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Implementation of the Analytical Hierarchy Process-PROMETHEE and Geographic Information System for Selecting Landfill Sites in Berau Regency

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***Abstract*— The population growth in Berau Regency, which reached 2.33% in 2022, has led to an increase in daily waste production, rendering the existing landfill unsuitable and located too close to residential areas. This study recommends the relocation of the landfill, following SNI 03-3241-1994 and the Ministry of Public Works and Housing Regulation No. 3/PRT/M/2013, which involve three stages: regional, screening, and determination. GIS was utilised for regional analysis using buffering and overlay methods, identifying zones with scores of 7 and 8 as potential alternative locations. AHP was employed in the screening stage to assign weights to criteria and rank alternatives. The Simpang Pagat Bukur area in Teluk Bayur Subdistrict was selected as the best alternative. These findings serve as a recommendation for the government in spatial planning for Berau Regency.**

***Keywords*— AHP, GIS, Landfill, MCDM,**

I. INTRODUCTION

It is crucial that the design and selection of alternative landfill (TPA) locations consider both environmental and economic factors. According to Merry N. M. Kosakoy et al. (2022), the determination of landfill locations involves several stages, including regional and exclusion stages. Many criteria can be assessed quickly and accurately with the assistance of Geographic Information Systems (GIS), which have been widely used for suitability analysis to determine the appropriateness of a specific area for certain purposes.

With the growing interest in GIS software, its integration with multi-criteria decision-making (MCDM) techniques has proven effective in solving practical problems and finding precise solutions (Chen et al., 2010). The Analytical Hierarchy Process (AHP) is an excellent tool or method for decision-making processes aimed at selecting the best option from several available alternatives, such as choosing a location, transportation mode, and other options (Saaty, 1980; Sk et al., 2020).

The Analytical Hierarchy Process (AHP) provides an analytical approach and can be combined with other MCDM methods, such as the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), to address AHP's limitations. AHP primarily quantifies qualitative criteria, whereas PROMETHEE can evaluate alternatives using quantitative criteria with specific patterns found in its six models.

Research conducted by Makan et al. (2012) has demonstrated the effectiveness of combining these methods for comprehensive decision-making.

II. LITERATURE REVIEW

A. Definition of Waste

Waste is material that is discarded or thrown away from natural or human sources that no longer has economic value. Households, agriculture, offices, businesses, hospitals, markets, and other places are sources of waste. People in both rural and urban areas complain about the waste problem, so it needs to be addressed to prevent it from becoming a sustainable issue (Sugiyani, 2017). According to Widiarti (2012), waste refers to items or materials that are no longer useful. It is the residual product or something made from the remnants of use, whose value is less than that of the product used by the consumer, thus being discarded or not reused (Widiarti, 2012).

In developing countries, most of the waste generated is not recycled. Improper and hazardous disposal of discarded items is a major problem. The lack of waste recycling makes it difficult to compost or recycle the waste. As a result, much solid waste is burned and dumped in open spaces in poor countries (Ziraba et al., 2016).

Landfills, which are typically large open areas or waterways, are places where garbage trucks often dump waste. Scavengers explore discarded waste to find items that can be recycled or reused. As an alternative, they often burn the waste to reduce the amount of waste disposed of (Ziraba et al., 2016). Good environmental management principles indicate that the management of governmental affairs related to natural resources and the environment should prioritize the protection and preservation of environmental functions to support better institutionalization (Nopyandri, 2011).

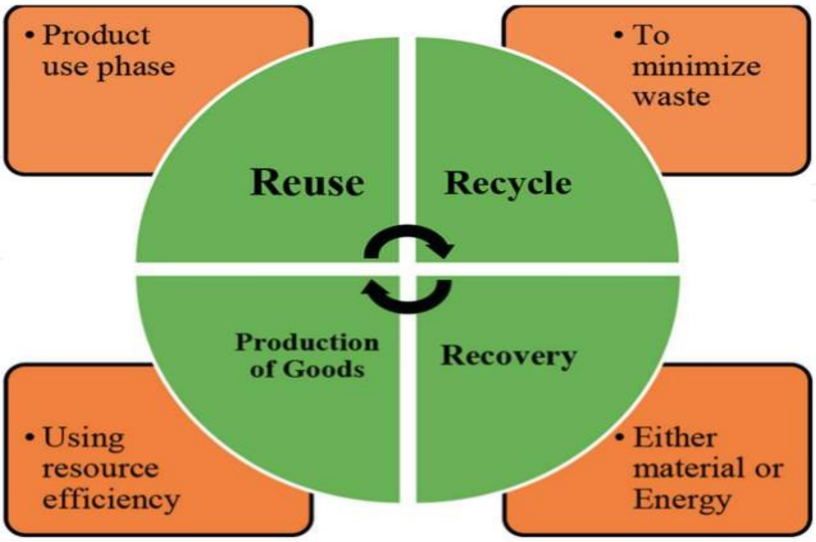

Fig 1. Safe disposal to minimize residual waste
Source: Ziraba et al. (2016)

B. Landfill Waste Management System

Open dumping is a simple disposal method where waste is simply placed in a location, left exposed without protection, and abandoned once the site is full. Due to limited resources (human, financial, etc.), many local governments still implement this system.

The controlled landfill system is an improved version of open dumping, representing a transition between open dumping and sanitary landfilling techniques. In this method, waste is covered with a layer of soil once the landfill is filled with compacted waste or after reaching a certain stage/period. The soil covering is not done every day but over a longer period of time. The process involves burying, leveling, and compacting the waste, followed by covering it with a soil layer at certain intervals to minimize harmful environmental impacts. Once the landfill reaches the end of its operational life, all the waste must be covered with a soil layer.

A sanitary landfill is a waste disposal system where waste is buried, compacted, and then covered with soil as a covering layer. This process is continuously carried out in layers according to a predetermined plan. The process of covering waste with soil is done every day at the end of the operating hours.

C. Stages of the Decision-Making Process

According to Herbert A. Simon (1977), there are several stages or phases in the decision-making process, which include three main phases: intelligence, design, and criteria. He later added a fourth phase, namely implementation.

Dr. Thomas Saaty, a professor at the University of Pittsburgh in 1977, proposed the Analytical Hierarchy Process (AHP), an integrated decision-making procedure. He continued to refine this method until AHP became a well-established multi-criteria decision-making theory in 1980 and 2001. In most decision-making problems, both quantitative and qualitative information must be considered, as the data is often complex. This complex decision-making system is transformed by the Analytical Hierarchy Process (AHP) into a simpler hierarchical system with one-way hierarchical relationships between levels.

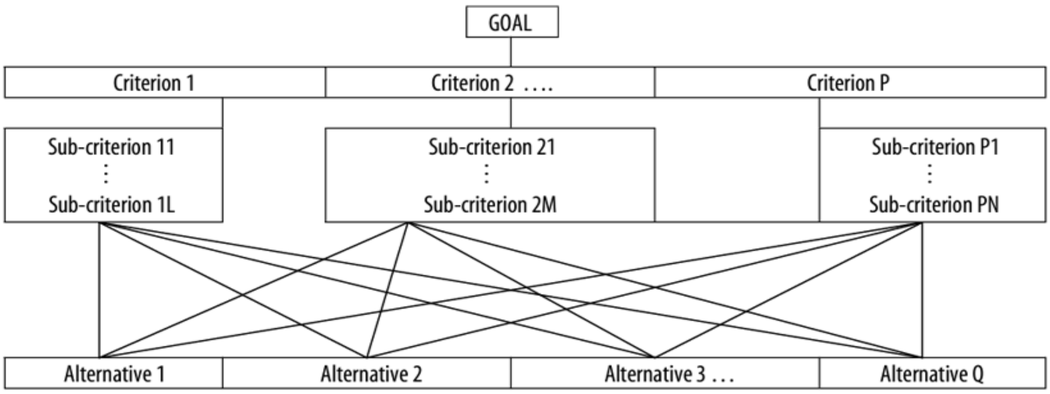

Fig 2. General Hierarchical Structure
Source: Bhushan & Rai, (2004)

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III. METHODOLOGY

This study is a case study of multi-criteria decision-making combined with GIS to select an alternative landfill (TPA) location in Berau Regency, using a rational, systematic, and scientific approach in the decision-making process. Below is the flow of the research conducted.
Data collection in this study includes the stages of analysis, types of data, methods of obtaining data, and data sources (Table 1). There are two types of data: primary data and secondary data. The analysis consists of three stages: regional analysis, exclusion analysis, and determination analysis, which include both primary and secondary data.

Software Used:

The software utilised by the author in this research includes:
a) Microsoft Excel 365 Enterprise/
b) Visual Promethee

Table 1. Data Collection Techniques

NO	STAGE OF ANALYSIS	DATA VARIABLE	DATA TYPE	DATA SOURCE/ACQUISITION METHOD
1	Regional	Slope Gradient	Secondary Data	Agency Survey
2		Geological Conditions	Secondary Data	Agency Survey
3		Hydrology	Secondary Data	Agency Survey
4		Residential Areas	Secondary Data	Agency Survey
5		Agricultural Cultivation	Secondary Data	Agency Survey
6		Protected Areas	Secondary Data	Agency Survey
7		Flood-Prone Areas	Secondary Data	Agency Survey
		Administrative Boundaries	Secondary Data	Agency Survey
8	Screening	Road Network	Secondary Data	Agency Survey
9		Population Data	Secondary Data	Agency Survey
10		Hydrogeology	Secondary Data	Agency Survey
11	Existing Data	Existing Conditions	Primary Data	Field Survey
12		Questionnaire	Primary Data	Field Survey
13	Determination	Selected Landfill Recommendation		

IV. RESULT AND DISCUSSION

A. General Overview of the Area

Berau Regency is one of the regencies located in the northernmost part of East Kalimantan Province, directly bordering North Kalimantan Province. The capital of Berau Regency is in Tanjung Redeb District, which is located 296 km from the provincial capital of East Kalimantan. Berau Regency is the third largest regency in East Kalimantan Province, after East Kutai and Kutai Kartanegara, with an area of 36,962.37 km², of which 22,232.54 km² is land and 14,729.86 km² is water, extending 12 miles from the coastline of the outermost islands.

Berau Regency consists of 13 districts, 10 urban villages, and 100 villages. Geographically, Berau Regency is located between 116°08'28" East Longitude to 119°03'31" East Longitude and 0°59'28" North Latitude to 2°37'32" North Latitude. The geographic boundaries of Berau Regency are as follows:

- To the North, it borders Bulungan Regency
- To the East, it borders the Makassar Strait
- To the South, it borders East Kutai Regency
- To the West, it borders Kutai Kartanegara Regency, Malinau Regency, and West Kutai Regency.

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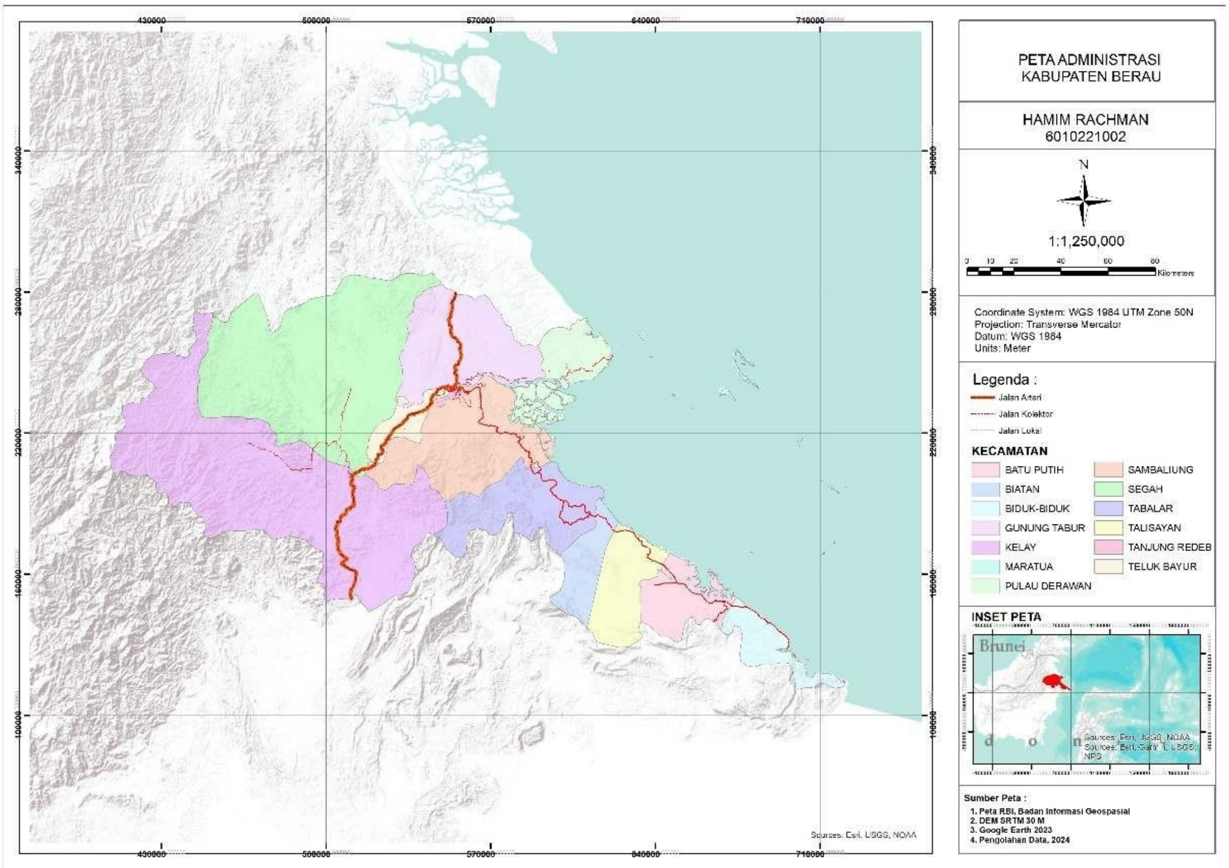

Fig 3. Administrative Boundary Map of Berau Regency

B. Population

The selection of a new landfill (TPA) location in Berau Regency takes into account population density. Berau Regency has experienced an increase in population from year to year, with a recorded population growth rate of 2.4% from 2020 to 2022. Below is the population and population density in each district of Berau Regency..

Table 2. Population and Population Density of Berau Regency

District	District	District	District
Kelay	9988	3.86	1.52
Talisayan	15326	5.93	9.45
Tabalar	7054	2.73	3.84
Biduk - Biduk	6719	2.60	2.77
Pulau Derawan	11734	4.54	2.65
Maratua	3698	1.43	0.66

Sambaliung	38925	15.06	19.05
Tanjung Redeb	71227	27.55	3099.83
Gunung Tabur	26962	10.43	14.33
Segah	15554	6.02	2.97
Teluk Bayur	32905	12.73	103.31
Batu Putih	9102	3.52	2.55
Biatan	9343	3.61	7.84
Berau	258537		

B, Existing Condition

Berau Regency has one Final Disposal Site (TPA), namely TPA Bujangga, which covers an area of approximately 11.35 hectares. It is located on Jl. Sultan Angng RT. 06, Sei Bedugun Sub-district, Tanjung Redeb District, and is managed by the Bujangga TPA Technical Implementation Unit (UPT). The site is situated 500 metres from residential areas.

TPA Bujangga has been operational since 2012, utilising a Controlled Landfill system. This system is an improved or upgraded version of open dumping, serving as a transitional phase between open dumping and sanitary landfill techniques. Currently, the utilised area is approximately 2 hectares, with an active landfill zone spanning about 1 hectare, while the remaining unused land covers around 9.35 hectares.

TPA Bujangga is equipped with various facilities and infrastructure, including:

- A management office with an area of 126 m²
- One weighbridge, which is currently damaged
- A wastewater treatment plant (WWTP) covering 1,600 m²
- A sludge treatment plant (STP), which is non-functional
- A guardhouse of 36 m²
- A security post
- A vehicle washing area
- A generator house
- A composting facility or waste processing unit covering 24 m²
- A bore well

Additionally, operational transportation and heavy equipment at TPA Bujangga include:

- One bulldozer
- Two excavators
- One loader

The site also has methane gas pipelines and utilisation facilities, although they are not currently managed.

At present, the waste pile at TPA Bujangga is overloaded, with an existing waste volume of 232,500 m³. Below is the existing data on the amount of waste at TPA Bujangga.

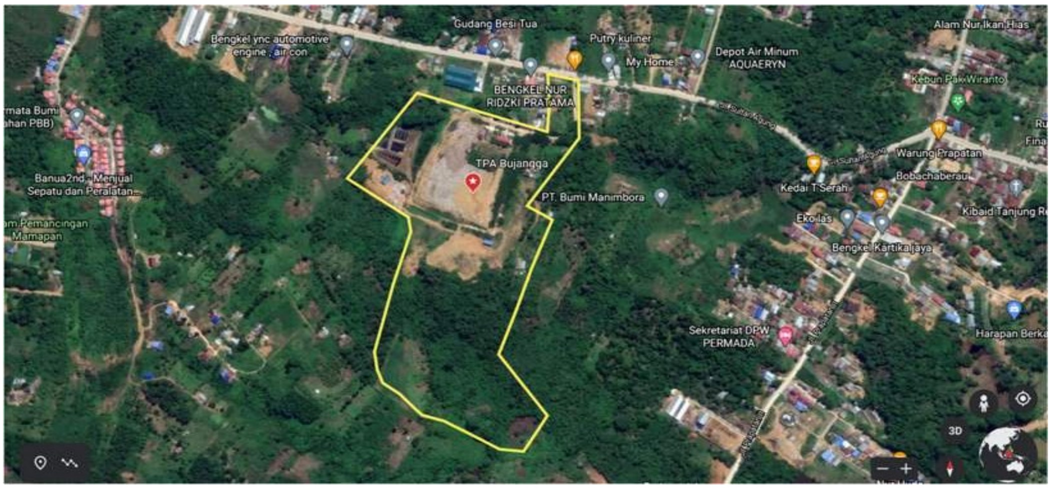

Fig 4. Existing Conditions of TPA Bujangga

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C. Alternative Location

Based on the regional stage analysis, four alternative locations for the new Final Disposal Site (TPA) have been identified, aligning with scores of 7 and 8 from the overlay intersect results.

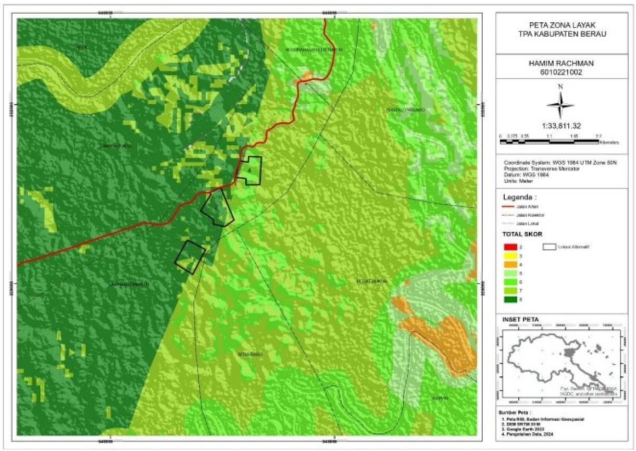

Fig 5. New Alternative Landfill Site

D. Screening Stage Analysis

The screening stage analysis is a process aimed at identifying one or two optimal locations among the selected sites from the feasibility zones determined in the regional stage. In this stage, criteria weighting is conducted using the Analytical Hierarchy Process (AHP) and combined with the PROMETHEE method to determine the alternative locations for the new Final Disposal Site (TPA).

Fig 6. Existing Conditions of Bujangga Landfill

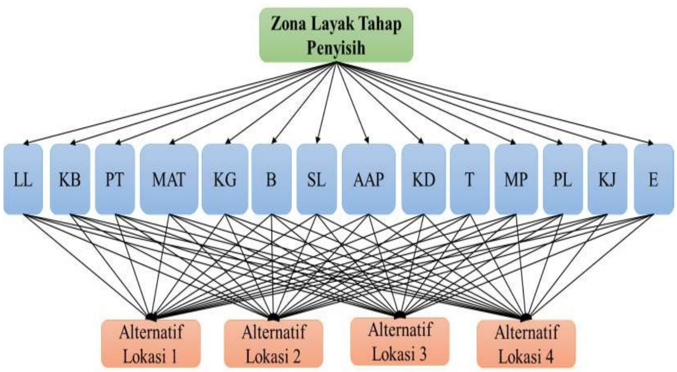

Fig 7. AHP Hierarchical Structure

E. Elimination Stage Analysis

The elimination stage analysis is the process of determining one or two of the best locations from several locations selected from the feasibility zones in the regional stage. In this stage, the determination of the criteria weights is carried out using the Analytical Hierarchy Process (AHP).

After selecting 4 alternative locations from the regional stage, the process continues with the calculation of the criteria weights in the elimination stage, based on the 14 criteria listed in Table 4.

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Table 3. Description of the criteria and sub-criteria for the Sorting Stage

No	Criteria	Sub-Criteria
1	Land Area/Capacity	Operational > 10 years
		Operational 5-10 years
		Operational < 5 years
2	Noise and Odour	There is a buffer zone
		There is a limited buffer zone
		No buffer zone
3	Soil Permeability	< 10^(-9) cm/day
		10^(-9) - 10^(-6) cm/day
		> 10^(-6) cm/day
4	Groundwater Depth	≥ 10 m, permeability < 10^(-9) cm/day
		< 10 m, permeability < 10^(-9) cm/day or ≥ 10 m, permeability 10^(-9)- 10^(-6) cm/day
		< 10 m, permeability > 10^(-6) cm/day
5	Geological Conditions	Far from fault lines
		Near fault lines
		Presence of fault lines
6	Flood Hazard	No flood hazard
		Flood risk > 25 years
		Flood risk < 25 years
7	Land Status	Local/Central Government
		Private (individual)/Community
		Private/Company
8	Groundwater Flow System	Discharge area/local
		Recharge area and local discharge area
		Recharge area regional and local
9	Drainage Conditions	Good
		Moderate
		None
10	Waste Transport	< 15 minutes from waste source centre
		16-60 minutes from waste source centre
		> 60 minutes from waste source centre
11	Cover Material	> 10 years
		5-10 years
		< 10 years
12	Landowner	1 household
		1-10 households
		> 10 households
13	Road Conditions	Present/Good
		Moderate
		Absent
14	Aesthetics	Operations protection not visible from outside
		Operations protection slightly visible from outside
		Operations protection visible from outside

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Based on the questionnaires that were distributed to the respondents/experts, the data was then processed using Microsoft Excel, resulting in the outcomes shown in Table 4. Below is the data from the respondents/experts.

Table 4. List of Respondents/Experts

No	Respondent/Expert	Occupation/Position
1.	Expert 1	Lecturer/Head Of Enviromental Engineering Departement, Muhamadiyah University Of Berau
2.	Expert 2	Civil Servant/Staf Of The Enviroment and Forestry Office
3	Expert 3	Civil Servant/Ministry Of Public Works and Housing, Drinking Water and Santiation Division
4	expert 4	Lecturer/Urban dan Regional Planning Study Program, Muhammadiyah Unversity Of Berau

To obtain a single value that represents multiple respondents, the weighted scores from several respondents in various assessment groups based on criteria or alternative assessments are averaged. This is referred to as the geometric mean.

Table.5. Summary of Criteria Weighting

No	Criterion	Weight	Ranking
1	Land Area	0.022281	12
2	Noise and Odor	0.024469	13
3	Soil Permeability	0.116148	3
4	Groundwater Table	0.114977	4
5	Geological Condition	0.114527	5
6	Flood Hazard	0.174628	1
7	Land Status	0.036913	8
8	Surface Water Flow	0.127095	2
9	Drainage Condition	0.083049	6
10	Transportation	0.036723	9
11	Covering Material	0.056274	7
12	Land Ownership	0.032604	11
13	Road Condition	0.037485	10
14	Aesthetics	0.022825	14

V. CONCLUSION

In the process of determining alternative landfill locations in Berau Regency, the Analytical Hierarchy Process (AHP) method was used to identify the weights of various important criteria that influence the decision. This stage aims to provide an objective and structured assessment in evaluating the alternative locations. Below are the main points related to the application of AHP in this study:

Based on the calculations using the AHP method, the criteria with the largest weight is the flood hazard criterion, which has a weight of 0.17. This means that the risk of flooding is considered the most significant factor in the decision-making process. On the other hand, the criteria with the smallest weights, each with a value of 0.02, are land area, noise and odor, and aesthetics. These factors are deemed less important in comparison to the others when evaluating potential locations or alternatives.

- The AHP method was applied in the screening stage to determine the weight of each criterion based on expert evaluations, with flood hazard (0.1746) having the highest weight.
- The criteria weights from AHP served as the basis for ranking the alternative locations using the PROMETHEE method, ensuring an objective evaluation of the locations.
- The analysis results showed that Location 2 (Simpang Pagat Bukur) is the best alternative for the landfill, supported by a sensitivity analysis that demonstrated the consistency of the results.

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