

## Multi-scenario location-allocation in decision-making for improving educational facility services in Kupang City

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ARTICLE INFO	ABSTRACT
<p><i>Article history:</i> Received January 25, 2024 Received in revised form Feb. 18, 2024 Accepted March 27, 2024 Available online April 01, 2024</p> <p><i>Keywords:</i> Education facilities Kupang City Location-allocation</p> <p><b>*Corresponding author:</b> Amandus Jong Tallo Department of Irrigation Design and Coastal Management Engineering, Department of Civil Engineering, Kupang State Polytechnic, East Nusa Tenggara, Indonesia Email: <a href="mailto:amandustallo@gmail.com">amandustallo@gmail.com</a> ORCID: <a href="https://orcid.org/0000-0002-4037-298X">https://orcid.org/0000-0002-4037-298X</a></p>	<p>Regional development is inseparable from the support of education facilities. Spatial disparities in education facilities' service scales occur unevenly in the Kupang city administration. Overlaying several thematic maps with Location-Allocation analysis provides a development scenario for the placement of the education facilities. Secondary data in in this study include the distribution of existing educational facilities, consisting of elementary schools (SD), junior high schools (SMP), and senior high schools (SMA) derived from Kupang City's Regional Spatial Plan (RTRW) data, and road network and building distribution based on the Open Street Map (OSM) publications. The comparison of the overall parameters shows that the most efficient scenario with the least positive impact and the least negative impact was the scenario with ¼ of the optimal number of new facilities for elementary and junior high schools, Meanwhile, for senior high schools, further consideration is needed to examine the scenario with the optimal number and the scenario with ¼ of the optimal number of new facilities in Kupang City.</p>

### Introduction

Regional development is inseparable from the support of education facilities (Papcunová et al. 2023). Spatial disparities in education facilities' service scales occur unevenly in the Kupang city administration. Overlaying several thematic maps with location-allocation analysis provides a development scenario for the placement of the education facilities (Abd El Karim and Awawdeh 2020; Meena, Tripathi, and Agrawal 2022). Secondary data in in this study include the distribution of existing educational facilities, consisting of elementary schools (SD), junior high schools (SMP), and senior high schools

(SMA) derived from Kupang City's Regional Spatial Plan (RTRW) data, and road network and building distribution based on the Open Street Map (OSM) publications (Kupang 2011). The comparison of the overall parameters shows that the most efficient scenario with the least positive impact and the least negative impact was the scenario with ¼ of the optimal number of new facilities for elementary and junior high schools, meanwhile, for senior high schools, further consideration is needed to examine the scenario with the optimal number and the scenario with ¼ of the optimal number of new facilities in Kupang City.



Context of movement within serviced facilities can be seen through points, orientations, and trajectories (Pafka, Dovey, and Aschwanden 2020; Cresswell 2023). Points will indicate the origin and destination of movement, orientation directs movement, and trajectory relates to the path to be traveled and the serialization process in the urban environment (M. Li et al. 2018). Moreover, service area coverage is an accessibility function (Uddin and Warnitchai 2020).

As the capital of East Nusa Tenggara Province, Kupang City has experienced significant population growth in recent years, i.e., 4.7% (Wikipedia 2018). This growth has increased the demand for adequate education. The growth, which is high compared to other regions, has led to gaps in education services (PUPR Kota Kupang 2010). The southern region of Kupang City still needs to be moved from education facilities.

The location of education facilities needs to be considered in planning Kupang's regional development to fulfil the community's needs equitably and efficiently (Devi, Patra, and Singh 2022). The location of educational facilities is determined by its accessibility (Curtis and Scheurer 2010).



**Figure 1.** Distribution of educational facilities and existing road network

Moreover, the placement of educational facilities needs to consider the local community's economic and social aspects (X. Li, Wang, and Yi 2017). This includes improving accessibility and equity in the education services (Cao, Li, and Church 2020). Decision-making related to the location of educational facilities must also consider aspects of environmental sustainability, such as impacts on the physical environment

(Benita, Kalashnikov, and Tunçer 2021) and social as well as potential conflicts with landowners or neighboring communities (Feng et al., 2021). Considering these factors, the use of Location-allocation in decision-making regarding educational facilities in Kupang City is important to ensure optimal and equitable placement to effectively and efficiently meet the community's needs.

## Methods

This study uses secondary data of the distribution of existing educational facilities, consisting of elementary schools (SD), junior high schools (SMP), and senior high schools (SMA) derived from the Kupang City Regional Spatial Plan (RTRW) data, road network, and building distribution obtained based on the Open Street Map (OSM) publication. The distribution and area of the building are then represented in a hexagon grid to be converted into an estimate of the population of each grid. The estimated population of each grid is based on the approach of the ground floor area of the building per grid, which is then divided by the minimum basic area requirement per person based on the guidelines of SNI 03-1733-2004 on the procedures for Planning Residential Environments in Urban Areas (Badan Standarisasi Nasional 2004), i.e., 9 m<sup>2</sup>. The grid was also used by Shahparvari, Fadaki, and Chhetri (2020), aiming to provide more macro allocation recommendations that can be adjusted based on the characteristics of each grid. The following map shows the distribution of educational facilities, the existing road network, and the estimated population distribution.



**Figure 2.** Estimation of population distribution based on grid

For the analysis method, this research uses a network analysis-based approach with weighting at the point of service demand, namely the closest facility analysis and location-allocation analysis based on multi-scenarios. The closest facility analysis is a network analysis used to evaluate the cost of traveling between an incident point and the nearest facility, determine the closest locations to each other, display the optimal route, calculate the total cost of travel, and provide the necessary driving directions (ESRI 2024). The closest facility analysis determines the average distance traveled to existing education facilities and how much of the population is reached based on the reach standard used (Baihaqi, Suprayogi, and Firdaus 2019). The location-allocation analysis can be defined as selecting a set of facilities that best match the demand from the surrounding area. This method allows the placement of facilities and the allocation of demand points to appropriate facilities.

Based on the location-allocation analysis, several scenarios were developed to find the optimal iteration of the number of new educational facilities. The optimal number scenario is based on minimized facilities, which will produce the optimal number and distribution to reach the entire population optimally. Scenarios 2 and 3 take from a half of the optimal number of new facilities and a quarter of the optimal number of new facilities with the maximum coverage method to maximize coverage. Based on these scenarios, a rapid assessment was then carried out to compare the results and impacts of each scenario to achieve a more appropriate decision-making recommendation. Figure 3 shows the research flow used.

## Results and discussion

Distribution and extent of reach of existing educational facilities

Based on data from the Kupang City RTRW, there are 26 existing elementary schools, 13 junior high schools, and 13 senior high schools spread across Kupang City. From the distribution of these facilities, an analysis was conducted using the closest facility to determine the level of service of existing educational facilities to the population and the average distance that needs to be traveled to reach educational facilities. The cutoff distance is taken from the standard radius of achievement at the SNI 03-1733-2004 on Procedures for Planning Residential Neighborhoods in Urban Areas (Badan Standarisasi Nasional 2004), 1000 meters for Elementary school and junior high schools, and 3000 meters for senior high schools. The results of the analysis are presented in the following table 1.

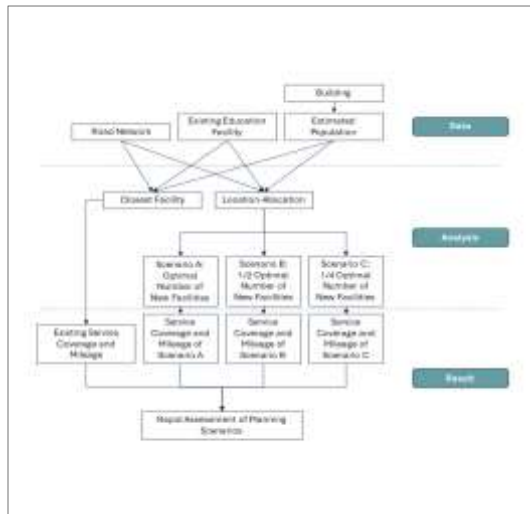


Figure 3. Research flow

Table 1. The results of the closest facility analysis of the existing education facilities

Facilities	Estimation of the Reachable population	Percentage of Reached population	Average distance	Total distance
Elementary School	881540	39.30%	627.15	1687663.27
Junior High School	535495	23.87%	656.13	1031444.11
Senior High School	1691755	75.43%	1664.47	8775060.51

Table 1 shows that the level of service of the existing education facilities is still not optimal, with only 39.3% of elementary school facilities, 23.87% of junior high school facilities, and 75.43% of senior high school facilities, referring

to SNI 03-1733-2004 coverage standards. The small percentage of the population coverage indicates that the existing educational facilities in Kupang City lack good accessibility to the population. The following map shows the

distribution of the existing educational facilities and the coverage of their services to the population.

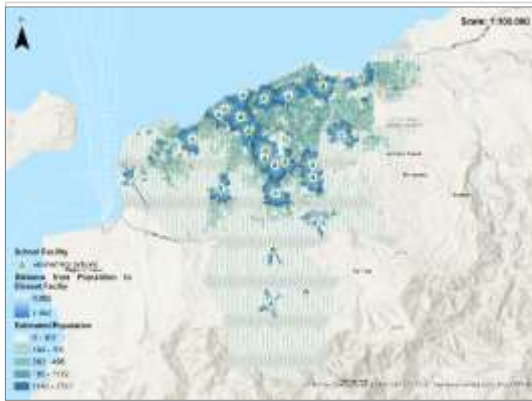


Figure 4. Level of coverage of the existing elementary school facilities

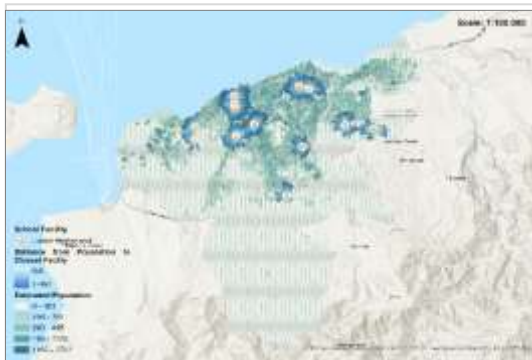


Figure 5. Level of coverage of the existing junior high school facilities



Figure 6. Level of coverage of the existing SMA facilities

Spatially, it can be seen that the reach of these existing educational facilities has not reached all of the population and areas of Kupang City. Therefore, with the level of service that is not optimal, recommendations for the distribution of

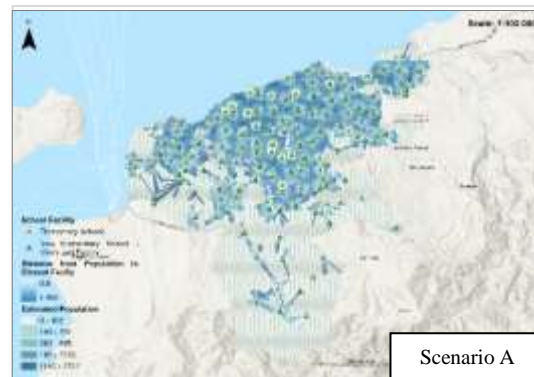
new education facilities are needed to optimize access to education in Kupang City.

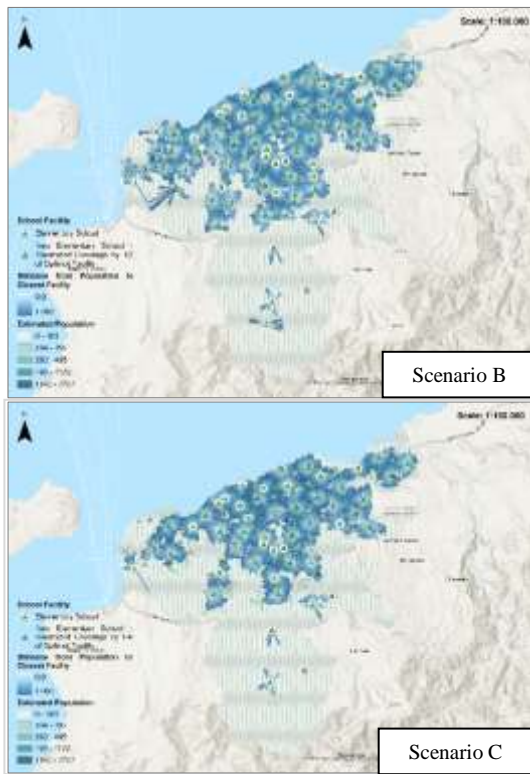
#### Multi-scenario location-allocation

With the existing gap in educational facility services, a multi-scenario-based location-allocation analysis provides recommendations for allocating new educational facilities, including elementary school, junior secondary, and senior secondary schools, based on the need to reach the population optimally. In this multi-scenario approach, three types of scenarios were used, including scenario A in the form of the optimal distribution and number of facilities using the minimized facility algorithm; scenario B with the distribution and number of facilities a half of the optimal scenario; and scenario C with the distribution and number of facilities a quarter of the optimal scenario. This scenario-based analysis provides a comprehensive picture of the plan options that can be carried out, thereby increasing participation and objectivity in decision-making.

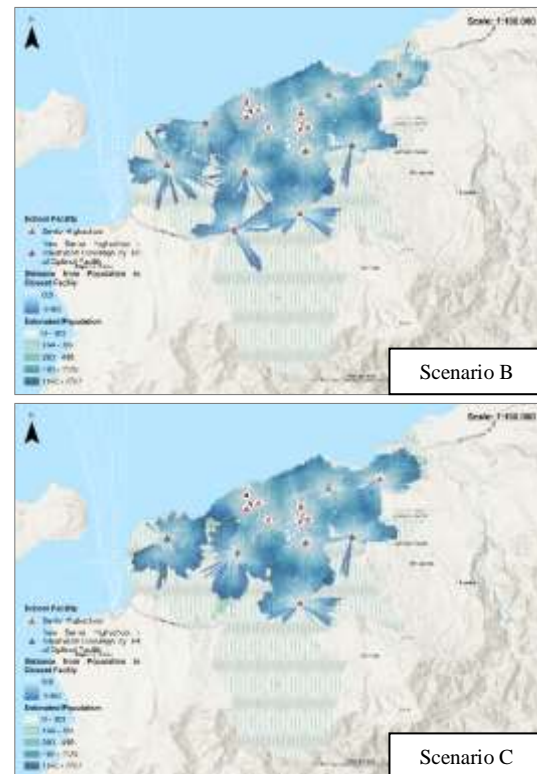
#### Multi-scenario recommendation for allocation of new elementary school facilities

The location-allocation analysis of the elementary school scenarios considered a distance limit of 1000 meters using the guidelines and the optimal population's achievement as the point of demand. From the analysis, the optimal number of new facilities based on scenario A is 111, scenario B is 56, and scenario C is 28. The map in figure 7 below shows the distribution of elementary school facility allocations in Kupang City.





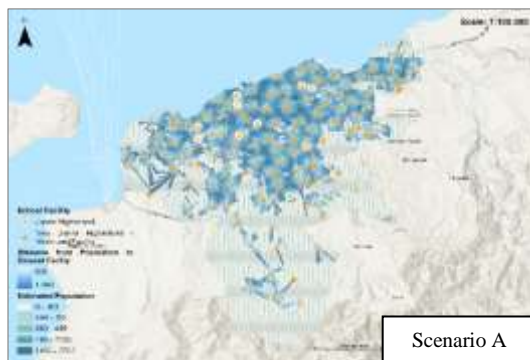
**Figure 7.** Multi-scenario map of recommendations for allocation of new elementary school facilities



**Figure 8.** Multi-scenario map of new high school facility allocation recommendations for each scenario

Multi-scenario recommendations for the allocation of New Junior High School facilities

The location-allocation analysis of the junior high school scenario was also carried out considered a distance limit of 1000 meters using the existing guidelines and achieving the optimal population as a demand point. From the results of these analyses, the optimal number of new facilities for scenario A is 116, scenario B is 58, and scenario C is 29. The map in figure 8 shows the distribution of junior secondary school facility allocations in Kupang City.



Rapid assessment of scenarios

By obtaining various alternative scenarios for allocating new educational facilities from the previous analysis results, a rapid assessment was then carried out for the existing conditions and impacts of each scenario for each educational facility. Some considerations of the effects include the estimated affordable population and percentage of the total population, average travel distance, total travel distance and its relation to transportation impact costs in the form of fuel per day in rupiah, i.e., Rp535.8 per kilometer (Apriathama 2022), and the impact of carbon emissions (CO<sub>2</sub>) generated from the trip, which is equivalent to 103 grams per passenger km for motorcycles (Priyantoro and Kurniawan 2022). School construction costs, assumed to be the average construction budget for senior high schools, vocational high schools, and special schools, are 3 billion rupiahs (Humas Jabar 2024). It is assumed that the elementary schools require one third budget and the junior high school requires two third of the high school budget. Tables 2, 3, and 4 present a compilation of the

various new facility allocation scenarios and their impacts.

**Table 2.** Rapid assessment of existing conditions, optimal number scenario, a half of optimal number scenario, and a quarter of optimal number scenario of new elementary school facilities

Existing	Existing	Optimal scenario	Scenario ½ optimal	Scenario ¼ optimal
New facilities	0	111	56	28
Number of facilities	26	137	82	54
Estimated population reached	881540	2242919	2216437	1998664
Percentage of Population Reached	39.30%	100.00%	98.82%	89.11%
Average distance	627.15	480.44	571.41	618.77
Total distance	1687663.27	4051511.54	4520971.29	4005280.63
School construction cost	IDR-	IDR 111,000,000,000.00	IDR 56,000,000,000.00	IDR 28,000,000,000.00
Transport impact cost/km (IDR)	IDR 904,249.98	Rp 2,170,799.88	IDR 2,422,336.42	IDR 2,146,029.00
CO <sub>2</sub> emission impact/passenger km (grams)	173829.317	417305.688	465660.688	412543.905

**Table 3.** Rapid assessment of existing conditions, optimal number scenario, a half of optimal number scenario, and a quarter of optimal number scenario of new junior high school facilities

Existing	Existing	Optimal scenario	Scenario ½ optimal	Scenario ¼ optimal
New facilities	0	116	58	29
Number of facilities	13	129	71	42
Estimated population reached	535495	2242919	2208422	1915220
Percentage of Population Reached	23.87%	100.00%	98.46%	85.39%
Average distance	656.13	492.18	587.85	635.57
Total distance	1031444.11	4149591.08	4568765.50	3744789.68
School construction cost	IDR-	IDR 232,000,000,000.00	IDR 116,000,000,000.00	IDR 58,000,000,000.00
Transport impact cost/km (IDR)	IDR 552,647.76	Rp 2,223,350.90	IDR 2,447,944.55	IDR 2,006,458.31
CO <sub>2</sub> emission impact/passenger km (grams)	106238.744	427407.881	470582.846	385713.337

**Table 4.** Rapid assessment of existing conditions, optimal number scenario, a hal of optimal number scenario, and a quarter of optimal number scenario of new senior high school facilities

Existing	Existing	Optimal scenario	Scenario ½ optimal	Scenario ¼ optimal
New facilities	0	13	7	4
Number of facilities	13	26	20	17
Estimated population reached	1691755	2242919	2225965	2166001
Percentage of Population Reached	75.43%	100.00%	99.24%	96.57%
Average distance	1664.47	1366.35	1497.20	1607.52
Total distance	8775060.51	11501969.10	11991112.20	12061217.75
School construction cost	IDR-	IDR 39,000,000,000.00	IDR 21,000,000,000.00	IDR 12,000,000,000.00
Transport impact cost/km (IDR)	IDR 4,701,677.42	Rp 6,162,755.04	IDR 6,424,837.88	IDR 6,462,400.47
CO <sub>2</sub> emission impact/passenger km (grams)	903831.233	1184702.817	1235084.549	1242305.428

Based on the results of the rapid assessment of each scenario of educational facilities, the percentage of the optimal population depends on the number of facilities allocated. However, there is g. Generally, each scenario has no significant differences and still reaches over 80% of the population. Meanwhile, the average distance of each scenario is inversely proportional to the

number of facilities, where the greater the number of facilities provided, the less distance that needs to be traveled.

In comparing development costs, the number of facilities allocated significantly affects the costs incurred in each scenario. The more facilities provided, the greater the costs that must be incurred. However, the estimated affordable

population is similar, so the minimum number of facilities can be selected in terms of development costs. Meanwhile, the transportation costs and the impact of CO<sub>2</sub> emissions depend on the total distance of the journey that needs to be traveled, where the transportation costs are not significantly different for each scenario. However, the impact of CO<sub>2</sub> is quite different, with a comparison between the most efficient scenarios being the least scenario for elementary and junior high school. In contrast, the maximum/optimal number scenario for high school is the most efficient.

## Conclusions

Multi-Scenario Location-Allocation can be considered by policymakers to determine the distribution of educational and health facilities. By comparing all parameters, it can be recommended that the most efficient scenario with the least positive and the least negative impact is the scenario with a quarter of the optimal number of new facilities for elementary and junior high schools. In contrast, for senior high schools, there needs to be further consideration between the scenario with the optimal number and the scenario with a quarter of the optimal number of new facilities in Kupang City.

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#### **Author(s) contribution**

**Amandus Jong Tallo** contributed to the research concepts preparation, methodologies, investigations, data analysis, visualization, articles drafting and revisions.

**Ali A. Alraouf** contribute to the research concepts preparation and literature reviews, data analysis, of article drafts preparation and validation.

**Caesaryo Arif Wibowo** contribute to methodology, supervision, and validation.