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Site Selection Based on Analytic Hierarchy Process in the Planning Process for Solid Waste Sanitary Landfills: The Case of Denizli City, Turkey

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Abstract

Waste management has grown into a significant matter for cities in line with the population growth and increased urbanization. Waste must be properly disposed to avoid causing a problem for environmental and human health. A variety of methods are used to dispose waste. Sanitary landfill, which is among these methods, is one of the common methods used for its safety and affordability. In the implementation of this method, a suitable site selection is a major factor that affects the whole process ranging from the construction to the operation of a sanitary landfill. It is aimed to determine the most suitable solid waste sanitary landfills (SWSL) for the city of Denizli in consideration of site selection criteria regarding solid waste landfills. The relevant legislation, academic studies and the current situation of the study area were taken into consideration to determine site selection criteria for SWSL. In this context, residential areas, primary traffic roads, protected areas, slope, aspect, water surfaces, rock structure, fault line, hydrologic soil groups, land use capability classification and land cover were determined as a site selection criteria. In the study, Geographic Information Systems (GIS) was used in spatial analysis, and analytic hierarchy process (AHP), one of the multi-criteria decision making methods, was used in weighting the site selection criteria. According to the suitability map which is generated as a result of the study, 19.536,40 hectares (1.76%) of 1.109.742,16 hectares of the area was determined to be the "most suitable" for sanitary landfill while 260.520,26 hectares (23.48%) of it was determined to be "suitable". An ideal area was determined for the construction of a sanitary landfill on the areas determined as the “most suitable" in consideration of the requirements of the city of Denizli based on the projections for the year 2040.

Keywords: Solid waste sanitary landfill, waste management, analytic hierarchy process, geographical information systems.

Katı Atık Düzenli Depolama Tesislerinin Planlanma Sürecinde Analitik Hiyerarşi Süreci İle Yer Seçimi: Denizli Kenti Örneği, Türkiye

Öz

Nüfusun ve kentleşmenin giderek artmasıyla birlikte atık yönetimi kentler için önemli bir konu başlığı haline gelmiştir. Atıkların çevre ve insan sağlığı açısından sorun oluşturmaması için uygun bir şekilde bertaraf edilmeleri gerekmektedir. Atıkların bertaraf edilmesinde farklı yöntemlerden faydalanılmaktadır. Bu yöntemler arasında yer alan düzenli depolama, güvenli ve ekonomik olması nedeniyle yaygın olarak kullanılan yöntemlerden birisidir. Bu yöntemin uygulanmasında uygun yer seçimi, depolama alanının inşasından işletilmesine kadar tüm süreci etkileyen önemli bir unsurdur. Bu kapsamda çalışmada katı atık depolama alanı yer seçim kriterleri dikkate alınarak Denizli kenti için en uygun katı atık düzenli depolama alanlarının belirlenmesi amaçlanmıştır. KAAD alanı yer seçim kriterlerini belirlemek amacıyla ilgili yasal mevzuat, konuyla ilgili yapılmış çalışmalar ve çalışma alanının mevcut durumu gözetilmiştir. Bu bağlamda çalışmada, yerleşim alanları, ulaşım hatları, korunan alanlar, eğim, bakı, su yüzeyleri, kayaç yapısı, fay, hidrolojik toprak grupları, arazi kullanım kabiliyet sınıfları, arazi örtüsü yer seçim kriterleri olarak belirlenmiştir. Çalışmada Coğrafi Bilgi Sistemleri (CBS) mekânsal analizlerde, çok kriterli karar verme yöntemlerinden analitik hiyerarşi süreci (AHS) ise yer seçim kriterlerinin ağırlıklandırılmasında kullanılmıştır. Çalışma sonucunda elde edilen uygunluk haritasına göre toplam 1.109.742,16 ha. alanın 19.536,40 ha (%1,76)’ı düzenli depolama alanları için “en uygun”, 260.520,26 ha. (%23,48)’ı ise “uygun” alanlar olarak belirlenmiştir. Denizli kentinin 2040 yılı projeksiyonları doğrultusundaki gereksinimler göz önüne alınarak “en uygun” tespit edilen alanlar üzerinde düzenli depolama tesisi inşası için ideal alan tespit edilmiştir.

Anahtar Kelimeler: Katı atık, düzenli depolama, atık yönetimi, analitik hiyerarşi süreci, coğrafi bilgi sistemleri.

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1. Introduction

The amount of consumption, which increased with the population growth and rapid urbanization, has made it necessary to make a series of regulations about waste management. According to the OG (2015) waste management states that activities of, *"Prevention of waste generation, reduction at its source, re-use, sorting by characteristic and type, accumulation, collection, temporary storage, transportation, interim storage, recycling, recovery including energy recovery, disposal of waste, monitoring, control and inspection after disposal of waste procedures". According to the integrated waste management hierarchy, it is essential to re-use of waste, recovery of waste through recycling and other processes aimed at obtaining secondary raw materials or energy source in case it is impossible to prevent and reduce the generation of waste and its harmful effects at the source (MEU, 2014). Any waste that cannot be processed and recovered by the aforementioned methods must be properly disposed to avoid causing a problem for environmental and human health. A variety of methods are used to dispose waste (OG, 2015). Among these methods, landfill is one of the most common used and affordable waste disposal methods (MEU, 2014). Landfill is described as "an area where waste is received in a well-controlled manner, and any waste generated as a result of reactions after it is stored is checked" (UMT, 2014).*

The disposal of waste by landfill method is governed by the provisions of the Regulation on the Landfill of Waste published in the Official Gazette No. 27533 of 3/26/2010 (OG, 2015). The site selection, technical design, construction, operation, decommissioning and post-decommissioning control and maintenance of sanitary landfills are carried out within the framework of the aforementioned regulation (OG, 2010).

To adopt this landfill method, a suitable site selection is a major factor that affects the whole process ranging from the construction to the operation of a sanitary landfill (UMT, 2014). The Regulation on the Landfill of Waste predicates the selection of a site for a sanitary landfill on consideration of "*whether a sanitary landfill affects the safety of air traffic or not, its proximity to areas protected for specific purposes, state of groundwater and surface water bodies and conservation basins in the region, level and flow direction of groundwater, and topographic, geological, geomorphologic, geotechnical and hydrogeological characteristics of the area, high risk for any flood, landslide, avalanche, erosion and earthquake, predominant wind direction and precipitation regime, natural or cultural heritage status, and proximity to residential areas"*, and also states that it shall not be located any pipeline and high-tension line in the area (OG, 2010). Apart from those stated in the regulation for the selection of a site for sanitary landfills, it is seen that various criteria are also considered in the literature, and these criteria vary by the current situation of the study area, local standards and experiences.

According to Eskandri et al. (2012), the combination of multi-criteria decision analysis techniques and GIS features produce spatial multi criteria decision analysis which is more convenient for ideal landfill site. There are many studies on the site selection of SWSL by integrating multi-criteria decision-making methods with GIS (Küçükönder and Karabulut 2007, Eskandari et al. 2012, Yıldırım 2012, Chabuk et al. 2016, Deniz and Topuz 2018, Karimi et al. 2019, Khorsandi et al. 2019, Pasalari et al. 2019, Karakuş et al. 2020, Ali et al. 2021).

The study of Küçükönder and Karabulut (2007) has been revealed that multi-criteria analysis method and GIS can produce an effective and applicable results by considering many physical, environmental, social and economic factors in the site. Similarly Karimi et al. (2019), Pasalari et al. (2019) and Ali et al. (2021) indicate that an integrating approach of GIS and multi-criteria decision analysis is effective in landfill site selection. Khorsandi et al. (2019) used AHP and order of preference technique according to similarity to ideal solution (TOPSIS) models to weight the layers and prioritize the determined areas, respectively. They indicated that the combination of multicriteria decision-making models (AHP and TOPSIS) can be properly utilized for the purpose of site selection.

AHP and GIS are effective integrated tools used to solve the problem of landfill site selection (Chabuk et al. 2016). AHP which is a multi-criteria decision-making method allows making a common scale assessment based on paired comparison of independent criteria. In the study, GIS was used in spatial analysis, and AHP one of the multi-criteria decision-making methods, was used in weighting the site selection criteria. The site selection criteria were determined based on the relevant legal legislation, the academic studies on the subject and the current situation of the study area, and suitability analyses were performed for SWSL. The results of the analyses were evaluated in consideration of the 2040 projection of the city of Denizli and an ideal area that may be the most suitable for the SWSL determined.

2. Material and Method

2.1. Study Area

The districts of Pamukkale and Merkezefendi in the province of Denizli were chosen as a study area. The districts of Pamukkale and Merkezefendi neighbor the district of Güney to the north, Tavas and Serinhisar to the south, Sarayköy, Buldan and Babadağ to the west, and Çal and Honaz to the east (Figure 1). The province of Denizli assumed the status of a metropolitan municipality in 2014, and the entire provincial border of Denizli was amended as a metropolitan municipality border under the Law No. 6360 following the local elections held in 2014. Upon the shift to the status of a metropolitan municipality, the central districts was divided into two: The districts of Pamukkale and Merkezefendi. According to the data of the Turkish Statistical Institute (TurkStat) for 2019, the district of Pamukkale has a population of 346.625 while the district of Merkezefendi has a population of 311.177.

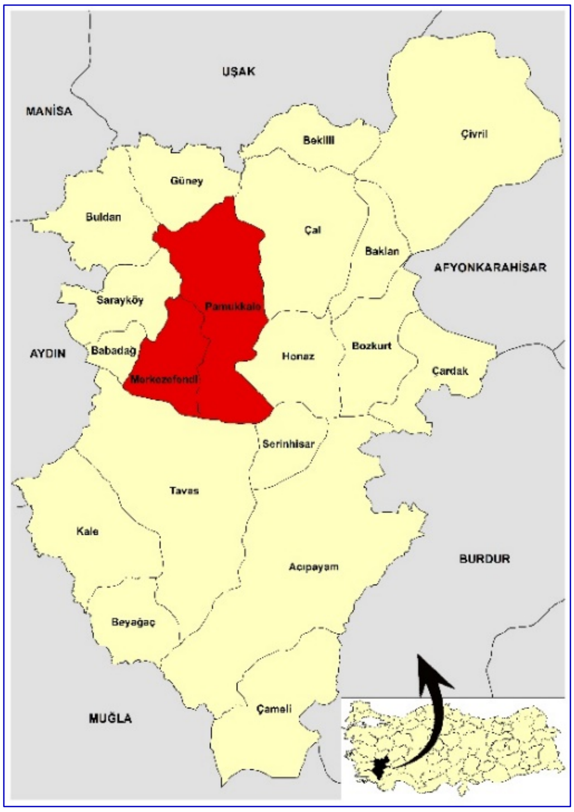


Figure 1. Location of the study area.

The city of Denizli is situated at an altitude of 145 to 2151 meters, with plenty of plains and dynamic topography surrounded by mountainous regions. The urban center is situated at an altitude of 354 meters. Surface features play a pivotal role in shaping the natural landscape of the study area, and the land form has quite a dynamic structure that is formed by slope, aspect, topography, altitude, geology and climate. The mountains, valleys, plains, rivers, lakes and highlands in this area provide opportunities for the formation of a rich landscape while the mountainous ecosystems contribute to the existence of highly valuable areas in terms of biological diversity. The plains for the agricultural landscape pattern, the clean air cure center, the highlands as a center of attraction for nature tourism, water and water based life sources that are necessary for all creatures, rivers, lakes, streams and wetlands are the significant natural resources of the study area (Zengin, 2017).

Pamukkale-Hierapolis, which was included both the cultural and natural category in the UNESCO World Heritage List in 1988 and Laodikeia Ancient City, which was included in the UNESCO World Heritage Temporary List in 2013 are located within the boundaries of the study area (MCT, 2020). Pamukkale Specially Protected Environment Area, a grade-1 natural site area (Pamukkale-Hierapolis, Karahayıt Red Water Pool, /Beyinli Cave, Servergazi Mausoleum), a grade-2 natural site area (Karahayıt Red Water Travertines and Honaz Mountain National Park) and a grade-3 natural site area (Atalar Neighborhood) are also located in the study area within the scope of protected areas (MAF, 2019).

Denizli Metropolitan Municipality operationalized the 1st phase of the SWSL in 2003, and the 2nd phase in 2010 in order to prevent unsanitary disposal (MEU, 2017). Constructed on an area of nearly 33,3 hectares, Denizli SWSL is located in Kumkısık neighborhood of the district of Merkezefendi that is situated 12,5 km northwest of the city center. Domestic waste collected from the city center and the district of Sarayköy and non-hazardous domestic waste caused by various industrial enterprises are currently disposed in the Denizli SWSL. In the landfill where 700 tons of domestic waste on average are transported per day, wastes are sorted and recycled, and the methane released from wastes are used to generate power, and compost fertilizer is obtained from vegetable waste (DMM, 2019).

2.2. Method

At the first stage of methodology, the Regulation on the Landfill of Waste, the academic studies on the subject and the current situation of the study area were taken into consideration to determine the site selection criteria for a sanitary landfill. In this context, 11 criteria (residential areas, primary traffic roads, protected areas, slope, aspect, water surfaces, rock structure, fault line, hydrologic soil groups, land use capability classification, land cover) were determined as a site selection criteria for a sanitary landfill. The data sources and features of the criteria are given in Table 1.

Table 1. Data sources and features on the criteria.

Criteria	Reference	Data Feature-Scale
Slope **Aspect**	U.S. Geological Survey (USGS, 2019)	ASTER GDEM - Digital Elevation Model (30 m resolution)
Residential area **Land cover**	CORINE 2012 Land Cover (CLC, 2019)	Digital vector data (1/25.000)
Water surface	Ministry of Environment and Urbanization Aydın-Muğla-Denizli Environmental Plan (MEU, 2019)	Digitized from raster map (1/100.000)
Primary traffic roads	OpenStreetMap participants (OSM, 2019)	Digital vector data
Hydrologic soil group **Land use capability classification**	General Directorate of Rural Services Denizli Province Land Potential Map (GDRS, 1999)	Digitized from raster map (1/25.000)
Rock structure **Fault line**	General Directorate of Mineral Research and Exploration (GDMRE, 2019)	Digitized from raster map (1/100.000)
Protected area	Ministry of Environment and Urbanization Aydın-Muğla-Denizli Environmental Plan (MEU, 2019)	Digitized from raster map (1/100.000)

At the second stage of the methodology, the criteria for the site selection were classified on a scale of 1 to 5 (1-Unsuitable, 2-Low suitable, 3-Moderately suitable, 4-Suitable, 5-Most suitable) according to the threshold values obtained by considering the relevant literature (Lunkapis et al., 2004; Şener, 2004; Kontos et al., 2005; Şener et al., 2006; Küçükönder and Karabulut 2007; Eskandari et al., 2012; Yıldırım, 2012; Cora, 2014; Jamshidi et al., 2015; Chabuk et al., 2016; Güler, 2016; Deniz and Topuz 2018; Şengün et al., 2018) and the legal legislations. In this context, digital maps were generated by performing the SWSL suitability analyses for each criteria by means of ArcGIS 10.4.1 software.

AHP technique, which is one of the multi-criteria decision-making methods, was used to determine the degree of influence of the site selection criteria on the most suitable sanitary landfills. AHP allows making a common scale assessment based on paired comparison of independent criteria. In this technique within the scope of 1-9 scale, these criteria were scored in line with their level of importance according to the Saaty (1990)'s relative importance scale given in Table 2. AHP comparison matrix was made by the researchers in this study for the criteria determined within the scope of selecting the most suitable areas and the weighted scores for the each criteria were obtained. The AHP technique was adapted into the study by ExpertChoice 11 software.

Table 2. Saaty's (1990) relative importance scale.

Level of Importance	Definition	Explanation
1	Equal importance	Two actions contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed

At the third stage of the methodology, the suitability maps generated based on the criteria were overlaid by ArcGIS software depending on their weighted scores, and for the sanitary landfill a digital map was generated for the areas as *"Unsuitable (1), low suitable (2), moderately suitable (3), suitable (4) and most suitable (5)"*. In addition, the required area size calculations were made for the facility that has the capacity to store solid waste for the year 2040 in the study area and the most suitable ideal area was determined for the sanitary landfill.

2.2.1 Calculation of the required area size for SWSL

Sanitary landfills should be determined and constructed in a way to store solid waste for no less than 20 years. An approximate area size can be calculated for a sanitary landfill based on the amount of waste generated per capita and the population projection (UMT, 2014).

To do so, the population and domestic waste projection of the study area for the year 2040 were calculated. The population projection of the study area for 2040 was calculated by an exponential method (BMM, 2015) and the population was projected to be 878.813 people. According to the TurkStat 2018 Municipal Waste Statistics that the amount of waste collected per capita is 1,16 kg a day on average (TSI 2018). Based on the Turkey Urban Solid Waste production forecast made by the Ministry of Environment and Urbanization Technical Assistance Project (EHCIP-2005) on Environmental Heavy-Cost Investment Planning, the waste generation per capita is projected to geometrically increase by nearly 2%~3% a year (Öztürk et al., 2010). BMM (2015) calculated the amount of waste by projecting that the unit amount of waste would geometrically increase by 2.2% per year based on the Solid Waste Master Plan and EHCIP figures.

The rate of increase was considered to be 2.2% for this study. Based on the annual geometric increase rate, the daily average amount of waste per capita was calculated to be nearly 1.87 kg for the year 2040. Accordingly, the total amount of waste was calculated to be nearly 9.079,467 tons (Table 3).

Table 3. Population and waste projection of the study area.

Year	Population	Amount of Waste Per Capita (kg/person.day 2.2% increase)	Amount of Waste Generated (kg/day)	Amount of Waste Generated (kg/year)	Amount of Waste Generated (tonne/year)
2020	685594	1.21	830666	303193183	303193
2021	695116	1.24	860732	314167213	314167
2022	704771	1.27	891886	325538447	325538
2023	714559	1.29	924168	337321262	337321
2024	704771	1.32	931561	340019700	340020
2025	714559	1.35	965279	352326661	352327
2026	724484	1.38	1000217	365079070	365079
2027	734547	1.41	1036419	378293051	378293
2028	744749	1.44	1073932	391985310	391985
2029	755093	1.47	1112803	406173158	406173
2030	765581	1.51	1153081	420874533	420875
2031	776214	1.54	1194816	436108022	436108

Table 3. Continued.

Year	Population	Amount of Waste Per Capita (kg/person.day 2.2% increase)	Amount of Waste Generated (kg/day)	Amount of Waste Generated (kg/year)	Amount of Waste Generated (tonne/year)
2032	786995	1.57	1238063	451892885	451893
2033	797926	1.61	1282874	468249079	468249
2034	809009	1.64	1329308	485197283	485197
2035	820245	1.68	1377422	502758924	502759
2036	831638	1.72	1427277	520956206	520956
2037	843189	1.75	1478937	539812136	539812
2038	854900	1.79	1532467	559350554	559351
2039	866774	1.83	1587935	579596161	579596
2040	878813	1.87	1645410	600574555	600575

According to the TurkStat 2018 Municipal Waste Statistics 67.2% of waste is disposed in sanitary landfills, 20.2% waste is transported in municipal dumpsites, 12.3% waste is transported in recycling plants, and 0.2% waste is disposed by incineration, digging in, or dump into rivers or lands (TSI, 2018). In this context, a total of 6.101,402 tons of waste will need to be disposed given the fact that 67.2% of the total 9.079,467 tons of waste to be generated from 2020 to 2040 will be transported to be disposed in sanitary landfills.

According to the Yeşilnacar and Çetin (1999) the specific weight for the compressed waste and cover material in a landfill is 0.85 kg/dm^3. In this context, it was calculated that a volume of 7.178.120 m^3 is required for a total of 6.101.402 tons of waste to be generated in the study area by the end of 2040. The literature offers various views on the height of the dumpsite in sanitary landfills. As the average height of the dumpsite in the study area was considered to be 6 meters as Zurbrügg et al. (2005) did, it was concluded that the area of a sanitary landfill should be no smaller than 120 hectares. In this context, as a result of the study, the areas with a similar/an exact size among the areas that are determined to be the most suitable for landfill were recommended as an ideal area to construct a sanitary landfill.

3. Results and Discussion

3.1 The Determination of Thresholds for Each Criteria and Mapping

Proximity to residential areas: Landfills built in close proximity to residential areas cause a variety of environmental and health problems. Scattered around off landfills, waste materials and gas emissions pose a threat to human health and cause visual pollution from the esthetic point of view (Deniz and Topuz, 2018). According to the Lunkapis et al. (2004) such landfills cause not only health problems but also complaints about noise and malodor. The article 15 of the Regulation on the Landfills of Waste imposes a limitation as follows: "The distance of the sanitary landfill boundaries to the settlements must be at least one kilometer for class I sanitary landfills and at least two hundred and fifty meters for class II and III sanitary landfills” (OG 2010). The studies in literature suggest that any distance within less than 1000 meters of residential areas is not suitable (Küçükönder and Karabulut, 2007; Eskandari et al., 2012; Yıldırım, 2012; Cora, 2014; Güler, 2016; Deniz and Topuz, 2018; Şengün et al., 2018) while Deniz and Topuz (2018) and Şengün et al. (2018) argue that the most suitable distance is 1500 meters, and it is 2500 meters according to the Küçükönder and Karabulut (2007) and Yıldırım (2012), and more than 4000 meters according to the Güler (2016). In line with this information, the areas within less than 1000 meters of residential areas were determined as "unsuitable" while those within more than 2500 meters of residential areas were determined to be "the most suitable” areas in the study area.

Proximity to primary traffic roads: One of the important criteria to take into account to locate a sanitary landfill is the proximity to transportation routes. According to the some researchers sanitary landfills should not be built far from any urban center for the waste handling cost and accessibility in any season. It is also emphasized that sanitary landfills should not be located within 100 meters of main roads, avenues or other transportation routes given the importance of esthetic factors (Lunkapis et al., 2004). For instance, unsuitable areas are considered to be within less than 100 meters and more than 1250 meters by Küçükönder and Karabulut (2007), less than 100 meters and more than 3250 meters by Deniz and Topuz (2018), less than 100 meters and more than 1000 meters by Yıldırım (2012). The most suitable areas are considered to be those within 1000 to 1250 meters by Küçükönder and Karabulut (2007) and 1000 to 2000 meters by Chabuk et al. (2016) and Deniz and Topuz (2018), and no less than 1000 meters by Şengün et al. (2018), and 750 to 1000 meters by Yıldırım (2012). In the study, threshold limits were set for each class where those located within less than 100 meters of transportation routes were considered unsuitable while those located within 1001 to 1250 meters were considered the most suitable areas.

Slope: In most cases, steep slopes are not technically suitable for the construction of a sanitary landfill (Kontos et al. 2005). Any site of slope greater than 20 degrees is not favorable for the construction of a sanitary landfill from the perspective of cost and safety (GEPA, 2004). Lin and Kao (1999) argue that pollutants are likely to drained into the environs of sanitary landfills situated on a steep slope, and heighten the risk for the seepage of water from high slopes into flat and low lands or water bodies (Chabuk et al., 2016). Many studies in literature suggest that the most suitable areas to construct a sanitary landfill are the ones where the slope is between 0 and 5° (Şener, 2004; Küçükönder and Karabulut, 2007; Chabuk et al., 2016; Güler, 2016; Deniz and Topuz, 2018; Şengün et al., 2018). The areas with slope equal to or greater than 20° and those greater than 25° were taken into consideration to determine them as unsuitable (Güler, 2016; Şengün et al., 2018). In this study, the areas with slope equal to or less than 5° were considered the most suitable areas while those with slope greater than 20° were considered unsuitable.

Aspect: Aspect is an essential parameter to assess the dominant wind direction for the site selection of sanitary landfills (Küçükönder and Karabulut, 2007). Sanitary landfills should not be constructed into the dominant wind direction to prevent malodor from spreading out and large or small materials from dispersing around by the winds. The aspect scores were determined based on the number of wind blows which belongs to the study area. NNW, which had the highest number of wind blows, was scored the lowest while SE, E, ESE, NE, S, SSE, and ENE were scored the highest in the study (Table 4). According to the long-term (1975-2014) wind statistics of the Turkish State Meteorological Service (TSMS, 2015), dominant wind direction in the study area is NNW based on the number of wind blows. It is followed by WNW and WSW.

Table 4. Number of wind blows and scores according to the aspect.

Aspect	Number of wind blows	Score	Aspect	Number of wind blows	Score
SE	5188	5	N	16265	4
E	6984	5	NNE	25049	3
ESE	9432	5	SW	26274	3
NE	10490	5	SSW	27579	3
S	10801	5	NW	29114	3
SSE	11316	5	WSW	38659	2
ENE	12934	5	WNW	42370	2
W	15964	4	NNW	56465	1

Proximity to water surfaces: Another important criteria regarding the selection of a site for a sanitary landfill is the proximity to water surfaces. According to the Lunkapis et al. (2004) a sanitary landfill should not be located within close proximity to any river, lake, stream or wetland. Rivers can cause environmental problems by directly carrying both the wastes and the pollutants leaking from wastes. The proximity to water surfaces becomes even more important given the fact that rivers or lakes also serve as a drinking and domestic water supply (Deniz and Topuz, 2018). The article 24 of the Regulation on the Protection of Wetlands governs codes of practice in buffer zones as follows: "*No permission shall be granted to allow for any SWSL, any solid waste disposal plant, the establishment and operation of any mine site except for those authorized by this Regulation, declarating of any industrial zone, establishment of any organized industrial site and any free trade zone and any operation as set out in Annex-1*". The word buffer zone set out in the aforementioned regulation stands for "*any zone at least 2500 meters away from any site of sustainable use or any vulnerable conservation site if it is situated in a flatland with no topographic and geographic limit or any zone that does not exceed the water retention limit of any wetland and is characterized by the protection of a wetland ecosystem depending on the geographic state of a wetland basin, its topographic characteristics and whether the land is currently utilized or not*" (OG, 2014). In literature, the unsuitable areas are considered to be within 100 meters or less than 100 meters of surface water by Lunkapis et al. (2004), Yıldırım (2012) and Deniz and Topuz (2018), within less than 500 meters of surface water by Güler (2016), less than 1000 meters of rivers by Chabuk et al. (2016) while the most suitable areas are considered to be within more than 2000 meters of surface water by Yıldırım (2012) and Güler (2016), and more than 1000 meters of rivers by Chabuk et al. (2016). However, the areas located within less than 2500 meters of water surfaces were considered unsuitable while those located within more than 3250 meters were considered the most suitable in this study based on the Regulation on the Protection of Wetlands.

Rock structure: It is not favorable to construct a sanitary landfill on top of any geological structures as they vary by porosity, permeability, cracks and fractures. Materials with low hydrologic permeability in terms of geology are favorable as they minimize the likelihood of pollution problem that may occur at a high level of ground water (Küçükönder and Karabulut, 2007). When their permeability rates are compared, unfractured crystalline rocks seem to have very low permeability whereas cemented sandstones have a higher water permeability. Due to higher permeability rates, other sedimentary rocks such as limestone and shale are more suitable for a landfill compared to sandstone. Shale formations are highly suitable for landfills as they serve as a bed that usually slows down or delays the discharge of fluids (Şener, 2004). The suitability state of various rock types for sanitary landfills is given in Table 5.

Table 5. According to the Oweis and Khera (1998) suitability of bedrocks for landfill (Şener, 2004).

Rock type	Suitability
Unfractured crystalline	Very high
Shale and clay	High
Limestone	Fair to poor
Sandstone	Poor to very poor
Unconsolidated sand/gravel	Unsuitable

The rock structures in the study area were analyzed based on their hydrologic permeability, and their permeability was scored as a result of interviews with a geologist in academia. The areas with highly permeable rocks such as alluvions and travertine were determined as unsuitable while the areas with high water-holding capacity and limited permeability or no permeability at all such as peridotite, schist and shale were determined as the most suitable areas. If rocks with high hydrological permeability are combined with rocks with less hydrological permeability, their permeability rates will vary. In this context, this situation was taken into consideration while creating the suitability classes of the rocks in the study.

Proximity to fault line: As fault lines have a potential for seismic activities and can cause ground water pollution through their cracks, sanitary landfills should be located far from fault lines. In literature, the threshold limits set for areas unsuitable for a sanitary landfill are 80 meters (Deniz and Topuz, 2018) and 100 meters (Küçükönder and Karabulut, 2007; Yıldırım, 2012) while the most suitable distance is more than 2500 meters (Küçükönder and Karabulut, 2007; Deniz and Topuz, 2018) and 2000 meters (Yıldırım, 2012). In this study, the areas within less than 500 meters of a fault line were considered unsuitable while those within more than 2000 meters of a fault line were considered the most suitable areas.

Hydrologic soil group: The permeability of soil and bedrocks has a major impact on the leakage seepage water in landfills (Lunkapis et al., 2004). Hydrologic soil groups approach was used to classify the permeability in this study. Özer (1990) reveals the hydrologic soil groups based on major soil groups, type of land and combination of soil properties, and classifies them into four groups:

- Group A (Low Runoff Potential - Good Drainage - Minimum Infiltration Rate:7.5-10 mm/hour): These soils have a high water permeability rate.
- Group B (Moderate Runoff Potential - Moderate Drainage - Minimum Infiltration Rate: 3-7.5 mm/ hour): These soils have a moderate water permeability rate.
- Group C (High Runoff Potential - Restricted Drainage - Minimum Infiltration Rate: 0.8-3 mm/hour): These soils have a low water permeability rate.
- Group D (Very High Runoff Potential - Very Restricted Drainage - Minimum Infiltration Rate: 0-08 mm/ hour): These soils have a very low water permeability rate.

The hydrologic soil groups and their classification rates based on major soil groups and combinations of soil properties of the study area are given in Table 6. The areas with a very low water permeability potential, which corresponds to Group D soils, were determined as "suitable" areas.

Table 6. Hydrologic soil groups and classification values (Özer, 1990).

Major soil groups	Combination of soil properties	Hydrologic soil group
Alluvial soil	3	A
	1, 4, 7	D
	2	C
Reddish Chestnut Soil	14	C
Red (or Brown) Mediterranean soils	6, 7, 11, 12, 15, 16	A
	19, 20, 23, 24	B
	28	C
Colluvial soils	4, 13, 14, 17, 22, 23, 24	B
	1, 10, 19, 20	C
Brown forest soils	5, 6, 7, 9, 10	B
	11, 14, 15, 16	C
	19, 20, 23, 24, 28	D
Limeless brown forest soil	11,15	C
	20, 24	D
Rendzina	7	B
	11, 12, 14, 15, 16	C
Limeless brown soils	7, 11, 12, 15, 19, 20	C
	23	D

Land use capability classification: Lands with a high agricultural value should not serve as sanitary landfills because sanitary landfills can cause pollution through seepage and pollutants and thus reduce the worth of agricultural lands. In this study, the class-I, class-II and class-III land use capability classification with a high agricultural value were determined as unsuitable while the class-VI, class-VII and class-VIII land use capability classification were determined as the most suitable areas.

Land cover: Land cover and use should be incorporated into the analysis to identify which areas would be suitable for a landfill. For instance, according to the Lunkapis et al. (2004) grasslands, forests, cultivation lands and other lands of use should be taken into consideration, and an appropriate classification should be made for land use suitability. In the study area such as water bodies, urban areas, agricultural lands, forest lands and marshes were determined as unsuitable while dump sites, bare rocks and sparsely vegetated areas were determined as the most suitable for a landfill.

Proximity to protected areas: Sanitary landfills located in close proximity to protected areas cause both environmental and visual pollution. Literature offers studies where areas within less than 1 km of protected areas (Güler, 2016) and 1 km of archaeological sites (Chabuk et al., 2016) are considered unsuitable while areas within more than 1 km of protected areas (Güler 2016) and 3 km of archaeological sites (Chabuk et al., 2016; Eskandari et al., 2012) are considered the most suitable areas. In this study, the areas located within less than 1000 meters of protected areas were determined to be not suitable while the areas located within more than 3000 meters of protected areas were considered to be the most suitable.

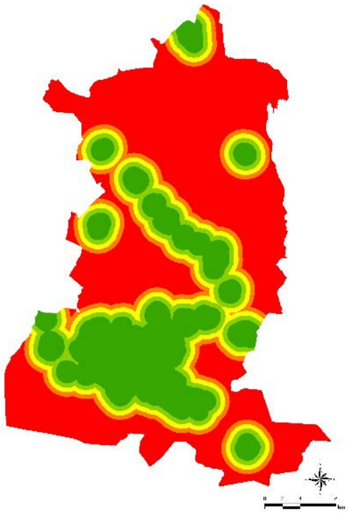
11 criteria and threshold/score values for site selection within the scope of the planning process of the SWSL in the city of Denizli are given in Table 7, and the suitability maps for each criteria generated as a result of the analyses are given in Figure 2.

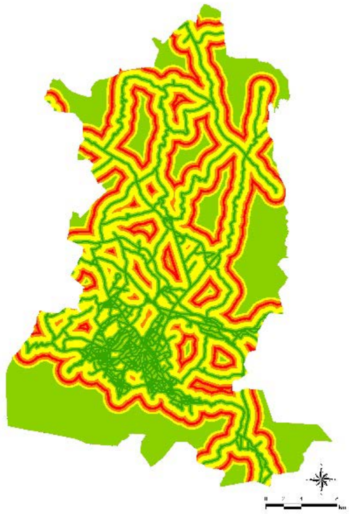
Table 7. Site selection criteria and threshold/score values.

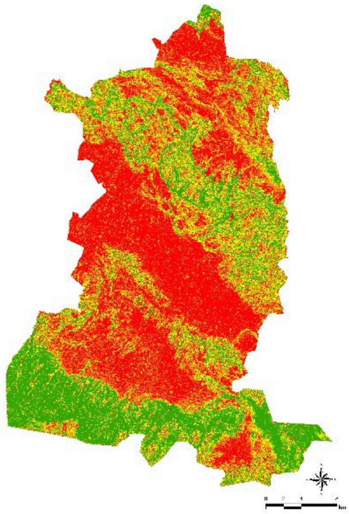
Threshold/ Score Criteria	Unsuitable (1)	Low suitable (2)	Moderately suitable (3)	Suitable (4)	Most suitable (5)
Proximity to residential areas	<1000 m	1000-1500 m	1501-2000 m	2001-2500 m	>2500 m
Proximity to primary traffic roads	<100 m	100-250 m >1750 m	251-750 m 1501-1750 m	751-1000 m 1251-1500 m	1001-1250 m
Slope	>20°	15-20°	10-15°	5-10°	0-5°
Aspect	NNW	WSW, WNW	NNE, SW, SSW, NW	W, N	SE, E, ESE, NE, S, SSE, ENE
Proximity to water surfaces	<2500 m	2500-2750 m	2751-3000 m	3001-3250 m	>3250 m
Rock structure	Alluvial, Alluvial fan, Travertine	Olistostrome	Breccia, Conglomerate, Marble, Limestone, Metasandstone-Metaconglomerate-Metapelite, Quartzite-Quartz schist, Talus	Cherty limestone, Conglomerate-Sandstone-Mudstone, Dolomite, Limestone with clay, Melange, Sandstone-Mudstone, Sandstone-Mudstone-Limestone, Spilite	Migmatite-Gneiss, Peridotite, Schist, Schale
Proximity to fault line	<500 m	500-750 m	751-1250 m	1251-2000 m	>2000 m
Hydrologic soil group	A	B	C	D	---
Land use capability classification	I, II, III	IV	---	V	VI, VII, VIII

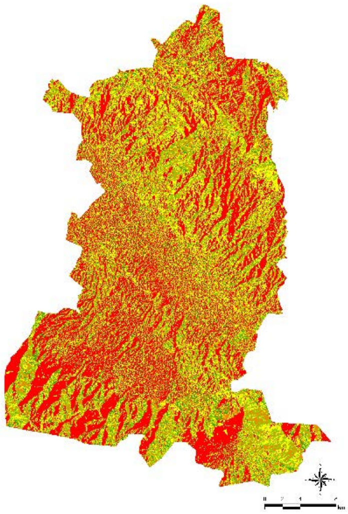
Table 7. Continued.

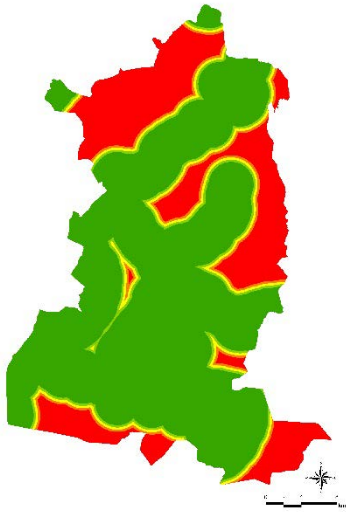
Threshold/ Score **Criteria**	**Unsuitable (1)**	**Low suitable (2)**	**Moderately suitable (3)**	**Suitable (4)**	**Most suitable (5)**
Land cover	Continuous urban fabric, Discontinuous urban fabric, Industrial or commercial units and public facilities, Mineral extraction sites, Non-irrigated arable land, Permanently irrigated arable land, Vineyards, Fruit trees and berry plantations, Broad-leaved forest, Coniferous forest, Mixed forest, Inland marshes, Water bodies	Complex cultivation patterns, Land principally occupied by agriculture, with significant areas of natural vegetation	Natural grasslands, Sclerophyllous vegetation, Transitional woodland-shrub	Pastures	Dump sites, Bare rocks, Sparsely vegetated areas
Proximity to protected areas	<1000m	1000-1500 m	1501-2000 m	2001-3000 m	>3000 m

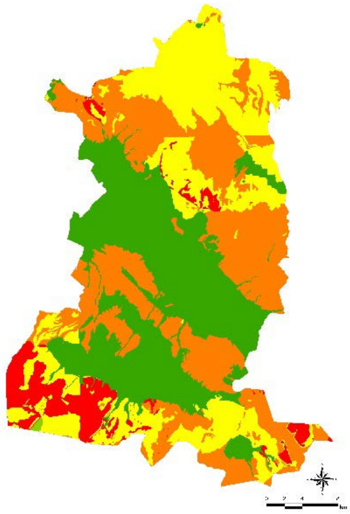

(Proximity to residential areas)


(Proximity to primary traffic roads)

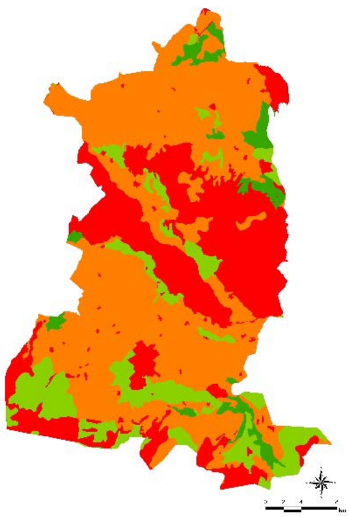

(Slope)

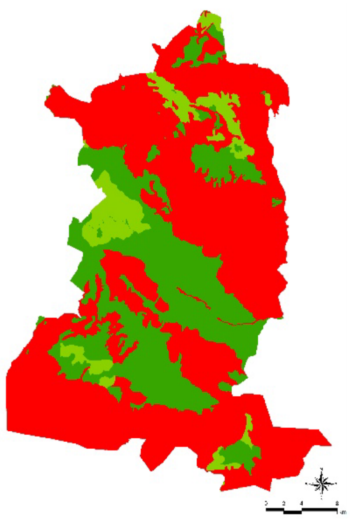

(Aspect)

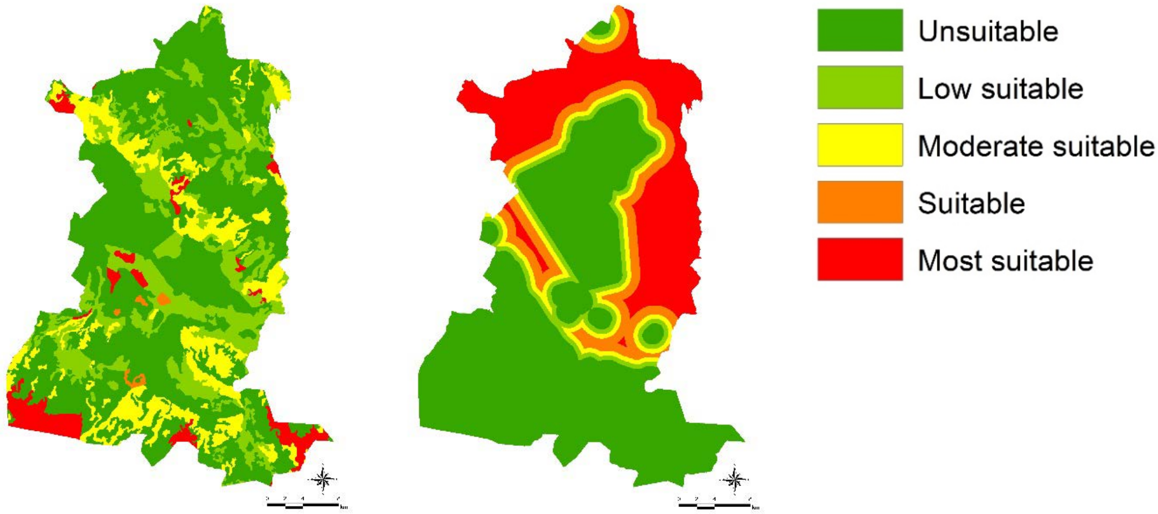

(Proximity to water surfaces)


(Rock structure)


(Proximity to fault line)


(Hydrologic soil group)


(Land use capability classification)



(Land cover) (Proximity to protected areas) (Legend)

Figure 2. Suitability maps for each criteria.

3.2 Weighting Site Selection Criteria and Generating Suitability Map

Paired comparisons were made by AHP technique to determine the extent of impact of the site selection criteria on the most suitable sanitary landfills. The weighting scores of each criteria based on the AHP matrix are given in Table 8. The validity of AHP technique was determined by the Consistency Ratio generated as a result of the analysis. The ratio is expected to be below 0,1 (10%) (Saaty, 1983). Since the consistency ratio was 0,09 in this study, it was considered scientifically valid.

Table 8. AHS weight scores of the site selection criteria.

	Water surface	Primary traffic road	Residential area	Slope	Aspect	Rock structure	Fault line	Land use capability classification	Hydrologic soil group	Land cover	Protected area	Weight Score
Water surface	1	7	5	1	5	5	3	5	3	5	1/3	0,161
Primary traffic road		1	1/3	1/7	1/5	1/7	1/9	1/7	1/9	1/7	1/9	0,011
Residential area			1	1/5	1/3	1/5	1/7	1/5	1/7	1/5	1/9	0,017
Slope				1	5	5	3	5	3	5	1/5	0,158
Aspect					1	1/5	1/5	1/3	1/7	1/3	1/9	0,024
Rock structure						1	1/3	3	1/3	1	1/5	0,057
Fault line							1	3	1	1	1/5	0,084
Land use capability classification								1	1/3	1	1/5	0,043
Hydrologic soil group									1	3	1/5	0,096
Land cover										1	1/7	0,051
Protected area											1	0,298

The suitability maps generated based on the site selection criteria were overlaid with the weighting scores generated by AHP and a map was generated for sanitary landfills as unsuitable, low suitable, moderately suitable, suitable and most suitable areas (Figure 3).

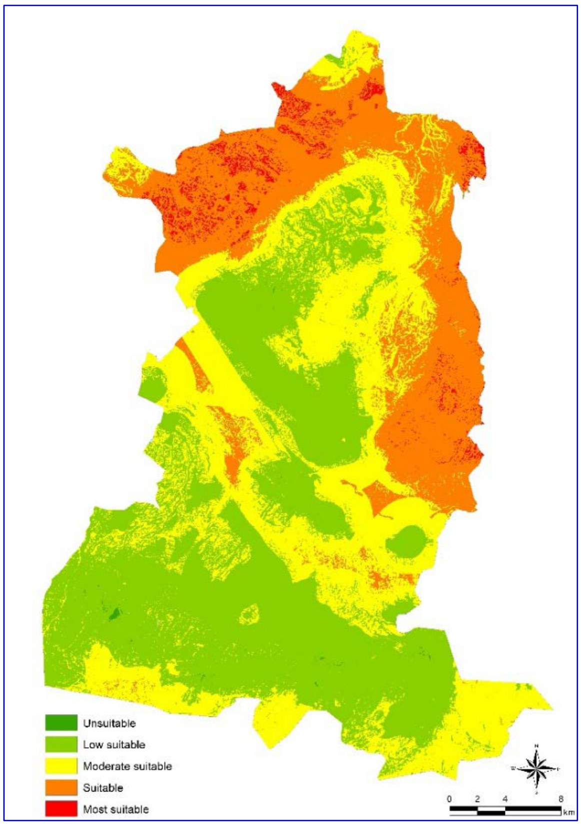


Figure 3. The suitability of the areas for SWSL.

In line with the site selection criteria considered in the study, it was intended to determine the ideal sanitary landfill area within the central district borders of Denizli by using GIS and AHP techniques. The area size of the classes obtained according to the suitability map are given in Table 9. 19.536,40 hectares of area in the study area were determined the most suitable to construct a sanitary landfill while 767,87 hectares of area were determined unsuitable to construct a sanitary landfill.

Table 9. Area size according to the suitability class.

	Unsuitable (1)	Low suitable (2)	Moderately suitable (3)	Suitable (4)	Most suitable (5)
Area (ha)	767,57	447106,37	381811,56	260520,26	19536,40
%	0.07	40.29	34.41	23.48	1.76

The most suitable areas in the study are largely located in the northern part of the study area (Figure 4). Since the moderately suitable (3) and low suitable (2) areas are usually home to settlements, fertile and agriculturally-valuable lands, protected areas, permeable rock formations, fault lines and water surfaces, the most suitable areas for a SWSL tend to be located in the northern part of Denizli.

To determine 120 hectares area required for a landfill, a 76 ha (63.33%) polygon, which has the maximum size in the “most suitable” class, was set out. 120 hectares of area, which is the intended area size, were created by means of the polygon closure technique adopted based on piecing corners of the polygon (76 ha) together. 44 hectares (36.66%) of the newly-created polygon were created out of the "suitable" areas around the polygon (Figure 4).

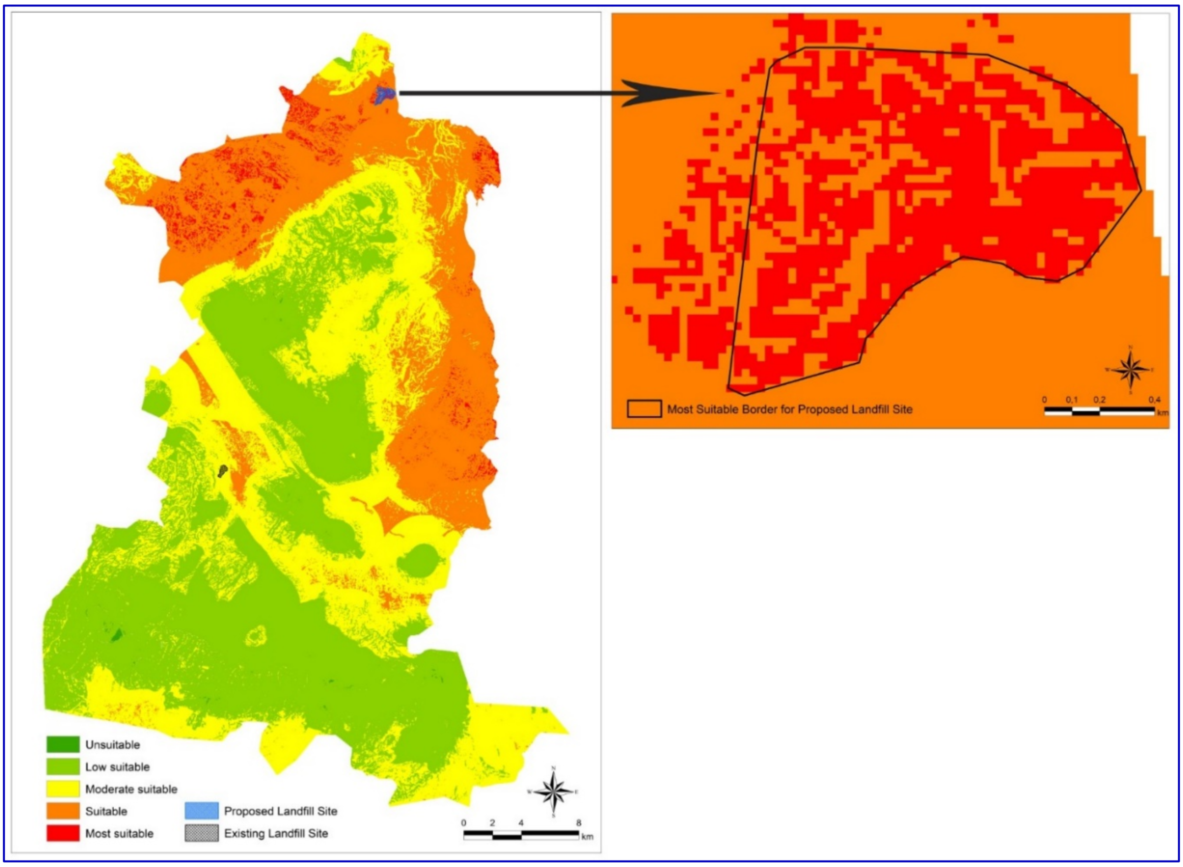


Figure 4. Recommended ideal area boundary for the SWSL and existing solid waste landfill area boundary.

The ideal area border recommended as a sanitary landfill is located on a land with a low degree of slope and soil permeability and poor agricultural value. There is not any large-scale settlement around the ideal area while there is only a small-scale rural settlement. Since these rural settlement are separated by 1 km distances during suitability analyzes, it is considered that the proposed ideal area for landfill will not pose a serious problem to these settlement. The fact that the ideal area is not located any urban development site direction eliminates the risk of being situated within an urban settlement in years to come.

A variety of methods are used to dispose solid waste through landfill method. One of these methods is used based on the topography, surface water and groundwater source of the area. Among the common methods used are ditch method, field method and cell method (MEU, 2014). The method to be adopted also affects the size of the area needed for a sanitary landfill. Therefore, the method of disposing waste should be taken into consideration to calculate the size of the area needed to construct a sanitary landfill. Literature offers various approaches on the height of the dumpsite for the calculation of the size of the area needed to sanitary landfill. Therefore, it should be considered that the size of the sanitary landfill varies by the method of waste disposal.

4. Conclusion

Compared with other works, this study also took into consideration hydrologic soil groups and land use capability classification as criteria set for the site selection of sanitary landfills. It is of importance to consider the agricultural value of the lands for site selection in the study area where agricultural lands abound.

The importance of taking into consideration the characteristics of the study area to set site selection criteria for a sanitary landfill was corroborated by this study. In terms of the sustainable planning studies, it is important to make the calculation of required area for SWSL facilities.

It has been determined that the existing Denizli SWSL, which operates in the study area, is located within the area identified as "moderately suitable" according to the suitability map (Figure 4). The existing Denizli SWSL is located right next to Denizli-Izmir highway and in close proximity to the urban center. The existing Denizli

SWSL is close to both the highway and the urban center indicates that it is not in a suitable location as a sanitary landfill. The existing landfill, originally put into operation in 2003, will soon reach full capacity and thus the conclusions of this study will guide decision-makers to select a new location for a landfill. According to the MEU (2014) environmental and social factors should also be taken into consideration while evaluating the most suitable areas in the selection of sanitary landfill. In addition, environmentally, financially and technically sustainable areas that are adoptable for all parties involved should be selected, and the views of local communities should be taken into consideration before a final decision is made.

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