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Landfill Site Selection Using Spatial Information Technologies: A Case Study for Bodrum District

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ABSTRACT

With the rapid increase of the world's population, waste production is also increasing exponentially. Although these wastes must be disposed of in landfill sites under control according to national and international decrees, some of the waste is still disposed of in wild irregular landfill sites. Environmental pollution and health risks occur as a result of these wild irregular landfill sites. Besides, criteria need to be considered for suitable areas that solid waste landfill sites to be built. One of the areas where solid waste is disposed of in wild irregular landfill sites is the Bodrum district of Muğla province. In this study, related literature for criteria selection was reviewed and analysis for the study area has performed. Since national and international regulations differ for restricted areas, common approaches in the reviewed studies have been used to identify restricted areas. Furthermore; the weight of the criteria was determined according to the usage frequency of each criterion in the literature. As the result, the reclassification maps according to each criterion and the site selection map obtained by weighting all the criteria were produced by the means of the spatial analysis methods of Geographical Information Systems.

1. INTRODUCTION

Today, some of the waste produced is still disposed of wild irregular landfill sites that cause environmental pollution and health risks. Therefore, an effective solid waste management system is needed (Özkan, 2018). The wastes must be collected, incinerated or recycled in an order determined by national and international decrees (Chabuk et al., 2016).

These landfill sites must be able to serve for long terms. The capacity and operating life of the landfill sites should be determined according to the population of the service region, waste produced per person today, and calculated waste produced per person for the following years. Then, it should be investigated whether there are sufficient alternative areas for the construction of the calculated storage area.

Solid waste landfill site selection is a complicated process because the suitability of alternative areas should be determined by paying attention to many environmental, economic, and social criteria (Özkan, 2018). For efficacious landfill site selections, the criteria must be determined by paying attention to national and international decrees, expert opinions, characteristics of the relevant region, and frequency of use in literature.

On the other hand; Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) should be used in landfill siting because they are powerful, integrated tools used to solve the problem of landfill site selection (Chabuk et al., 2016; Abdel-Basset et al., 2021; Meng et al., 2021; Zolfaghary et al., 2021; Paul et al., 2021). Among the MCDA methods, Analytical Hierarchy Process (AHP) is the most common and popular, used to identify criteria weights using a pairwise comparison matrix (Mohammed et al., 2019).

In Muğla, Bodrum where this study uses as the application area, wild irregular landfill sites that are close to residential zones, affects the environment and human health negatively due to methane gas explosions

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chained by the increase in heat during the summertime (Staines et al., 2004; Kılıç, 2017).

Also, Bodrum is one of the most touristic regions of Turkey and the summer population is much higher than the winter population. Therefore, the size of the landfill site should be taken into account according to the amount of waste in the summer population. Consequently, a solid waste landfill site appears to be needed in Bodrum.

In this study, the frequency of use of the criteria in the literature and the national and international decrees that were considered in the criterion constraints were examined. Then, a landfill site suitability map was created using the frequency of use of criteria as weights and GIS.

1.1. The Study Area

The study area is Bodrum (Fig. 1) district, which is located within the borders of Muğla province in the Southwestern Aegean Region. With a 656,1 km^2 area, Bodrum is one of the most touristic regions of Turkey. Therefore, the summer population is much higher than the winter population. According to Turkey Statistical Institute (TSI) data for 2019, the resident population of Bodrum is 175,435. However, this population exceeds 1 million in the summertime (Atacan, 2011; Öner et al., 2019). The majority of the resident population live on the coastlines. Also, there is an airport used for military purposes and a natural monument and nature parks taken under protection in the region.

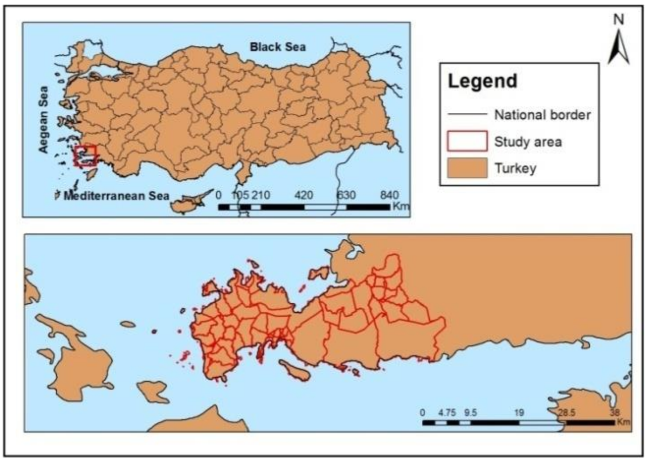

Figure 1. Location map of the study area

2. METHOD

GIS and AHP are often used for the alternative landfill site selections. AHP divides the decision problems into understandable parts; each of these parts is analyzed separately and integrated in a logical manner (Rahmat et al., 2016). AHP is a method used to determine the severity of effective measures in decision making with binary comparisons. The method helps to evaluate multi-criteria decision-making problems under uncertainty by including the GIS professionals' experience, knowledge, and intuition as the decision maker. Though there are many scales used in AHP (Franek & Kresta, 2014), 1 to 9 grades of importance offered by Saaty (2002) is the most common (Avşar, 2018; Zhang et al., 2021; Aguarón et al., 2021; Pham et al., 2021; Labella et al., 2021). Therefore; in order to find the weights of the criteria, 1-9 grades of importance are used in the study.

The reason for designating severity grades is to determine whether the decision-decider behaves consistently when comparing criteria. Weights can be used in comparison matrices as a result of the consistency rate being less than 10%.

In this study, accessible publications from the last ten years were evaluated and the frequency of use of criteria has been examined. These countries of the examined studies are; Bangladesh, Cameroon, Egypt, Ethiopia, Ghana, India, Iran, Iraq, Italy, Malaysia, Morocco, Pakistan, Serbia, and Turkey.

Frequency of use of the criteria is shown in the Fig. 2 below. The least mentioned criteria in the literature were collected under the name of the other group. This group consists of state border, forests, snow/glacier, plantation, military areas, thalwegs, landscape, borehole, flooding, nonferrous exploitation fields, and distance to industrial areas.

The 28 examined criteria were weighted according to their frequency of use. The weighting table was shown in Table 1. Then, taking into account the characteristics of the region, the selected 12 criteria were reweighted. The reweight table was shown in Table 2.

A suitability map has been created using these weights and GIS. Data pertaining to the criteria have been obtained from different sources and institutions. Settlement areas, airport and land use/land cover data were obtained from CORINE Land Cover (2018) Copernicus Land Monitoring Service and Google Maps. Road data was obtained from Geofabrik GmbH Company. Surface water data was obtained from CORINE Land Cover (2018) and Geofabrik GmbH Company. Geology and fault data was obtained from General Directorate of Mineral Research and Exploration of Turkey Geoscience Map Viewer and Drawing Editor. Protected areas data was obtained from Republic of Turkey Ministry of Agriculture and Forestry General Directorate of Nature Conservation and National Parks. Aspect data was obtained from USGS Earth Explorer and Bodrum Municipality Meteorology Directorate. Coastline data was obtained from Bodrum Municipality Directorate of Development and Urbanization. Finally, the population data of the quarters was obtained from Turkey Statistical Institute. Restriction map and reclassified maps of criteria were produced in the ArcGIS/ArcMap software (version 10.6.1) of ESRI company. This study used the World Geodetic System (WGS) 1984 Datum and the Universal Transverse Mercator (UTM) projection Zone 35N coordinate system.

3. RESULTS

In this study, the criteria to be considered in the selection of solid waste landfill site locations were examined. The criteria have been examined on a total of 23 sources of the last ten years from 14 different countries. As Fig. 2 suggests, the most commonly used criteria are; distance to roads, distance to surface waters, slope, distance to settlements, and land use/land cover with the weights of 0.10, 0.09, 0.08, 0.08, 0.08, respectively.

These five criteria were seen to be the most important criteria for landfill site selections. Other criteria have been seen to change according to the characteristics of the region.

For Bodrum district, 12 criteria were selected from the presented 28 criteria. Criteria were determined by considering the data obtained from open source and the characteristics of the region. These criteria are distance to roads, distance to surface waters, slope, distance to settlements, land use/land cover, geology, distance to protected areas, distance to airports, aspect, distance to the coastline, population density, and distance to faults.

Then, the 12 selected criteria were reweighted. In the reweighting for the selected 12 criteria, distance to roads, distance to surface waters, slope, distance to settlement areas, and land use/land cover criteria were found to take high weights. Respectively weights are 0.14, 0.13, 0.13, 0.13, 0.11. Determined criteria and their weight were shown in Table 2.

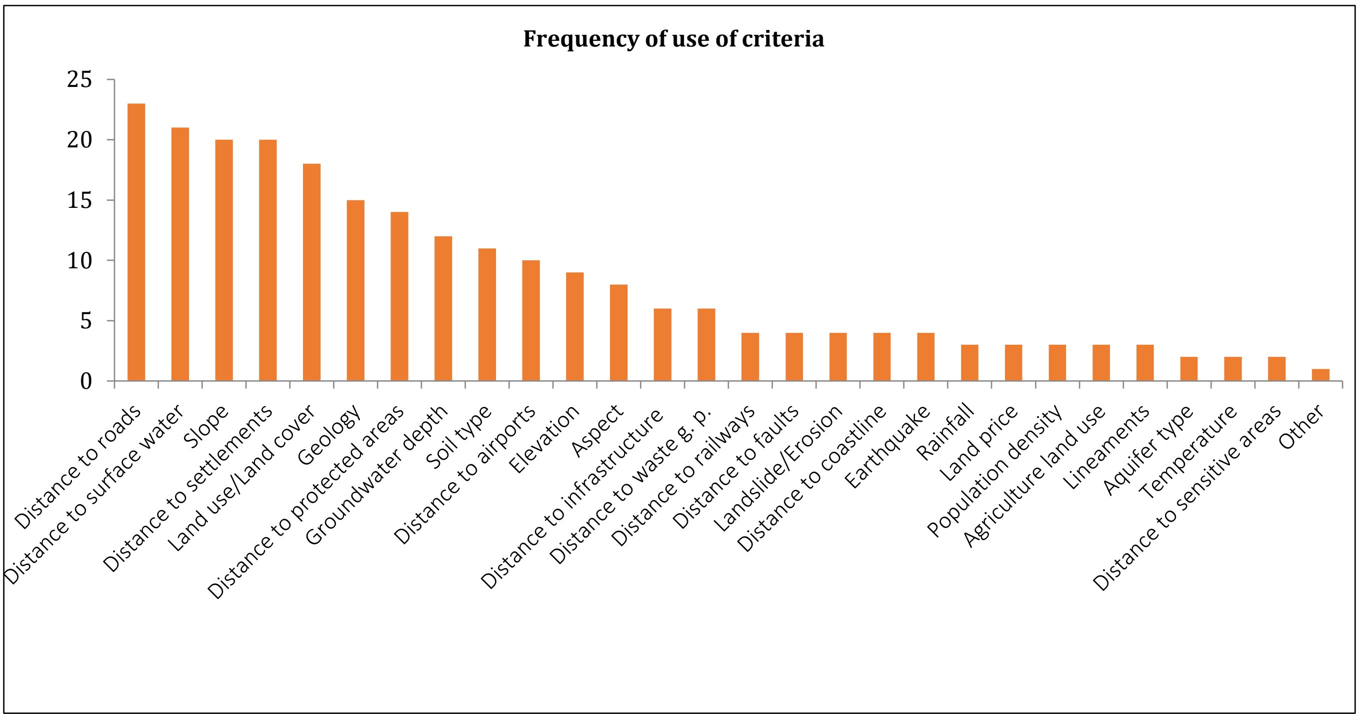

Figure 2. Frequency of use of criteria in literature

Table 1. Criteria in literature and their weight

Criteria	Weight	Criteria	Weight	Criteria	Weight	Criteria	Weight
D.t.roads	0.10	G.water depth	0.05	D.t.railw.	0.02	Popul. Den.	0.01
D.t.s.water	0.09	Soil type	0.05	D.t.faults	0.02	Agri. l. use	0.01
Slope	0.08	D.t.airports	0.04	L.S./Eros.	0.02	Lineaments	0.01
D.t.settl.	0.08	Elevation	0.04	D.t.coastl.	0.02	Aquifer ty.	0.01
L.U./L.C.	0.08	Aspect	0.03	Earthquake	0.02	Temperat.	0.01
Geology	0.06	D.t.infrast.	0.03	Rainfall	0.01	D.t.sens. a.	0.01
D.t. prot.ar.	0.06	D.t.waste g.	0.03	Land price	0.01	Other	0.00
						Summation	1.00

Table 2. Determined criteria and their weight

Criteria	Weight	Criteria	Weight
D.t.roads	0.14	D.t.p.a.	0.09
D.t.s.w.	0.13	D.t.air.	0.06
Slope	0.13	Aspect	0.05
D.t.settl.	0.13	D.t.c.l.	0.02
L.U./L.C.	0.11	Pop.de.	0.02
Geology	0.09	D.t.faul.	0.03
		Sum.	1.00

3.1. Evaluation of Determined Criteria

Distance to roads

Landfill sites should be built close to the roads, considering the cost of transporting waste. At the same time, landfill sites should not be built too close to the roads, considering the problem of visual pollution (Gebre & Getahun, 2020).

Distance to surface water

Landfill sites should be built away from the surface waters taking into account human health and environmental pollution (Ghoutum et al., 2020).

Slope

Excavation-filling operations in high slope areas increase the cost. Therefore, landfill sites should be built in areas where the slope is low (Dar et al., 2018).

Distance to settlements

Landfill sites should be built away from settlements so that human health and the environment are not adversely affected. According to the Turkey Solid Waste Control Regulation (1991), landfill sites should be built at least 1000 m away from the settlements. At the same time, taking into account the cost of waste transportation, solid waste landfill sites should not be too far from settlements.

Land use/Land cover

Forests and agricultural lands are not suitable for landfill sites. Sclerophile vegetation and pasture areas are better suitable for the construction of landfill sites.

Geology

Landfill sites should be built in areas with low water permeability. Landfill sites need to be built on a sealed floor (Aksoy, 2016; Chaudhry et al., 2020).

Distance to protected areas

Landfill sites should be built away from natural, ecologically, and culturally protected areas.

Distance to airports

Landfill sites attract wild animals because they contain organic waste. One of them is birds. In order for planes to land and take off safely, it is important to pay attention to the surrounding bird population. At the same time, gas emissions and methane gas explosions in storage areas can also compromise flight safety (Deniz & Topuz, 2018). Therefore, landfill sites should be built away from airports.

Aspect

The aspect criterion is an important criterion for evaluating the prevailing wind direction. Areas exposed to strong winds are areas that are not suitable for landfill sites (Şener et al., 2011; Özkan, 2018).

Distance to coastline

Coastal areas are regions where groundwater levels are on or near land. In addition, the population density of coastal areas is high (Barzehkar et al., 2019). Therefore, landfill sites should be built away from the coastline.

Distance to population density

Landfill sites should be built in areas with low population density, taking into account human health.

Distance to faults

Landfill sites should be built away from fault lines. Because the stabilization of the storage areas to be established on the fault lines may be disrupted as a result of seismic movements and may cause the waste piles to collapse or even slide (Deniz & Topuz, 2018).

First, areas, where the landfill sites cannot be built, have been identified (Fig. 3). Criteria restrictions were shown in Table 3. Criterion restrictions were determined taking into account the recommended values in the literature. Only the distance specified in the Turkey Solid Waste Control Regulation (1991) has been taken into account in limiting the distance to the settlements.

When the literature was examined, it was seen that most countries were inadequate when determining the criteria restrictions. Later in the article, this topic was also discussed.

Forests are areas that are not suitable for the construction of landfill sites. Moreover, it was observed that there are many forests in the study area. When forests were determined as a restricted criterion, it was seen that there was not enough area for landfill sites. Therefore, a value of 1 was assigned to the forest criterion in the study.

Table 3. Determined criteria and their weight

Criteria	Restrictions
D.t. airports	1500 m
D.t. surface water	500 m
D.t. settlements	1000 m
D.t. coastline	1000 m
D.t. protected areas	1000 m
Land use/Land cover	Industrial areas, burnt areas
Slope	>35°

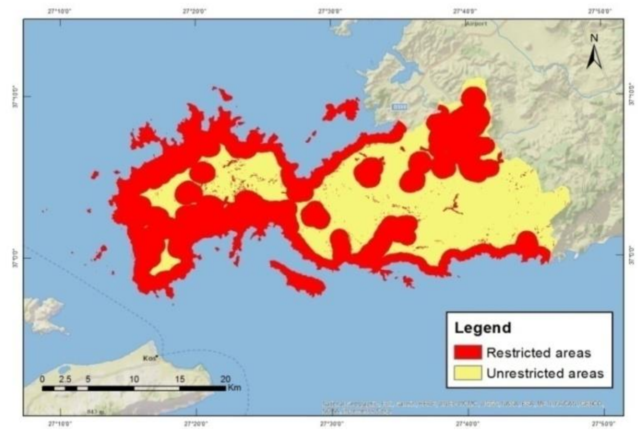

Figure 3. Restriction map of the study area

Afterwards, the reclassification map of each criterion was produced (Fig. 4). Criteria ratings were determined by considering the ratings in the literature and the characteristics of the region. Ratings were graded between 0 and 10 points. A value of 10 was specified as the most suitable areas, and a value of 0 was specified as unsuitable areas.

The ranking of each criterion were shown in Table 4. The criteria ratings specified in the table were generated by taking into account the studies of Yıldırım (2012), Güler (2016), Deniz & Topuz (2018), Randazzo et al. (2018) and Barzehkar et al. (2019).

Table 4. Ratings of criteria

Criteria	Buffer Zone	Rating	Criteria	Buffer Zone	Rating
Distance to	0-250 m	1	Geology	Volcanic	10
roads	250-500 m	4		Metamorphic	5
	500-750 m	7			
	750-1000 m	8	Distance to	>1000 m	10
	1000-1250 m	10	protected areas	0-1000 m	0
	1250-1500 m	8			
	1500-1750 m	6	Distance to	>7000 m	10
	1750-2000 m	3	airports	5000-7000 m	7
	>2000 m	1		3000-5000 m	5
				1500-3000 m	3
Distance to	>2000 m	10		0-1500 m	0
surface water	1500-2000 m	7			
	1000-1500 m	5	Aspect	SSW ,WSW, W	10
	500-1000 m	3		WNW, ESE, E	10
	0-500 m	0		ENE,SSW, NW	9
				S, NNW	6
Slope	0°-5°	10		SSE	5
	5°-10°	9		SE, NE	2
	10°-25°	7		N, NNE	1
	25°-35°	3			
	>35°	0	Distance to	>1000 m	10
			coastline	0-1000 m	0
Distance to	0-1000 m	0			
settlements	1000-2000 m	2	Population	0-200	10
	2000-3000 m	4	Density	200-700	8
	3000-4000 m	6	(persons per/km^2)	700-1800	6
	4000-5000 m	8		1800-3000	4
	5000-6000 m	10		3000-4500	2
	>6000 m	5		>4500	1
Land Use/	Wild irregular sites	10	Distance to	>2500 m	10
Land Cover	Mine areas	10	faults	2000-2500 m	9
	Grasslands	8		1500-2000 m	8
	Sclerophile	6		1000-1500 m	6
	Agriculture	4		500-1000 m	5
	Natural vegetation	3		250-500 m	3
	Forest, swamp	1		100-250 m	2
	Burnt areas	0		0-100 m	1
	Industry areas	0			

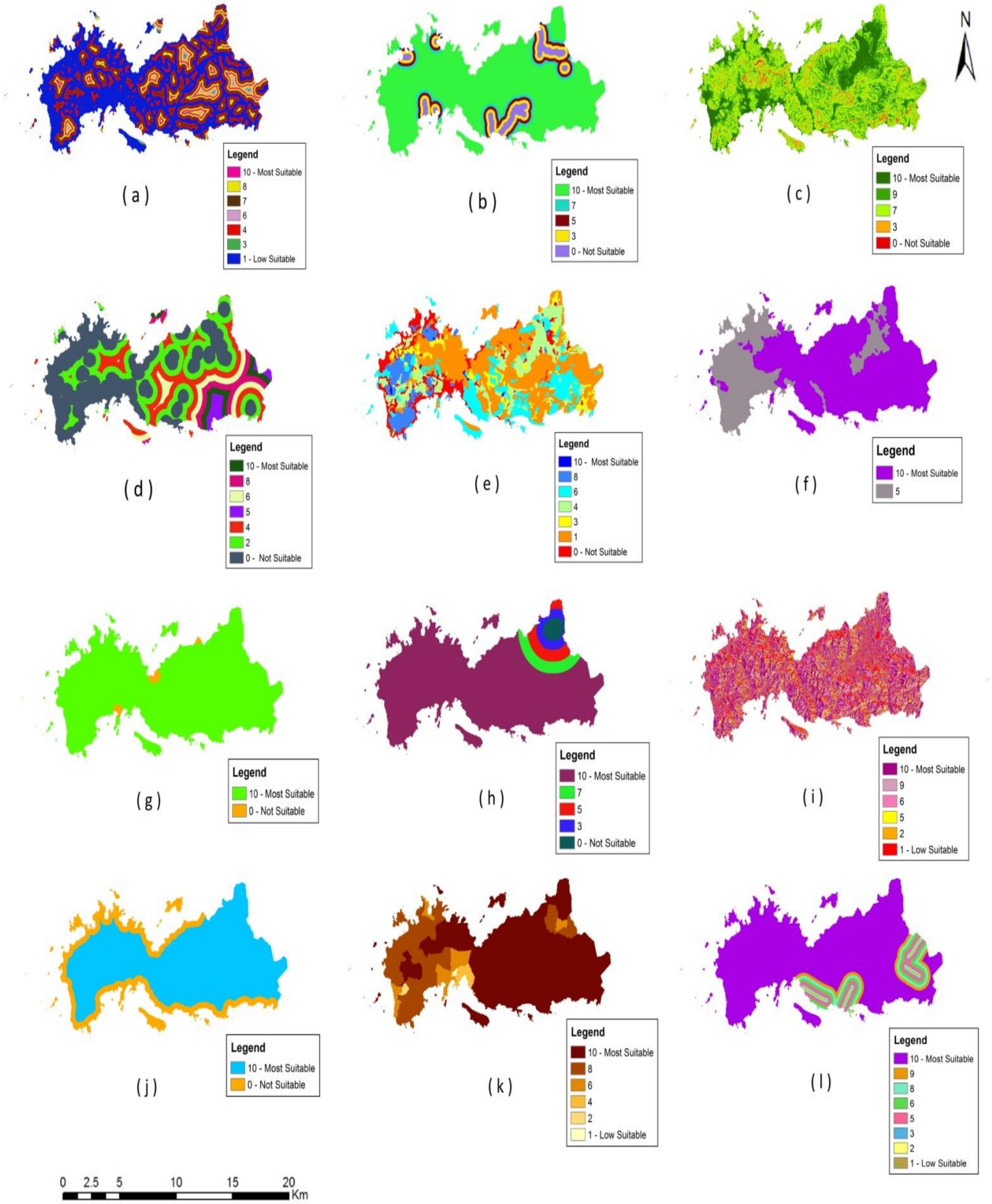

Figure 4. Reclassification maps (a) Distance to roads, (b) Distance to surface waters, (c) Slope, (d) Distance to settlements, (e) Land use/Land cover, (f) Geology, (g) Distance to protected areas, (h) Distance to airports, (i) Aspect, (j) Distance to coastline, (k) Population density, (l) Distance to faults

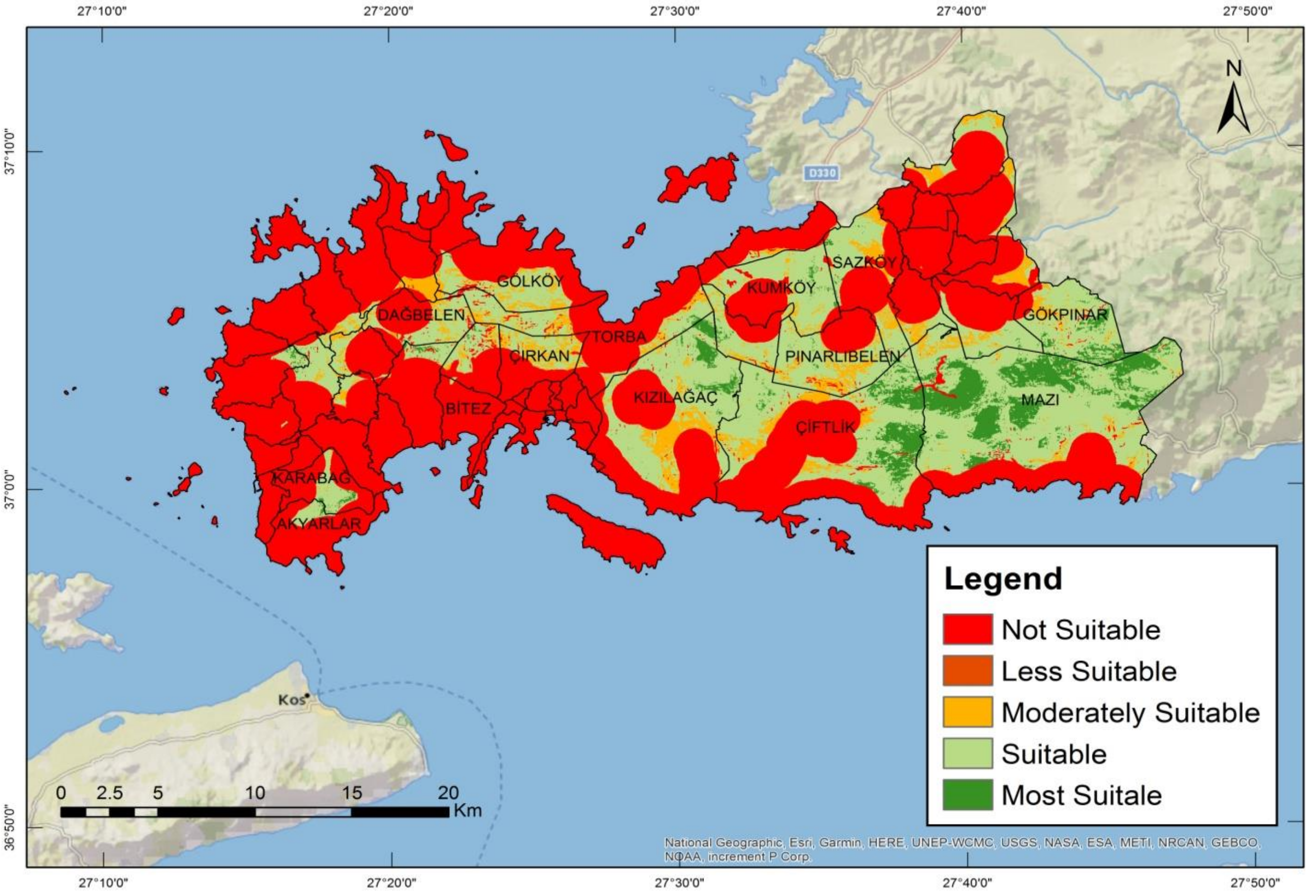

Figure 5. Solid waste landfill site suitability map for Bodrum district

When the suitability map (Fig. 5) is examined, the most suitable areas for landfill site can be observed in the quarters of Mazı, Gökpınar, Çiftlik and Gökpınar.

The study, also examined whether there are national-international decrees set by countries. When the studies carried out in Iran were examined; in 2019 it was observed that Barzehkar and others took into account the decrees in his study. In 2016, Rahmat and others' study mentioned that decrees were taken into account, but it was observed that Barzehkar and others did not match each other compared to the restrictions on his study.

It has also been observed that Ghana and India take into account national decrees when determining criteria restrictions. Studies conducted in other countries have observed that expert opinions, questionnaires, and national-international decrees together were taken into account in determining criteria restrictions.

4. DISCUSSION

These findings suggest that the first five criteria were significant according to the weightings process. The first most commonly used criterion is the distance to roads criterion. Landfill sites need to be close to roads because moving waste over long distances will increase the cost. At the same time, landfill sites should not be too close to roads and should not create visual pollution. Therefore, it has been seen that the distance to roads criterion is one of the criteria to be considered the most.

The second crucial criterion is the distance to surface water. In this criterion, landfill sites must be built away from surface waters to avoid environmental pollution. The third most commonly used criterion was the slope criterion. Building landfill sites in areas with high slopes will cost a lot of money due to excavation-filling operations. Therefore, landfill sites should be built where the slope is low.

Landfill sites should be built in areas far from settlement areas. The environment and human health should not be compromised. The fifth most widely used criterion in the literature is the land use criterion. Land use/Land cover is the fifth most widely used criterion in the literature. Landfill sites should not be built in forest areas. It can be said that these criteria are the main criteria to be considered in future studies. These areas are not determined as restricted areas because forests are too many in the study area.

The ratings of the criteria determined in the study were determined by taking into account the ratings in the literature and the characteristics of the region. Using these ratings and calculated weights, a suitability map has been created in the ArcGIS/ArcMap program. It has been observed that the most suitable areas were in the Mazı, Çiftlik, Kızılağaç, and Gökpınar quarters.

When criterion restrictions were examined, it was observed that 3 out of 14 countries were bound by decrees. In the studies examined, it was observed that the researchers applied different references when determining the criteria. As a result of the reviews, it is clear that the national decrees of the countries were inadequate.

5. CONCLUSION

In Bodrum, wild irregular landfill sites imperil the environment and human health. Therefore, a solid waste landfill site appears to be needed in Bodrum. In this study, the frequency of use of the criteria used in the selection of solid waste landfill sites in the literature for Bodrum district was examined. The 28 criteria determined as a result of the literature review were weighted according to their frequency of use. The most commonly used criteria were observed as a result of weighting. 12 criteria were determined for the Bodrum district. The criteria were determined by taking into account the characteristics of the region and the data obtained. It was observed that the criteria vary according to regional characteristics in the sources examined.

Using these weights, suitable areas for landfill sites were analyzed. The ratings of the criteria were determined by taking into account the ratings in the literature and characteristics of region. Later in the study, criterion ratings and their weights will be determined within the expert opinions. Then, the results obtained in this study and the results to be obtained within the opinions of experts will be compared.

At the same time, it was examined whether national-international decrees were taken into account in the criterion restrictions. It has been observed in most sources that national-international decrees were not taken into account. It is clear that national-international decrees must be taken into account for an efficient outcome. This study will guide future studies.

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