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Integration of Sentinel Imagery and Geographic Information System for Analysing Spatial Distribution of Senior and Vocational High School Education Facilities in West Bandung Regency, Indonesia

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Abstract: Disparity in the distribution of educational facilities in developing regions is an issue to achieve equity in access to education. For example, access to senior high school (SMA) and vocational high school (SMK) has remained unequal across different sub-districts within West Bandung Regency of Indonesia and will pose a problem in attaining 12 years of compulsory education. In this research, the methods of remote sensing and GIS were integrated for analyzing the spatial distribution and accessibility to senior and vocational high school. Using data from Google Maps in 2021 and Sentinel imagery, the ANN and kernel density methods have been used in identifying the distribution pattern, while conducting buffer analysis to map coverages. In fact, there is a clustered distribution in sub-districts like Lembang, Padalarang, and Cipongkor, with isolated sub-districts like Parongpong and Rongga showing huge accessibility gaps where settlement exists over 7.5 km away from the school. These findings raise awareness of the pressing need for concerted infrastructure planning and investment at sub-national levels in pursuit of equal opportunities that are imperative for sustainable development and social equity in developing countries.

Keyword: Average Nearest Neighbour, Sentinel-2 Imagery, & Spatial Distribution of Educational Infrastructure.

INTRODUCTION

The uneven regional development in West Java Province, Indonesia has negative impacts on many aspects, one of which is the quality of education (Irawan, 2024). The disparity in access to education affects the quality of education in West Java Province (Asih, 2023). West Bandung Regency, as one of the region located in West Java Province, Indonesia, faces challenges in ensuring equitable access to senior high school (SMA) and vocational senior high school (SMK) education due to its diverse geographical conditions and uneven population distribution. For example, certain sub-districts, particularly Parongpong and Rongga, exhibit longer travel distances to schools, posing potential barriers to educational attainment for students in these areas. The uneven distribution of educational facilities in West Bandung Regency highlights the pressing need for strategic planning and targeted development to address these disparities and ensure equitable access to high-quality education for all residents. Addressing the accessibility gaps and ensuring that educational opportunities are available to everyone, regardless of their location, is crucial for promoting sustainable development and social equity within the region (Murad et al., 2020).

Studying the spatial distribution of educational facilities, especially SMA and SMK, is crucial for ensuring equitable access to high-quality education for all students, regardless of their location. The distribution of educational infrastructure can significantly impact student outcomes, as it determines the proximity and accessibility of schools to residential areas (Murad et al., 2020). By analysing the spatial patterns of educational facilities, policymakers and planners can identify underserved regions and prioritise the establishment of new schools or the expansion of existing ones. This can help address issues of educational inequality, improve overall educational attainment, and contribute to the sustainable development of communities (Sharma & Patil, 2021).

Remote sensing and GIS can be applied for capturing the land use/cover (Pradana et al, 2023; Wardana & Jumadi, 2024) and understanding geographical fenomena related education (Dewa et al., 2023; Ningsih et al., 2024). Remote sensing is the process of gathering information about objects or areas from a distance, typically using aircraft or satellites equipped with specialized sensors. These sensors detect and record various forms of electromagnetic radiation reflected or emitted by the Earth's surface. This data is then processed and analyzed to understand different features and phenomena on Earth (Awange & Kiema, 2018). In the context of mapping built-up areas and schools to analyze areas needing improved educational facilities, remote sensing offers several advantages such as for mapping built-up areas, mapping schools, and Analyzing Areas Needing Improvement. High-resolution satellite imagery can effectively differentiate between built-up areas (representing concentrations of population) and other land cover types (Hadibasyir et al., 2023). This information is crucial for understanding population distribution and density, which directly relates to the demand for educational services.

In addition, the Average Nearest Neighbor (ANN) analysis in GIS is a crucial tool for understanding the spatial distribution of schools. It calculates the average distance between each school and its closest neighboring school, then compares this average to a hypothetical random distribution. This comparison reveals whether schools are clustered, dispersed, or randomly distributed across the study area. This information is valuable for educational planners, as it can highlight areas with either over-concentration or insufficient coverage of schools, informing decisions regarding resource allocation, new school construction, and school sub-districts boundaries. By quantifying the spatial arrangement of schools, the Average Nearest Neighbor analysis provides objective insights into accessibility and equity in education provision (Ghodousi et al., 2020).

Remote sensing data of such as Sentinel imagery data and ANN could be utilised to map educational disparity as well as to propose areas requiring additional SMA/SMK. By overlaying school location data with land cover information from Sentinel imagery, policy

makers have been able to evaluate the proximity of settlements to SMA/SMK facilities and identify regions that require additional educational infrastructure. This integrated approach has proven effective in supporting data-driven decision-making for the equitable provision of high-level education, contributing to the sustainable development of communities. Based on the aforementioned background, this research aims to a) to analyse the spatial distribution of SMA/SMK, b) to analyse the level of coverage of SMA/SMK, c) to map areas that require additional SMA/SMK in West Bandung Regency, West Java Province, Indonesia.

METHOD

Study Area

The research was conducted in West Bandung Regency, which is an expansion of Bandung Regency, West Java Province. The northern part of West Bandung Regency borders Purwakarta Regency, the western part borders Cianjur Regency, the southern part borders Bandung Regency, and the eastern part borders Cimahi City. This regency consists of 16 sub-districts with the regency center in Ngrampah sub-district. This area with an altitude of 789.559 meters above sea level. The total area of West Bandung Regency is 1.305,77 km^2. The largest sub-district in West Bandung Regency is Gununghalu sub-district, while the smallest sub-district is Batujajar sub-district.

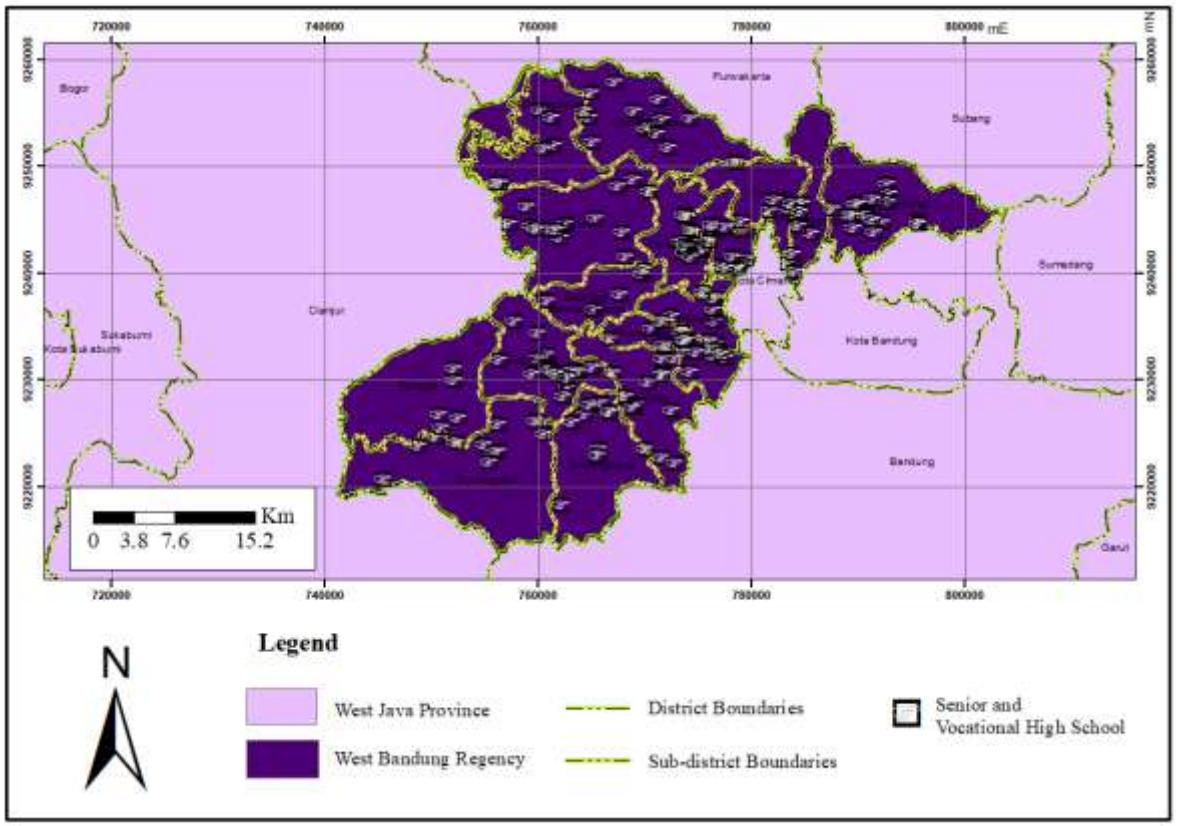

Figure 1. Research Location Map

Data Used

This research uses administrative boundary data from West Java Province, specifically West Bandung Regency, coordinate data of public and private senior high schools and vocational high schools in West Bandung Regency, and Sentinel land cover imagery from 2023. The coordinates of SMA and SMK were obtained from Google Maps, which were then used to analyze the distribution pattern using Nearest Neighbor Analysis. After determining

the distribution pattern, density analysis was performed using the kernel density algorithm, which is visualized using different color levels.

The mapping of areas for the equitable distribution of SMA and SMK was carried out based on the coverage range of SMA and SMK and the distribution of built-up areas in West Bandung Regency. The analysis of the coverage area of educational facilities was carried out using a 2.5 km buffer. The distribution of built-up areas was extracted from the 2023 Sentinel land cover data at a spatial resolution of 10 m. Then, a map overlay was performed between the SMA/SMK coverage level results and the built-up areas of all sub-districts in West Bandung Regency. The results of the map overlay can be used to determine the difference in distance between settlements and SMA/SMK in each sub-district in West Bandung Regency.

Data Processing and Analysis

The availability of school facilities requires consideration of the radius of the service area related to the basic infrastructure needs that must be met. The mapping of senior high schools and vocational high schools in West Bandung Regency is carried out spatially because it cannot be identified and analyzed statistically. The need for SMA/SMK facilities in West Bandung Regency requires mapping data on the coverage range of SMA/SMK with the amount of built-up land. The distribution of built-up land is extracted according to the 2023 Sentinel Land Cover data, which has a resolution of 10 m. Location coverage analysis is carried out by taking the coordinate data of SMA/SMK based on My Maps and the buffer process with intervals of 2.5 km - 10 km.

The processed data is overlaid to obtain variations in the distance between schools and community settlements in each sub-district, the distribution pattern of SMA/SMK in West Bandung Regency, and the priority planning for school needs in West Bandung Regency. The Nearest Neighbor Analysis method is used to describe the distribution pattern of the points of the region's locations, considering distance, the number of location points, and the area. Kernel Density Analysis is used to map and analyze the spatial distribution of SMA/SMK schools in West Bandung Regency. The Kernel Density Analysis method makes it easier to understand the distribution pattern of SMA/SMK and identify areas with high or low concentrations of educational facilities scattered in West Bandung Regency. The Buffering analysis method results in the area of the SMA/SMK coverage zone against the number of settlements, used to analyze the coverage range of SMA/SMK and community settlements in West Bandung Regency from the school location points with the determination of intervals of 0 - 2.50 km; 2.51 - 5.0 km; 5.01 - 7.50 km; 7.51 - 10 km; and >10 km.

Educational facilities are used as a support for social infrastructure in a region. Equitable provision of educational facilities and strategic locations will reduce inequalities between regions. Mapping the final coverage of senior and vocational high school (SMA/SMK) facilities in West Bandung Regency is useful for analyzing the priority scale of regions in each sub-district in West Bandung Regency that require SMA/SMK facilities adjusted to the number of settlements. The following research flow chart is presented in Figure 2.

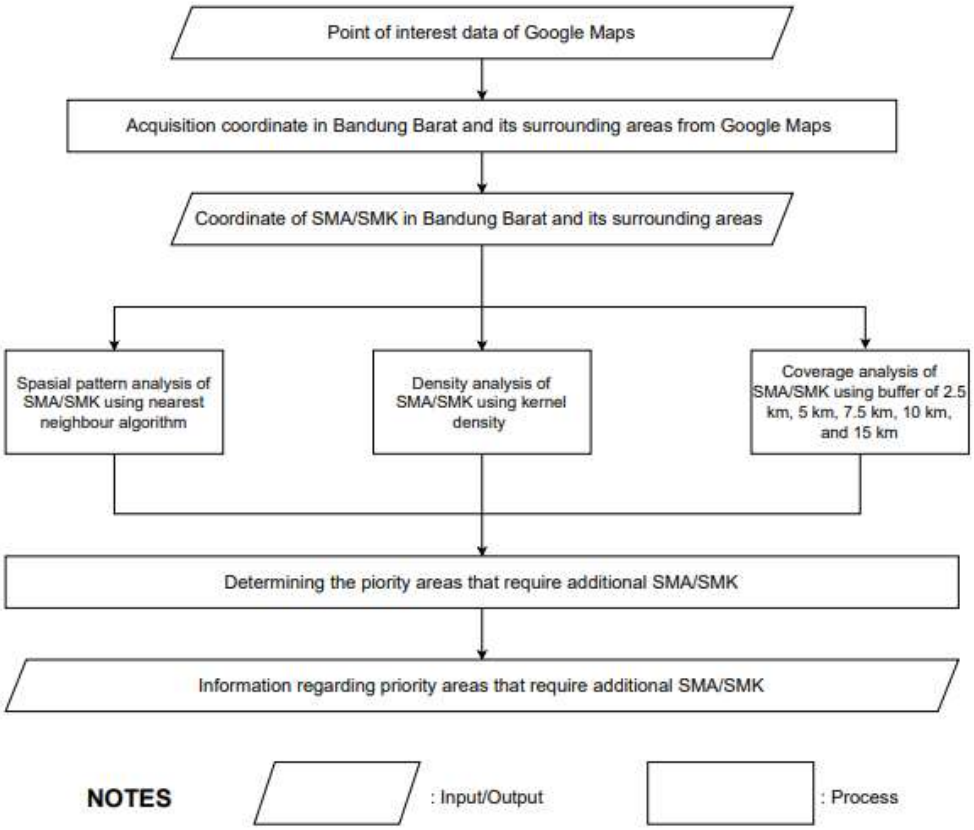

Figure 2. Research Flow Chart

Several strategies were used in this study to ensure the validity of methods and reduce biases in the mapping process using Google Maps data. First, the accuracy of school location data was cross-verified against official government records and satellite imagery to reduce potential errors in geolocation. Second, ground truthing was conducted on a sample of schools to confirm their exact locations and operational status. Thirdly, the data consistency was ensured through the use of a single coordinate system and spatial resolution in performing overlay and buffer analysis. The anomalies that were excluded included outlier points outside of the study area and those in non-residential zones to avoid distortion in the spatial analysis of the data. These measures combined not only build confidence in the results but also ensured a sound process leading to the identification of gaps in the accessibility of educational facilities.

RESULTS AND DISCUSSION

Spatial Distribution of SMA/SMK

Both public and private senior high schools and vocational high schools are distributed across all sub-districts in West Bandung Regency. The distribution pattern of senior and vocational high school in West Bandung Regency was determined using Nearest Neighbor Analysis. This analysis explains the distribution pattern of points from a location using calculations that consider distance, the number of points, and the area of the region itself. The data processing results using ArcGIS software show that the distribution of public and private senior and vocational high school in West Bandung Regency with 172 location points falls into the clustered pattern category with a TI value of 0.698. The z-score value of -7.566 also proves that the clustered pattern is statistically significant at the 0.01 level. Most of the SMA and S senior and vocational high school in West Bandung Regency are located in sub-districts of Cipongkor, Cihampelas, Padalarang, Ngrampah, and Lembang. This can be caused by an increase in population, resulting in an increased need for educational facilities.

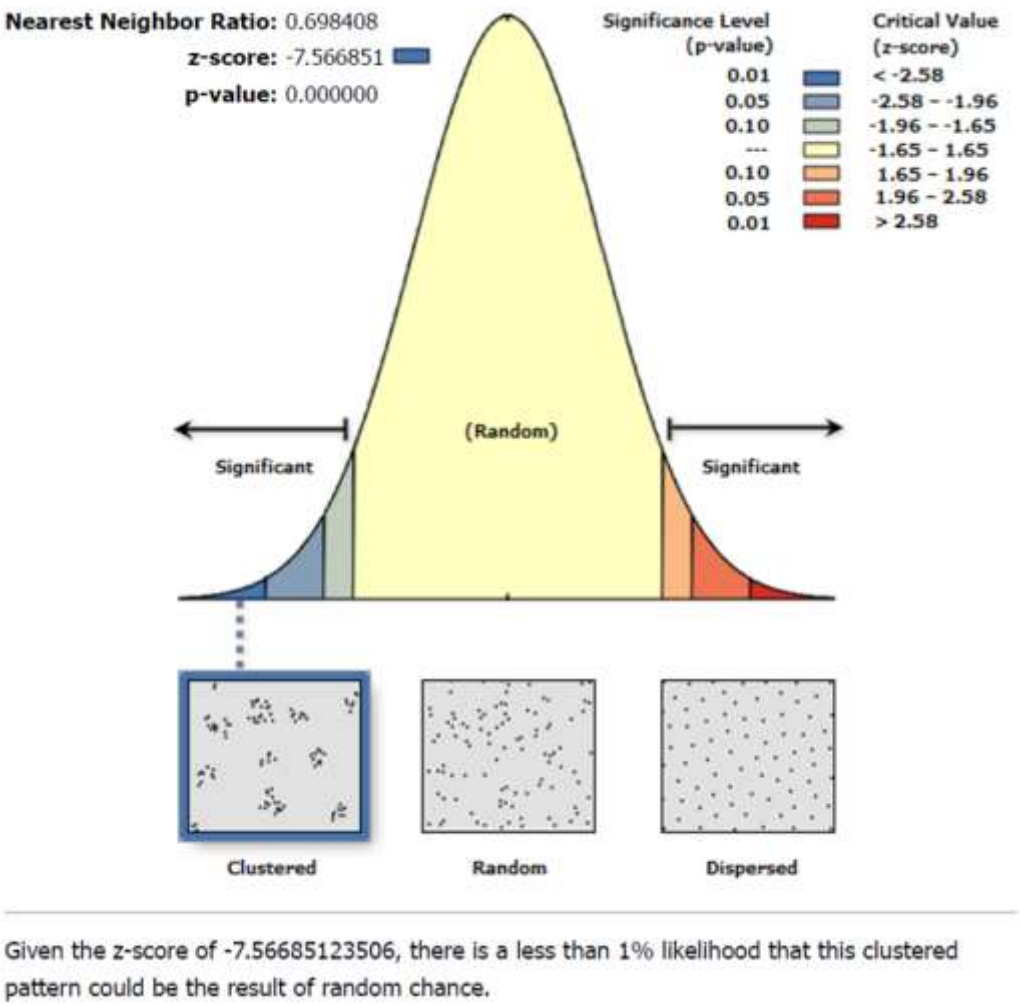

Figure 3. ANN Results

The visualization of the density of senior high schools and vocational high schools in West Bandung Regency is known using kernel density, which is depicted using different levels of color. Areas with darker colors are indicated to be the central locations of senior and vocational high school in West Bandung Regency. The areas with high density of senior and vocational high school in West Bandung Regency are scattered in several points, namely in sub-districts of Lembang, Padalarang, Ngrampah, Cihampelas, Batujajar, and Cipongkor. In these areas, the number of schools ranges from 0.375-0.619 schools per square kilometer. This is directly proportional to the high population in these sub-districts in West Bandung Regency. The high population must be balanced with the availability of public facilities as supporting infrastructure, including educational facilities.

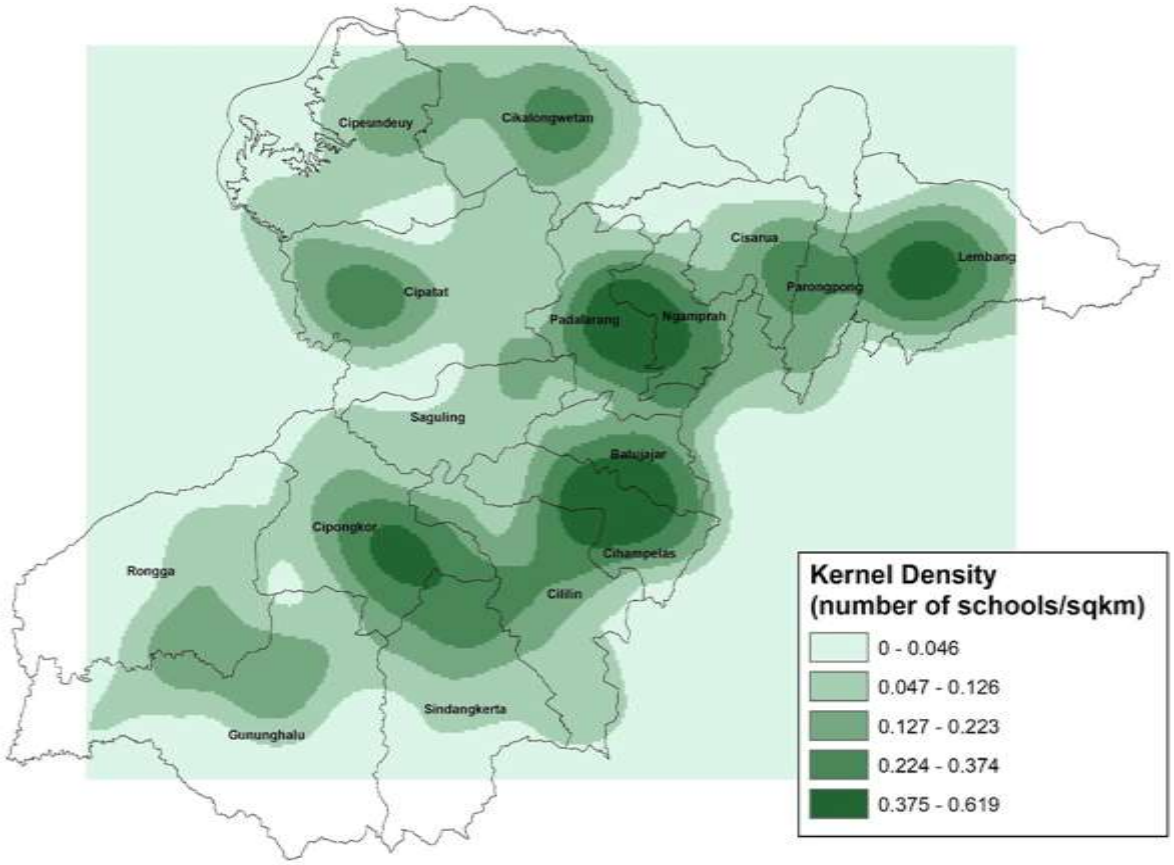

Figure 4. Kernel Density Results

Coverage Level of SMA/SMK

According to the buffer analysis map in West Bandung Regency, the region is classified into 5 distance ranges. The distance between senior and vocational high school and built-up areas is classified as 0 - 2.5 km; 2.51 - 5 km; 5.01 - 7.50 km; and 7.51 - 10 km. The distribution of senior and vocational high school points is already spread across all sub-districts, but in some sub-districts, the school coverage range is still too far from settlements. The dominant school coverage range of 0 - 2.50 km is in the eastern part of West Bandung Regency. This area includes sub-districts of Lembang, Ngamprah, Padalarang, Batujajar, Cililin, and Cikalongwetan. This is because the eastern part of West Bandung Regency is directly adjacent to the City of Bandung, so the built-up land conditions and supporting facilities are also more accessible.

According to the Regulation of the Ministry of Education and Culture of the Republic of Indonesia number 17 of 2017 concerning the Admission of New Students, regional governments are required to accept prospective students residing in the nearest zone radius, at least 90% of the total students. This regulation makes the planning of educational facilities closely related to location theory. The development of appropriate educational facilities can reach all residents in the region. The sub-districts in West Bandung Regency with the farthest coverage range of 5.01 - 7.5 km are Parongpong sub-district and Rongga sub-district. The influencing factors are due to the mountainous geographical conditions, which affect the difficulty of infrastructure access in these areas. Another factor is the low number of built-up land in Parongpong sub-district and Rongga sub-district, as well as the existing number of SMA/SMK in these areas is less than in other sub-districts. The following are the results of the buffer distance between SMA/SMK and residential areas in West Bandung Regency.

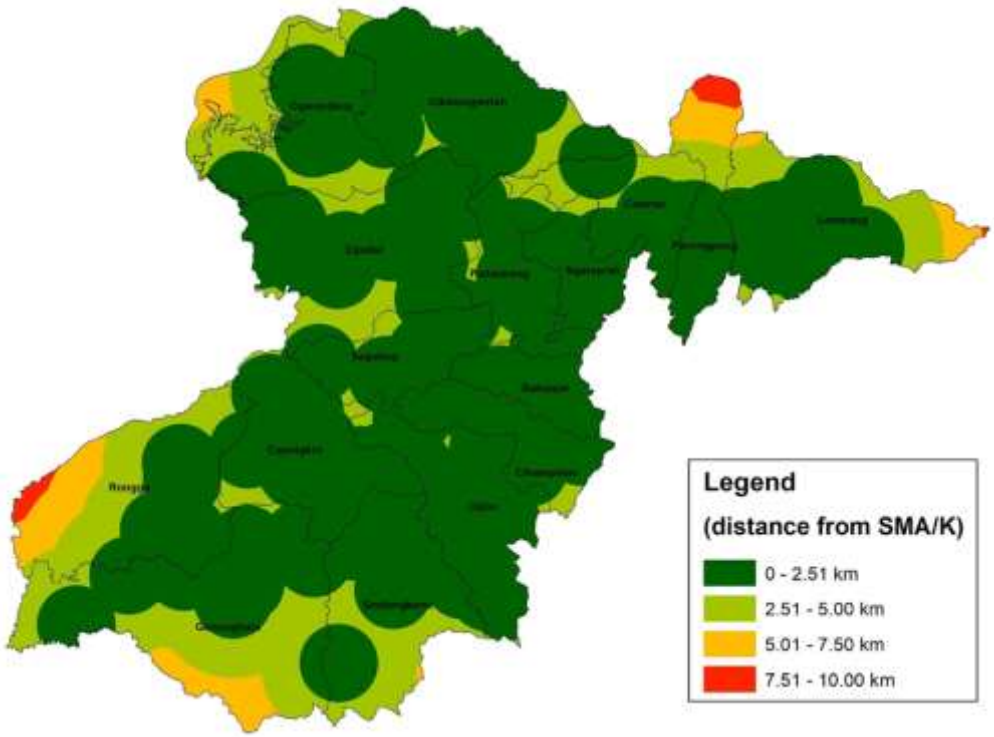

Figure 5. SMA Buffer Results

Areas Need Additional SMA/SMK in West Bandung Regency

To identify regions requiring additional vocational or senior high school for equitable secondary education distribution, an overlay analysis was conducted. This analysis combined supply factors, as represented by existing school accessibility (Figure 5), with demand factors, proxied by the extent of built-up land. The latter was derived from Sentinel imagery and visualized in Figure 6. The assumption is that built-up land correlates with population distribution.

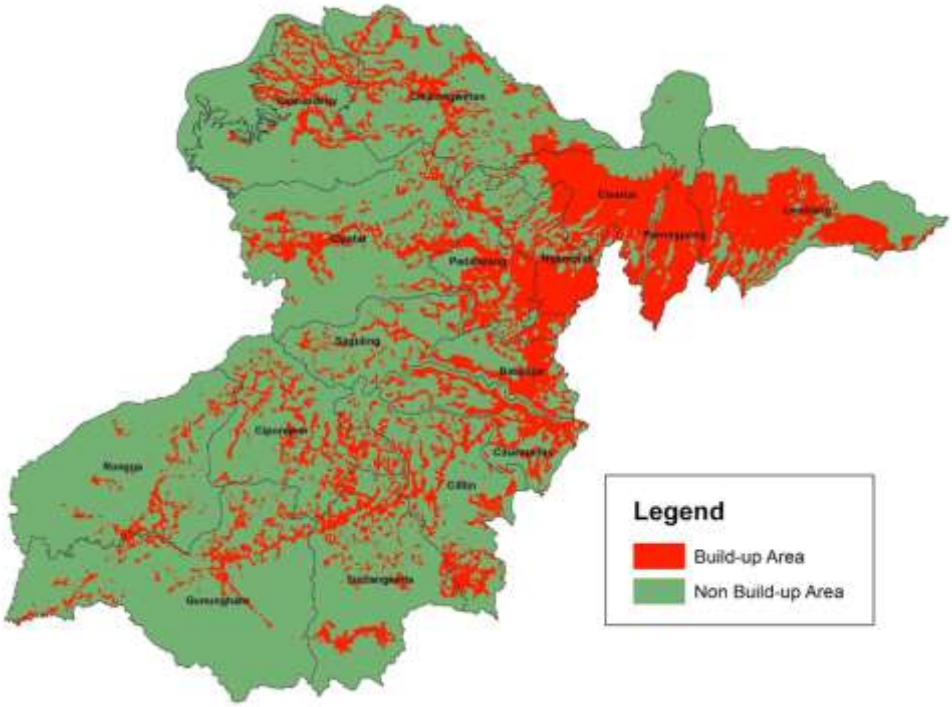

Figure 6. Land Cover Map

Table 1. Summary of Residential Distance to Senior and Vocational High Schools in Each Sub-district of West Bandung Regency

Sub-district	Residential extent from various distances to senior and vocational high schools					Extent of residential areas (ha)
	0-2.5 km	2.5-5 km	5-7.5 km	7.5-10 km	> 10 km	
Rongga	5,632.25	3,655.41	2,023.38	346.32		11,657.36
Gununghalu	8,657.29	5,762.25	1,494.24			15,913.78
Sindangkerta	6,714.77	2,672.85	42.10			9,429.71
Cililin	7,701.09	180.13				7,881.22
Cihampelas	4,279.50	252.67				4,532.17
Cipongkor	7,787.92	556.03				8,343.95
Batujajar	3,147.70	22.24				3,169.94
Saguling	4,532.51	11.98				4,544.49
Cipatat	10,364.60	1,811.36				12,175.96
Padalarang	4,809.07	416.61				5,225.68
Ngamprah	3,063.41	194.82				3,258.22
Parongpong	2,422.37	659.43	1,071.69	468.18		4,621.67
Lembang	6,690.70	2,561.99	724.10	17.90		9,994.69
Cisarua	3,975.67	1,285.03				5,260.70
Cikalongwetan	10,281.40	1,145.98				11,427.38
Cipeundeuy	6,122.61	4,013.06	560.76			10,696.43
Total (ha)	96,182.85	25,201.82	5,916.27	832.40	0.00	128,133.33

The results of the overlay analysis comparing vocational or high school coverage to built-up areas are tabulated in Table 1. To facilitate data analysis, the study classified the distance between homes and schools into five categories, with the shortest distance being within the 0-2.5 km range and the longest being greater than 10 km. Bere et al. (2008) and Nelson et al. (2008) conducted studies that determined the ideal walking distance for adolescent students to travel from their homes to school to be between 1.3 and 3 kilometers, while the optimal cycling distance was found to be between 4 and 8 kilometers. The results indicate that a substantial portion of settlements in West Bandung Regency, approximately 96,182.85 hectares, are located within a 5 km radius of a vocational or high school. This indicates that approximately 75% of settlements in West Bandung Regency have adequate access to vocational or senior high school facilities.

Proximity to school, as evidenced by research conducted by Ebinum, Akamagune, and Ugbong (2017), is a salient variable in parental decision-making regarding school selection, as well as a potential determinant of student academic outcomes and attendance. While the overall accessibility to vocational or senior high schools in West Bandung Regency is considered adequate, a significant area of 832.4 hectares falls within the 7.5-10 km distance category. This indicates a considerable distance between homes and schools in certain areas. Specifically, the sub-districts of Parongpong, Rongga, and Lembang have settlements that fall within this category. Further analysis reveals that the northern part of Parongpong sub-districts, encompassing 468.18 hectares, and Rongga sub-districts, with 346.32 hectares, require priority in future development of vocational or senior high schools due to the relatively long distances to existing educational facilities. Notably, no settlements were found to be situated more than 10 km away from a vocational or high school.

The findings bring forth significant policy implications, especially for recommendations in addressing educational inequality in the most remote areas. The clustered distribution of

senior and vocational high school within highly populated sub-districts like Lembang and Padalarang presents a stark contrast with the limited accessibility in mountainous regions such as Parongpong and Rongga, therefore underlines the necessity of focused government intervention and private sector investment to establish more schools in these less accessible areas. By improving access to education in these areas, policymakers will increase not only enrollment rates but also reduce travel burdens among students and create equal opportunities for all students within West Bandung Regency. This contributes toward greater social and economic development.

CONCLUSION

The spatial analysis techniques employed in this study revealed a clustered distribution pattern of senior and vocational high school across West Bandung Regency. Kernel density mapping indicated that these educational facilities were predominantly concentrated within the sub-districts of Lembang, Cikalongwetan, Padalarang, Ngamprah, Cihampelas, and Cipongkor. However, the sub-districts of Parongpong and Rongga were identified as areas where a significant proportion of settlements, spanning 468.8 hectares and 346.32 hectares respectively, were situated more than 7.5 kilometres away from the nearest senior and vocational high school. To address this unequal distribution of secondary education resources, these sub-districts should be prioritised for the establishment of new schools, whether through government or private sector initiatives.

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