JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
Volume 9, Number 2 (January 2022):3405-3413, doi:10.15243/jdmlm.2022.092.3405
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

Multi-criteria decision making for determining landfill location in Malaka Regency, East Nusa Tenggara Province of Indonesia

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Article history:
Received 21 November 2021
Accepted 25 December 2021
Published 1 January 2022

Keywords:
land capability
land suitability
landfill
soil suitability

Abstract

The absence of a landfill has increased the illegal waste disposal sites in Malaka Regency, which was established between 2013 and 2021. Therefore, this study aimed to analyze suitable and available land for the development of a landfill. The methodology used consisted of 2 analysis steps, namely land suitability and land availability. Land suitability was analyzed using a multi-criteria decision-making method, which included the slope, stone type/geology, lithology, soil type, soil texture, soil depth, soil drainage, distance from settlements, and water sources. The criteria were then weighted using the Analytical Hierarchy Process (AHP) and geographic information system for overlaying. Furthermore, the results of the land suitability analysis were used to determine its availability with the aid of spatial and regional planning (RTRW), land use, and forest area maps. The results showed that the highly suitable (S1) and available terrain for the landfill in Malaka Regency covered an area of 203.37 ha or 1.73% of the regency. Also, the analysis results indicated that there was still adequate land available for the landfill.

To cite this article: Rame, L.S., Widiatmaka, Hartono, A. and Firmansyah, I. 2022. Multi-criteria decision making for determining landfill location in Malaka Regency, East Nusa Tenggara Province of Indonesia. Journal of Degraded and Mining Lands Management 9(2):3405-3413, doi:10.15243/jdmlm.2022.092.3405.

Introduction

Urban pressure is an important factor, which causes environmental damage due to an increase in waste production owing to the large number of people living in cities (World Bank, 2018). According to Kong and Ma (2020), waste buried in the ground reduces soil quality and productivity. Also, harmful substances in the sewage and garbage may infiltrate the groundwater and pollute the environment after long-term accumulation, resulting in major secondary environmental pollution. This occours due to the deposition of waste in the wrong location. Therefore, the existence of a landfill is essential to properly process waste. Several criteria, such as altitude, slope, stone type/geology, soil type, and land use are necessary for determining this location (SNI 03-3241-1994) (BSN, 1994),

Based on the Geographic Information Systems (GIS) and Analytical Hierarchy Process (AHP) method, the landfill site is selected with the use of multi-criteria decision analysis to determine suitable and available lands. This process involved several predetermined criteria, such as land use, slope, soil, geology distance to residences, and road access (Sehnaz et al., 2010; Fidelis et al., 2020; Muheeb and Mir, 2021). The use of GIS and AHP in determining the location of landfills has been widely applied in several countries, including India, Turkey, and Nigeria.

Also, landfill locations were identified using a multi-criteria method, which was integrated with GIS and AHP methods (Nima et al., 2020; Michael et al., 2020; Sanu and Sarkar, 2021). This process is comprised of several predetermined criteria, such as distance from roads, railway lines, and agricultural land, altitude, protected areas, and water sources. The landfill suitability map was then divided into several classes, namely, highly suitable (S1), moderately suitable (S2), marginally suitable (S3), currently not suitable (N1), and permanently suitable (N2). According to Hardjowigeno and Widiatmaka (2018), actual and potential suitability were the two major factors associated with land suitability.

The determination of the landfill location using the multi-criteria method, GIS and AHP was also conducted by Mohamed et al. (2020) and Yadeta et al. (2021). This procedure included several criteria, namely demographics, land use, topography, hydrological aspects, residential areas, roads, groundwater, airports, drainage, land use/cover, and slope. The study results successively showed that 2% of the study area was the most suitable location for the landfill. Also, subsequent analysis revealed that 5.79% of this region was also very suitable.

Subsequently, Pece et al. (2021) and Yashar et al. (2020) performed a similar study using multi-criteria decision-making, GIS, AHP method, and other approaches in the selection of landfill sites. The criteria used included groundwater depth, proximity to surface water, elevation, land slope, soil permeability, and soil stability. Also, flood susceptibility, lithology and stratification, faults, land use types, nearby settlements and urbanization, proximity to cultural and protected sites, wind direction, roads, railways, proximity to building materials, pipelines and power lines, and proximity to airports were employed. The AHP was used to develop various alternative decisions for landfill suitability, evaluate the importance of the criteria, and generate weights for the predetermined criteria.

Landfilling is a well-known method used for the treatment and disposal of municipal solid waste and dumps globally (Chabuk et al., 2017; Powell et al., 2018; Gautham et al, 2020). Several studies have been conducted using GIS to easily assess/find landfills (Sener et al., 2011; Spigolon et al., 2018). Simcek et al. (2014) developed a tool for site selection and also used the index to assess the estimated usable parameters, such as spatial area, odor, visibility, proximity to the landfill using GIS, and remote sensing (RS). Therefore, this study aimed to describe the land suitability and availability required to determine the landfill location in Malaka Regency.

Materials and Methods

Study location

This study was initiated in Malaka Regency, East Nusa Tenggara Province (NTT), in 2020 due to the absence of a landfill. Furthermore, this regency has an area of 1,160.63 km^2 and is located between the coordinates of 124º-38'-32.17" East Longitude (E) – 125º-5'-21.38" E and 9º-18'-7.19" South Latitude (S) – 9º 47'26.68" S. The topography also varies from 0 to $\underline{+}$806 meters above sea level (masl) while the land slope is predominantly between 0-15%. Malaka Regency consists of two seasons, namely the dry season and the rainy season. The rainy season takes place in December, January, February and March, while the dry season takes place in April, May, June, July, August, September, October and November. The land use of the Malaka Regency area is currently divided into two main groups, namely wetland/rice fields and dry land. Consequently, the wetlands are used for semi-technical, simple, and village irrigations, as well as rainfed rice fields, while the drylands/fields and grasslands encompass the other land use categories (Malaka Regency, 2017).

Data

The data used in this study included the slope information on a scale of 1: 250,000 from the digital data on RBI maps and stone types/geology and aquifer lithology on a scale of 1:200.000 from the Geological Research and Development Center, Ministry of Energy and Mineral Resources (ESDM). Also, records on the soil type, texture, depth, and drainage of 1:50,000 from the Center for Agricultural Land Resources (BBSDLP) were utilized. Data on distance from settlements (land cover map) on a scale of 1:250,000 from the Ministry of Environment and Forestry (KLHK), proximity to water sources on a scale of 1: 250,000 from digital data from RBI maps, and Landuse Plan (RTRW) of Malaka Regency, forest area and land use data from the Ministry of Environment and Forestry (KLHK) were employed.

Analysis

Land suitability and availability analysis were conducted to identify the landfill location. First, the multi-criteria decision-making method was used to perform the land suitability assay with the AHP to obtain the weight of the criteria. The land suitability criteria considered for the Malaka Regency landfill selection included slope, stone type (geology), aquifer lithology (hydrology), soil type, texture, depth, and drainage, distance from settlements, and water source (river, spring, lake/reservoir) (SNI 03-3241-1994) (BSN, 1994). Figure 1 illustrates the spatial data for these criteria, while Table 1 describes the quantitative distribution. The AHP in this study showed 5 experts and used the pairwise comparison of Saaty. Also, the relevance of each pair on a scale of 1 to 9 was presented in Table 2 (Saaty, 2008). This process was further termed valid if the consistency ratio (CR) is less than 10% (0.1) (Saaty, 2008) and below the parameter weights of the pairwise comparison results. The criteria are presented in Table 3. The second analysis is to create land cover matrix (available land). The matrix consists of 3 elements, namely the Space pattern plan, the Forest area map, and the Land use/land cover map. These elements will be overlaid using the help of a GIS on the overlay technique and using ArcGIS software. The smaller the overlay value, the more inappropriate the landfill location, the greater the overlay value, the more feasible the landfill location. Rock outcrop is not covered a major of earth surfaces because superficial deposits are covered by a mantle of soil and vegetation so that it is invisible and examined carefully. However, in some locations where is the soil lost due to erosion and tectonic uplift processes, the rock will be exposed or called an outcrop. These have commonly occurred in an area with a higher erosion rate than the weathering rate, such as in steep hillsides, ridges and peaks of mountains, rivers, and active tectonic areas.

Table 1 column -d- shows that each criterion was scored according to importance. Specifically, the slope parameters of 0-5%, 5-10%, and 10-20% had scores of 10, 8, and 5, respectively, while a slope of >20% was given a score of 1. Also, the landfill is selected based on SNI 03-3241-1994 (BSN, 1994) if the slope of the zone is less than 20%. The gradient of the slope is related to the ease of construction work and the operation of the landfill, where a steep location results in difficulties during construction and operation. Furthermore, the danger of landslides due to rain on the large slope may result at a value >20% (SNI 03-3241-1994) (BSN, 1994).

Table 1. Distributions of the criteria in the study area (Malaka Regency).

Parameter	Weight	Criteria	Score	Area	
				ha	%
(a)	(b)	(c)	(d)	(e)	(f)
Slope	0.185	0-5%	10	43,894.91	39.28
		5-10%	8	11,218.51	10.04
		10-20%	5	28,284.84	25.31
		>20%	1	28,352.43	25.37
Stone Type/Geology	0.041	Sedimentary Rock	5	111,648.34	99.91
		Igneous Rock	10	102.35	0.09
Aquifer Lithology (Hydrology)	0.084	Release Deposit	6	40,071.83	34.89
		Solid Rock	8	30,438.89	26.50
		Limestone	3	44,274.97	38.55
		Malihan and Igneous Rock	10	57.89	0.05
Soil Type	0.081	Vertisols	6	425.13	0.37
		Inceptisols	10	51,736.42	45.14
		Entisols	8	29,233.6	25.51
		Mollisols	6	25,939.42	22.63
		ROC, Settlement	0	7,276.75	6.35
Soil Texture	0.138	Fine	6	78,100.97	68.14
		Currently	10	21,665.88	18.90
		Rough	1	7,567.72	6.60
		ROC, Settlement	0	7,276.75	6.35
Soil Depth	0.060	In	10	67,177.9	58.61
		Currently	8	1,268.94	1.11
		Shallow	3	21,174.63	18.48
		Very Shallow	1	17,713.10	15.45
		ROC, Settlement	0	7,276.75	6.35
Soil Drainage	0.126	Hampered	6	10,678.71	9.32
		Well	10	91,039.78	79.43
		Fast	1	5,616.08	4.90
		ROC, Settlement	0	7,276.75	6.35
Distance from Settlement	0.121	>500 m	10	66,867.57	58.22
		0-500 m	1	47,976.01	41.78
Distance from Water Source (River, Spring, Lake/Reservoir)	0.165	>500 m	10	14,844.84	12.93
		0-500 m	1	99,998.71	87.07
	1.000				

ROC = Rock outcrop.

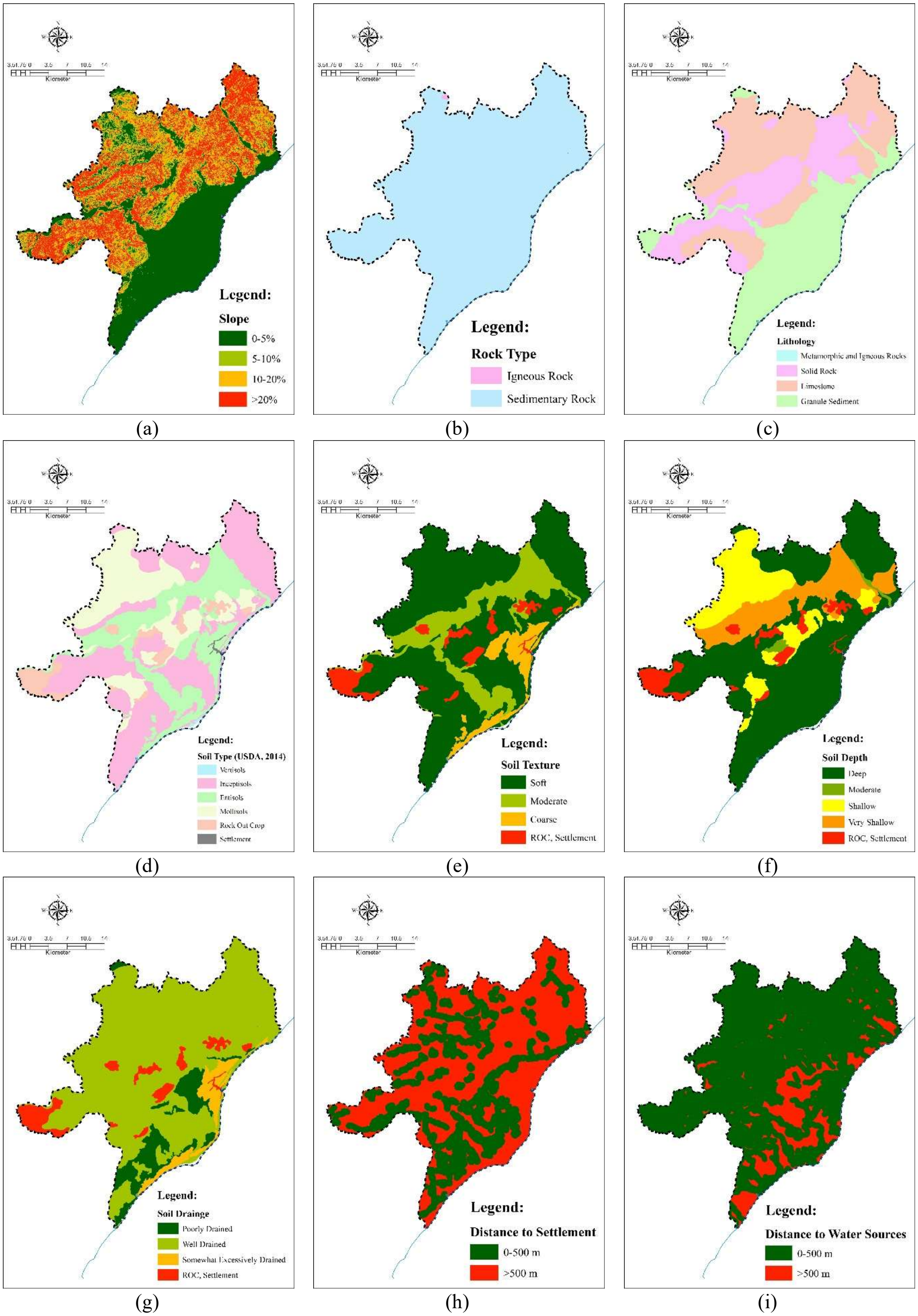

Figure 1. Spatial distribution of: (a) slope, (b) rock type, (c) lithologi, (d) soil type, (e) soil texture, (f) soil depth, (g) soil drainage, (h) distance to settlement, and (i) distance to water sources.

Table 2. Rating for pairwise comparison according to Saaty (2008).

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very strongly	Extremely
Less Important					More Important			

Table 3. The results of Analytical Hierarchy Process (Geometrik Mean 5 Experts).

	Normalization									Weight
	Slope	**Geology**	**Lithology**	**Soil**	**Texture**	**Depth**	**Drainage**	**JP**	**JSA**	
Slope	0.179	0.175	0.162	0.236	0.204	0.212	0.191	0.149	0.156	**0.185**
Geology	0.043	0.042	0.041	0.034	0.038	0.032	0.044	0.044	0.051	**0.041**
Lithology	0.092	0.085	0.083	0.085	0.095	0.084	0.067	0.087	0.074	**0.084**
Soil	0.058	0.094	0.075	0.077	0.066	0.087	0.083	0.088	0.097	**0.081**
Texture	0.118	0.149	0.118	0.158	0.135	0.144	0.145	0.148	0.127	**0.138**
Depth	0.049	0.076	0.058	0.051	0.055	0.058	0.070	0.059	0.064	**0.060**
Drainage	0.118	0.121	0.157	0.117	0.117	0.105	0.126	0.146	0.129	**0.126**
JP	0.148	0.118	0.118	0.108	0.112	0.121	0.106	0.123	0.133	**0.121**
JSA	0.195	0.139	0.189	0.134	0.180	0.156	0.167	0.156	0.170	**0.165**
Total Weight										**1.000**

Description: JP = Distance from settlement JSA = Distance from water.

Max eigenvalue (γmax) = 9.118 n = 9
Consistency index (Ci) = (γmax - n)/(n - 1) = 0.015
Random index (Ri) = 1.45
Consistency ratio (Cr) = Ci/Ri = 0.010140329
CR score = 0.010140329, which is less than 10% (CR<0.1), hence the CR score can be accepted.

Another parameter to consider for the landfill location is the soil texture suitability. Suitable soil is neither clayey nor too sandy and is also well-drained to effectively eliminate and reduce the possibility of pollution. Sandy soil may also bind to toxic elements; therefore, smooth and rough soil was assigned a value of 6 and 1, respectively, during the soil texture evaluation process with a score of 10. Table 1 column –b- describes the weight analysis results using the AHP method from the 5 experts involved. The slope, stone/geological type, aquifer lithology, soil type, and soil texture parameters had weights of 0.185, 0.041, 0.084, 0.081, and 0.138, respectively. Also, parameters, including soil depth, soil drainage, distance from settlements, and water sources (rivers, springs, lakes/reservoirs), had weights of 0.060, 0.126, 0.121, and 0.165, respectively. Based on these criteria, the AHP scores can be the basis for making land availability maps.

Results and Discussion

The results of pairwise comparison analysis presented in Table 3 show that these findings were valid, as indicated by the CR value of less than 0.1. This value implies that decisions are not made by chance (Saaty, 2008). The results of the criteria weighting also showed that the slope had the highest role in determining the land suitability for landfills in Malaka Regency. This parameter was followed by distance from water sources (rivers, springs, lakes/reservoirs) and sequentially by soil texture, soil drainage, distance from settlements, aquifer lithology, soil type, soil depth, and rock types. Figure 2 and Table 4 illustrate the data from the land suitability analysis of the waste landfill in Malaka Regency. The results of the land suitability for landfill analysis in Figure 2 shows that 12.88% of the land in Malaka Regency was Highly Suitable (S1) as landfill location with the majority of 63.66% Suitable (S2) to be used as a landfill location in Malaka Regency.

The results of the analysis of the land suitability class for the landfill in Malaka Regency showed that the Highly Suitable/S1 had an area of 14,728.46 ha (12.88%), the Suitable/S2 had an area of 72,776.68 ha (63.66%), the Marginal Suitable/S3 had an area of 21,885.46 ha (19.14%), and Not Suitable/N had an area of 4,923.81 ha (4.31%). The criteria used to classify land suitability classes are range. The range is the distribution of values from the multiplication between weight and the score. After that, the minimum (0.928) and maximum (9.475) values are divided into four parts.

Determination of landfill location based on Manurung and Santoso (2019), who studied using AHP and GIS methods also found that landfill location was classified as feasible, fairly feasible, less feasible and not feasible with several assessment indicators such as slope, geological conditions, hydrogeological conditions, proximity of water sources, distance to settlements and other indicators.

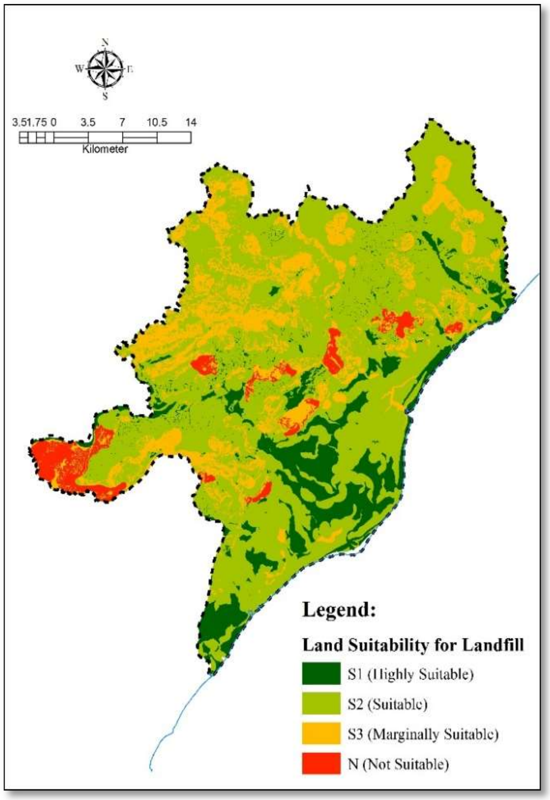

Figure 2. Land suitability for landfill in Malaka Regency, East Nusa Tenggara.

One of the criteria in selecting a landfill site is slope because the steeper an area, the more difficult the construction and operation of the landfill. Areas with a slope of >20% were not suitable for landfill sites. The results of these findings are important to know the suitable location as a landfill. The selection and determination of the landfill conducted by Pahlawati et al. (2019), also found three potential locations for landfill with several criteria such as slope, geological conditions, distance to water sources, distance to residential areas, soil conditions and other criteria. Usually, there are two main categories in determining the location of a landfill, namely regional feasibility and allowance feasibility. These criteria are very important in determining the location of the landfill so that there are no mistakes in determining landfill location so that environmental pollution does not occur due to selecting the wrong landfill location. Forest area, land use, and Landuse Planning (RTRW) maps were used to analyze land availability. The land use (RTRW) map and the availability of terrain for landfills in Malaka Regency showed that Dry Land Agriculture was available.

Table 4. Quantitative analysis results.

Suitability Class	**Range**	**Area**	
		ha	**%**
S1 (Highly Suitable)	7.338-9.475	14,728.46	12.88
S2 (Suitable)	5.202-7.338	72,776.68	63.66
S3 (Marginally Suitable)	3.065-5.202	21,885.46	19.14
N (Not Suitable)	0.928-3.065	4,923.81	4.31
Total		**114,314.41**	**100.00**

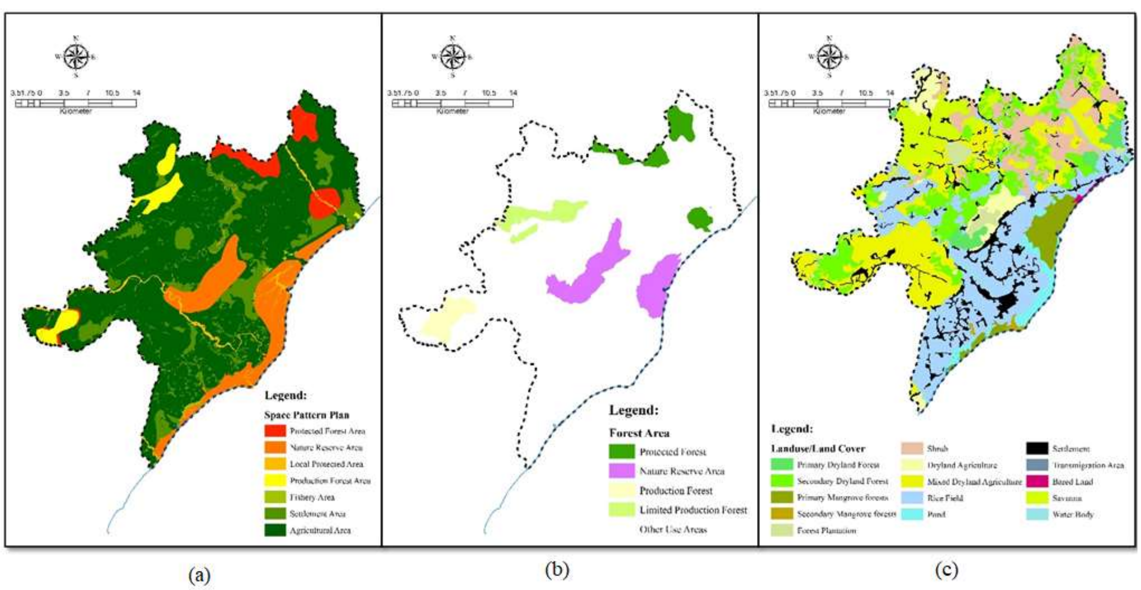

Figure 3. (a) Space pattern plan, (b) Forest area, dan (c) Landuse/land cover.

Meanwhile, the analysis results of the forest areas and land availability for the landfill in Malaka regency showed that the land available for the landfill location was only accessible in Other Use Areas (APL). The assay of land use and availability for the landfill location in Malaka Regency indicated that Bushes, Dry Land Agriculture, Mixed Shrub Dry Land Agriculture, Savanna/Grasslands, and Open Land were available for the landfill location. Figure 3 depicts the analysis results of the spatial pattern plan (RTRW), forest areas, and land use for the location of the landfill in Malaka Regency.

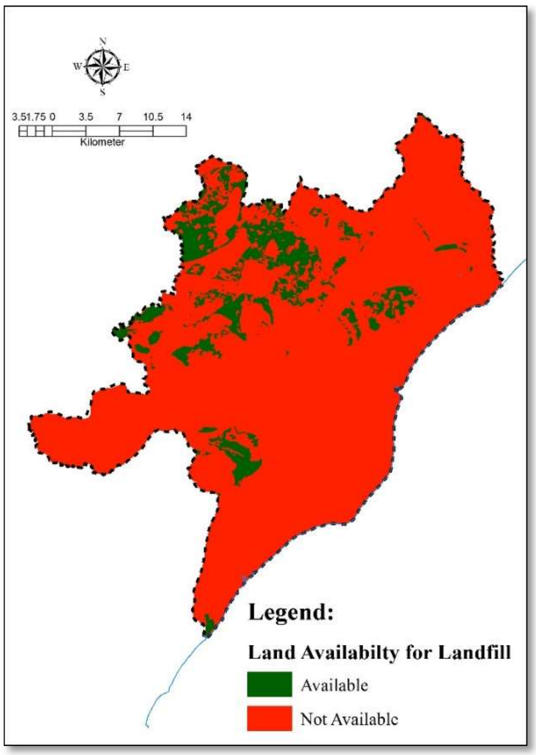

Figure 4. Map of available land for landfill in Malaka Regency, East Nusa Tenggara.

Based on the analysis of several maps, which were used as a basis or condition for determining the availability of landfill sites in Malaka Regency, "Available Locations" for the waste landfill in Malaka Regency covered an area of 11,781.05 ha, signifying 10.27% of the land. Meanwhile, the "Unavailable Locations" comprised an area of 102.879.97 ha, representing 89.73% of the terrain. Table 5 presents the distribution of Land Availability for landfill locations in Malaka Regency. The Land Availability map for the landfill location in Malaka Regency showed that the colored locations were Unavailable while the green color was Available, as presented in Figure 4. In Table 5, it can be explained that the land availability criteria are obtained from the results of the overlay between the Space pattern plan, Forest area and landuse/landcover.

Table 5. Distribution of land availability for landfill in Malaka Regency, East Nusa Tenggara Province.

No	Land Availability	Area	
		ha	%
1	Available	11,781.05	10.27
2	Not Available	102,879.97	89.73
	Total	**114,661.02**	**100.00**

Groundwater is a criterion in determining the landfill location because it is natural water below the ground surface contained in aquifers as a source of clean water. If the selection of a landfill site does not pay attention to groundwater conditions, it can cause contamination of groundwater as the source of clean water because the hydrogeological requirement for the construction of a landfill is that there is no groundwater at a depth of less than 3 meters from the ground surface (the shallower the groundwater level, the easier it is for contamination to occur). Research conducted by Tongkukut et al. (2019), found that there are aquifers at the landfill construction site at the research location with different depths.

The Land Suitability analysis for available landfill terrain in Malaka Regency consisted of four classes, namely land suitability class S1 (Highly Suitable), class S2 (Suitable), class S3 (Marginally Suitable), and class N (Not Suitable) with areas of 203.37 ha, 6,873.08 ha, 4,027.42 ha, and 651.98 ha, respectively. Based on the results, the most extensive land suitability category was the S2 class (Suitable) with an area of 6,873.08 ha. Figure 5 represents the Land Suitability Map of Landfill in Available Land in Malaka Regency, while the distribution of land suitability is presented in Table 6.

Determination of the landfill location by Wijayakusuma and Satiawan (2019), using the AHP and GIS methods, found two alternative locations with several indicators, namely slope, geological conditions, hydrogeological conditions, land use, distance to settlements and other indicators that produce land suitability maps for landfill locations. The results showed that the land use indicator, namely the distance to the settlement, was the most influential factor in the selection of the landfill location, while the physical and ecological indicators, such as the hydrogeological condition, became the most influential factors in the selection of the landfill location.

Environmental geology aspects become very influential on the process of selecting landfill sites that consist of lithology, groundwater, slope, rainfall, potential for soil movement and land use. Rock type is one of the criteria in selecting landfill site because rock types play a role in reducing leachate pollution. The potential for soil movement is also one of the criteria in determining the location of a landfill because areas prone to landslides are considered unfit to become a landfill because soil movement can damage the construction of the landfill. The results of this study resulted in 3 zones, namely the not feasible zone, the moderate feasible zone, and the low feasible zone (Susanti et al., 2020).

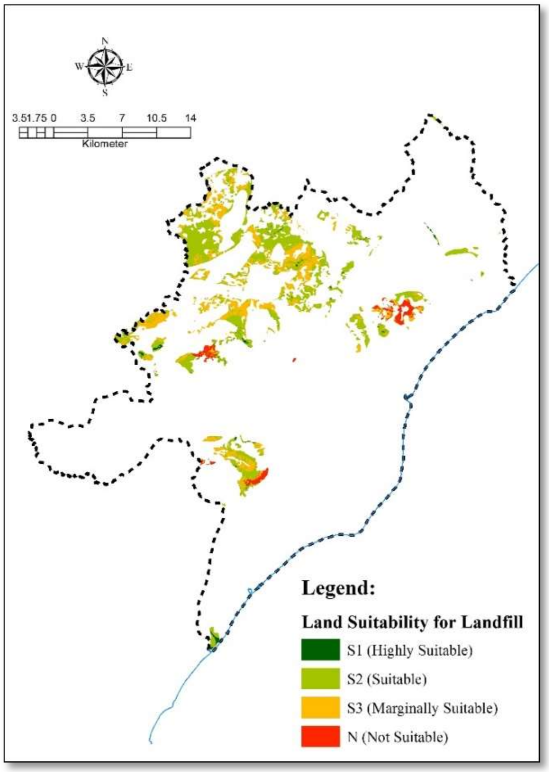

Figure 5. Land suitability map of landfill in available land in Malaka Regency, East Nusa Tenggara.

Table 6. Distribution of sustainable land for landfill in available land in Malaka Regency, East Nusa Tenggara.

Suitability Class	Area	
	ha	%
S1 (Highly Suitable)	203.37	1.73
S2 (Suitable)	6,873.08	58.47
S3 (Marginally Suitable)	4,027.42	34.26
N (Not Suitable)	651.98	5.55
Total	**11,755.85**	**100.00**

The land availability is land that is available for landfill location, while land suitability is land for certain uses that must be in accordance with the terms or conditions. Therefore, the selection of the location of the waste landfill in Malaka Regency must be analyzed for land availability and land suitability because the available land does exist, but not all available land in Malaka Regency is suitable for landfill location. The difference between Table 4 and Table 6 is that Table 4 shows the land suitability class for landfill as a whole in the Malaka Regency, while Table 6 is the distribution of land suitability for landfill only in available locations for landfill.

The selection of landfill locations using AHP and GIS was also carried out by Pasalari et al. (2019). They stated that the selection of the landfill location must be made properly to prevent environmental problems, including water pollution caused by an unhealthy landfill. This study used a multi-criteria decision-making method to ensure the best landfill location. Some of the important criteria used were surface water, groundwater, land use, soil type, slope and several other criteria. The results showed that the distance from settlements and groundwater become the most important criterion in selecting the landfill location at the research location. Analysis of landfill location suitability with a multi-criteria approach carried out with the AHP and GIS approaches using morphological, environmental and socio-economic parameters (13 criteria) aimed at reducing the environmental pollution. The results of the analysis showed that there were several criteria such as very suitable, suitable, fairly suitable and not suitable (Kamdar et al., 2019; Demesouka et al., 2019).

Conclusion

The results showed that highly suitable land (S1) for the landfill in Malaka Regency covered an area of 203.37 ha, while the available land comprised 203.37 ha, accounting for 1.73% of the regency. Furthermore, the analysis indicated that there was enough land available for the landfill. The results of the analysis of land availability showed that the available land for landfill in Malaka Regency was 11,781.05 ha or 10.27% of the total area of Malaka Regency.

Acknowledgements

The first author thanks the local government of Malaka Regency of East Nusa Tenggara for awarding a scholarship to complete this study.

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