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Assessment of Potential Landfill Sites and Route Optimization in Kendal Regency, Indonesia Utilizing Geographic Information Systems

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Abstract: Kendal Regency faces significant challenges concerning the management of solid waste due to the constraints of its only landfill, Darupono Baru, which is situated adjacent to the environmentally sensitive Pagerwunung Nature Reserve. Recent assessments have indicated that the landfill has suffered from landslides on its northern and western flanks. The regency generates approximately 410 tons of waste daily, while the landfill's operational capacity is limited to 150 tons per day, leading to predictions of overload by 2027. In light of these issues, this study employed overlay scoring techniques and network analysis, specifically the fastest route methodology, in accordance with the standards set forth in SNI No. 03-3241-1994, to identify potential new landfill sites across a total area of 2,566 hectares within the regency. Six sites were identified as viable candidates: Gebangan Village in Pageruyung District, Kalibareng Village in Patean District, Kedungasri Village in Ringinarum District, Kalices Village in Patean District, Sojomerto Village in Gemuh District, and Singorojo Village in Singorojo District. The evaluation process employed elimination assessments, which rated Kedungasri Village the highest with a score of 548 out of a maximum of 690, while Singorojo Village received the lowest score of 393. The existing Darupono Baru landfill was found to score 424 out of 690, meeting only 5 out of the 10 assessment criteria established for new sites. Additionally, it was noted that Kendal Regency operates 155 temporary waste disposal sites and maintains 44 waste collection routes, which include 8 routes for tricycles, 20 for armrolls, and 16 for dump trucks. This study contributes valuable insights into waste management strategies and landfill site selection in Kendal Regency, emphasizing the urgent need for sustainable solutions in the context of increasing waste generation.

Keywords: Geographic Information Systems (GIS); Network analysist; Landfill; Overlay; Kendal Regency; Scoring; Routes; Potential

1 Introduction

Waste production increases proportionally with daily community activities and population growth. Rapid urbanization, in addition to increasing resource consumption, also raises the production of both industrial and household waste [1]. According to Law of the Republic of Indonesia Number 18 of 2008 about Waste Management, waste can be interpreted as the remnants of daily human activities and/or natural processes in solid form [2]. Waste management in question is the handling and minimization of waste production, which can be achieved by improving service quality, expanding the scope of services, and offering various waste management support services [3]. Local governments often face challenges in choosing a landfill location due to the many elements that need to be considered, including land prices, road difficulties, and other related factors [4].

Kendal Regency only has one landfill in operation, namely the Darupono Baru Landfill, which was built in 2020 and actively started operating in 2022 and is located in Darupono Village, South Kaliwungu District. Previously, Kendal Regency had two landfills that were also located in Darupono Village. Darupono Lama landfill has been closed in 2020 because it is overloaded with garbage so that the garbage appears on the side of the road and causes odors around it. The Darupono Baru Landfill presents an issue for the adjacent Pagarwunung Nature Reserve due to its proximity. In 2024, landslides occurred at the Darupono Baru Landfill in the north and west, causing the waste to spread [5].

Kendal Regency produces up to 410 tons of waste per day, while the Darupono Baru Landfill can only accommodate 150 tons per day. Kendal Regency has a total waste pile of 149,652 tons/year and has only been reused 754 tons/year (0.5%) and waste handling in landfills 59,696 tons/year (39.9%), so that unmanaged waste is 89,202 tons/year (59.6%). It is projected that the Darupono Baru Landfill will be full or overloaded by 2027, as it has a capacity of only 6 years with an area of 8 hectares. It is important to create a new landfill site in Kendal Regency [6].

According to SNI-03-3241-1994, to find out the potential location of the landfill, it is based on three stages of criteria, namely regional criteria, exclusion criteria, and determination criteria. Regional criteria are used in creating potential and non-potential zones. Followed by the exclusion criteria to evaluate the output of the regional criteria. Meanwhile, the determination criteria produce a map by showing the highest potential area [7].

Similar research has been conducted by Kusuma [8] who raised the topic "Analysis of Location Determination and Alternative Routes for Waste Landfills in Temanggung Regency Using Geographic Information Systems". In previous research conducted by Faisal [9] on "Analysis of Final Disposal Site Location Determination (TPA) in Tidore Islands City" using the GIS method, namely overlay with each parameter given a weight according to its impact on land suitability for landfill locations, the results are 5 locations that have potential. Then in Nahdi's research [10] discussing the "Application of the Spatial Multi Criteria Evaluation (SMCE) Method for Planning the Location of Waste Landfills in Surabaya City", the most suitable place to plan landfill development is in Benowo and Lakasantri Districts, which have very low, low, medium, high, and very high suitability.

GIS can serve as a valuable tool for analysing potential landfill locations by overlaying data with predetermined parameters. Additionally, GIS can facilitate the analysis of truck travel routes from temporary disposal sites to the landfill through network analysis [11]. This research aims to identify the distribution of potential landfill sites in Kendal Regency by evaluating regional and elimination criteria in accordance with SNI No. 03-3241-1994. Furthermore, it seeks to assess the potential value of the Darupono Baru landfill, as the existing landfill in the regency, and to determine the optimal routes from temporary disposal sites to the proposed alternative landfill locations, consistent with the standards outlined in SNI No. 03-3241-1994.

2 Methodology

This study is divided into several stages: preparation, data collection, and data processing [12, 13]. The data processing stage involves a GIS using QGIS. Stage-1 involves regional analysis to identify potential landfill locations. Then continued Stage-2, namely the analysis of the elimination stage so that the most optimal and potential location for landfills in Kendal Regency was produced. As well as processing data from the Darupono Baru Landfill as a landfill existing in Kendal Regency to see the comparative value with the selected landfill location [7]. Finally, the study determines the route from the temporary disposal sites to the alternative landfill locations based on SNI No. 03-3241-1994.

2.1 Study Area

Kendal Regency at Figure 1 borders the Java Sea to the north. Temanggung is to the south, Batang is to the west, and Semarang City and Semarang Regency are to the east. The study was conducted in Kendal Regency, located in Central Java, Indonesia. The location of Kendal Regency is at $109°40' - 110°18'$ East Longitude and $6°32' - 7°24'$ South Latitude. Kendal Regency has a total area of 1,006.47 km^2 divided into 20 sub-districts with 266 villages and 20 urban villages. The distance from West to East is 40 km, and from North to South is 36 km. The elevation ranges between 0 and 2,579 meters above sea level [5].

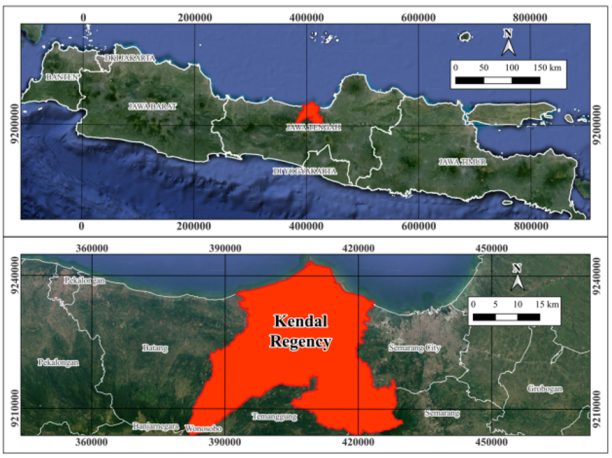

Figure 1. Maps of the study area

Kendal Regency has a total waste pile of 149,652 tons/year and has only been reused 754 tons/year (0.5%), and waste handling at the landfill is 59,696 tons/year (39.9%), so there is 89,202 tons/year (59.6%) of unmanaged waste. It is predicted that in 2027 the Darupono Baru Landfill will be full or overloaded because it only has a capacity of 6 years with an area of 8 hectares. This is important to create a new landfill location in Kendal Regency [6].

2.2 Data Preparation

Data collection involved conducting interviews and requesting relevant data for the research. An interview was conducted with the Kendal Regency Environment Office to find out the condition of waste and landfills, temporary disposal sites, and its relationship with the potential value of landfill selection in Kendal Regency. Furthermore, to the Department of Public Works and Spatial Planning Kendal Regency Office to request data based on the required parameters in accordance with SNI 03-3241-1994. There are two types of data used in this study, namely primary data and secondary data. Primary data was carried out by interviews and observations for data collection of potential landfill locations in Kendal Regency, such as road conditions to the location, transportation, biological conditions, agriculture, and visualization documentation about landfills. Observations were also conducted at the temporary disposal sites to determine the cubic meter (m^3) capacity that each site can accommodate. In accordance with Table 1, the secondary data referenced in this study comprises spatial data and supporting information that are utilized as parameters for the analysis.

Table 1. Research data

Data	Format	Year	Source
Map of administrative	Vector	2020	
Rock type	Vector	2020	
River flow	Vector	2020	
Aquifer types	Vector	2020	
Airport area	Vector	2023	Department of Public Works and Spatial
Rainfall	Vector	2021	Planning, Kendal Regency
Land use	Vector	2023	
Land tenure data	Vector	2020	
Road network	Vector	2018	
Water infiltration data	Vector	2018	
Garbage collection points	Vector	2023	Kendal Regency Environmental Agency
Slope	Raster	2023	Indonesia Geospatial Information Agency
Landslide vulnerability	Vector	2021	
Active fault	Vector	2020	Kendal Regency Regional Disaster Management Agency
Flood vulnerability	Vector	2021	

2.3 Regional Stage Processing

The regional stage outlined in Table 2 serves as the initial screening phase to ascertain whether a potential zone is suitable for use as a landfill. This stage aims to clearly delineate areas that are considered either suitable or unsuitable for landfill designation at a regional level. During the data processing phase, GIS techniques, such as buffers and overlays, are employed. At this stage, weighting is applied to the criteria based on the assigned scores [8].

Table 2. Paramaters of regional stage

Criteria	Parameter	Score
Geology	Rocks have low permeability	1
	Not in the Holocene fault zone	1
	Not in an area with high landslide-prone	1
Hydrogeology	It has a distance of more than 100 m from the river	1
	Not a productive aquifer	1
Topography	Zone slope less than 20%	1
Airport distance	The airport must be more than 3,000 m away	1
Land use	It has a distance of more than 300 m from residential areas	1
	Not in a protected area	1
	Not in a high flood-prone area	1

For rock types with low permeability, such as lava lithology [14], the low permeability rocks in Kendal Regency include basalt, Gajah Mungkur Volcano, Jembangan Volcano, Semalon & Sangku Volcanoes, Kerek Formation, Jongkong Formation, Penyetan Formation, and Kaligesic Volcano. On the other hand, rocks with high permeability include alluvial deposits, Damar Formation, and Kaligetas Formation.

For land use criteria related to residential areas, potential landfill sites must not be located within residential or industrial zones due to environmental and social impacts, as residents may be disturbed by landfill operations. Therefore, such sites should be situated more than 300 meters away from these areas.

In Kendal Regency, there are two areas: conservation areas and cultivation areas. Conservation areas, including mangrove ecosystems, conservation zones, local protection zones, groundwater protection areas, and their underlying protection areas, cannot be used as landfill sites. In contrast, cultivation areas such as holding zones, production forests, fishing zones, residential areas, and agricultural zones can be utilized for landfills.

Then overlay all regional parameters, this aims to find out the calculation of the placement of potential landfill locations in Kendal Regency as shown in Figure 2.

Figure 2. Result overlay

The results overlay revealed that areas identified as potential and non-potential locations yielded the highest score when it came to determining new landfills in Kendal Regency. In the calculation, the potential value of the regional stage landfill is orange if it gets a value of 10, which means it meets all parameters, and white if the value is less than 10, which means it does not meet one or more of the specified parameters [15].

2.4 Processing of the Elimination Stage

After the regional process that results in potential or non-potential areas to be used as landfills, the next stage is the elimination stage. The elimination stage involves two aspects, the first is the general parameters, and the second is to narrow down the area that is really potential to be used as a landfill with physical environmental parameters [16].

To carry out the stage of the landfill exclusion criteria that will be assessed, several parameters are needed, namely the general and physical environment as shown in Table 3.

Based on the results of the selection of these criteria, tabular data will be generated that shows the value of the landfill potential elimination stage. The location with the highest score will serve as the best reference for determining the routes from the temporary disposal sites to the landfill [17].

2.5 Processing of Temporary Disposal Sites to Landfill Route

The location of the landfill with the highest score is a reference in determining the route from the temporary disposal sites to the landfill. At the stage of determining the route, road analysis from the temporary disposal sites to the location of the alternative landfill was carried out using network analysis with road data, temporary disposal site data, and data on the potential location of the selected landfill [18].

Categorize temporary disposal sites into three vehicles [19]:

A. Tricycle;

B. Armroll;

C. Dumptruck;

Group temporary disposal sites based on capacity and paths passed by trucks [20]. Then, to find out if the route of the truck from the temporary disposal sites to the landfill is suitable for selection by using network analysis and choosing the shortest path, the path type uses the fastest so that the truck can use the fastest road so that the time in delivering waste is effective and avoids local roads that are sometimes roads that cannot be passed by vehicles [21].

Table 3. Parameters of elimination stage

No.	Parameter	SNI Criteria	
		Weight	Score
	General		
1.	**Administrative boundaries**	5	
	a. Be within administrative boundaries		10
	b. Beyond administrative boundaries but in one integrated landfill management system		5
	c. Beyond administrative boundaries outside the integrated landfill management system		1
	d. Going beyond administrative boundaries		1
2.	**Administrative boundaries**	3	
	a. Government and regional/central government		10
	b. Private (one)		7
	c. Private/corporate (one)		5
	d. More than one owner of the right to land ownership status		3
	e. Social/religious organizations		1
3.	**Land capacity**	5	
	a. 10 years		10
	b. 5 years - 10 years		8
	c. 3 years - 5 years		5
	d. Less than 3 years		1
4.	**Number of landowners**	3	
	a. One (1) family		10
	b. 2 - 3 months		8
	c. 4 - 5 months		5
	d. 6 - 10 months		3
	e. More than 10 families		1
5.	**Community participation**	3	
	a. Spontaneous		10
	b. Driven above		5
	c. Negotiation		1
	Physical Environment		
1.	**Groundwater flow system**	3	
	a. Discharge area/local		10
	b. Recharge area and discharge area local		5
	c. Recharge regional and local areas		1
2.	**Related to groundwater utilization**	3	
	a. Low utilization possibilities with hydraulic limits		10
	b. Projected for utilization with hydraulic limits		5
	c. Projected to be utilized without hydraulic limits		1
3.	**Flood hazards**	2	
	a. No flood danger		10
	b. Possible flood hazards > 25 years		5
	c. Possibility < 25 years reject (unless there is technological input)		0
4.	**Cover soil**	4	
	a. Enough cover soil		10
	b. Ground cover is enough 1/2 of the lifespan		5
	c. No cover soil		1
5.	**Rain intensity**	3	
	a. Below 500 mm per year		10
	b. Between 500 mm to 1000 mm per year		5
	c. Above 1000 mm per year		1
6.	**Directions to the location**	5	
	a. Flat with good condition		10
	b. Flat with bad condition		5
	c. Up/down		1

Continued

	Waste transport (one way)	5	
7.	a. Less than 15 minutes from the garbage centroid		10
	b. Between 16 minutes – 30 minutes from the garbage centroid		8
	c. Between 31 minutes – 60 minutes from the garbage centroid		3
	d. More than 60 minutes from the garbage centroid		1
	Entrance	4	
8	a. Garbage trucks do not pass through residential areas		10
	b. Garbage trucks pass through medium-density residential areas ($\leq$ 300 people/ha)		5
	c. Garbage trucks through high-density residential areas ($\geq$ 300 people/ha)		1
	Traffic	3	
9.	a. Located 500 m from public road		10
	b. Located < 500 m on low traffic		8
	c. Located < 500 m on moderate traffic		3
	d. Located on high traffic		1
	Land use	5	
10.	a. Has a slight impact on the surrounding land use		10
	b. Has a moderate impact on the surrounding land use		5
	c. Has a major impact on the surrounding land use		1
	Agriculture	3	
11.	a. Located on unproductive land		10
	b. There is no impact on the surrounding agriculture		5
	c. There is a negative influence on the surrounding agriculture		1
	d. Located on productive farmland		1
	Protected areas/nature reserves	2	
12.	a. There are no protected areas/nature reserves in the vicinity		10
	b. There are protected areas/nature reserves around that are not negatively affected		1
	c. There are protected areas/nature reserves around them that are negatively affected		1
	Biological	3	
13.	a. Low habitat value		10
	b. High habitat value		5
	c. Critical habitat		1
	Noise and odor	2	
14.	a. There is a poenyangga zone		10
	b. There are limited buffer zones		5
	c. No buffer		1
	Aesthetic	3	
15.	a. Landfill operations are invisible from the outside		10
	b. The stockpiling operation is slightly visible from the outside		5
	c. The stockpiling operation is seen from the outside		1

3 Result and Discussion

3.1 Regional Stage

The regional stage employs ten parameters to evaluate the potential landfill sites in Kendal Regency at a regional level. These parameters are illustrated in Figure 3.

3.1.1 Potential area regional stage

The regional stage, as depicted in Figure 4, assesses the potential value of landfill sites using ten parameters, namely rock type, active faults, landslide-prone areas, aquifer type, river proximity, slope, airport locations, protected areas, flood-prone regions, and residential areas. The scope of the regional stage for sub-districts is detailed in Table 4.

3.1.2 The suitability value of the Darupono Baru landfill as an existing landfill

The regional stage incorporates ten parameters to evaluate potential landfill sites. It is noteworthy that the Darupono Baru landfill, as the existing landfill, is not included in this regional assessment. The exclusion of the Darupono Baru landfill from the potential zone at the regional stage is attributed to insufficient scores in determining its suitability as a landfill location. The suitability value of the Darupono Baru landfill can be found in Table 5.

The Darupono Baru landfill does not meet the criteria for a suitable regional zone, achieving only a score of 5 out of 10 evaluation parameters.

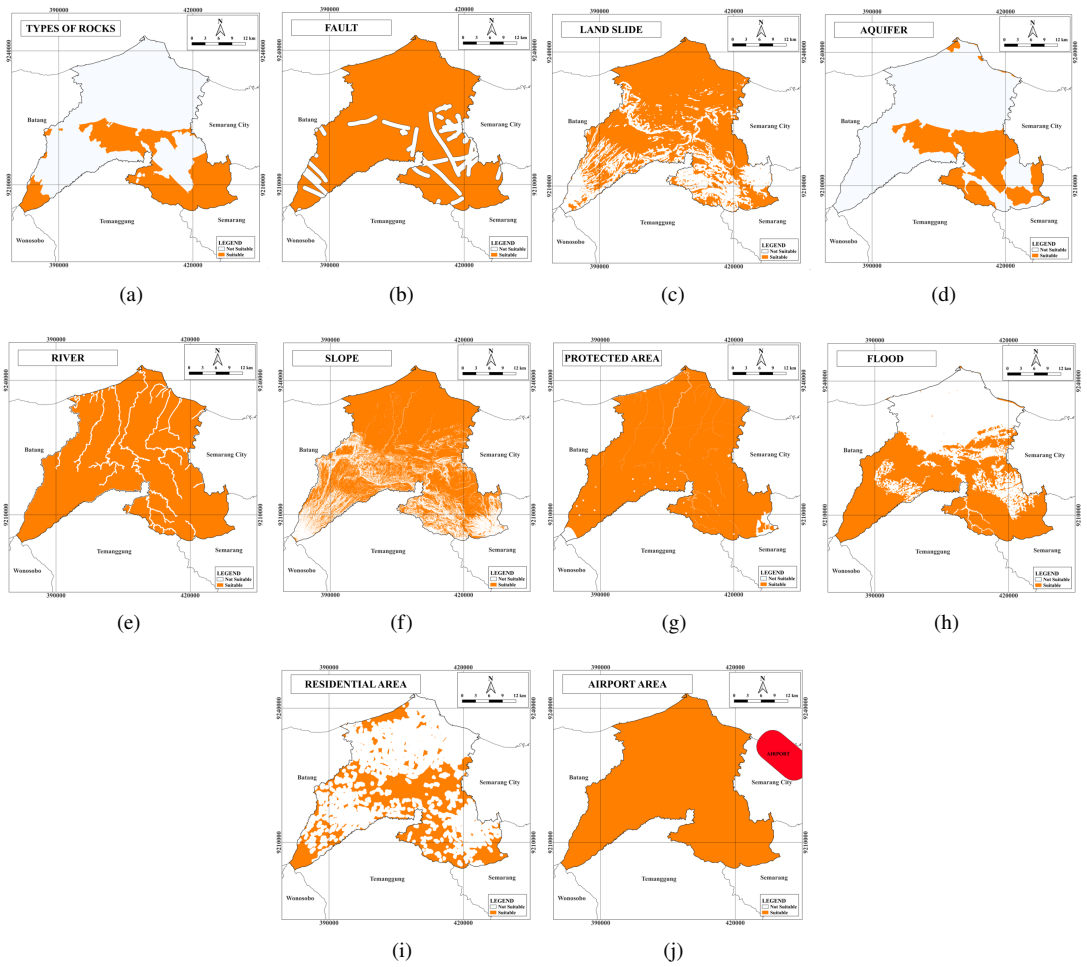

Figure 3. Regional stage parameter (a) Types of rocks; (b) Fault zone; (c) Land slide; (d) Aquifer; (e) River; (f) Slope; (g) Protected area; (h) Flood; (i) Residential area; (j) Airport area

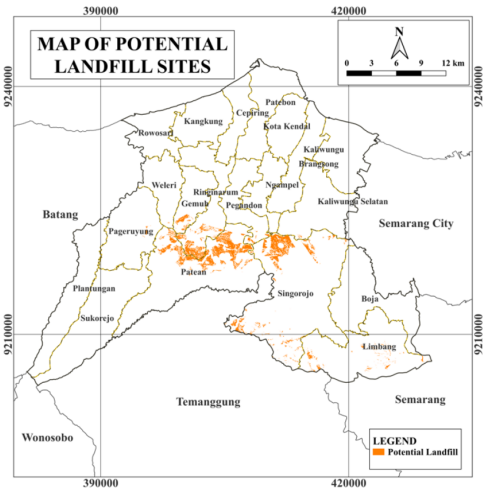

Figure 4. Potential landfill area

3.1.3 Result of potential landfill site location

The data above is the result of the calculation of the potential location of the landfill in Kendal Regency based on SNI 03-4231-1994. From the processing results, there are several potential landfill locations with a reference to roads used for 4-wheeled vehicles, among others, which can be seen in Figure 5.

Table 4. Regional stage area

No.	District	Not Potential (Ha)	%	Potential (Ha)	%
1	Boja	6,184	6.14	3	0.00
2	Brangsong	3,444	3.42	0	0.00
3	Cepiring	2,527	2.51	0	0.00
4	Gemuh	3,914	3.89	363	0.36
5	Kaliwungu	4,357	4.33	0	0.00
6	Kaliwungu Selatan	5,132	5.10	10	0.01
7	Kangkung	3,544	3.52	0	0.00
8	Kota Kendal	2,870	2.85	0	0.00
9	Limbangan	7,684	7.63	127	0.13
10	Ngampel	2,502	2.49	1	0.00
11	Pageruyung	5,172	5.14	17	0.02
12	Patean	9,255	9.20	1,090	1.08
13	Patebon	4,429	4.40	0	0.00
14	Pegandon	3,039	3.02	34	0.03
15	Plantungan	5,175	5.14	0	0.00
16	Ringinarum	2,444	2.43	86	0.09
17	Rowosari	2,965	2.95	0	0.00
18	Singorojo	13,127	13.04	833	0.83
19	Sukorejo	7,360	7.31	0	0.00
20	Weleri	2,957	2.94	2	0.00
	Total	98,081	97.45	2,566	2.55

Table 5. The value of suitability of the Darupono Baru landfill land

No.	Parameter Regional	Value	Suitability
1	Types of rocks	0	Not suitable
2	Fault zone	0	Not suitable
3	Land slide	1	Suitable
4	River	1	Suitable
5	Aquifers	0	Not suitable
6	Slope	0	Not suitable
7	Airport	1	Suitable
8	Protected areas	1	Suitable
9	Residential areas	0	Not suitable
10	Flood	1	Suitable
	Total	5 Parameters	

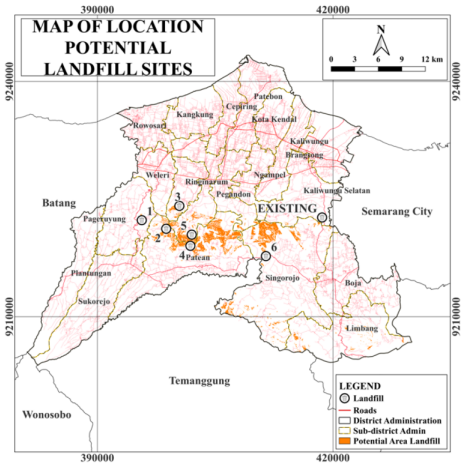

Figure 5. Potential landfill

Potential landfill sites in Kendal Regency:
1. Gebangan Village, Pageruyung District
2. Kalibareng Village, Patean District
3. Kedungasri Village, Ringinarum District
4. Kalices Village, Patean District
5. Sojomerto Village, Gemuh District
6. Singorojo Village, Singorojo District

This landfill site is situated on low-permeability rock with a slope gradient of 0-20%, not located in landslide-prone areas, and positioned more than 500 meters from active fault zones. It has limited access to aquifers and is more than 100 meters away from the nearest river. Additionally, this site is located over 300 meters from residential areas to avoid disturbing residents, is not within protected zones, and is free from flood risks.

3.2 Elimination Stage

The elimination stage involves 20 parameters, each with its own weight and score, to determine the best value among the potential landfill sites in Figure 6.

3.2.1 Result elimination stage value of the Darupono Baru landfill as an existing landfill

The suitability value of the Darupono Baru landfill, as the existing landfill in Kendal Regency, is calculated by multiplying the weight assigned to each parameter by its corresponding score and summing the values of all 20 established parameters. The resulting land suitability value is presented in Table 6.

At the elimination stage, the Darupono Baru landfill received a score of 424 out of a maximum of 690, based on the evaluation of 20 elimination parameters.

3.2.2 Result elimination stage value of potential landfill

The elimination stage is undertaken to identify the most suitable landfill site location in Kendal Regency by calculating and aggregating the values from the 20 established parameters. The location with the highest total score will be selected as the preferred landfill site, as detailed in Table 7.

Table 6. Elimination stage value of existing landfill

No.	**Elimination Stage Value SNI Criteria 03-3241-1994**			
	General Parameters	**Weight**	**Score**	**Value**
1	Administrative boundaries	5	10	50
2	Land rights owners	3	10	30
3	Land capacity	5	8	40
4	Number of landowners	3	10	30
5	Community participation	3	7	21
	Physical Environment Parameters	**Weight**	**Score**	**Value**
1	Groundwater flow system	3	1	3
2	Related to groundwater utilization	3	10	30
3	Flood hazards	2	10	20
4	Cover soil	4	10	40
5	Rain intensity	3	1	3
6	Directions to the location	5	1	5
7	Waste transport (one way)	5	8	40
8	Entrance	4	5	20
9	Traffic	3	3	9
10	Land use	5	5	25
11	Agriculture	3	1	3
12	Protected areas/nature reserves	2	1	2
13	Biological	3	1	3
14	Noise and odor	2	10	20
15	Aesthetic	3	10	30
	Total			424

The maximum possible score for all parameters is 690, while the minimum is 77. In this calculation, the best potential landfill location value is obtained at Potential Landfill location 3 with a value of 548 out of 690 with 20 parameters, while the lowest value is Landfill Location 6 with a value of 393 out of 690 with 20 parameters.

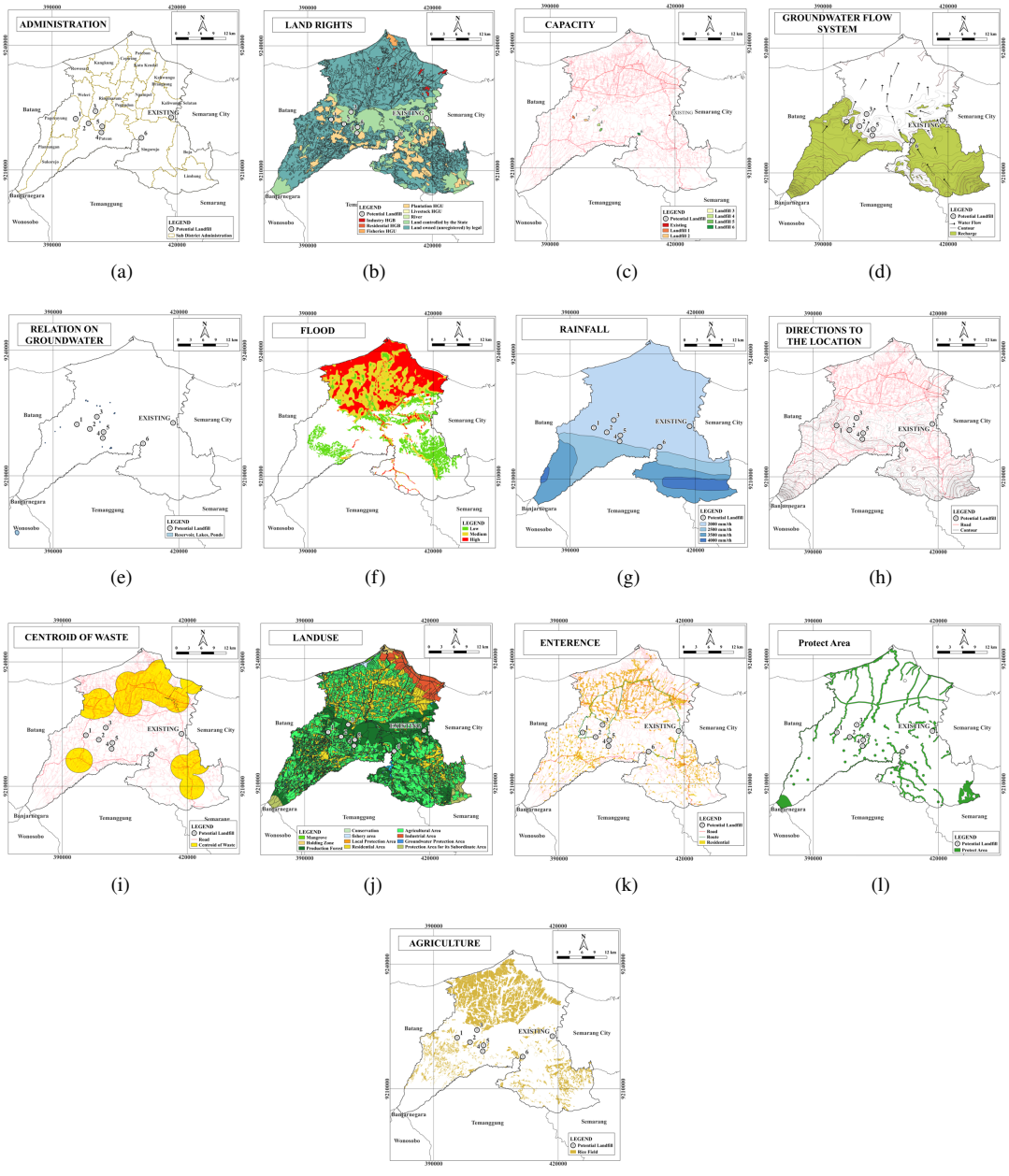

Figure 6. Elimination stage parameter (Spatial) (a) Administration; (b) Land rights; (c) Capacity; (d) Groundwater flow; (e) Relation groundwater; (f) Flood; (g) Rainfall; (h) Direction location; (i) Centroid waste; (j) Landuse; (k) Enterence; (l) Protected area; (m) Agriculture

The Darupono Baru landfill as an existing landfill in the results of the regional stage analysis did not meet the parameter criteria mentioned in SNI No. 03-3241-1994, then at the elimination stage only got a score of 424, which means that the landfill has the 5th place with a lower score than the Potential Landfills 2, 3, 4, 5.

3.3 Results and Analysis of Route Temporary Disposal Sites to Landfill Route

The waste transportation route in Kendal Regency has three ways, namely using tricycles, armrolls, and dump trucks. The routes obtained in the temporary disposal site research to the landfill are 44 routes spread across Kendal Regency. The route is made based on the volume of waste from July 13 to 14, 2024, and based on the proximity between temporary disposal sites.

Table 7. Elimination stage value

No.	Potential Landfill Location SNI Criteria 03-3241-1994						
	Potential Landfill	**1**	**2**	**3**	**4**	**5**	**6**
	General			Value			
1	Administrative boundaries	50	50	50	50	50	50
2	Land rights owners	9	9	30	30	30	9
3	Land capacity	50	50	50	50	50	50
4	Number of landowners	3	3	30	30	30	3
5	Community participation	3	3	3	3	3	3
	Physical Environment			Value			
1	Groundwater flow system	15	30	30	30	30	30
2	Related to groundwater utilization	30	30	30	30	30	30
3	Flood hazards	20	20	20	20	20	20
4	Cover soil	40	40	40	40	40	40
5	Rain intensity	3	3	3	3	3	3
6	Directions to the location	5	5	25	5	5	5
7	Waste transport (one way)	10	10	40	10	10	10
8	Entrance	20	20	20	20	20	20
9	Traffic	24	24	24	24	24	9
10	Land use	50	50	50	50	50	50
11	Agriculture	3	3	3	3	3	3
12	Protected areas/nature reserves	20	20	20	20	20	20
13	Biological	15	30	30	30	30	15
14	Noise and odor	20	20	20	20	20	20
15	Aesthetic	30	15	30	15	15	3
	Total	420	435	548	483	483	393

3.3.1 Route of tricycle

For waste transportation using tricycles, there are 8 routes, as shown in Figure 7, with the fastest route being route 2 to go to the Patukangan transfer depot with a time of 0.4 minutes and a distance of 0.3 km, and the route with a late time is route 8 to go to the Patebon container with a time of 4 minutes and a distance of 2.93 km. The tricycle route can be seen at Table 8.

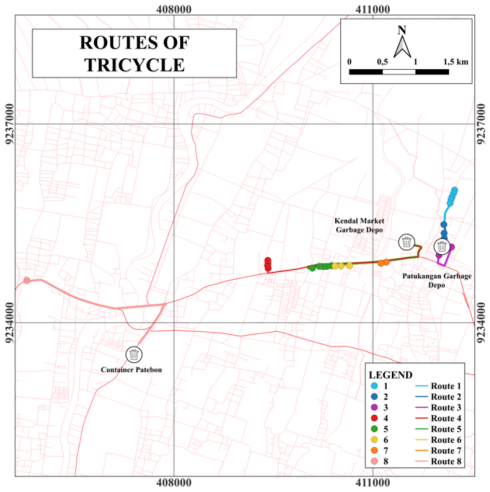

Figure 7. Routes of tricycle

3.3.2 Route of armroll

As illustrated in Figure 8, there are 20 waste transportation routes utilizing armroll trucks. The fastest route is Route 12, which leads to Potential Landfill 3, taking 20.7 minutes to cover a distance of 8.3 km. Conversely, the slowest route is Route 24, which requires 85.4 minutes and spans a distance of 57.0 km. Details of the armroll routes can be found in Table 9.

Table 8. Routes of tricycle

Route	Towards	Capacity (m^3)	Max Capacity (m^3)	Route Distance (km)	Time (minutes)
1	Patukangan depot	3	8	0.9	2.1
2	Patukangan depot	2.5	5	0.3	0.4
3	Patukangan depot	3	3	0.7	0.4
4	Kendal market depot	1.25	4	2.7	3.8
5	Kendal market depot	2.5	3	1.0	1.5
6	Kendal market depot	3	6	1.9	2.5
7	Kendal market depot	3.5	9	2.4	2.8
8	Container Patebon	1	1	2.9	4

3.3.3 Route of dumptruck

In the transportation analysis using dump trucks, as shown in Figure 9, there are 16 routes identified. The fastest route is Route 42, which leads to Potential Landfill 3, taking 20.9 minutes to cover a distance of 9.7 km. In contrast, the slowest route is Route 38, requiring 40.8 minutes and spanning a distance of 26.2 km. The details of the dump truck routes are presented in Table 10.

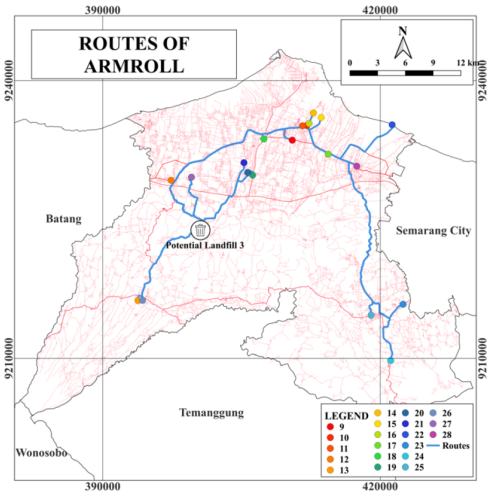

Figure 8. Routes of armroll

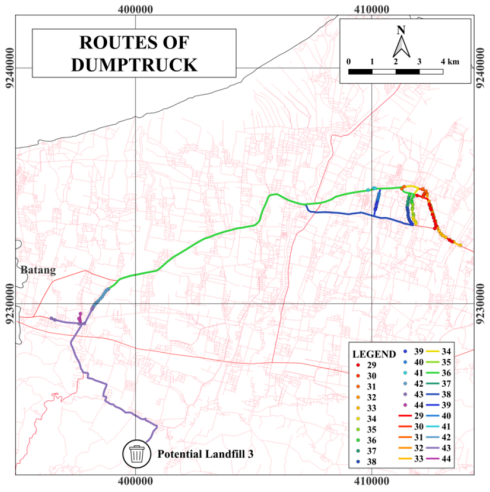

Figure 9. Routes of dumptruck

Table 9. Routes of armroll

Route	Depot/Container to Potential Landfill 3	Capacity (Container)	Route Distance (km)	Time (minutes)
9	Tunggulrejo Transfer Depot	2	24.3	39.2
10	Patukangan Transfer Depot	3	24.9	37.7
11	Kendal Market Transfer Depot	3	24.3	36.8
12	Weleri Market 2 Transfer Depot	4	8.3	20.7
13	Depo Transfer Terminal Sukorejo	1	12.2	30.0
14	Tire Container	1	26.5	42.4
15	Karangsari Container	1	27	43.3
16	Container of RSUD Soewondo	3	25.3	38.7
17	Perum Brangsong Container	1	28.7	41.2
18	Patebon Market Container	1	20.4	33.7
19	Pegandon Market Container	1	11.0	30.0
20	Tamangede Village Container	1	9.2	27.6
21	Pandes Village Container	1	9.6	28.7
22	Port Containers	1	38.0	52.4
23	Campurejo Village Container	1	53.8	78.1
24	Limbangan Market Container	1	57.0	85.4
25	Boja Market Container	2	50.5	75.9
26	Sukorejo Market Container	1	11.8	29.2
27	Kendal RSI Container	2	7.7	23.2
28	Kaliwungu Container	2	32.0	44.3

Table 10. Routes of armroll

Route	Towards	Capacity $(\mathbf{m^3})$	Max Capacity $(\mathbf{m^3})$	Route Distance (km)	Time (minutes)
29	Potential Landfill 3	6.75	18	28	38.1
30	Potential Landfill 3	6.5	7	25.2	37.9
31	Potential Landfill 3	6.25	9	25.0	37.2
32	Potential Landfill 3	6	17	26.5	38.7
33	Potential Landfill 3	5	11	27.8	40.0
34	Potential Landfill 3	7	8	26.2	40.8
35	Potential Landfill 3	7	12	25.9	39.1
36	Potential Landfill 3	7	12	25.1	37.7
37	Potential Landfill 3	7	10	24.9	39.1
38	Potential Landfill 3	7	11	25.3	40.8
39	Potential Landfill 3	6	16	26.1	36.9
40	Potential Landfill 3	6	11	23.5	35.8
41	Potential Landfill 3	3	3	22.8	35.0
42	Potential Landfill 3	5.75	13	9.7	20.9
43	Potential Landfill 3	6.5	8	11.4	21.6
44	Potential Landfill 3	4.25	5	8.3	21.6

4 Conclusions

Based on the research conducted, the following conclusions can be drawn:

(1) The Darupono Baru landfill, as the existing landfill, does not satisfy the criteria for a suitable zone at the regional stage, having achieved only 5 out of 10 assessment parameters. At the elimination stage, the Darupono Baru landfill scored 424 out of a possible 690 based on 20 elimination parameters, indicating that its suitability is lower than that of the identified potential locations for landfills 2, 3, 4, and 5.

(2) The landfill potential analysis, guided by SNI No. 03-3241-1994, which outlines the regulations and procedures for determining landfill locations, revealed a potential area of 2,566 hectares, representing 2.55% of Kendal Regency. Six sites were identified as viable alternatives for landfill development: Gebangan Village (Pageruyung District), Kalibareng Village (Patean District), Kedungasri Village (Ringinarum District), Kalices Village (Patean District), Sojomerto Village (Gemuh District), and Singorojo Village (Singorojo District). Among

these, the highest-scoring potential landfill location is Potential Landfill 3 in Kedungasri Village (Ringinarum Sub-District), with a score of 548 out of 690. Conversely, the lowest-scoring potential location is Potential Landfill 6 in Singorojo Village (Singorojo District), with a score of 393 out of 690.

(3) Kendal Regency is equipped with 155 temporary disposal sites. The waste transportation routes in the regency encompass three modes: tricycles, armroll trucks, and dump trucks. A total of 44 routes were identified for transporting waste from the temporary disposal sites to the landfill. Specifically, there are 8 routes for tricycle transportation, 20 routes for armroll trucks, and 16 routes for dump trucks.

It is recommended that future research incorporate all relevant parameters, as this study excluded two critical parameters—land and groundwater—due to insufficient data. Subsequent research should also focus on calculating the average weekly or monthly waste volumes transported from each temporary disposal site to enhance the efficiency of truck transportation routing.

Data Availability

The data used to support the research findings are available from the corresponding author upon.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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