

## Multi-Criteria Spatial Analysis in Determining the Location of Centralized Domestic Waste Disposal on a Small City Scale

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**Abstract:** Indonesian government is working to improve how household waste is handled in small cities as part of its efforts to support long-term development in providing clean water and sanitation for all, as reviewed in Sustainable Development Goal 6 (SDG 6). The objective of the country is to ensure that by 2025-2045, at least 70% of people have access to proper sanitation according to the National Long-Term Development Plan (RPJPN). Therefore, this study aimed to identify the best location to build an integrated waste disposal sites in small towns, using Muara Rupit City, the newly designated capital of North Musi Rawas Regency as an example. To identify suitable location, the study used a method that looked at different factors together called Multi-Criteria Spatial Analysis (MCSA) and a decision-making tool known for as the Analytic Hierarchy Process (AHP). The data used in the analysis came from several sources, including land use and plant coverage from satellite images (Sentinel 1 A), Digital Elevation Model (DEM) with a 2.5 m resolution, a spatial plan map of Muara Rupit City, as well as natural conditions such as rainfall and soil type. This study classified and scored different areas using GIS (Geographic Information Systems) technology. AHP was then used to calculate how important each factor was in selecting location. The analysis showed a consistency ratio of 2.8%, meaning the results were reliable. The study found that GIS-based method was effective in helping decision-makers select suitable places for waste disposal. The final result was a map showing areas that ranged from not very suitable to highly suitable. However, only a small part around 10% of the total study area was considered suitable, with just 2% being ideal for integrated waste disposal. In total, about 4722.21 hectares in the district were found to be appropriate for these facilities.

**Keywords:** Integrated domestic waste disposal, AHP, GIS, MCSA, Sustainable.

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## 1. Introduction

A major driver of sustainable development is the expansion of environmental infrastructure. Among these, improving access to sanitation for domestic wastewater plays a crucial role. Addressing sanitation issues is essential, specifically in light of the 2045 target by Indonesia to achieve 70% coverage of proper sanitation, as reviewed in the National Long-Term Development Plan (RPJPN) 2025–2045.

This objective supports the national commitment to the Sustainable Development Goals (SDGs) of the country, particularly SDG 6,

which focuses on ensuring access to clean water and sanitation for all (Lebu et al. 2024). SDG 11 also aims to build inclusive, safe, resilient, and sustainable cities as well as communities (Wood, et al, 2018). The target includes ensuring that 70% of households have access to safe and proper sanitation. In addition, the objective is to ensure that all communities including urban as well as rural are entirely free from the practice of open defecation (BABS). Despite ongoing efforts, challenges remain according to the 2023 report by the Central Statistics Agency (BPS) of Indonesia approximately 11 million people still engage in open defecation. Although there has been a 1% decrease in the national rate of open defecation compared to the previous year, 3.2% of households

continue this practice. Currently, only 74.6% of households have access to proper sanitation, and the percentage of the population practicing open defecation remains high at 9.36%, equivalent to about 25 million people.

This puts Indonesia in third place globally for the highest number of people still defecating in the open (Xu et al. 2024).

Indonesia is committed in expanding access to adequate sanitation to meet the SDG targets by 2030, promoting equitable hygiene practices, and eliminating open defecation entirely. A central component of this strategy is the implementation of Community-Based Total Sanitation (STBM), which is built around five pillars. These pillars include stopping open defecation (SBS), handwashing with soap, safe food and drinking water processing, proper household waste management, as well as effective treatment of household liquid waste to prevent environmental pollution. In terms of infrastructure, large-scale, centralized domestic wastewater treatment systems are considered the most suitable solution for urban sanitation needs (Monachese et al. 2025). These systems are specifically viable in commercial and industrial zones, as observed in many other countries. However, decentralized systems—designed to serve individual properties or small groups—are acquiring traction globally. These systems offer multiple benefits, including nutrient and energy recovery, freshwater conservation, as well as helping to maintain access to clean water sources during periods of water scarcity (Neo et al. 2022). Following the discussion, decentralized systems tend to be more cost-effective. Estimates show that investment costs of the systems are 20–50% lower than those of traditional centralized plants, with operating and maintenance expenses reduced by 5–25%. Centralized domestic waste disposal may still be implemented in rural areas, where residential buildings are more spread out (Jucherski et al. 2024). In such areas simplified systems for waste collection, drainage, and wastewater treatment are often used. When soil conditions are favorable, such as the presence of sandy or permeable soils, these disposal systems can be low-cost, effective, and safe. On the other hand, regular maintenance is critical to ensure long-term functionality. In areas with dense clay, shallow rock layers, or high groundwater tables, alternative solutions may be required due to limited soil absorption capacity (Shaaban 2024).

## 2. Literature Review

Many experts use a method called Life Cycle Assessment (LCA) to better understand how domestic waste systems affect the environment (Gerbino, Quentier, and Pénicaud 2022). The method is an important sub-field of industrial ecology that follows the ISO14040 series (Bellur et al. 2022). LCA is a method for assessing several potential environmental impacts and resources used throughout the life cycle of a product or service, namely from raw material acquisition to final disposal or so-called 'from start to finish' (Orieschnig et al. 2022). This method has been widely used to assess environmental impacts in waste management studies. MCDM (Multi Criteria Decision Making) method is applied to find a suitable location for the selected waste treatment/disposal/recycling site. In this study (Vinogradova-Zinkevič, Podvezko, and Zavadskas 2021), MCDM method is used to determine geographical (territorial) criteria and sustainability criteria and then prioritize the selected alternative locations manually or systematically. In some studies, the method is

incorporated with a geographic information system (GIS) to address the problem of site selection more accurately as well as reliably by considering land characteristics, different types of land use in an area, and others (Borrelli et al. 2017). Based on previous studies, various integrated domestic waste disposal site selection methods had been developed over the past few decades to improve efficiency. Since the process of selecting an integrated domestic waste disposal site depends on various regulations, compliance, consideration of certain parameters, and extensive spatial data that should be evaluated and processed. In the current development of IT technology, GIS has been widely used to select the right waste disposal site (Higgs 2006).

### Multi-Criteria Spatial Analysis (MCSA) using GIS

The use of Multi Criteria Analysis (MCA) methods is widely used to overcome the complexity faced by decision makers when handling extensive and complex information (Solomonov et al. 2022). The integration of GIS and MCA is widely used in decision making to determine a location, which applies a lot of data related to digital geospatial data (Putranto, Fitriani, and Andriani 2020). In the end, the multi-criteria methods that uses geospatial data is widely known as Multicriteria Spatial Analysis (MCSA). This method in the decision-making process includes various criteria that are often related to spatial data, such as land use data, road network data, and soil type data obtained from data from satellite image interpretation results as well as other thematic map sources showing the position or location of each object used as a decision-making parameter. However, in determining the weights for various consideration factors in determining the location, it is often determined based on the significance of each data used (Dey et al. 2020). MCSA method reduces the complexity of decision making by simplifying the assessment to be easily managed, analyzing each element individually and then integrating it logically according to the decision to be taken (Vaissi and Sharifi 2019). The application of the method to the appropriate domestic waste disposal location determination system, the lack of interpretation tools to convert MCSA results into relevant information for decision making in a concise and transparent manner makes the outcomes rarely conclusive in addition to the various advantages that can be offered (Figueroa-Miranda et al. 2018). In some cases, the assessment results of each parameter in location determination can be weighted and summed across categories to determine one score indicator for each location determination option. During other cases, studies use a limited number of location determination categories to facilitate interpretation of the results, only considering the contribution of land use types to the problem. The main weakness of this method is the objectivity of the relevant assessment method (Zimmermann and Gutsche 1991). Decision making also becomes more difficult when the sustainability assessment includes other sustainability criteria, namely economic and social criteria. In such conditions, the decision-making process turns into a complex multi-criteria problem with multiple objectives, which poses a risk of conflicting results. Therefore, a comprehensive sustainability assessment method that can simultaneously address environmental, economic and social criteria is necessary to achieve a truly sustainable siting system (Chen, Guo, and Judge 2024).

### Analysis Process using GIS

Spatial MCDM is a method that helps turn map-based information

into useful decisions. It uses geographic data, such as maps and satellite images, along with the preferences of decisions-makers. Moreover, the method follows certain rules or conditions to combine different types of location-related information into simple scores. These scores make it easier to compare and select between different options.

Different from basic decision-making methods, Spatial MCDM handles more detailed information and more complex relationships between factors (Belton and Stewart 2002). Due to this complexity, tools such as GIS and MCSA are often used to improve accuracy and efficiency. When these tools are combined, the process is called Multicriteria Spatial Analysis (MCSA). In this study, MCSA is presented using a map evaluation table, as shown in Figure 1 (Brouwer and Van Ek 2004). When the purpose of the analysis is to rank a set of alternatives, the evaluation table should be converted into a single, clear ranking. However, defining the exact function for this transformation can be quite complicated. To simplify the process, the function is broken down into two major operations, namely the aggregation of spatial components and criteria. These two operations can be performed in two different sequences, commonly referred to as Path 1 and 2, as shown in Figure 2a. The main difference between these two paths lies in the order in which the aggregations are performed. In Path 1, the process starts with the aggregation across spatial units, where spatial analysis plays a dominant role. After the process, the analysis continues with the aggregation of criteria, where MCA becomes central. This order is reversed in Path 2b as the criteria are aggregated first, followed by the spatial units. In the first case (Path 1), the outcome for each alternative and each criterion is represented as a map. This method is particularly useful for evaluating spatial problems that require a visual representation of alternatives. Consequently, Path 2 is more suitable when the focus is on individual location, where each point is treated as a separate, non-spatial, or 0-dimensional problem.

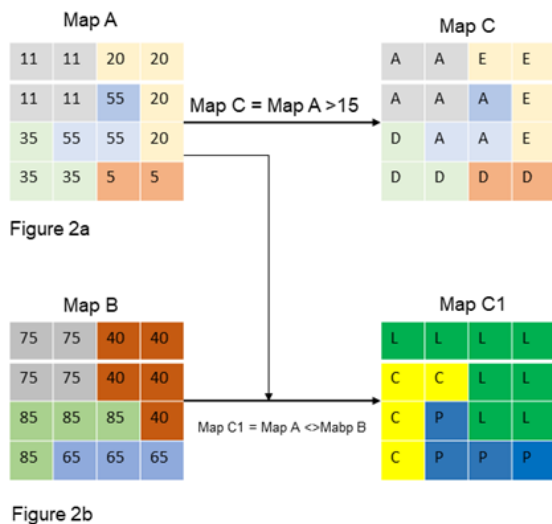


Figure 1. Some examples of Boolean Statements in MCSA with GIS

### 3. Methodology

#### Data and Location

The study location was the development area of the capital city of North Musi Rawas Regency in Muara Rupit City, South Sumatra Province, Indonesia. The coordinates of the development area of

the city were at Longitude Coordinates 48o 30' 38" – 48o 59' 17" East Longitude and between latitude - 2° 41' 27" - 2° 49' 30" South Latitude. Moreover, the development area of Muara Rupit City included two sub-districts (Figure 2), namely Rupit Sub-district which comprised the villages of Lawang Agung, Lubuk Rumbai, Tanjung Beringin, Noman, Batu Gajah, Maur Baru, Maur Lama, Bingin Rupit, and Muara Rupit as well as Karang Dapo Sub-district, having Kertasari, Karang Dapo I, and Rantau Kadam. Location was projected to become the new Government and Urban Center of the Capital City of North Musi Rawas with an area of 262,598 Km<sup>2</sup>. Following the descriptions, the Muara Rupit capital city development area was located in two sub-DAS areas, namely the Rupit Hilir sub-Catchment with an area of 37.80 Km<sup>2</sup> and the Rawas Hilir sub-Catchment having an area of 224.80 Km<sup>2</sup>. This area was observed to have the highest area altitude of 70 m above sea level and the lowest 20 m above sea level, respectively.

#### Data

The data used was sourced from geographically based data, as the basis for parameters in determining location of incorporated domestic waste disposal, which included the following. (1) Slope class map, obtained from the analysis of the Digital Elevation Model (DEM) of the study area with a Contour interval of 2.5 m from DEMNAS Indonesia. (2) Land use map of the study area, obtained from the interpretation and classification of Sentinel 1A composite imagery (April, 2024), which was classified based on vegetation density level, type of land use, and infiltration coefficient value, verified by field identification. Additionally, (3) A Detailed Spatial Plan Map of Muara Rupit City, which showed the road network plan, clean water network plan as well as location of the main clean water sources, and main activity centers. (4) Soil type map and interpretation of the potential ability of the soil as waste processor and decomposer. (5) Watershed Morphometry Map, which classified the level of drainage density as a basis for interpreting the ease of water flow. Finally, (6) Map of rainfall distribution conditions in the study area as a basis for determining climate conditions.

#### Study Methods

**Determination of Spatial Criteria:** In this study, MCDM was mostly used without focusing on specific location. The method relied on average or total values that were assumed to represent the whole area (Robert J. Tkach and Slobodan P. Simonovic 1997). The main difference between spatial and non-spatial decision-making was that spatial analysis clearly included location-based information. Due to this reason, spatial decision-making needed data about the geographic location or location-based values of each criterion. To support the decision-making process, the data was analyzed using both MCDM and GIS tools.

Selecting the right location for an integrated domestic waste disposal site included a comprehensive evaluation using MCSA method. GIS-based maps helped to rule out areas that were not environmentally suitable, which reduced bias when judging each factor. Moreover, each factor was grouped into four or five categories, including not suitable, less suitable, fairly suitable, very suitable, and most suitable, respectively. These categories were rated using only odd numbers, namely 1, 3, 5, 7, and 9 starting from the lowest (less suitable) to the highest (very suitable), as shown in Table 2.

Table 1. Area of Sub-Catchment Development Area of Muara Rupit City

Catchment	Km2	Village area
Rupit downstream	37,80233602	Muara Rupit, Lawang Agung, Bingin Rupit, Maur Lama
Rawas downstream	224,7959915	Lubuk Rumbai, Kerta Sari, Rantau Kadam, Karang Dapo 1, Maur Baru, Batu Gajah, Muara Rupit, Noman

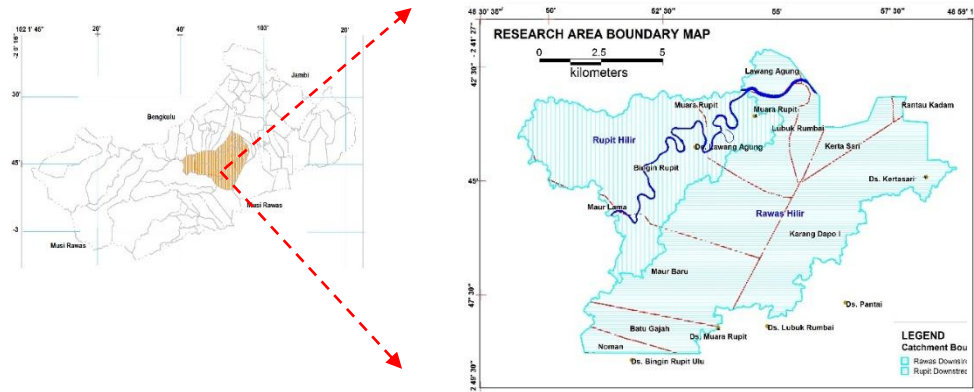


Figure 3. Sub-Catchment Boundaries of the Muara Rupit City Development Area

Table 2. Reclassify Ranges for suitable integrated domestic waste site selection factors

No.	Name of criteria	Classes (Km2)	Ranking	Reference
1	Flow density	0,00 – 0,09	7	((Ferdowsi and Behzadian 2024)Ahmad et al., 2016; Chabuk et al., 2016; Ebistu & Sewnet Minale, 2013; Ohri et al., 2015; Şener et al.,2011; Yildirim, 2012)
		0,09 – 0,24	5	
		0,24 – 0,39	3	
		0,39 – 0,79	1	
2	Slope	> 4 %	1	(Chabuk et al., 2016)
		3 – 4 %	3	(Rodrigues and Bacani 2016)
		2 – 3 %	5	
		1 – 2 %	7	
		< 1 %	9	
3	Vegetation Density	Sparse Density	9	(Tohirin, Suryanto, and Sadono 2021)(Ebistu & Sewnet Minale, 2013; Ohri et al., 2015)
		Very low	7	
		Medium Density	5	
		Semi Dense Forest	3	
		Dense Forest	1	
4	Land use	Vacant Land	9	
		Seasonal Crops	7	
		Plantation Land	5	
		Agricultural Land	3	
		Forest Land	1	
5	Climate Regim	Very Dry	1	(El Kamali et al. 2021)Philipp Pattberg and Oscar Widerberg, 2018
		Dry	3	
		Semi Dry	5	
		Humid	7	
		Semi Humid	9	

6	Distance Center/ Industry	From City	0 – 1 Km	1	(Ma et al. 2023)(Xiong, Xiao, and He 2021)Chabuk et al., 2016; Ebistu (Ma et al. 2023)(Putranto, Fitriani, and Andriani 2020)& Sewnet Minale, 2013; Ohri et al., 2015)
			1 – 2 Km	3	
			2 – 3Km	5	
			3 – 4 Km	7	
			4 – 5 Km	9	
7	Distance From Road	Main	0 – 200 m	1	
			200 – 400 m	3	
			400 – 600 m	5	
			600 – 800 m	7	
			800 – 1000 m	9	
8	Distance to Clean Water Source		0 – 200 m	1	
			200 – 400 m	3	
			400 – 600 m	5	
			600 – 800 m	7	
			800 – 1000 m	9	
9	Soil Type		Clay	9	McGauhey dan Winneberger (Sarino, Yuono, and Putranto Dinar 2019)(2020)
			Sandy Loam	7	
			Sandy Loam	5	
			Yellow Brown Regosol	3	
			Brown Andosol	1	

MCSA method gave different levels of importance (weights) to help sort and rank the most suitable location. These weights and rankings were applied to each category of every factor in the spatial data. In addition, experts were relied on to compare these categories and help build a numerical chart (matrix). Figure 4 showed a step-by-step flowchart explaining the procedures and methods used to find the best location for centralized, integrated domestic waste disposal sites.

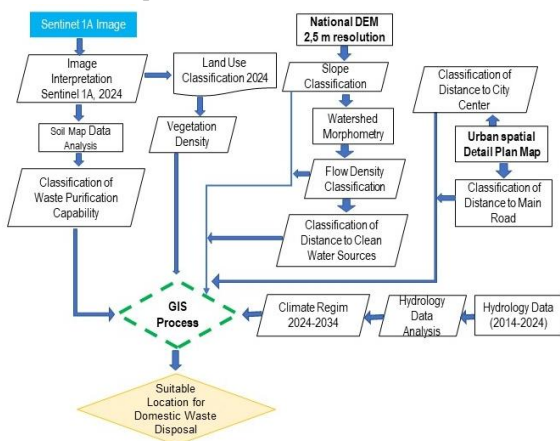


Figure 4. Flow Chart of Methodology Workflow of Integrated Domestic Waste

**Analysis Process using GIS:** Satellite images from Sentinel 1A were used to make a land use and land cover map of the entire study area. After the images were prepared through pre-processing, analysis was performed using the Intensity, Hue, and Saturation (HIS) interpretation method. This method helped identify and

describe different types of land use, how dense the vegetation was, and the types of soil. In the end, the land use and land cover map was divided into specific categories based on set criteria, namely agricultural land, barren land, water bodies, and built-up areas. During the process, a numerical matrix was then created to support further analysis.

#### 4. Results and Discussion

##### Data Visualization/Preparation of Criteria Map

**Main Road Network:** When selecting location for an integrated domestic waste disposal site, the main road network was an important factor. How close the site was to main roads affected access to drainage and the ability to transport waste from temporary collection points to the final disposal site (States, 2024). According to Mornya et al. (Pathak, 2024), waste disposal sites should not be placed closer to main roads because of health risks and how the areas might look or smell to people passing by. As shown in Figure 5a, any site less than 600 meters from a main road was considered unsuitable due to health and sanitation concerns, including odor. On the other hand, sites located more than 1000 meters away were observed as most suitable, as location could also help lower transportation costs when waste had to be moved to the final disposal area.

**Distance with Center of Clean Water Source:** Location that was farther away from clean water sources, rivers, and streams were given higher priority when selecting suitable sites for integrated domestic waste disposal (Borselli, Cassi, and Torri 2008). To protect the health of water sources, a minimum distance of more than 600 meters from the center of any clean water source was

preferred. Sites that were far from water bodies were considered the most suitable. As shown in Figure 5b, areas less than 600 meters from clean water sources were marked as restricted, while areas farther away were marked as suitable for selecting waste disposal sites.

**Slope:** Slope was an important factor in selecting a site for integrated domestic waste disposal since flatter areas helped reduce construction costs for digging and site preparation(Rai et al. 2020). A DEM was used to measure and classify the slope of the land. As shown in Figure 5c, areas with a slope of less than 1% were considered the most suitable for building waste disposal sites

**Flow Density:** The density of water flow in the sub-watershed area affected how quickly surface water could move down into the main water channel(Munoth and Goyal 2020). In other words, the more dense the flow, the faster water could travel. However, areas with high flow density were considered less suitable for waste disposal, as this increased the risk of leachate (liquid waste) seeping into the soil and polluting the environment. Figure 5d showed how the flow density was classified across the study area.

**Distance to City Center/Industrial Center:** Another important factor in selecting a site for integrated domestic waste disposal was the distance from city centers, industrial zones, or residential areas. The process was performed to protect these areas from health risks and disturbances caused by domestic waste. According to Mornya et al. (Ma et al. 2023), disposal sites should not be placed near cities, factories, or homes. Figure 5e showed that sites located far from residential, industrial, or city centers were given the highest priority, to preserve the appearance and environment of the city.

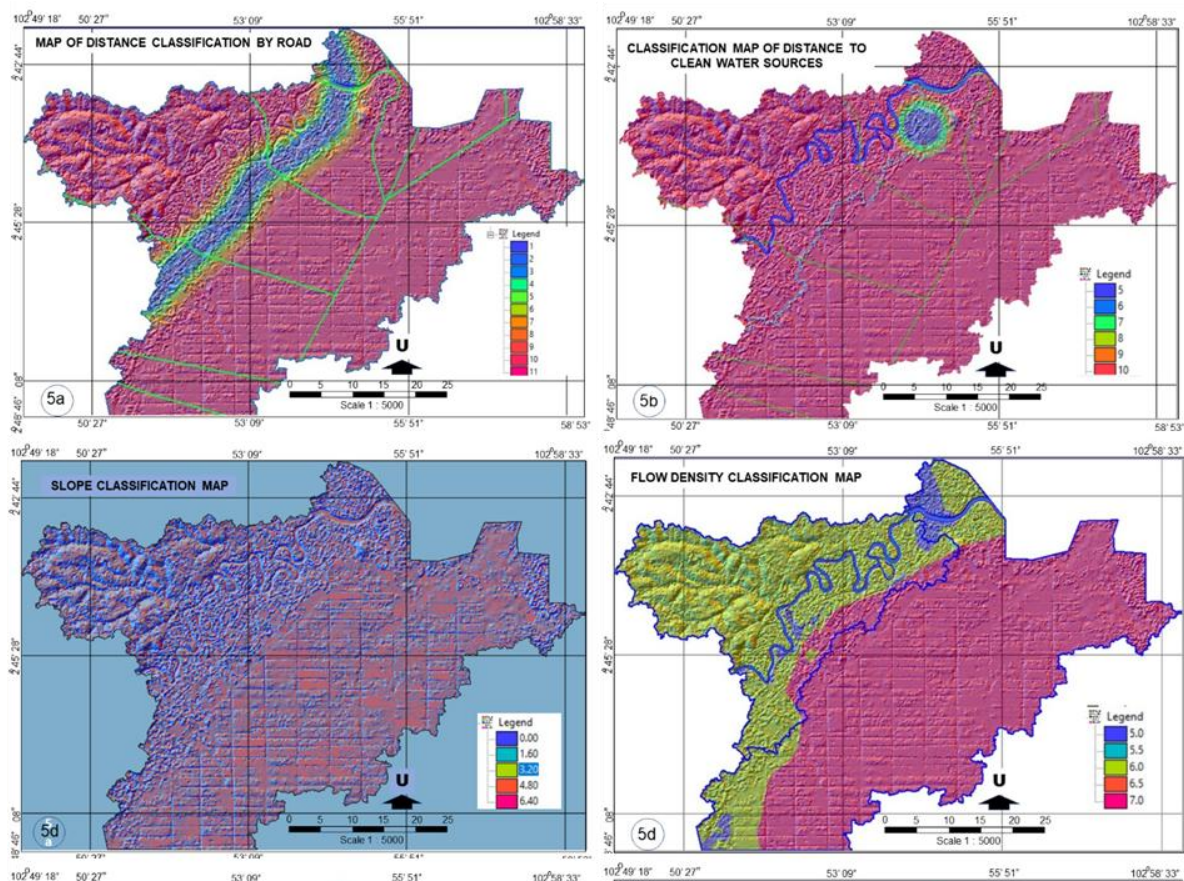
**Vegetation Type/Land Use:** Various types of vegetation coverage

are considered in determining location of integrated domestic waste disposal, including agricultural areas/water bodies are considered very limited while grasslands and barren lands are given higher priority(Chengbin Deng 2018). Figure 5f, shows the classification of the best-suggested vegetation types for the placement of the most integrated domestic waste disposal location in small cities.

**Vegetation Density:** Vegetation density was one of the factors considered when selecting location for integrated domestic waste disposal. Areas with sparse vegetation were given higher priority, as location was more suitable for waste disposal. Consequently, areas with dense vegetation were considered less suitable during the analysis(Indrayani et al. 2017). Figure 5g, showed how vegetation density was classified in the study area, with grasslands and barren land, having sparse vegetation ranked as top priorities

**Soil Type:** Soil type was another important factor in selecting the right location for an integrated domestic waste disposal site. This was because different soils had different abilities to break down waste. Clay soil was given higher priority because it can decompose waste more effectively(Truu et al. 2021). Figure 5h, showed the classification of suitable areas, with location that had clay soil marked as the most preferred waste disposal sites.

**Climate Regime:** The amount of daily rainfall in the study area was an important factor in deciding where to place integrated domestic waste disposal sites. Areas with low or infrequent rainfall were given higher priority because location was less possibly to cause water-related problems such as leachate spread[39]. Figure 5i, showed the classification of rainfall distribution across the study area, helping to identify the most suitable location.



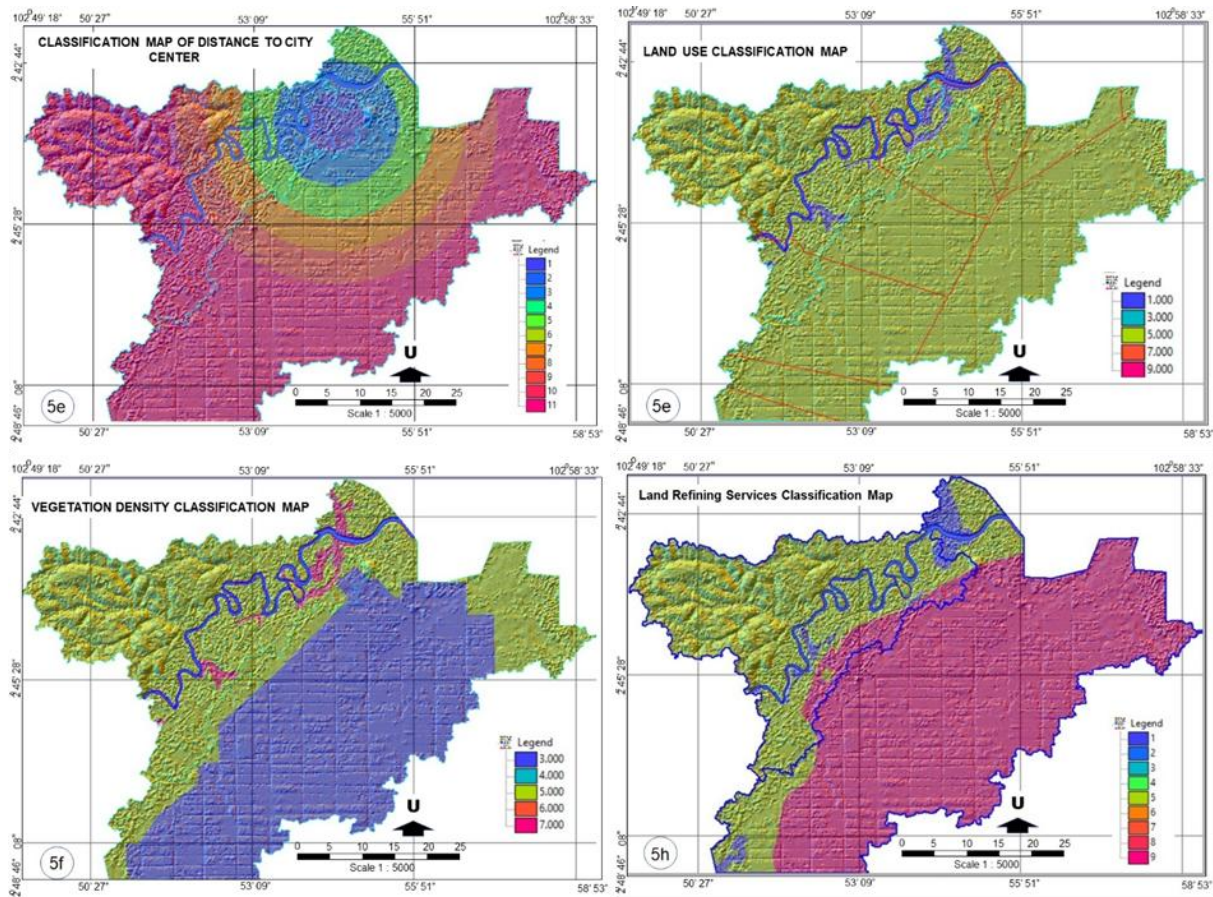


Figure 5. Integrated Domestic Waste Location Determination Criteria Parameter Classification Map

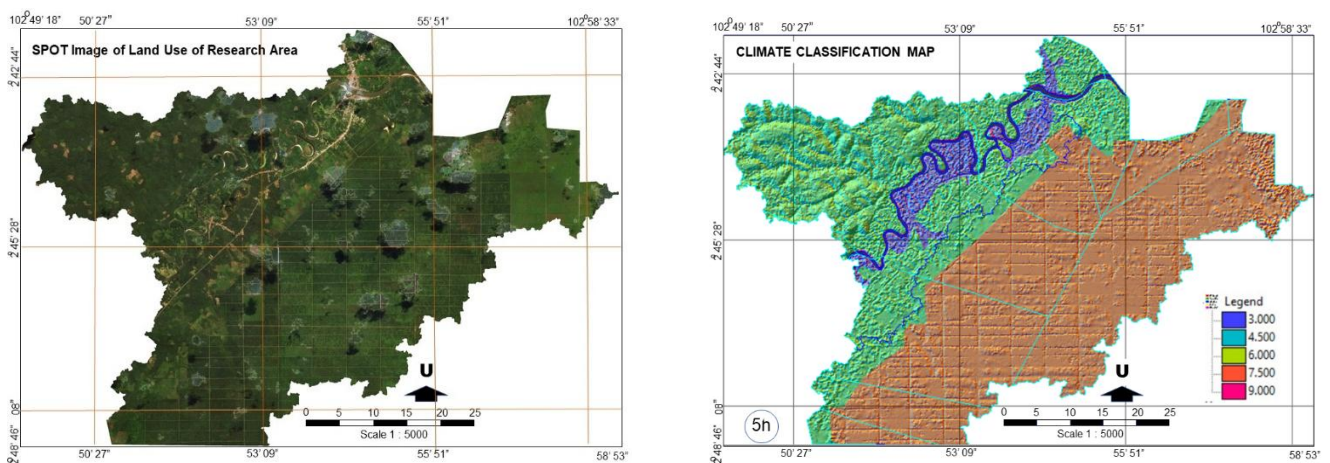


Figure 6. Integrated Domestic Waste Location Determination Criteria Parameter Spot Image and Climate Classification Map (

### Integrated Domestic Waste Suitability Map

The final suitability map for the integrated domestic waste disposal site was formed by combining both suitability and limiting factors. The analysis showed that about 77% of the total study area was classified as limited or unsuitable. The unsuitable areas were mostly found in the downstream part of the Rupit sub-watershed. This was because the land there had a slope greater than 4%, was close to the mouth of the Rupit River, and was part of the city center or capital area of North Musi Rawas Regency.

In the context of the study, the area should be excluded from being used as a site for integrated domestic waste disposal, as it could

lead to serious environmental and health issues or negatively affect the appearance of the city. About 22% of the total area was found to be the most unsuitable, while only around 14% was considered suitable. This showed there is no area in the capital city of North Musi Rawas Regency, Muara Rupit that was very suitable for waste disposal site. The suitability map showed that the most appropriate location for an integrated domestic waste disposal site is in a former oil palm plantation area in Karang Dapo 1 Village, Rawas Ilir District. Meanwhile, areas such as Kertasari Village and Muara Baru Village are considered suitable for temporary waste disposal or as sub-centers for waste collection).

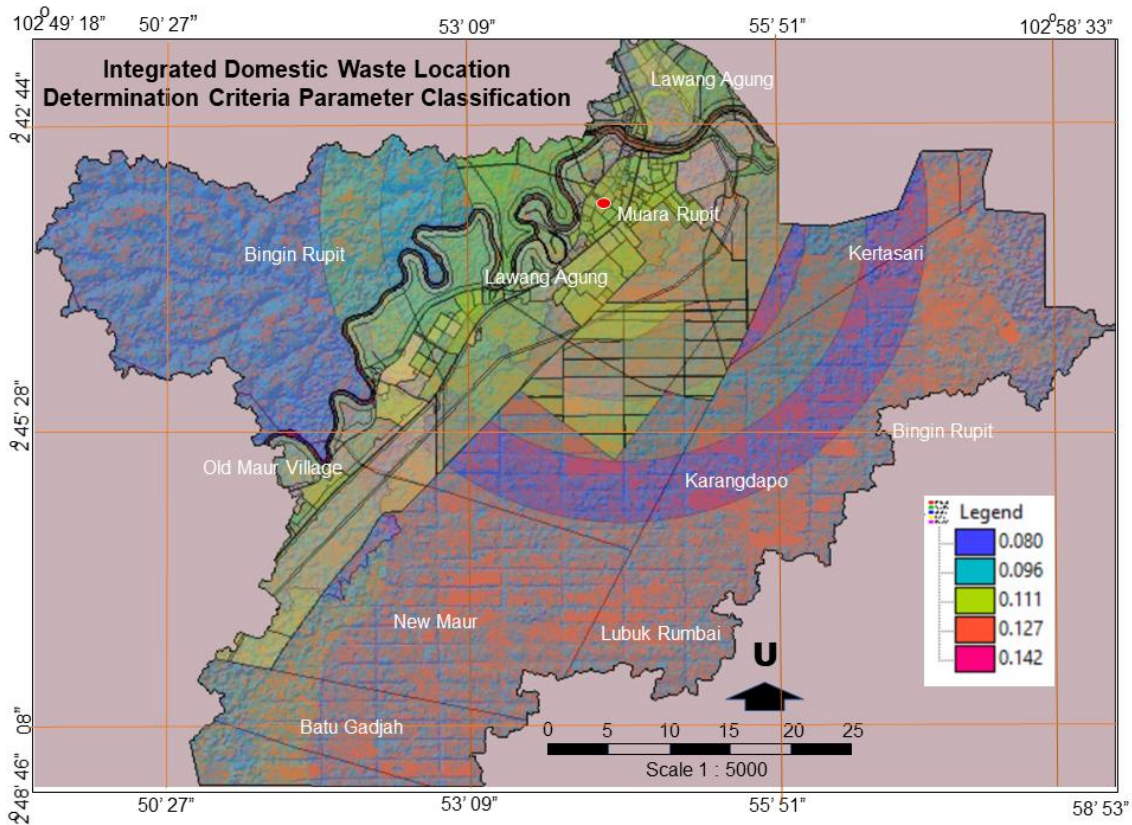


Figure 6. Integrated Domestic Waste Location Determination Criteria Parameter Classification Map

## Conclusion

In conclusion, Muara Rupit District experienced rapid population growth and urban development in recent years after being named the capital of North Musi Rawas Regency, which was formed as a new division from the former Musi Rawas Regency. As Muara Rupit became the capital, there was a growing need to plan and develop environmental facilities, specifically those related to managing household waste. However, since the Detailed Spatial Plan for the city was completed, location for an integrated domestic waste disposal site had not yet been decided. This made identifying a suitable location for waste disposal both urgent and important. In this study, GIS were combined with the AHP-MCSA method to discover the most suitable sites for waste disposal. During the analysis, AHP was used to assign importance (weights) to various factors, such as land use/land cover, distance from roads, water bodies, and the city center. This helped in ranking and prioritizing the different factors considered in the analysis. A total of nine parameters were used in the study, allowing for a more detailed and accurate assessment. During the process, each factor was classified into five levels of suitability. Understanding the soil properties of potential sites, specifically how water moves through the soil (such as hydraulic conductivity and permeability) and the ability of the soil to break down waste were also found to be valuable in selecting the best location for domestic waste disposal site.

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