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ZONING SCHOOLS BY PROXIMITY, RADIUS, OR NETWORK: SPATIAL METHOD PERFORMANCE AND ITS EQUITY IMPLICATIONS IN LANGSA CITY

ZONASI SEKOLAH BERBASIS KEDEKATAN, RADIUS, DAN JARINGAN: PERBANDINGAN KINERJA METODE SPASIAL DAN IMPLIKASI PEMERATAAN DI KOTA LANGSA

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ABSTRACT
The school zoning system used in Indonesia's New Student Admission (PPDB) is meant to equalise access to education, yet in Langsa City it is still drawn from administrative boundaries that say little about whether students can actually reach a school. This study compares three ways of delineating zones for public junior and senior high schools, judged by how well each covers residential areas: the Thiessen polygon, the buffer, and network analysis (service area). All three were built in a Geographic Information System, with a Model Builder workflow used to automate the mapping. Coverage varied markedly across methods. At the junior high level the Thiessen polygon reached the highest residential coverage at 98.21%, ahead of the service area at 79.63% and the buffer at 75.37%. At the senior high level the ranking changed: the buffer led with 88.50%, followed by the service area at 79.21% and the Thiessen polygon at 71.62%. The reversal shows that no single method is best everywhere; methods that account for the road network and travel distance describe accessibility more faithfully, while purely geometric partitions can mislead where schools are few and clustered. Automating the workflow in Model Builder made the analysis reproducible and transferable to other regions. Together the results offer a defensible, accessibility-based footing for designing fairer educational zones.
Keywords: *Buffer, Model Builder, Network Analysis, School Zoning, Thiessen Polygon*

ABSTRAK
Sistem zonasi dalam Penerimaan Peserta Didik Baru (PPDB) bertujuan mewujudkan pemerataan akses pendidikan. Namun, penerapannya di Kota Langsa masih mengacu pada batas administratif yang tidak mempertimbangkan aspek spasial keterjangkauan. Penelitian ini bertujuan membandingkan tiga metode zonasi fasilitas pendidikan negeri jenjang SMP dan SMA berdasarkan keterjangkauan terhadap permukiman, yaitu Thiessen Polygon, Buffer, dan Network Analysis (Service Area). Analisis dilakukan dengan bantuan Sistem Informasi Geografis (SIG), disertai perancangan Model Builder untuk mengotomatisasi proses pemetaan. Hasil penelitian menunjukkan cakupan permukiman bervariasi antar metode. Pada jenjang SMP, cakupan tertinggi diperoleh dari Thiessen Polygon (98,21%), diikuti Service Area (79,63%), dan Buffer (75,37%). Untuk SMA, Buffer memiliki cakupan tertinggi (88,50%), disusul Service Area (79,21%), dan Thiessen Polygon (71,62%). Perbedaan ini menunjukkan bahwa pendekatan spasial yang mempertimbangkan jaringan jalan dan waktu tempuh lebih akurat dalam merepresentasikan aksesibilitas. Selain itu, Model Builder terbukti efisien dalam mengotomatisasi analisis dan dapat direplikasi di wilayah lain. Penelitian ini memberikan dasar ilmiah bagi perumusan zonasi pendidikan berbasis keterjangkauan spasial yang lebih adil dan efektif.
Kata Kunci: *Buffer, Model Builder, Network Analysis, Thiessen Polygon, Zonasi Sekolah*

1. INTRODUCTION

Deciding where to place a public facility is one of the oldest concerns in spatial planning, because the position of a school, a clinic, or a market quietly decides who is served well and who is left at the margins.

Facility location theory gives this concern a formal language. It treats the siting of a limited number of service points as a problem of balancing the cost of travel against the share of the population that can be reached within an acceptable distance, as in the classic maximal covering location problem (Church and ReVelle, 1974). Accessibility, in this view, is not a fixed property of a single site but a relationship among the supply of facilities, the spatial distribution of demand, and the network that connects them (Hansen, 1959; Geurs and van Wee, 2004). When the facility is a school, the question carries an added weight of fairness: education is a public entitlement, so an uneven spatial distribution of schools translates almost directly into unequal opportunity (Talen and Anselin, 1998). For this reason the spatial modelling of access to educational facilities has grown into an active field, and recent Indonesian studies have applied location-allocation and network-based methods to test how well the existing pattern of schools actually serves the population it is meant to reach (Utami et al., 2022; Utami et al., 2023). The present study sits within this tradition, asking a deceptively simple question: which spatial method most faithfully represents the way students reach their schools, and what does the answer imply for how zones should be drawn.

The government's efforts to promote educational equity in Indonesia are regulated in Minister of Education and Culture Regulation No. 1 of 2021 concerning policies for the admission of new students. This policy stipulates that 50% of new student admissions for junior high schools and senior high schools will be accepted through a zoning system aimed at reducing the gap between favored and non-favored schools and ensuring equitable access to and quality of education across all regions (Nurjaningsih, 2021). One country that has implemented a school zoning system is Australia, which uses Thiessen polygons to divide zones based on school distribution (Vatresia et al., 2023). In Indonesia, school zoning is typically determined using buffer techniques and administrative boundaries (Utami et al., 2023).

The implementation of the zoning system in public schools in Langsa City is determined by one division based on administrative boundaries, in accordance with Langsa Mayor Regulation No. 22 of 2020 (Walikota Langsa, 2020) on guidelines for the admission of new students. The Redaksi team (2023) explains that the school zoning system in Langsa City for the 2023/2024 academic year has caused many problems, with many parents disappointed because their children were assigned to schools far from their homes. The lack of adequate public transportation makes the administrative boundary-based zoning system in Langsa City less relevant due to the varying shapes and sizes of administrative boundaries (Urfan & Ningrum, 2022). This situation will result in inconsistencies in the distance students must travel. The use of a zoning system based on administrative boundaries does not consider how far students must travel daily, which could ultimately lead to disparities in access to education (Awana, 2023).

Langsa City does not yet have a similar free public transportation service. As a result, many students drive private vehicles to school. However, according to Law Number 22 of 2009 concerning traffic and road transportation, students under the age of 17 are not legally allowed to drive motor vehicles. This situation underscores the importance of considering distance as a key factor in school zoning policies. When access to schools is influenced by the proximity of students' residences, the use of a zoning approach that prioritizes distance becomes more relevant (Utami et al., 2022). The distance requirements for accessing education are divided into absolute distance and relative distance. Absolute distance is the actual distance between two locations, measured in meters and kilometers. Relative distance, on the other hand, is the amount of time it takes to travel to a location, measured in terms of time and cost between two different objects. (Maulia, 2020).

Previous research conducted by Awana, (2023) compared network analysis (service area) and buffer methods to optimise the senior high school zoning system in Banda Aceh City, and concluded that a service area approach produced the most optimal zoning. That study, however, leaves two gaps that matter for a city such as Langsa. First, it evaluated only two methods; the Thiessen polygon, which underlies the Australian zoning model and operationalises the nearest-school principle directly, was never placed in the same comparison, so it remains unknown how a proximity-based allocation performs against radius-based and network-based methods under identical conditions. Second, no study has compared the methods at the junior and senior secondary levels simultaneously, even though the number of schools and their spatial spread differ sharply between the two levels and may favour different methods. The stakes here are practical rather than merely technical. Langsa has no public transport system to absorb long commutes, and students below the legal driving age cannot lawfully ride a motor vehicle to school, so a zoning rule that ignores actual travel distance does not simply lose accuracy: it reproduces inequity in who can realistically reach a school at all. A further limitation of earlier work is its reliance on manual, step-by-step geoprocessing. The Model Builder environment can automate the entire workflow, which makes the analysis faster, reproducible, and transferable to other local governments, and it has already proven useful in adjacent spatial tasks such as land use modelling (Nabila, 2023).

Based on the above, this study aims to compare the buffer, network analysis, and Thiessen polygon methods to be used for zoning Junior High Schools and Senior High Schools in Langsa City so that school services can be accessed on foot without relying on private vehicles. The design of the Model Builder will facilitate the replication and adaptation of the model by other local governments or researchers in different regions.

2. DATA AND METHODS

2.1 Location and Time Research

This research was carried out in Langsa City (figure 1), a coastal city in the eastern part of Aceh Province, Indonesia, covering roughly 224 square kilometres across five districts, with its public secondary schools concentrated near the urban core. The study began in September 2024 and drew on a review of scientific articles, relevant reports, and earlier theses to frame the problem. All data used in the analysis were secondary.

Figure 1. Study location map: Langsa City, Aceh Province, Indonesia

2.2 Types and Data Sources

The data collection technique used in this study was secondary data collection, or data collected indirectly from the field. The data obtained was sourced from the official websites of the Geospatial Information Agency and the Public Works and Public Housing Agency of Langsa City. The data collected from Geospatial Information Agency includes administrative boundary data for the City of Langsa and the distribution of educational facilities for junior high schools and senior high schools. Additionally, from the

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Public Works and Public Housing Agency of Langsa City, the data collected includes road network data and settlement data for the City of Langsa and its surrounding areas.

In total the analysis drew on four secondary datasets, each with a defined role. The administrative boundary of Langsa City, obtained from the Geospatial Information Agency (BIG), delimited the study area. The point locations of all public junior and senior high schools, also from BIG, served as the facilities to be zoned. The road network, provided by the Public Works and Public Housing Agency (PUPR) of Langsa City, supplied the travel impedance for the service area computation. Settlement data for Langsa City and its immediate surroundings defined the demand against which the coverage of each method was measured. Because the analysis operates in distance rather than in administrative units, the settlement and road data were deliberately extended beyond the city boundary.

2.3 Data Analysis Techniques

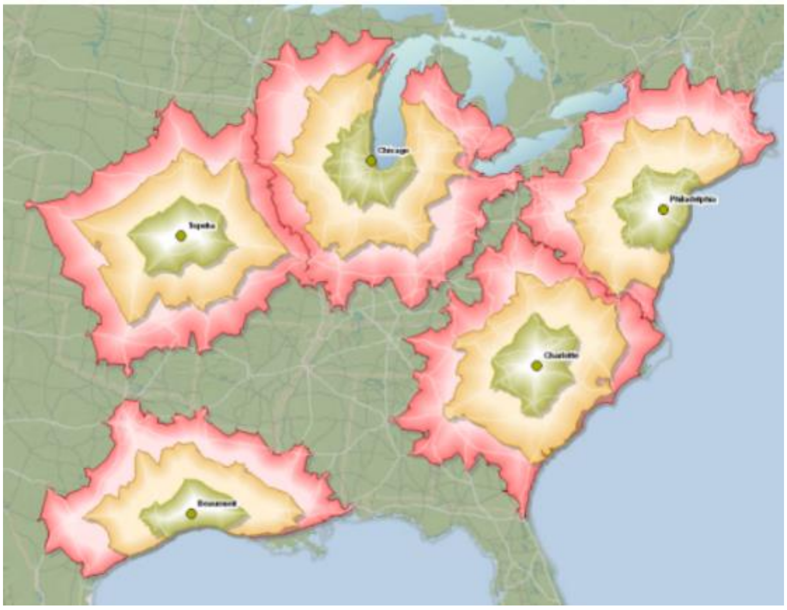
The analysis will be conducted using Geographic Information Systems (GIS), which is a method used to analyze geographic data. The term “geographic” refers to spatial aspects that emphasize issues related to the Earth's two- or three-dimensional surface. (Alviana et al., 2023). GIS's ability to process geographic data consists of four stages: (a) input, (b) output, (c) data management, (d) data analysis and manipulation. (Pharahasta 2005 dalam Alviana et al., 2023).

The data obtained will be processed in ArcGIS software in stages, and the results will be interpreted using comparative analysis and descriptive analysis. The school zoning pattern analysis will be analyzed using quantitative analysis methods, namely quantitative descriptive analysis, spatial network analysis, and residential service coverage analysis. The analysis will not be limited to Langsa City alone, but will also consider settlements outside Langsa City. This is because the pattern analysis will utilize distance or impedance rather than administrative boundaries, in accordance with (Rotinsulu et al., 2017), who state that the use of distance in assessing the coverage of settlements by educational facilities will allow settlements outside the study area to also be included in the coverage of settlements by those educational facilities.

Each method is scored on a single, explicit criterion: the settlement service coverage ratio, that is, the percentage of the settled area that a method brings within a school zone at a given impedance distance; the ratio is defined formally under the comparative analysis below. For each school level the three methods are then ranked on this value, and a method is judged more suitable when it both reaches higher coverage and sustains that coverage consistently across the junior and senior secondary levels. Areal coverage, the share of total land area falling within a zone, is reported alongside as a secondary, descriptive indicator.

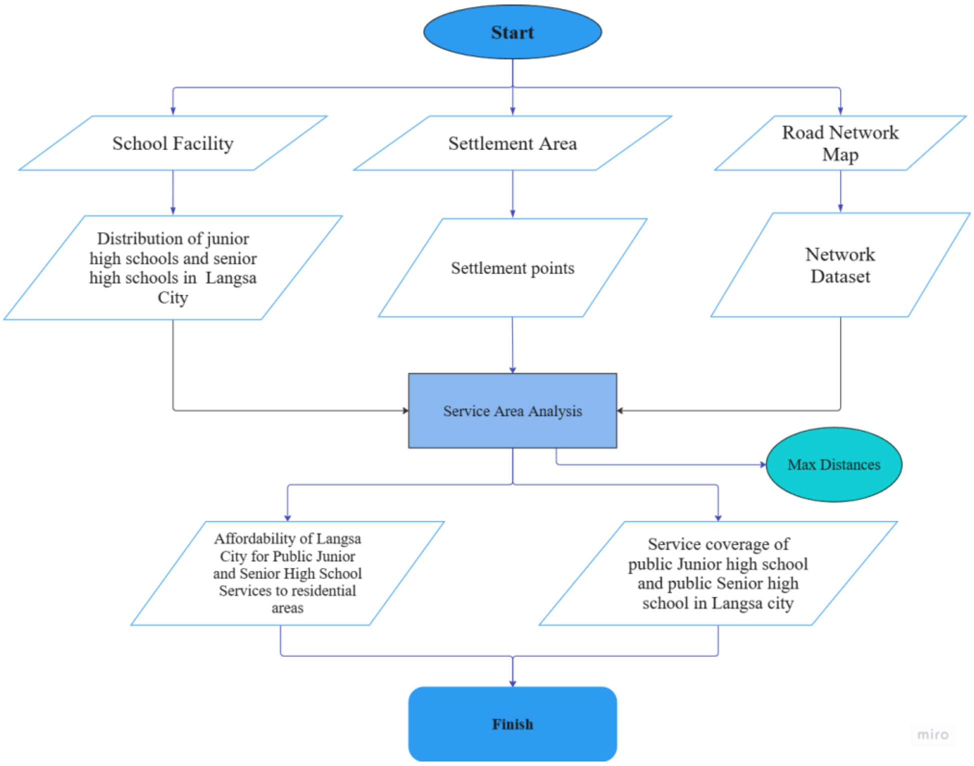
2.3.1 Service Area Analysis

Service area is one of the analysis in network analysis that focuses on analyzing the accessibility of a facility to other objects, such as residential areas. Service area analysis can be performed using ArcGIS and requires network topology as the main data for the analysis (Lolita et al., 2022).



Source: Esri (2021)

Figure 2. Service Area Analysis



Source: Analysis, 2024

Figure 3. Flowchart Service Area Analysis

Service area analysis takes into account road length and forms the reach area of a facility using a polygon feature type. This reach area is derived from distance and travel time used to analyze facility accessibility, including how far the distance required to reach the facility and how long the time required to reach the facility being analyzed (Susanta & Aditya, 2020). The following flow of service area analysis in the zoning pattern of educational facilities in Langsa City.

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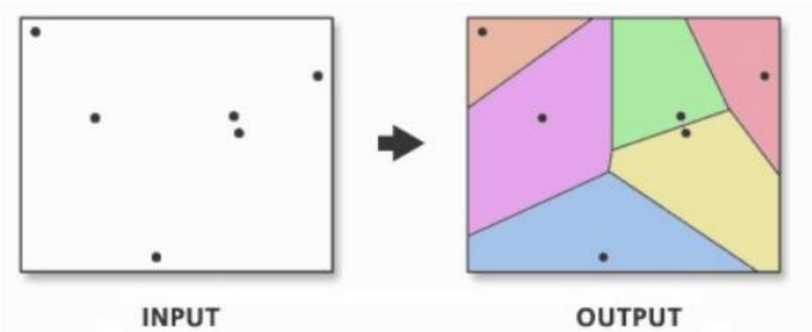
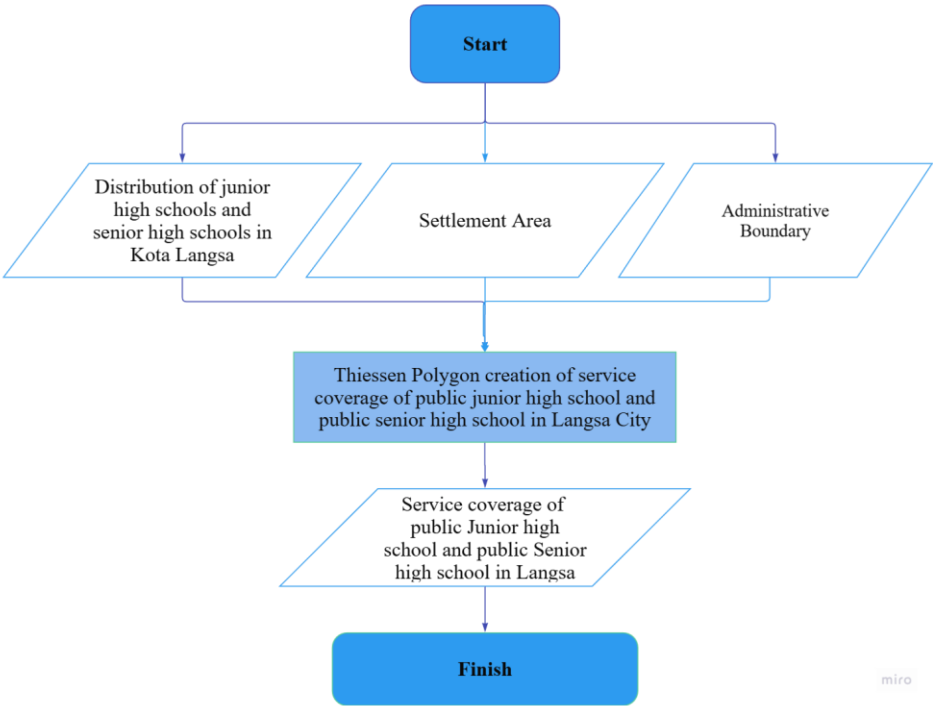
2.3.2 Thiessen Polygon Analysis

A Thiessen polygon is a representation of the influence of a point in a specific area that forms polygon network (Banata, 2010 in Andari et al., 2020). The shape of the Thiessen polygon is a triangulation network (TIN) formed by connecting the points that are the objects of study in this research, namely junior high schools and senior high schools with uneven distribution, which will then be divided into two triangulation networks (Andari et al., 2020).



Source: Esri, (2021)

Figure 4. Thiessen Polygon Analysis



Source: Esri (2021)

Figure 5. Flowchart Thiessen Polygon Analysis

The zoning pattern using Thiessen polygons still uses distance, but the distance is based on the spatial proximity of each public school distribution, which is then connected by lines between the schools to form polygons. The polygons formed from the combination of these lines become the zoning pattern that can be used to see the zoning coverage (Andari et al., 2020).

The Thiessen polygon is included here for a specific reason rather than for completeness. Of the three methods it is the only one that allocates space purely by proximity: every location is assigned to its single

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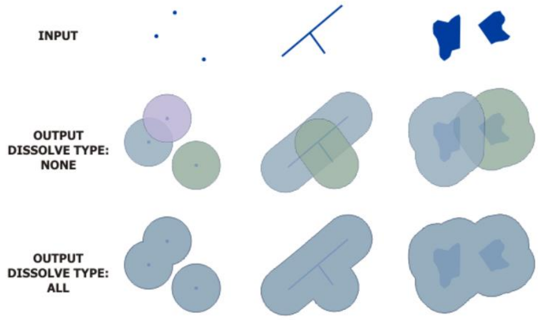
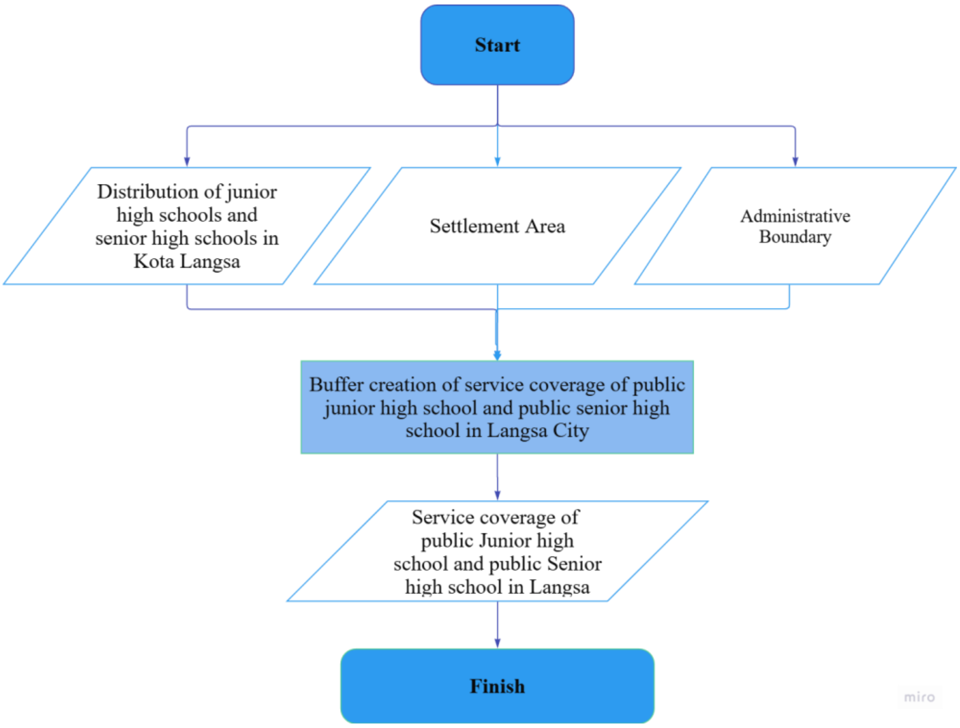
nearest school, with no overlap and no gap. This is exactly the assumption an idealised zoning rule makes when it sends a child to the closest available school, which is why the same construction underpins the Australian zoning model (Vatresia et al., 2023). In this study the Thiessen polygon therefore plays a double role. It is a candidate zoning method in its own right, and it acts as a geometric baseline: a pure nearest-neighbour partition against which the radius-based buffer and the network-based service area can be judged. Reading the other two methods against this baseline makes visible how much difference is introduced first by imposing a fixed service radius, and then by replacing straight-line proximity with travel along the actual road network.

2.3.3 Buffer Analysis

Buffering is one of the techniques that can be performed with GIS. This analysis creates zones around point, line, and polygon features to indicate that the area is a buffer area (Alviana et al., 2023). This buffer area will be visualized in the form of an area following the shape of the buffered feature (Prisecilia, 2024).



Source: Esri (2021)
Figure 6. Buffer Analysis



Source: Analysis, 2024
Figure 7. Flowchart Buffer Analysis

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The creation of a buffer area will form a coverage area or wrap the spatial feature on the map (buffer area object) with a distance that can be determined (Chang et al., 2019). Thus, this feature wrapping area is used to review the spatial range of map objects from other objects around them (Prahasta, 2002 in Alviana et al., 2023).

2.3.4 Comparative Analysis

A comparative analysis was conducted to determine the zoning patterns of each method using GIS based on service coverage area, which best describes student travel and distance range (Awana, 2023). This will enable the design of a spatial model. Because the three methods generate zones of different geometry, they cannot be compared on shape alone. They are made comparable through a single performance measure: the proportion of the settled area that each method succeeds in bringing within a school zone. For a given method m at a given school level, the settlement service coverage is defined as:

$$SC(m) = [\ A\_served(m) / A\_total\ ] \times 100\%$$

Where SC(m) is the settlement service coverage of method m expressed as a percentage, A_served(m) is the area of settlements that fall within the zone generated by method m, and A total is the total settlement area of the study region. The same ratio is applied to areal coverage by substituting total land area for settlement area. Expressing every method on this one scale allows a direct comparison both across methods and across the junior and senior secondary levels, and it is this coverage value that serves as the criterion for judging which method most realistically represents accessibility (Figure 7). The comparison procedure is summarised in Figure 7 and is carried out separately for each school level using the impedance distances reported with the results.

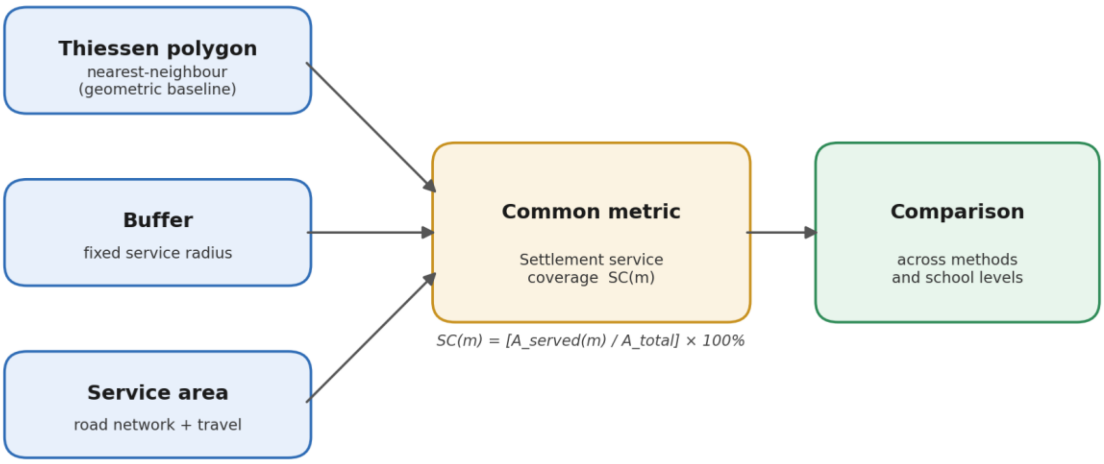
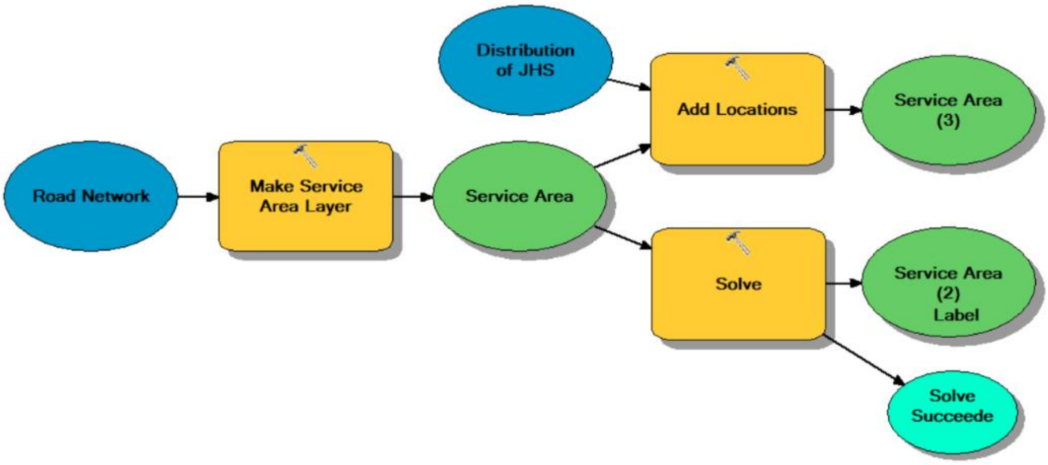


Figure 8. Framework of the Comparative Analysis of the Three Zoning Methods

2.3.5 Spatial Model Design

The Model design will utilize Model builder, which is one of the tools in ArcGIS that is used to design and model the workflow of an analysis and allows users to run the model so that it will produce the analysis that has been previously modeled (David, 2016). This spatial modeling has three main elements used to give commands for an analysis, namely: input, geoprocess, and output (Csafordi et al., in Melinda et al., 2022). Model design will greatly assist and automate the spatial analysis process in ArcGIS, making it more practical and faster. Models created in Model Builder use colors to distinguish the three main elements. White color on these three elements indicates that the model has no data entered and cannot be run. Blue color indicates input, yellow color indicates geoprocess, and green color indicates output or results (Ghazal et al., 2017).

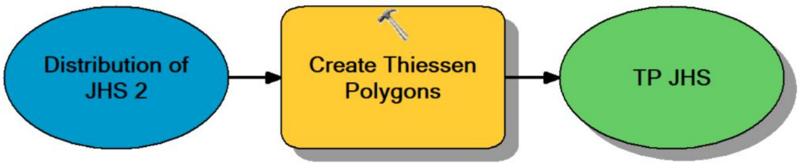
In this study, spatial modeling using Model Builder was applied to simplify the analysis process for each technique used, including Service Area, Thiessen Polygon, and Buffer. Model Builder enables automation in spatial data processing, allowing analysis to be conducted more efficiently and consistently without the need to manually repeat steps (Purnama et al., 2019). The first model designed was the Model Builder for service area analysis. The following is the spatial model design for the service area.



Source: Analyisis, 2025

Figure 9. Spatial Model of Service Area Analysis

The analysis of service areas in school zoning using GIS aims to determine the coverage of school services based on the road network in Langsa City. This model is designed to understand the extent to which students can access schools given the existing road network conditions. The main factor considered in this analysis is travel distance in meters. The second model designed is the Thiessen Polygon analysis model, as shown in the Thiessen polygon design in the model builder.



Source: Analyisis, 2025

Figure 10. Spatial Model of Thiessen Polygon Analysis

In school zoning analysis, Thiessen Polygons are used to determine the service areas of each school based on spatial proximity (Dewi et al., 2020). This process begins by entering the location data of the schools, in this case public junior high schools in Langsa City, as input for the creation of Thiessen Polygons. Additional facilities can be configured in the "Create Thiessen Polygon" section by selecting the facilities to be analyzed. The Thiessen Polygon spatial analysis model can be viewed in Figure 9. The final model designed is the buffer analysis model. In buffer analysis, the Multiple Ring Buffer tool is used to determine the school's accessibility zone based on three different levels of impedance. Each level of school facilities will have different buffer distances according to their accessibility characteristics (Djunaedi Junyar et al., 2020). The use of Multiple Ring Buffer allows for the creation of concentric zones around the school location, which helps in understanding the extent of the school's reach to its surrounding environment. The following is the buffer design in the model builder. The spatial buffer analysis modeling can be seen in Figure 10.

Source: Analyisis, 2025

Figure 11. Spatial Model of Buffer Analysis

3. RESULT AND DISCUSSION

3.1 Service Area Zoning Patterns Based on Service Coverage Accessibility to Settlements

School zoning is an important strategy in educational planning to ensure the accessibility oeducational facilities for students. One method commonly used in school zoning analysis is the service area technique, as mentioned by (Utami et al., 2022). This technique enables the analysis of school service coverage based on a specific distance, which in this study refers to three different impedances. Referring to the standards outlined by De Chiara and Koppelman in Ramadhana & Prakoso, (2018) as well as the Indonesian National Standards from National Standards Agency, (2004) the service area distances used for junior high schools are 0.8 km, 1 km, and 1.2 km, while for senior high schools they are 1.2 km, 1.6 km, and 3 km. The following is the coverage of zoning and residential areas served using Service Area analysis based on accessibility and residential service at the Public Junior High School and Senior High School levels in the city of Langsa.

Table 1. Coverage of the Service Area Zoning for Public Junior High School in Langsa City

No	Distances (Km)	Coverage Area (km^2)	Percentage (%)	Serviced Settlement (km^2)	Percentage (%)
1.	0,8	14,94	6,66	9,02	41,95
2.	1	25,51	11,37	14,05	65,35
3.	1,2	40,28	17,96	17,12	79.63

Source: Analysis, 2024

Based on Table 1 shows that at a distance of 0.8 km, the area of coverage reaches 14.94 km2 with a percentage of 6.66% of the total area of Langsa City. Meanwhile, the settlements served at this distance are 9.02 km2 or about 41.95% of the total settlements of Langsa City. When the distance is increased to 1 km, the zoning coverage increases to 25.51 km2 with a percentage of 11.37% of the total area of Langsa City. While the area of settlements served increased to 14.05 km2 or about 65.35% of the total settlement area of Langsa City. At the farthest distance of 1.2 km, the zoning coverage is getting wider until it reaches 40.28 km2 with a percentage of 17.96% of the total area of Langsa City, and the area of settlements served reaches 17.12 km2 or around 79.63% of the total settlement area of Langsa City. However, it should be noted that the data in Table 1. only covers zoning within Langsa City, while outside Langsa City which is within the zoning of Langsa City Junior High School is only found at a distance of 1.2 km with a total zoning coverage area of 0.15 km2 with 0.03 km2 of served settlements. The zoning map of Public Junior High School Kota Langsa using the service area can be seen in Figure 11.

In addition to the service area zoning pattern at Public Junior High School in Langsa City, the service area zoning pattern at the Senior High School level must also be visualized. The zoning pattern of senior high school Langsa City also uses three impedances to visualize the service area zoning pattern, but the impedances used are different from those of Public Junior High School. The following is a table of the results of the zoning coverage of the Langsa City public senior high school service area along with the settlements that can be served.

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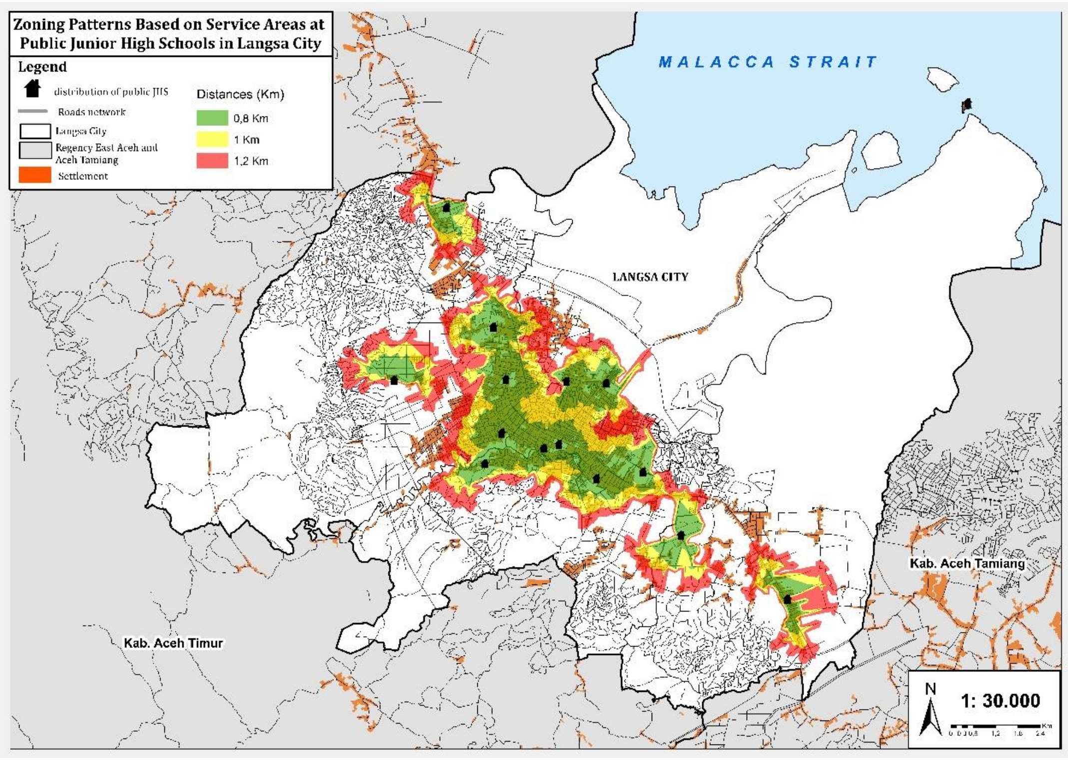
Table 2. Coverage of the Service Area Zoning for Public Senior High School in Langsa City

No	Distance (Km)	Coverage Area (km²)	Percentage (%)	Serviced Settlement (km²)	Percentage (%)
1.	1,2	10,13	4,52	6,89	32,05
2.	1,6	16,93	7,55	10,06	46,79
3.	3	45,47	20,27	17,13	79.21

Source: Analysis, 2024

In Table 2. it is known that at a distance of 1.2 km the zoning coverage area reaches 10.13 km2 with a percentage of 4.52% of the total area of Langsa City, while the area of settlements included in the service coverage is 6.89 km2 or about 32.05% of the total settlement area of Langsa City. With an increase in distance to 1.6 km, the zoning coverage increased to 16.93 km2 with a percentage of 7.55% of the total area of Langsa City, while the area of settlements covered increased to 10.06 km2 with a percentage of 46.79% of the total settlement area of Langsa City. At a distance of 3 km, the zoning coverage area reaches 45.47 km2 with a percentage of 20.27% of the total area of Langsa City, and the area of settlements that have access to education services is 17.13 km2 or about 79.21% of the total settlement area of Langsa City. The service area zoning map of public senior high school Langsa City can be seen in Figure 12.



Source: Analysis, 2024

Figure 12. Map of Service Area Zoning Pattern of Public Junior High School in Langsa City

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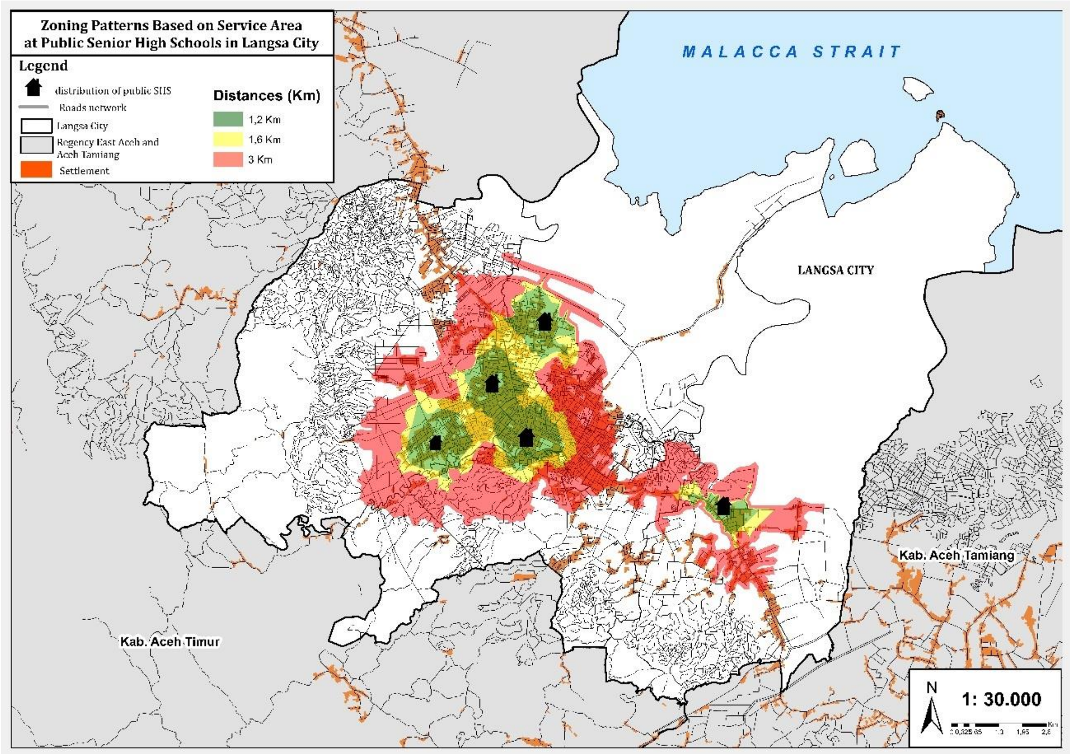

Source: Analysis, 2024

Figure 13. Map of Service Area Zoning Pattern of Public Senior High School in Langsa City

3.2 Thiessen polygon zoning pattern based on accessibility and service coverage to settlements

In educational planning, school zoning plays an important role in ensuring equal access to education for students. One method that can be used to analyze school zoning is the Thiessen Polygon, which divides an area based on spatial proximity to school locations. The zoning pattern for public junior high schools in Langsa City has a total coverage area of 245.46 km2, with a coverage area in Langsa City of 176.72 km2 or 78.78% of the total area of Langsa City, meaning that the coverage area outside Langsa City is 68.74 km2. The residential areas served by the Public Junior High School Langsa City zoning using Thiessen Polygon have a total area of 23.15 km², with the residential area served within Langsa City being 21.11 km² or 98.21% of the residential area of Langsa City, which means that the area of residential areas served outside the city of Langsa is 2.04 km². The zoning pattern map of Public Junior High School Langsa City using Thiessen Polygon can be seen in Figure 13. Unlike the zoning pattern of Public Junior High School in Kota Langsa, at the public senior high school level in Kota Langsa, there are a total of five public schools available, and the locations of these five schools are in the city center, resulting in a limited zoning pattern within the city area. The zoning pattern of public senior high school in Langsa City using Thiessen Polygons has a total area of 48.56 km² or 21.65% of the total area of Langsa City, with a serviced residential area of 15.32 km² or 71.62%. The zoning pattern map of Thiessen Polygons for public senior high school can be seen in Figure 14.

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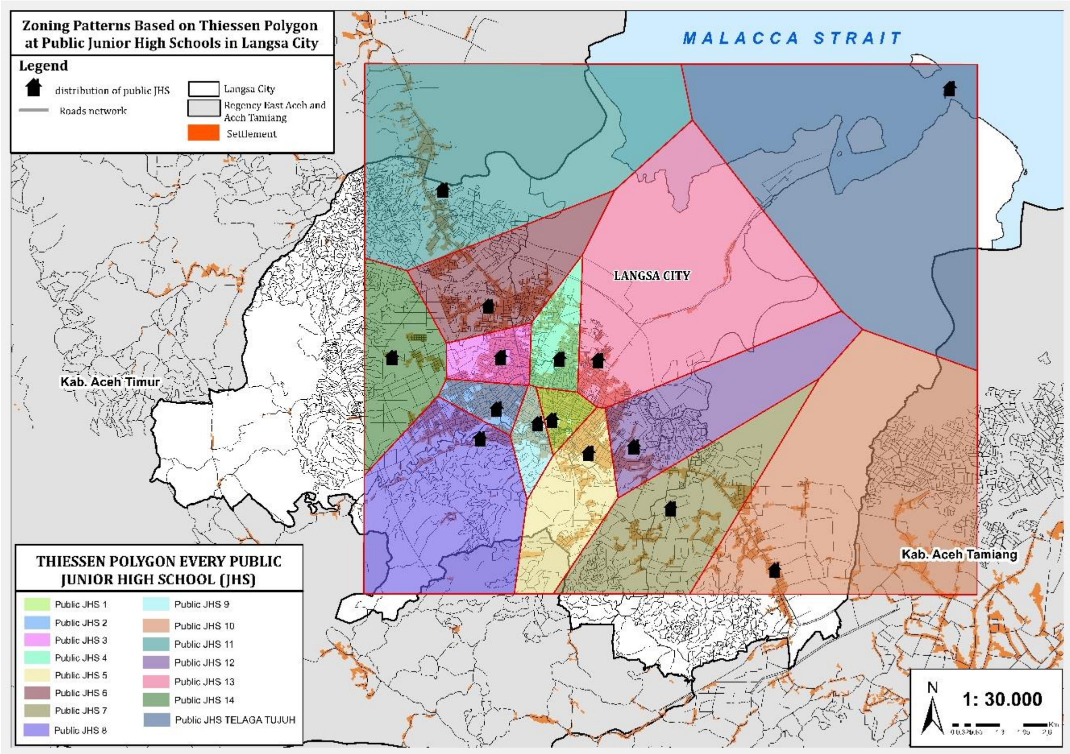
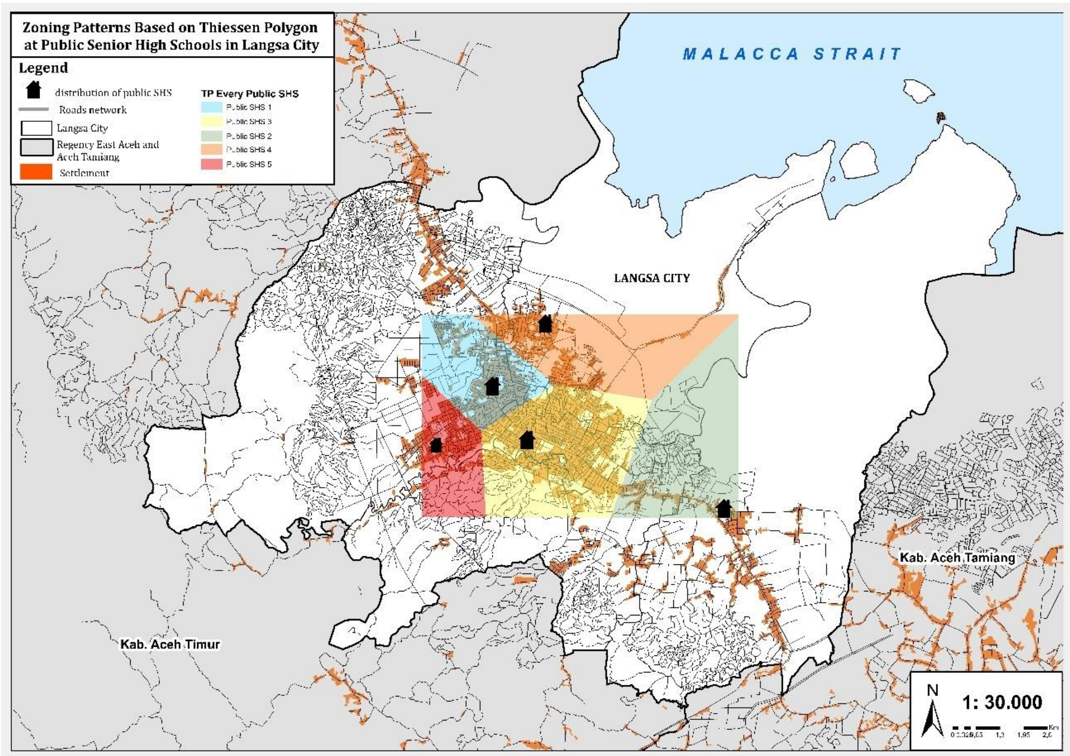


Source: Analysis, 2025

Figure 14. Map of Thiessen Polygon Zoning Pattern for Public Junior High School in Langsa City



Source: Analysis, 2025

Figure 15. Map of Thiessen Polygon Zoning Pattern for public Senior High School in Langsa City

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3.3 Buffer zoning patterns based on service accessibility to settlements

School zoning is an important strategy in educational planning to ensure the accessibility of educational facilities for students. One method commonly used in school zoning analysis is the buffer technique, as mentioned by (Utami et al., 2022). This technique enables the analysis of school service coverage based on a specific distance, which in this study refers to three different impedances. Referring to the standards proposed by De Chiara and Koppelman and the Indonesian National Standards, the buffer distances used for junior high schools are 0.8 km, 1 km, and 1.2 km, while for public senior high schools they are 1.2 km, 1.6 km, and 3 km. The following is the coverage of zoning and residential areas served using buffer analysis based on accessibility and residential services at the public junior high school and public senior high school levels in Langsa City.

Table 3. Coverage of the Buffer Zoning for Public Junior High School in Langsa City

No	Distances (Km)	Coverage Area (km^2)	Percentage (%)	Serviced Settlement (km^2)	Percentage (%)
1.	0,8	24,65	10,99	11,22	52,19
2.	1	34,89	15,55	14,08	65,49
3.	1,2	45,20	20,15	16,21	75.37

Source: Analysis, 2024

Based on Table 3, zoning coverage using buffers for junior high schools in Langsa City uses three impedances. At a distance of 0.8 km, the zoning coverage area is only 24.65 km^2 or approximately 10.99% of the total area of Langsa City, with a served residential area of 11.22 km^2 or 52.19% of the total residential area of Langsa City. When the buffer radius is increased to 1 km, the coverage area increases to 34.89 km^2 or 15.55% of the total area of Langsa City, with a serviced residential area of 14.08 km^2 or approximately 65.49% of the total residential area of Langsa City. At a distance of 1.2 km, the coverage area becomes even larger, with a total area of 45.20 km^2 or 20.15% of the total area of Langsa City, with the serviced residential area increasing to 16.21 km^2 or 75.37% of the total residential area of Langsa City.

The data in Table 3 only includes the coverage area within Langsa City. In addition to the coverage within Langsa City, there is also zoning outside Langsa City that falls within the buffer zone of public junior high school Langsa City. At a distance of 0.8 km, the coverage area of the zoning outside Langsa City is 2.25 km^2, but the area of serviced residential areas is very small, only 0.003 km^2. When the buffer distance is expanded to 1 km, the coverage area of the zoning outside Langsa City increases to 3.63 km^2, with the area of serviced residential areas increasing to 0.036 km^2. At the farthest buffer distance of 1.2 km, the zoning coverage outside Langsa City increases to 5.07 km^2, with the area of residential zones served increasing to 0.13 km^2. The buffer zoning map for Public Junior High School Langsa City can be viewed in Figure 15.

In addition to the buffer zoning pattern for public junior high schools in Langsa City, the buffer zoning pattern for senior high schools must also be visualized. The zoning pattern for senior high schools in Langsa City also uses three impedances to visualize the buffer zoning pattern, but the impedances used are different from those for public junior high schools. The following table shows the results of the buffer zoning coverage for senior high schools in Langsa City along with the settlements that can be served.

Table 4. Coverage of the Buffer Zone for Public Senior High School in Langsa City

No	Distance (Km)	Coverage Area (km^2)	Percentage (%)	Serviced Settlement (km^2)	Percentage (%)
1.	1,2	21,68	9,66	10,11	47,01
2.	1,6	33,97	15,14	12,71	59,10
3.	3	89,59	39,94	19,03	88.50

Source: Analysis, 2024

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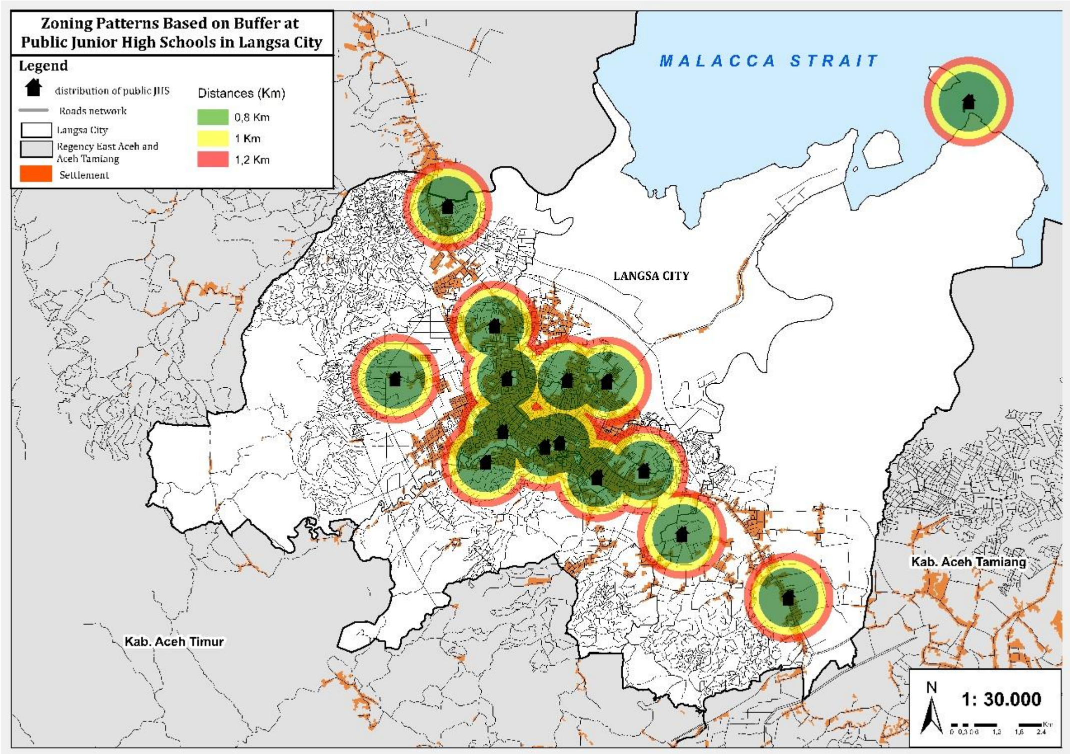
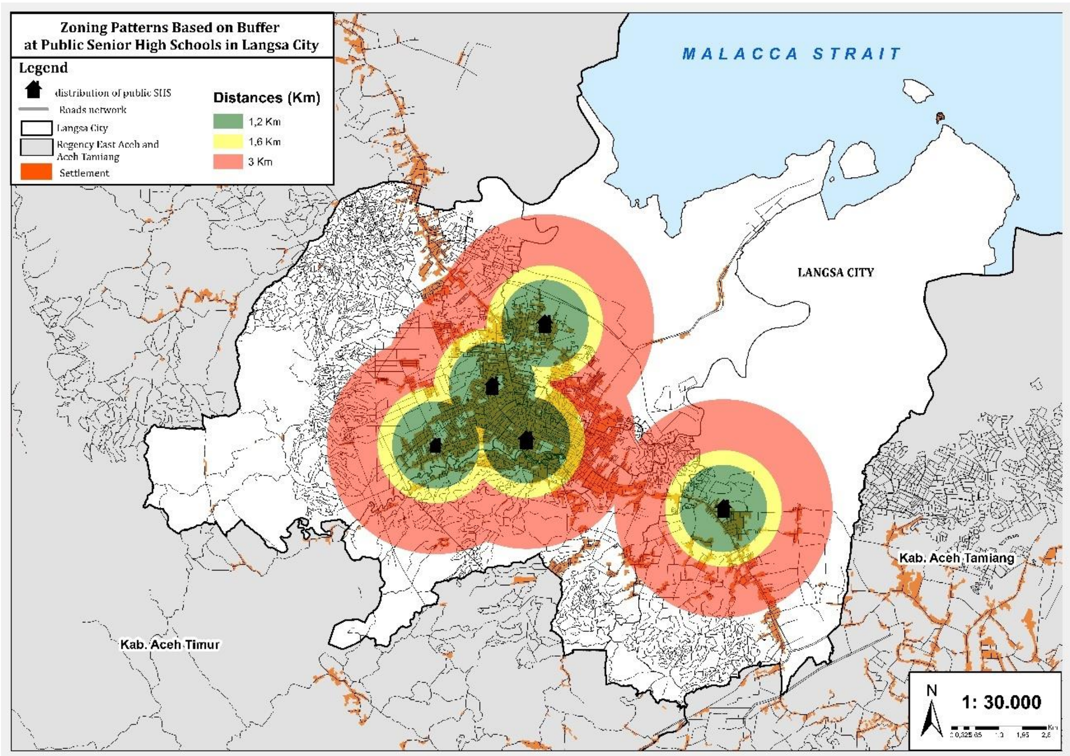


Source: Analysis, 2025

Figure 16. Map of Buffer Zoning Pattern for Public Junior High School in Langsa City



Source: Analysis, 2025

Figure 17. Map of Buffer Zoning Pattern for Public Senior High School in Langsa City

Based on Table 4, it shows that at a distance of 1.2 km, the coverage area of the public senior high school zoning reaches 21.68 km² or 9.66% of the total area of Langsa City, with the area of residential areas served being 10.11 km^2 or 47.01% of the total residential area of Langsa City. As the buffer distance increases to 1.6 km and 3 km, the coverage area increases to 33.97 km^2 and 89.59 km^2, respectively, representing 15.14% and 39.94% of the total area of Langsa City. At distances of 1.6 km and 3 km, the areas served are 12.71 km^2 and 19.03 km^2, respectively, or 59.10% and 88.50% of the total residential area of Langsa City. Based on Figure 16, it is known that the buffer zone pattern of Senior High School Langsa City is only within Langsa City, unlike the buffer zone of Public Junior High School Langsa City, which has a zone coverage outside Langsa City.

3.4 Comparison of Zoning Patterns in Langsa City

To understand how zoning patterns can affect school coverage, a comparison was made between three zoning methods, namely Thiessen Polygon, Buffer, and Service Area. The zoning patterns applied in the education system play a crucial role in determining the extent to which school accessibility can be reached by students. Using the Thiessen Polygon, Buffer, and Service Area methods, school zoning in Langsa City was analyzed to examine differences in coverage areas and the number of settlements that can be served by each approach (Awana, 2023). Each method has its own characteristics in describing school accessibility patterns, including the extent of zoning coverage, the number of settlements that can be served, and its relevance to the distance students travel to school.

At the junior high school level, the differences in zoning coverage between the three methods are quite significant. Thiessen Polygon produces a wide coverage area of 245.46 km^2, with 176.72 km^2 or 78.78% located within Langsa City, while 68.74 km^2 are outside the city. This approach divides the area based on spatial proximity to schools without considering road networks, so zoning boundaries are formed geometrically following the division between schools. Unlike this method, Buffer shows more flexible zoning coverage because it can be adjusted to a specific radius from the school. With an impedance of 0.8 km, the zoning coverage reaches 24.65 km^2 or 10.99%, with the zoning coverage area outside Langsa City being 2.25 km^2, then increases to 34.89 km^2 or 15.55% at a distance of 1 km with the zoning coverage area outside Langsa City being 3.63 km^2, and reaches 45.20 km^2 or 20.15% at a distance of 1.2 km, with the coverage area outside Langsa City being 5.07 km^2. Meanwhile, the Service Area method, which considers road network conditions, shows a smaller but more realistic coverage in representing accessibility. At a distance of 0.8 km, the coverage area is only 14.94 km^2 or 6.66%, increasing to 25.51 km^2 or 11.37% at a distance of 1 km, and reaching 40.28 km^2 or 17.96% at a distance of 1.2 km with a coverage area outside Langsa City of 0.15 km^2.

The coverage of serviced settlements also shows different patterns for each method. Thiessen Polygon covers almost all settlements in its zone, with a total area of serviced settlements inside and outside Langsa City reaching 23.15 km^2, where the coverage of settlements in Langsa City is 21.11 km^2 or 98.21% of the total settlements in Langsa City, while the coverage of settlements outside Langsa City is 2.04 km^2. However, since this method does not consider geographical barriers, there may be areas within the zoning coverage that have limited access to schools. The buffer, which is more flexible, shows that residential coverage increases as the zoning radius increases. At a distance of 0.8 km, the residential coverage within Langsa City reaches 11.22 km^2 or 52.19%, and the residential coverage outside Langsa City is 0.003 km^2. At a distance of 1 km, the residential coverage within Langsa City increases to 14.08 km^2 or 65.49%, and the residential coverage outside Langsa City is 0.036 km^2. At a distance of 1.2 km, the residential coverage within Langsa City reaches 16.21 km^2 or 75.37%, while the residential coverage outside Langsa City is 0.13 km^2. The Service Area, considering the road network, results in a smaller residential coverage but better reflects the actual accessibility conditions. At a distance of 0.8 km, the residential coverage of Langsa City is only 9.02 km^2 or 41.95%, then the residential coverage of Langsa City increases to 14.05 km^2 or 65.35% at a distance of 1 km, and then the residential coverage of Langsa City reaches 17.12 km^2 or 79.63% at a distance of 1.2 km, while the residential coverage outside Langsa City is 0.03 km^2. In terms of distance relevance, the methods used also yield varying results.

Thiessen Polygon produces a wide zoning coverage by only measuring the distance between schools, but it does not consider accessibility conditions, so there are some areas that appear to be within one school zone but have geographical barriers that make the journey to school longer. Buffer, although more flexible, still only considers a fixed radius without considering road conditions, so it is not always relevant to students' travel patterns. In contrast, the Service Area method shows patterns closer to reality because it considers available road routes and surrounding obstacles.

Similar differences also occur at the high school level, where zoning patterns are more limited compared to junior high schools due to the smaller number of schools. All zoning patterns at the public senior high school Kota Langsa level only include zoning coverage and residential coverage within the city. Thiessen Polygon shows a smaller zoning coverage compared to the junior high school level, with a total of 48.56 km² or 21.65% of the area of Langsa City. This method divides the zoning evenly based on school locations, but since senior high schools are more concentrated in the city center, the resulting zoning coverage is smaller and uneven. The buffer, with a larger impedance radius than junior high schools, produces a wider coverage area, from 21.68 km² or 9.66% at a distance of 1.2 km, increasing to 33.97 km² or 15.14% at a distance of 1.6 km, and reaching 89.59 km² or 39.94% at a distance of 3 km.

Meanwhile, the Service Area produces a smaller coverage area but is closer to the reality of school accessibility. At a distance of 1.2 km, the coverage area is only 10.13 km² or 4.52%, increasing to 16.93 km² or 7.55% at a distance of 1.6 km, and reaching 45.47 km² or 20.27% at a distance of 3 km. In terms of the coverage of served settlements, the Thiessen polygon method shows that the coverage of settlements is smaller compared to the junior high school level, with the area of served settlements being 15.32 km² or 71.62% of the total settlements in Langsa City. The buffer shows a wider residential coverage, with 10.11 km² or 47.01% at a distance of 1.2 km, increasing to 12.71 km² or 59.10% at a distance of 1.6 km, and reaching 19.03 km² or 88.50% at a distance of 3 km.

Meanwhile, the service area, with a smaller but more accurate coverage in representing accessibility, shows that the coverage of served settlements increases from 6.89 km² or 32.05% at a distance of 1.2 km, to 10.06 km² or 46.79% at a distance of 1.6 km, and reaching 17.13 km² or 79.21% at a distance of 3 km. In terms of the relevance of distance differences in the zoning patterns of public senior high school, this indicates that each method has its advantages and disadvantages in describing educational accessibility. Thiessen Polygon provides a small coverage area and does not consider geographical barriers or road networks, buffer provides a more flexible coverage area but still does not account for students' travel conditions, while service area is more suitable for depicting actual travel patterns because it considers available transportation routes.

From the results of comparative analysis at the Public Junior High School and public senior high school levels in Langsa City, it is known that Thiessen Polygon appears to be dominant at the Public Junior High School level, but this does not apply at the public senior high school level, which instead shows that its zoning coverage is narrower than other methods. This proves that this method is highly dependent on school distribution and is not flexible to variations in regional conditions. The Buffer method, although flexible, is still unable to accurately depict actual access due to its disregard for road conditions. On the other hand, the Service Area method emerges as the most consistent in depicting student travel, although its zoning coverage and residential coverage are smaller compared to the Buffer method at both the Public Junior High School and Public Senior High School levels. Thus, the comparison of these three methods further highlights the importance of using an approach that comprehensively considers spatial aspects in the development of school zoning.

In this context, the use of Geographic Information Systems (GIS) becomes a highly effective tool as it can process and analyze spatial data in detail (Setiawan, 2016) . Through GIS, zoning patterns can be designed based on actual geographical conditions, including road networks, school distribution, and residential distribution, resulting in outcomes that are far more relevant and accurate than zoning based solely on administrative boundaries. The conventional zoning pattern based on administrative boundaries in Langsa City becomes less relevant due to the varying shapes and sizes of administrative areas. This situation leads to inconsistencies in students' travel distances (Rotinsulu et al., 2017). The use of zoning patterns that follow administrative boundaries does not consider road networks, school distribution, spatial distribution of the population, and the distance students must travel daily, which can ultimately result in disparities in access to education (Redaksi, 2023). Therefore, the zoning patterns derived from Thiessen polygon, buffer, and service area analyses based on GIS demonstrate variations in accessibility that can only be identified through GIS-based spatial analysis. Thus, integrating GIS into the school zoning system could be a strategic step toward improving equitable access to education in Langsa City.

4. CONCLUSION

The three methods do not fall into a single fixed ranking; their performance depends on how many schools serve a level and on how those schools are spread across the city. For junior high schools, which are relatively numerous and fairly evenly distributed, the Thiessen polygon brought almost the entire settled area within a zone, covering 98.21 percent of settlements inside Langsa City. The same method performed worst at the senior high school level, where only five schools cluster near the city centre, leaving large settled areas grouped into a single zone and covering just 71.62 percent of settlements. The buffer method proved the most flexible, since its radius can be tuned to each level, but it stays blind to the road network and therefore tends to overstate reach across physical barriers. The service area method produced the most realistic and the most consistent result across both levels, because it measures access along the roads that students actually travel.

Read together, these results carry a clear message for how zones should be drawn in Langsa. A zoning rule tied to administrative boundaries, as currently applied under the Mayor Regulation, ignores the geography of access and can place a school nominally inside a zone that students cannot easily reach. A network-based delineation, by contrast, aligns the zone with real travel and offers a fairer basis for allocating school places, which matters acutely in a city that has no public transport and many students below the legal driving age. Choosing a method is therefore not a purely technical decision: it shapes who gains and who loses access to a public school.

Building the analysis inside Model Builder allowed the whole workflow, from input data to final zone, to be automated and rerun without manual repetition. The value of this lies less in speed than in reproducibility and transfer: the same model can be applied to other cities or rerun as school locations change, which lowers the barrier for local governments to adopt spatial methods in their own zoning decisions. The contribution of this study is to place three commonly used delineation methods on a single comparable footing and to show, for both secondary levels at once, how the choice of method translates into measurable differences in equitable access.

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