Tengah—where education development is high but surrounded by areas with low education development. This result is consistent with the analyses by Wang et al. (2024) and Tipayalai and Subchavaroj (2024), which highlight disparities in education development in specific regions.

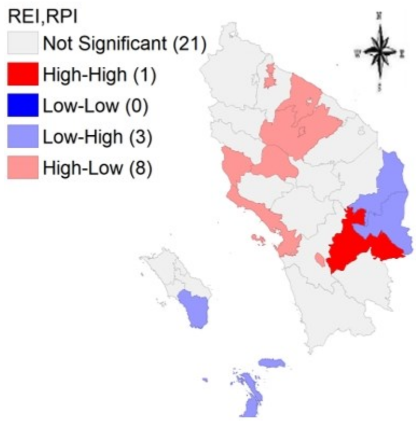

Figure 10. LISA cluster of REI.

Based on the spatial patterns of the three education development variables, certain districts and cities emerge as hotspots, particularly those in the high-high category. Conversely, cold spots are represented by areas in the low-high category. Labuhanbatu Selatan and Labuhanbatu are identified as priority locations for provincial government oversight in education policy. Labuhanbatu Selatan consistently shows low values across all variables (SFII, SPRI, REI) and is surrounded by regions with higher education development. Similarly, Labuhanbatu exhibits consistently low values for SPRI and REI, with its surrounding areas showing higher levels of education development. This observation aligns with data from the Central Statistics Agency (2024), which ranks these two districts fifth and sixth in terms of average RPI values, reflecting significant disparities in education development within North Sumatra Province.

The Local Indicator of Spatial Autocorrelation (LISA) analysis reveals distinct patterns across the three designated zones in North Sumatra. In the Eastern Coastal Region, which includes major cities like Medan, educational development often falls into the high-low category. This indicates that while educational facilities in centers such as Medan are well-developed, they are surrounded by less developed areas. This pattern is also evident in school participation rates and education indices in this region, highlighting a disparity between major centers and their surrounding areas. In the Bukit Barisan Mountains Region, encompassing areas such as Padang Lawas Utara and Samosir, a similar high-low pattern emerges. Padang Lawas Utara demonstrates high levels of school facilities development but is encircled by less developed regions. This pattern extends to school participation rates and education indices, suggesting that while educational development is robust in key centers, surrounding areas face ongoing challenges.

Conversely, in the Islands and Western Coastal Region, including areas like Nias Selatan, the educational development pattern reflects a high-high category. Nias Selatan, for instance, shows high levels of school facilities development and school participation rates, surrounded by areas with similarly high development. This indicates a consistent and high concentration of educational development in this region, contrasting sharply with the patterns observed in the Eastern Coastal and Bukit Barisan Mountains regions. Overall, the educational development patterns across the three zones reveal significant variations. The Eastern Coastal and Bukit Barisan

Mountains regions typically exhibit high-low patterns, where central areas have advanced educational development while surrounding regions lag behind. In contrast, the Islands and Western Coastal Region, particularly Nias Selatan, demonstrates a sustained high level of educational development. Addressing these regional disparities may require tailored approaches to enhance educational equity across each zone.

Figure 11 displays clustering levels across various districts and cities based on statistical significance. Dark green (p = 0.001) indicates areas with the highest likelihood of clustering, covering six districts and cities. This aligns with Kirk (2022), who states that areas with highly significant p-values show a high concentration of the studied variable. Medium green (p = 0.01) indicates moderate clustering, covering one district or city, while light green (p = 0.05) indicates smaller clustering, covering four districts and cities. These findings support mapping efforts that assist in identifying priority areas for resource allocation (Tipayalai and Subchavaroj, 2024).

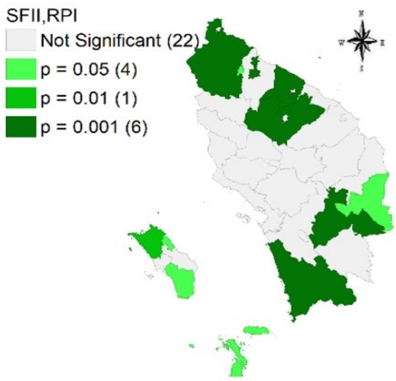

Figure 11. Significance of SFII.

Figure 12 shows the significance of the relationship between school participation rates and poverty. Areas in dark green (p = 0.001) indicate the highest likelihood of clustering. This map is consistent with Sánchez-Romero et al. (2022), who found that education significantly impacts poverty, especially in areas with high significance levels. Conversely, medium green (p = 0.01) and light green (p = 0.05) indicate lower significance levels with a smaller effect on poverty. This map provides a clear picture of the impact of education in local contexts and facilitates more targeted policy formulation.

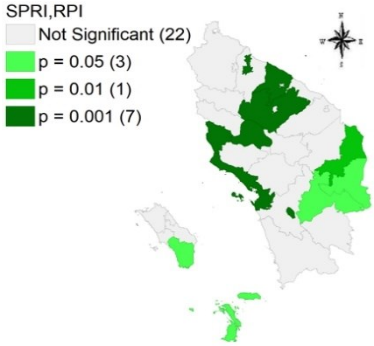

Figure 12. Significance of SPRI.

Figure 13 displays clustering probabilities based on different *p*-values. Dark green ($p = 0.001$) indicates areas with the highest likelihood of clustering, covering nine districts and cities. This aligns with Kirk (2022), who found that highly significant *p*-values often indicate strong clustering patterns. Medium green ($p = 0.01$) shows moderate clustering probability, with one district or city, while light green ($p = 0.05$) indicates smaller clustering probabilities, covering two districts and cities. This map is important for understanding potential clustering distributions and planning more focused interventions, as discussed in the literature (Smith and Johnson, 2021).

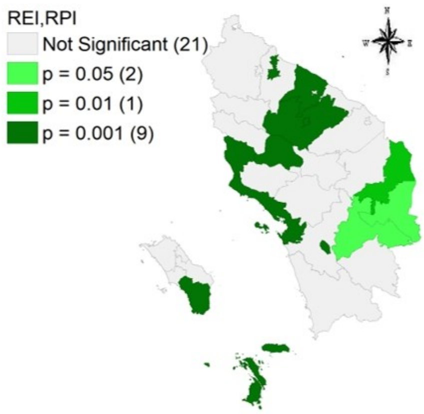

Figure 13. Significance of REI.

Based on the identification of significant clustering patterns using educational development indicators such as SFII (School Facilities Infrastructure Index), SPRI (School Participation Rate Index), and REI (Regional Education Index) across different zones in North Sumatra, the findings are as follows: Firstly, in the East Coast Zone, which includes Medan, Deliserdang, and Serdang Bedagai, significant clustering is observed with $p = 0.001$, indicating a high concentration of relevant educational variables. This area also shows a significant relationship between school participation rates and poverty, with a greater impact on reducing poverty. The strong clustering patterns in this zone reflect the need for focused educational interventions to optimize socioeconomic outcomes.

Secondly, the Bukit Barisan Mountains Zone, encompassing areas such as Padang Lawas Utara and Tapanuli Selatan, also exhibits significant clustering with $p = 0.001$ in several districts and cities, indicating a high concentration of educational indicators. The relationship between school participation and poverty in this zone is also this zone is also significant, suggesting that improvements in education can have a substantial impact on poverty reduction. The high clustering probability in this area highlights the need for targeted attention in educational resource planning and allocation. Thirdly, in the Islands and West Coast Zone, which includes regions like Nias and Padang Lawas, significant clustering with $p = 0.001$ is less frequent. Although there are some areas with significant relationships between education and poverty, the impact may not be as pronounced as in other zones. The high clustering probability in this zone still indicates important patterns related to educational indicators, requiring a strategic approach to educational interventions to improve learning outcomes and social well-being. This analysis underscores the need for differentiated approaches in planning educational interventions across each zone, based on the clustering significance and probabilities identified. This will assist in more effectively allocating resources and designing policies tailored to the specific needs of each zone.

Spatial analysis in the context of educational development often highlights the uneven distribution of educational facilities and its impact on educational outcomes across regions. McGranahan and Beale (2002) examined the role of education and information technology in rural revitalization, while Chen et al. (2024) explored the spatial distribution of educational facilities and educational attainment in the U.S. Lu and Wong (2008) discussed spatial analysis of school facilities and educational attainment in urban areas and how this analysis can be used to evaluate distribution patterns. Vidyattama et al. (2019) highlighted spatial inequalities in the distribution of educational resources, while Arbia and Baltagi (2009) provided guidance on using spatial econometrics in educational research. Grothe et al. (1996) analyzed the spatial patterns of educational infrastructure and its implications for urban planning.

5. Discussion

5.1. Spatial distribution patterns of educational development in districts/cities in North Sumatra

Despite the uniform allocation of education budgets, set a minimum of 20% per region (regency/city), significant disparities in educational infrastructure development remain evident across North Sumatra. Research by Rustiadi and Pravitasari (2021) underscores that equitable budget distribution does not necessarily translate into uniform improvements in educational quality. This disparity is reflected in the educational development index data for regencies and cities in North Sumatra from 2019 to 2022, revealing ongoing imbalances despite equal budget allocations.

5.1.1. East coast zone

In the East Coast Zone, encompassing Medan, Deliserdang, and Serdang Bedagai, disparities in educational infrastructure development persist despite uniform budget allocations. The School Facilities Infrastructure Index (SFII) indicates that several areas within this zone continue to struggle with low levels of infrastructure development, which aligns with the findings of Wiratama et al. (2023). Their research highlights that equitable budget distribution alone does not ensure uniform development of educational facilities. The Regional Education Index (REI) further reflects this issue, showing deficiencies in education quality in some regions despite improvements in infrastructure.

Conversely, the School Participation Rate Index (SPRI) for the East Coast Zone shows relatively better results, suggesting some progress in student involvement. However, the ongoing low levels of infrastructure development in specific areas point to the need for targeted improvements to sustain and enhance educational participation. The strong clustering patterns observed in this zone emphasize the importance of focused interventions to address infrastructural gaps and optimize the socioeconomic benefits of educational development.

5.1.2. Bukit Barisan mountains zone

The Bukit Barisan Mountains Zone, which includes areas such as Padang Lawas Utara and Tapanuli Selatan, exhibits significant gaps in educational infrastructure development. The SFII data reveals low levels of infrastructure development in several regions, indicating an imbalance despite consistent budget allocations. This disparity is reflected in the Regional Education Index (REI), which shows uneven educational quality across the zone. According to Tyas et al. (2024), factors such as teaching quality and inadequate facilities contribute to lower education indices, revealing challenges that extend beyond mere infrastructure improvements.

Despite these challenges, the School Participation Rate Index (SPRI) shows relatively better participation rates in this zone. This suggests that while school participation has improved, it does not fully align with the quality of educational facilities and overall infrastructure development. The high clustering probability observed in this zone highlights the need for targeted educational resource planning and intervention strategies to address both infrastructure and quality disparities effectively.

5.1.3. Islands and West Coast Zone

In the Islands and West Coast Zone, including regions such as Nias and Padang Lawas, the distribution of educational infrastructure shows less frequent significant clustering compared to other zones. The SFII data indicates that while some progress has been made in infrastructure development, many regions still lag behind. The Regional Education Index (REI) reveals ongoing disparities in educational quality, with some areas continuing to show low education indices despite infrastructure enhancements. This highlights a persistent gap between infrastructural advancements and actual educational outcomes.

The School Participation Rate Index (SPRI) for the Islands and West Coast Zone shows slightly better results, indicating improvements in school participation rates, although not uniformly across the zone. The high clustering probability in certain areas underscores the need for a strategic approach to educational interventions. Addressing both infrastructure deficits and educational quality will be crucial for achieving more equitable and effective educational development in this zone.

5.2. Spatial autocorrelation of education development in districts/cities of North Sumatra

Educational development in North Sumatra shows significant regional variations, influenced by different geographical and social factors. To understand these dynamics, spatial autocorrelation analysis was conducted using three main indicators: School Facilities and Infrastructure Index (SFII), School Participation Rate (SPRI), and Regional Education Index (REI). These indicators help evaluate the relationship between educational infrastructure development and education quality across various zones.

5.2.1. Eastern Coastal Region

In the Eastern Coastal Region of North Sumatra, which includes major cities such as Medan and Tanjungbalai, spatial autocorrelation analysis reveals that the School Facilities and Infrastructure Index (SFII) exhibits positive spatial autocorrelation. This means that areas with good educational facilities tend to influence their surrounding regions similarly, creating significant infrastructure development clusters. This finding is supported by research by Pravitasari et al. (2015) and Anselin (1995), which indicates that growth centers with good educational facilities can attract investments and strengthen regional development patterns in surrounding areas.

However, despite the relatively good infrastructure development in this region, the Regional Education Index (REI) shows negative spatial autocorrelation. This suggests that improvements in infrastructure are not accompanied by a corresponding increase in education quality. This disparity may be due to the education system's inability to leverage existing facilities to enhance educational quality and student learning outcomes. Tipayalai and Subchavaroj (2024) highlight that infrastructure development often does not correlate with improvements in education quality or programs that encourage higher school participation. Additionally, the School Participation Rate Index (SPRI) in the Eastern Coastal Region also shows negative spatial autocorrelation. This indicates that despite the development of educational facilities, student participation does not increase proportionally. This issue may be due to a lack of programs supporting participation or a mismatch between existing facilities and student needs. This imbalance reflects challenges in improving student participation in regions with good educational infrastructure.

5.2.2. Bukit Barisan mountain region

In the Bukit Barisan Mountain Region, which includes areas such as Padang Lawas Utara and Tapanuli, the analysis shows that the School Facilities and Infrastructure Index (SFII) has positive spatial autocorrelation. This means that improvements in educational infrastructure in one area tend to affect neighboring areas similarly, creating clusters of infrastructure development. Research by Wang et al. (2024) and Vidyattama et al. (2019) confirms that infrastructure improvements often have a positive effect on surrounding areas.

However, despite infrastructure improvements, the School Participation Rate Index (SPRI) in this region shows negative spatial autocorrelation. This means that although some areas have good facilities, student participation does not increase uniformly. This may be due to a lack of supportive educational programs or other local factors affecting student engagement. Chen et al. (2024) emphasize the importance of educational policies and human resource development to support increased participation and academic achievement. Additionally, the Regional Education Index (REI) in this region also shows negative spatial autocorrelation, indicating that although educational infrastructure has been improved, the overall quality of education has not increased uniformly. This may be due to imbalances in the implementation of educational policies and quality development across the region.

5.2.3. Islands and Western Coastal Region

In the Islands and Western Coastal Region, which includes areas such as the Nias Islands, the analysis shows that the School Facilities and Infrastructure Index (SFII) exhibits positive spatial autocorrelation. This means that improvements in educational facilities in one area tend to impact surrounding regions similarly, creating significant infrastructure development clusters.

However, the School Participation Rate Index (SPRI) in this region shows negative spatial autocorrelation, indicating that despite the development of educational infrastructure, student participation does not increase proportionally. Tipayalai and Subchavaroj (2024) suggest that physical development is not always followed by improvements in education quality or programs that support student participation.

Local factors such as educational accessibility, teaching quality, and social factors can significantly impact student participation rates. Additionally, the Regional Education Index (REI) in the Islands and Western Coastal Region also shows negative spatial autocorrelation. This indicates that despite adequate facilities in some areas, improvements in education quality and accessibility are not yet evenly distributed. This reflects challenges in aligning infrastructure development with educational policy improvements and quality development in this region.

Spatial autocorrelation analysis in North Sumatra reveals imbalances between educational infrastructure development and improvements in education quality and student participation. In the Eastern Coastal Region, although infrastructure is good, education quality has not increased uniformly. In the Bukit Barisan Mountain Region, infrastructure improvements have not been matched by increased student participation. In the Islands and Western Coastal Region, despite infrastructure advancements, student participation remains a challenge. Each zone in North Sumatra faces unique challenges that require tailored approaches to ensure that physical infrastructure development effectively supports improvements in education quality and student participation.

5.3. Priority locations for education development policies in districts/cities of North Sumatra

Labuhan Batu and Labuhan Batu Selatan, which are dominated by the palm oil plantation industry, face significant challenges in education development, making them priority locations for intervention. The limitations in educational facilities and infrastructure in these areas are evident, with higher budget allocations for the plantation sector rather than for education. This results in poor educational facilities, affecting the effectiveness of learning and student participation (Central Statistics Agency, 2022; World Bank, 2021). Additionally, school participation rates are low, particularly among children from low-income families who prefer to work in the plantation sector for immediate income rather than pursuing formal education (Suhartini et al., 2018).

The Regional Educational Index (REI) also reveals significant disparities. Although Labuhan Batu and Labuhanbatu Selatan make substantial contributions to North Sumatra's Gross Regional Domestic Product (GRDP), the economic benefits from the plantation sector are often uneven, benefiting large companies and landowners more than local workers. This results in low access and quality of education for the local population, exacerbating poverty and slowing social mobility (McKay and Thorbecke, 2015). High poverty levels in these areas hinder access to education, with many families struggling to finance their children's education and opting for immediate employment to meet daily needs (Central Statistics Agency, 2022). Dependence on low-wage plantation work also affects families' decisions to invest in their children's education, as inadequate and unstable income reduces their ability to support long-term educational investments (Harrison and Scaramozzino, 2020). The quality of teaching and curriculum in these regions may be affected by insufficient investment, resulting in potentially inadequate teaching quality and curriculum relevance (Hill, 2014). Accessibility to education, including distance to schools and availability of transportation, is also an issue, especially in large and remote areas (World Bank, 2021). Furthermore, health and nutrition issues affect children's ability to learn, with high school absenteeism and poor academic performance resulting from poor health conditions (Central Statistics Agency, 2022). Social and cultural factors, such as norms that prioritize work over education, also influence schooling decisions, adding complexity to the challenges faced (Harrison and Scaramozzino, 2020).

5.4. Policy implications from educational discussions in North Sumatra

Despite uniform budget allocation for education in North Sumatra, disparities in educational infrastructure development reveal the need for a more targeted and data-driven policy approach. Research indicates that even with equal budget distribution, significant differences in educational quality persist (Pravitasari et al., 2015). To address this issue, policies should involve more adaptive budget planning tailored to local needs. Regular, in-depth evaluations are necessary to ensure that investments in educational infrastructure effectively enhance educational quality. Al-Samarrai et al. (2019) emphasize the importance of resource allocation that responds to specific local needs to achieve equitable educational outcomes.

In various geographic zones, such as the East Coast Zone and the Bukit Barisan Mountains Zone, there are discrepancies in educational quality despite improvements in infrastructure. This suggests that physical development alone is insufficient to boost educational quality (Wiratama et al., 2023). The policy implication is that there needs to be an integration of infrastructure development with comprehensive educational quality enhancement efforts. This approach should include teacher training, curriculum development, and education quality improvement programs tailored to local contexts (Hanushek and Woessmann, 2010). Integrating these elements is crucial to ensure that improved educational infrastructure effectively supports educational quality enhancement.

Furthermore, the analysis indicates that in some regions, improvements in infrastructure have not led to increased student participation (Pravitasari et al., 2021). This highlights the need to address other factors such as student motivation and support in educational policies. To enhance student participation, policies should include strategies for providing scholarships, family support, and increased accessibility to education (Febriaty, 2018). Programs addressing social issues like poverty and work culture are also vital for supporting equitable student participation (Grothe et al., 1996). Therefore, educational policies should incorporate strategies to tackle school absenteeism and health and nutrition issues that contribute to educational success.

The findings from this research underscore the need for more comprehensive and responsive educational policies that address specific regional challenges. An integrated approach, based on local data and addressing multifaceted needs, will be more effective in achieving equitable improvements in educational development across North Sumatra (Gertler et al., 2012). Policies that combine infrastructure development, quality education improvement, and student participation support will create a greater and more sustainable impact on the education system.

6. Conclusion

The spatial distribution of educational infrastructure development in North Sumatra reveals notable disparities across regions. Specifically, there are 9 districts with low school participation rate index (SPRI), 11 districts with low school facilities and infrastructure index (SFII), and 11 districts with low regional education index (REI). The average results of spatial autocorrelation analysis indicate that the development of SPRI, SFII, and REI exhibits negative spatial autocorrelation, indicating poor connectivity and collaboration in educational services between neighboring regions, which causes educational inequality.

These findings underscore the need for targeted intervention in regions that exhibit significant disparities. The negative spatial autocorrelation indicates that the distribution of educational resources and opportunities is uneven, with certain areas falling behind in educational development. This is consistent with international research that highlights how disparities in educational infrastructure can perpetuate social inequality and hinder overall development (Ghosh, 2010; Malczewski and Jackson, 2000).

As identified, Labuhan Batu Selatan and Labuhan Batu districts are critical areas that require focused attention from the provincial government. Prioritizing these districts for educational development policies will be crucial in addressing the uneven allocation of educational resources. Implementing effective policies and ensuring the strategic use of the minimum 20% education budget will be essential in mitigating these disparities and fostering a more equitable educational environment. This approach aligns with the findings of global studies which emphasize the importance of targeted investments in underdeveloped regions to reduce educational inequality and enhance overall human development (Glewwe and Muralidharan, 2015; Wicaksono and Aliem, 2022).

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