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ORIGINAL ARTICLE

Identification of suitable future municipal solid waste disposal sites for the Metropolitan Mersin (SE Turkey) using AHP and GIS techniques

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Abstract The municipal solid waste disposal site (MSWDS) selection process is a complex multi-criteria decision-making problem, which requires consideration of a wide spectrum of physical information, legal requirements, and constraints that should satisfy the expectations of a number of stakeholders with conflicting opinions or interests. In this paper, analytic hierarchy process (AHP) and geographic information system (GIS) techniques were jointly used to identify suitable MSWDSs for the Metropolitan Mersin (SE Turkey) utilizing 12 decision criteria (i.e., lithology, aquifer type, distance from lineaments, distance from landslides, land use, distance from settlements, distance from roads, distance from surface waters, distance from springs and wells, elevation, aspect, and slope). For assessment of site suitability, selected decision criteria (i.e., raster-based thematic map layers) were integrated in the GIS environment using the weighted linear combination aggregation method after standardizing and assigning weights to each criterion using AHP technique. The classified suitability map indicates that 0.73 % of the study area is most suitable, 2.75 % is suitable, 3.39 % is moderately suitable, 4.77 % is poorly suitable, 3.47 % is least suitable, and 84.89 % is completely unsuitable (i.e., restricted areas) for siting MSWDSs. Before the final decision is made, detailed field investigations must be carried out at the candidate sites to protect water resources and land.

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Introduction

Site selection is one of the most critical aspects of all modern engineering projects and structures where municipal solid waste disposal sites (MSWDSs) deserve a special attention because land filling is still the most common mode of waste disposal in many countries. Large amounts of solid waste generated by daily activities of residential, commercial and industrial sectors eventually finds their way into these long-term storage facilities with little or no treatment, especially in developing countries such as Turkey (see Berkun et al. 2011; Kanat 2010; Turan et al. 2009 for reviews). If not sited, designed, and operated properly, MSWDSs may become a gross pollution source for water resources, soil, and atmosphere and pose a potentially serious health threat to the public through various pathways. Literature abounds with case histories from around the world, which illustrate the various pollution problems that have resulted from improper site selection, design, and management of MSWDSs (e.g., Abu-Rukah and Al-Kofahi 2001; Akoteyon et al. 2011; Basberg et al. 1998; Kayabalı et al. 1998; Srivastava and Ramanathan 2008; Statom et al. 2004; Weaver 1964). Contamination of water resources and land around these facilities generally result from infiltration/percolation of recharge waters (e.g., precipitation, surface water runoff, irrigation return flow, etc.) and liquid produced from decomposition of waste and/or direct contact of the waste material with the underlying shallow groundwater table (Bahaa-Eldin et al. 2008; Lema et al.

1988; Weaver 1964). Environmentally hazardous leachate plume emanating from the MSWDS can extend several kilometers away from the source (Abu-Rukah and Al-Kofahi 2001) and may continue to contaminate the environment, for decades and even centuries after closure of the site (Christensen et al. 2001). Even though, long-term monitoring studies suggest that concentrations of most chemical constituents mobilized by the leachate display a decreasing trend with aging of the landfill (Chian and DeWalle 1976; Lu et al. 1985; Statom et al. 2004), disposal and/or treatment of leachate from MSWDSs is recognized as one of the most complicated tasks related with their operation due to uncertainties in leachate production and characteristics (Kawai et al. 2012; Lema et al. 1988; Weng et al. 2011; Wiszniowski et al. 2006). Nevertheless, proper siting together with adoption of state-of the-art engineering and management practices in MSWDSs can help reduce the formation of a highly contaminated leachate and ensure maximum protection of the surrounding environment.

Use of GIS-based multi-criteria decision analysis (MCDA) methods in site selection problems has dramatically increased over the last several decades (see Bathrellos et al. 2012; De Feo and De Gisi 2014; Demesouka et al. 2013; Youssef et al. 2014) due to mainly improved capabilities of computer systems and GIS/remote sensing software in handling, integrating, processing, and visualizing large volumes of geospatial data (Siddiqui et al. 1996; Vatalis and Manoliadis 2002; Youssef et al. 2011). In addition, finding suitable MSWDSs has become a very complex and multi-attribute decision-making task recently due to increased cost and shortage of land, more restrictive legal requirements, and overwhelming opposition of the public. Therefore, MCDA methods such as preference ranking organization method for enrichment evaluations (PROMETHEE) (Briggs et al. 1990; Vuk and Koželj 1991), analytic hierarchy process (AHP) (Erkut and Moran 1991; Siddiqui et al. 1996), technique for order preference by similarity to ideal solution (Cheng et al. 2002, 2003), weighted product method (Cheng et al. 2002, 2003), cooperative game theory (Cheng et al. 2002), simple additive weighting (Eskandari et al. 2012; Şener et al. 2006), elimination and choice translating reality (ELECTRE) (Aydi et al. 2013; Norese 2006), and analytic network process (Aragonés-Beltrán et al. 2010; Banar et al. 2007) received much attention due to their potential use in the GIS-based MSWDS suitability assessments. All these MCDA methods can utilize a great number of both qualitative and quantitative criteria to reach a decision among a finite set of alternatives satisfying predetermined constraints. Among these, use of the AHP technique (Saaty 1980) in site selection problems is far more common than any other MCDA method (Bathrellos et al. 2012; Huang et al. 2011; Thapa and Murayama 2008; Youssef et al. 2011). The use of GIS-based MCDA techniques in the site suitability analyses can improve understanding of information used to make decisions, increase the objectivity and accuracy of the assessment, provide decision makers with the tools to make better-informed choices, and alleviate problems concerned with various aspects of MSWDS selection.

This paper presents a methodology to identify suitable MSWDSs for the Metropolitan Mersin (SE Turkey) using the AHP technique developed by Saaty (1980) and ArcGIS 9.3.1 software (ESRI 2009). In this study, 12 decision criteria (i.e., lithology, aquifer type, distance from lineaments, distance from landslides, land use, distance from settlements, distance from roads, distance from surface waters, distance from springs and wells, elevation, aspect, and slope) were utilized for the assessment of site suitability.

Description of the study area

Geographic location, land use, and climate

The study site, covering an area of 2086 km^2, is located at the easternmost margin of the Mersin province in SE Turkey and lies between the latitudes 36°38′15″–37°03′25″ N and the longitudes 34°23′10″–35°10′54″ E (Fig. 1). This

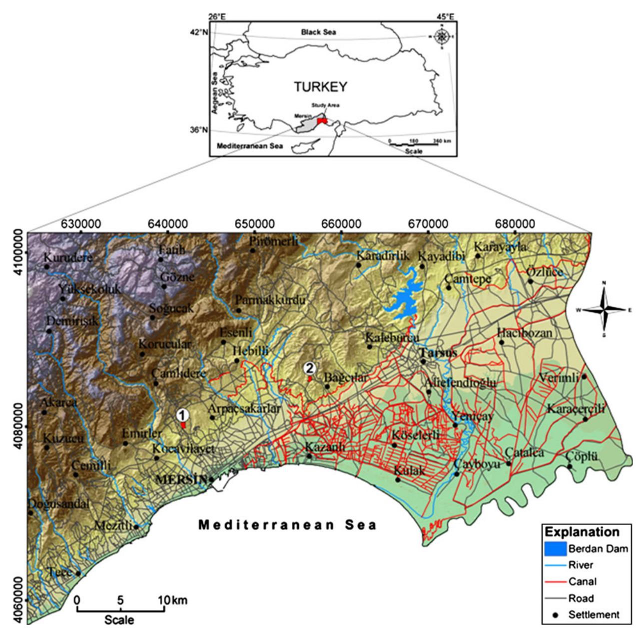

Fig. 1 Location of the Mersin province within Turkey and detailed map showing the surface water drainage and road network in the coastal and upslope areas of the SE Mersin. *Circled numbers* (i.e., ① and ②) indicate locations of Çavuşlu (closed in 2008) and Bağcılar (active since 2008) municipal solid waste disposal sites (MSWDSs), respectively

area is bordered on the southern side by the coastal plains stretching along the Mediterranean Sea, whereas its northern boundary is delineated by the Taurus Mountains with peaks locally reaching ca. 1,760 m. This area is extremely varied in topography, land use, and population density, where historically urban population has been confined primarily to the coastal zone. Large population clusters in the coastal part owe their economic growth mostly to agricultural crop production and a variety of industrial investments (see Güler 2009; Güler et al. 2012, 2013 for details). According to census data for the 2012, Mersin is the 10th most populated province in Turkey with a population of 1,682,848 people and annual average growth rate of 0.66 % (Turkish Statistical Institute 2014a). The climate is of semi-arid Mediterranean type with a long-term (1960–2012) average annual temperature of 19.1 °C (ranging between 10.2 °C in January and 28.3 °C in August) and an average annual rainfall of about 595 mm, nearly 80 % of which occurs between November and March (Turkish State Meteorological Service 2014).

Municipal solid waste management in the area

The Metropolitan Mersin has two MSWDSs: one closed recently (Çavuşlu) and one actively operating at present (Bağcılar) (see Fig. 1). The Çavuşlu MSWDS, nearly 32.5 ha in area, had been used for over 20 years before its closure in 2004 due to severe nuisance caused to nearby settlements (e.g., through noise, air and visual pollution) (MPDEF 2008). At this site, waste disposal activities inevitably continued four more years until 2008 due to legal issues related to the use of newly selected Bağcılar MSWDS (MPDEF 2008). The total volume of the solid waste dumped in the Çavuşlu MSWDS is around 5 million m^3. The sealing process at this site has involved several actions, including waterproofing, installation of systems related to surface water drainage, biogas drainage/burning, leachate collection, and groundwater monitoring (Mersin Metropolitan Municipality 2014). Finally, the site was landscaped as a picnic ground and sports/play field, to enhance the residential character of the neighborhood. The surface confinement, however, was probably insufficient, as highly contaminated leachate continues to leak out of the site (Karaca 2002).

The Bağcılar MSWDS, situated to the 15.5 km NE of the Çavuşlu MSWDS, started operations in November 2008 and it has a storage capacity of about 4,98 million m^3 and projected life span of about 13 years (Karaca 2008). The site was placed on abandoned raw material quarries of a cement factory and covers nearly 24 ha in area. Considering the relatively small area of the site, it is currently a pressing issue for city managers to make plans for a new MSWDS, which would replace the existing one. Designed as a modern waste disposal facility, Bağcılar MSWDS receives waste from four metropolitan sub-provincial municipalities (i.e., Akdeniz, Mezitli, Toroslar, and Yenişehir), where unsorted waste generated in 2012 averaged to 915 ton/day (MPDEF 2013). In the same year, the average waste generation in the Metropolitan Mersin was reported as 1.05 kg/capita/day (Turkish Statistical Institute 2014b), but this figure may vary depending on the year, season, and region (MPDEF 2013). Waste generated in Metropolitan area of Mersin is composed of approximately 57.66 % organic matter, 11.48 % plastic and rubber, 10.29 % paper and cardboard, 5.74 % glass, 0.48 % metal, 0.48 % electronic equipment, 0.24 % hazardous material, 0.24 % municipal waste, and 13.39 % unclassified material and fines (MPDEF 2013).

Methodology

The methodology used in this paper consists of five major stages, including: (1) selection of decision criteria; (2) data acquisition and integration into a GIS database; (3) standardization of decision criteria to a common scale of measurement; (4) calculation of relative criteria weights using the AHP technique; and (5) derivation of the final suitability map using weighted linear combination (WLC) aggregation method within a GIS-based framework. The following sections provide details of the methodology employed in this study.

Selection of decision criteria

In view of the local conditions and circumstances, the number of decision criteria used in the MSWDS selection process may greatly differ from one region to another (Ghobadi et al. 2013; Şener et al. 2010). In this study, selection of the appropriate criteria has been based on the regional characteristics of the site; relevant legislations, guidelines, and regulations; review of similar studies from the literature (e.g., Aydi et al. 2013; Donevska et al. 2012; Gemitzi et al. 2007; Şener et al. 2006); expert opinions; and data availability. In this work, a total of 12 decision criteria (see Table 1) involving geologic/hydrogeologic, environmental, and socioeconomic information are considered to be pertinent in identifying suitable MSWDSs in the Metropolitan Mersin (SE Turkey). It should be noted that this list is not exhaustive and only decision criteria that would be most relevant for the present work were considered here.

Data acquisition and integration into a GIS database

The spatial database used in this study was created using a wide variety of sources ranging in scale or resolution (see Table 1). Published maps (e.g., geologic, topographic and

Table 1 List of site selection criteria (i.e., thematic map layers) utilized in this study and their sources, format and scale/resolution

Parameter	Source	Format	Scale or resolution	Date	Used to create (layer)
Lithology	Geologic Reports: Alan et al. (2007;) Koç et al. (1999); Şenol et al. (1998)	Hard copy	1:25,000 1:250,000 1:100,000	1998 1999 2007	Classified lithology
Aquifer type	Interpretation of geology map compiled from: Alan et al. (2007); Koç et al. (1999); Şenol et al. (1998)	Digital	1:25,000	This study	Classified aquifer type
Lineament	Geologic Reports: Alan et al. (2007); Koç et al. (1999); Şenol et al. (1998)	Hard copy	1:25,000 1:250,000 1:100,000	1998 1999 2007	Distance from lineaments
Landslide	Landslide Inventory of Turkey—Adana sheet: Duman et al. (2009)	Hard copy	1:500,000	2009	Distance from landslides
Land use	Multispectral QuickBird Satellite Imagery	Digital	2.44 m	2004	Land use
Settlement	Multispectral QuickBird Satellite Imagery	Digital	2.44 m	2004	Distance from settlements
Road	Multispectral QuickBird Satellite Imagery	Digital	2.44 m	2004	Distance from roads
Surface water	Multispectral QuickBird Satellite Imagery	Digital	2.44 m	2004	Distance from water bodies
Spring and well	Published/unpublished maps or reports and field investigations	Hard copy and digital	1:25,000	This study	Distance from springs and wells
Elevation	Topographic maps: Turkish Ministry of National Defense, General Command of Mapping: N32 Karaman, N33 and N34 Adana, O32, O33 and O34 Mersin toposheets with 10-m contour interval	Hard copy	1:25,000	1989–1995	Digital Elevation Model
Aspect	Calculated from Digital Elevation Model	Digital	10 m	This study	Aspect (Wind direction)
Slope	Calculated from Digital Elevation Model	Digital	10 m	This study	Slope

landslide inventory) were used to create lithology, aquifer type, lineament, landslide, and elevation map layers. Digital elevation model was used to derive aspect and slope map layers. In addition, land use, settlement, road, and surface water map layers were prepared by visual interpretation of the high-resolution (2.44 m) multispectral QuickBird satellite imagery acquired (in GeoTIFF format) primarily in 2004. Map layer depicting spring and well locations were compiled from diverse sources, including field surveys (Table 1). All data layers were georeferenced within GIS environment using the UTM projection system (Zone 36 N and European Datum 1950). They were then stored, integrated, manipulated, analyzed, and visualized using ArcGIS version 9.3.1 software and its extensions, namely, 3D Analyst and Spatial Analyst (ESRI 2009). The thematic map layers representing the decision criteria were then converted into raster grid format (with 7011 columns and 4523 rows) consisting of cells 10 m × 10 m in size, which constitute the basis of all subsequent GIS analyses. Each grid cell is considered as a homogenous unit for any given map layer (i.e., criterion). The methodology used in the creation of GIS data layers and suitability analysis is depicted in Fig. 2 and briefly described below.

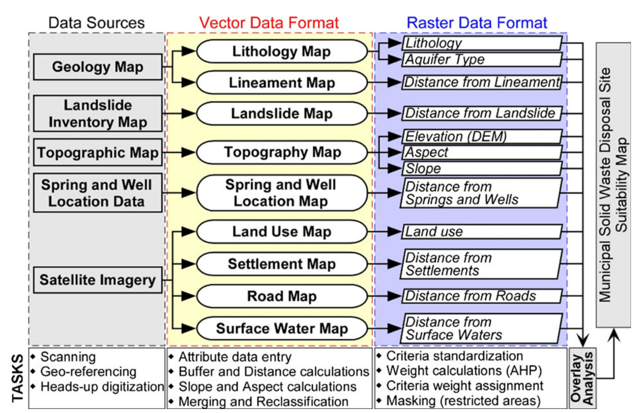

Fig. 2 Methodology used in the creation of GIS data layers and municipal solid waste disposal site (MSWDS) suitability analysis

Lithology plays an important role in MSWDS selection due to its capacity to provide protection from contamination (Demesouka et al. 2013; Khamehchiyan et al. 2011). In this study, the lithology layer was derived from the geology maps prepared by Alan et al. (2007), Koç et al. (1999), and Şenol et al. (1998). The geological units (Table 2) with similar lithological characteristics were

Table 2 Lithologic descriptions and hydrogeological characteristics of the geological units found in the study area (SE Mersin, Turkey) (data compiled from Alan et al. 2007; Koç et al. 1999; Şenol et al. 1998)

Geologic age	Formation name	Thickness (m)	Description	Aquifer type
Holocene	–	10–340	Alluvium and coastal sand dunes	Permeable
Upper pleistocene	–	0–50	River terrace deposits, delta/coastal deposits and terrestrial sediments	Permeable
Lower–upper pleistocene	–	0–25	Terra rosa and talus deposits	Permeable
Lower–upper pleistocene	–	0.5–3	Caliche	Semi-permeable
Pliocene-lower pleistocene	–	1–25	Alluvial fan (mainly conglomerate), fan delta and coastal deposits	Permeable
Pliocene	Sebüçova	100	Conglomerate, sandstone and clayey limestone	Permeable
Upper miocene-pliocene	Handere	50–500	Claystone, marl, siltstone, oolitic limestone, gypsum, sandstone and conglomerate	Impermeable
Middle-upper miocene	Kuzgun	50–1600	Sandstone, conglomerate, reefal limestone, tuffite, claystone, siltstone and marl	Permeable
Lower-middle miocene	Güvenç	50–600	Clayey limestone, marl, claystone and siltstone	Impermeable
Lower-middle miocene	Karaisalı	2–600	Reefal limestone	Karstic permeable
Lower-middle miocene	Kaplankaya	50–640	Limestone, siltstone, sandstone, conglomerate and marl	Semi-permeable
Oligocene-lower miocene	Gildirli	0–400	Conglomerate, sandstone, siltstone, claystone, clayey limestone and marl	Semi-permeable
Upper cretaceous	Mersin ophiolite	6000	Gabbro, harzburgite, dunite, clinopiroxenite, diabase and radiolarite	Impermeable
Upper cretaceous	Kızılcadağ ophiolitic mélange	250	Serpentinite, radiolarite, chert, limestone, dunite and harzburgite	Semi-permeable
Upper cretaceous	Yavca	100–500	Limestone, sandstone, siltstone and shale	Semi-permeable
Jurassic-upper cretaceous	Çamlık	200–800	Limestone, dolomite and dolomitic limestone	Karstic permeable
Jurassic-upper cretaceous	Koçakkaletepe	200–800	Recrystalized limestone, dolomite and calcschist	Karstic permeable
Jurassic-cretaceous	Tavşancıdağtepe	300–800	Recrystalized limestone and dolomite	Karstic permeable
Lower-middle triassic	Kocatepe	100–250	Schist, calcschist and recrystalized limestone	Semi-permeable
Upper permian	Karlığıntepe	300–400	Recrystalized limestone and dolomitic limestone	Karstic permeable
Paleozoic	Karahamzauşağı	>500	Carbonate rocks, schist and quartzite	Karstic permeable

combined into homogeneous zones (i.e., polygons) in the GIS environment by classifying and merging them into five discrete classes as shown in Table 3. This vector layer was then converted into a raster grid format, in which areas covered with lithological units unsuitable for MSWDS were assigned lower ratings and weights (Fig. 3a; Table 3), whereas those that are deemed suitable were assigned higher values.

Aquifer type refers to properties of the aquifer units found in the study area and has a great importance regarding the attenuation processes of pollutants (i.e., leachate) emanating from MSWDSs (Babiker et al. 2005). In the present study, thematic map layer representing aquifer type has been derived from the compiled geology map. Geological formations with similar hydrogeological characteristics (Table 2) were combined into homogeneous zones (i.e., polygons) in the GIS environment by classifying and merging them into four discrete classes as shown in Table 3. This vector layer was then converted into a raster grid format, in which areas covered with porous permeable

Table 3 Pairwise comparison matrix, standardized ratings (r_i) and normalized weights (w_i) for 12 site selection criteria and for the classes within each criterion (i.e., sub-criteria) utilized in AHP analyses

Site selection criteria	Pairwise comparison matrix												W_i
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	
[1] Lithology	1												0.0860
[2] Aquifer type	2	1											0.1158
[3] Distance from lineaments	1	1/2	1										0.0820
[4] Distance from landslides	1/2	1/3	1/3	1									0.0419
[5] Land use	1/2	1/3	1/2	2	1								0.0580
[6] Distance from settlements	2	2	2	5	3	1							0.1570
[7] Distance from roads	1/3	1/3	1/3	1/2	1/2	1/3	1						0.0396
[8] Distance from surface waters	2	2	3	5	3	1	3	1					0.1629
[9] Distance from springs and wells	2	2	3	5	3	1	3	1	1				0.1629
[10] Elevation	1/4	1/4	1/3	1/2	1/3	1/5	1/2	1/5	1/5	1			0.0264
[11] Aspect (wind direction)	1/4	1/5	1/4	1/3	1/2	1/7	1/3	1/7	1/7	1/2	1		0.0191
[12] Slope	1/2	1/3	1/2	1	1/2	1/3	2	1/3	1/3	2	3	1	0.0484
													$\sum = 1.0$

Classes within each criterion	Pairwise comparison matrix								r_i	w_i
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]		
Lithology										
[1] Metamorphic rocks	1								5	0.0349
[2] Ophiolitic rocks	1/2	1							4	0.0215
[3] Sedimentary rocks	1/3	1/2	1						3	0.0143
[4] Carbonate rocks	1/3	1/2	1/2	1					2	0.0098
[5] Unconsolidated sediments	1/5	1/4	1/3	1/2	1				1	0.0054
Aquifer type										
[1] Porous permeable units	1								1	0.0058
[2] Karstic permeable units	2	1							2	0.0098
[3] Semi-permeable units	5	3	1						4	0.0237
[4] Impermeable units	9	7	5	1					5	0.0765
Distance from lineaments										
[1] 0–100 m	1								0	0.0026
[2] 100–250 m	2	1							1	0.0041
[3] 250–500 m	3	2	1						2	0.0057
[4] 500–1000 m	5	3	2	1					3	0.0098
[5] 1000–2000 m	7	5	5	3	1				4	0.0209
[6] >2000 m	9	7	7	5	3	1			5	0.0389
Distance from landslides										
[1] 0–500 m	1								0	0.0015
[2] 500–1000 m	2	1							1	0.0023
[3] 1000–1500 m	3	2	1						2	0.0037
[4] 1500–2000 m	4	3	2	1					3	0.0058
[5] 2000–2500 m	5	4	3	2	1				4	0.0091
[6] >2500 m	9	7	5	4	3	1			5	0.0195
Land use										
[1] Usable areas	1								5	0.0483
[2] Forest and agricultural areas	1/5	1							1	0.0096
Distance from settlements										
[1] <1000 m	1								0	0.0067

Table 3 continued

Classes within each criterion	Pairwise comparison matrix								r_i	w_i
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]		
[2] 1000–1500 m	3	1							1	0.0170
[3] 1500–2000 m	5	2	1						2	0.0293
[4] 2000–2500 m	6	3	2	1					4	0.0441
[5] >2500 m	7	3	2	2	1				5	0.0599
Distance from roads										
[1] 0–100 m	1								0	0.0012
[2] 100–250 m	2	1							1	0.0018
[3] 250–500 m	3	2	1						2	0.0032
[4] 500–750 m	7	5	3	1					4	0.0081
[5] 750–1000 m	9	7	5	3	1				5	0.0172
[6] >1000 m	7	5	3	1	1/3	1			4	0.0081
Distance from surface waters										
[1] 0–200 m	1								0	0.0058
[2] 200–300 m	2	1							1	0.0102
[3] 300–1000 m	5	2	1						2	0.0195
[4] 1000–2000 m	7	5	3	1					4	0.0430
[5] >2000 m	9	7	5	3	1				5	0.0845
Distance from springs and wells										
[1] 0–50 m	1								0	0.0065
[2] 50–300 m	5	1							1	0.0216
[3] 300–1000 m	7	2	1						3	0.0595
[4] >1000 m	9	3	2	1					5	0.0753
Elevation										
[1] 0–100 m	1								4	0.0068
[2] 100–250 m	2	1							5	0.0098
[3] 250–500 m	1/2	1/2	1						3	0.0049
[4] 500–1000 m	1/2	1/3	1/2	1					2	0.0031
[5] >1000 m	1/4	1/4	1/3	1/2	1				1	0.0018
Aspect (Wind direction)										
[1] North	1								2	0.0010
[2] Northeast	1/2	1							1	0.0004
[3] East	7	9	1						4	0.0049
[4] Southeast	4	6	1/2	1					3	0.0026
[5] South	1/3	3	1/3	1/2	1				2	0.0011
[6] Southwest	3	5	1/3	1	2	1			3	0.0022
[7] West	7	9	1	3	5	3	1		5	0.0055
[8] Northwest	3	3	1/3	1/2	1	1/2	1/3	1	2	0.0015
Slope										
[1] 0°–5°	1								2	0.0036
[2] 5°–10°	7	1							5	0.0238
[3] 10°–20°	5	1/2	1						4	0.0150
[4] 20°–30°	1	1/7	1/5	1					3	0.0044
[5] >30°	1/3	1/9	1/7	1/5	1				1	0.0016
										$\sum = 1.0$

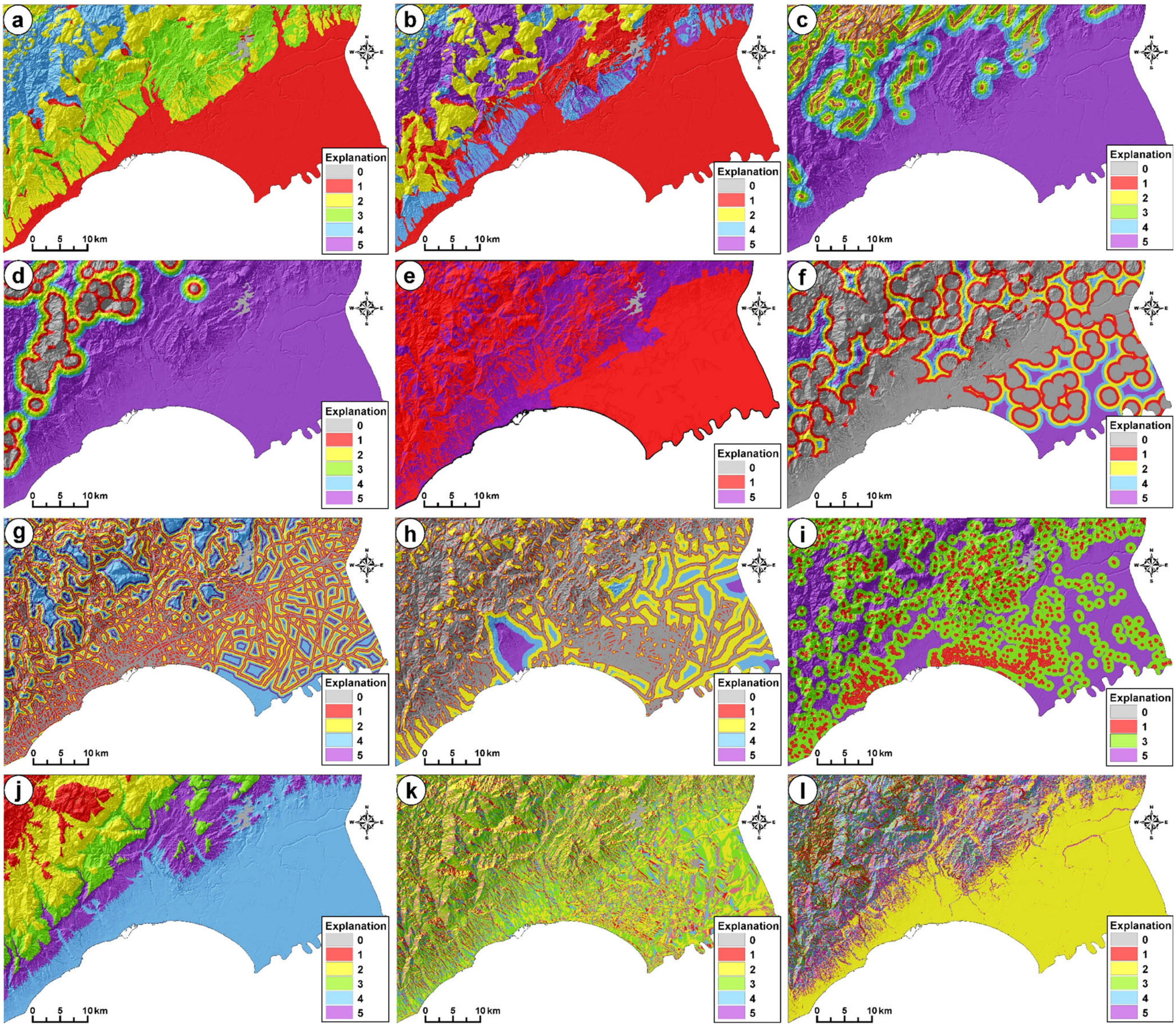

Fig. 3 Spatial distribution of rating values (r_i) for the thematic map layers representing 12 decision criteria utilized in the municipal solid waste disposal site (MSWDS) selection: **a** lithology, **b** aquifer type, **c** distance from lineaments, **d** distance from landslides, **e** land use, **f** distance from settlements, **g** distance from roads, **h** distance from surface waters, **i** distance from springs and wells, **j** elevation, **k** aspect, and **l** slope (for details please see Table 3). Rating values are as follows: *0* restricted areas, *1* least suitable, *2* poorly suitable, *3* moderately suitable, *4* suitable, and *5* most suitable

units (e.g., sands and gravels) were assigned lower ratings and weights (Fig. 3b and Table 3), while impermeable units (e.g., clay-rich formations) were assigned higher values.

Distance from lineaments need to be taken into account when siting MSWDSs, since these weakness zones can act as effective pathways for contaminant migration between overlying and the underlying geologic units. In the present study, lineaments have been digitized and compiled from the geology map. Then, distances from lineaments were calculated using the Euclidean distance operator. Sites within a distance of 100 m from the major structural discontinuities are excluded to minimize seismic hazard and potential aquifer contamination. In this study, all identified lineaments were buffered and categorized into six discrete classes as shown in Table 3. This vector layer was then converted into a raster grid format, in which ratings and weights (Fig. 3c; Table 3) assigned for each buffer zone increase with increasing distance.

MSWDSs should not be constructed in an area of close proximity to the historical and active landslides since these areas are most subject to recurring catastrophic failures capable of seriously threatening long-term integrity of the liner and cap system. In this study, distance from landslides layer was produced using the landslide inventory created by Duman et al. (2009). According to this inventory, the study area contains 20 active and 53 inactive landslides covering a total area of 9.21 and 34.42 km^2, respectively. Distances from landslide prone areas were calculated using the Euclidean distance operator. Sites within a distance of 500 m from the landslide prone areas are excluded to ensure effective operation of the landfill. In this study, all the landslides were buffered and categorized into six discrete classes as shown in Table 3. This vector layer was then converted into a raster grid format, in which ratings and weights (Fig. 3d; Table 3) assigned for each buffer zone increase with increasing distance.

Land use is an important factor when siting MSWDSs. In this study, land use map was initially prepared in vector form by heads-up digitizing technique, where high-resolution multispectral QuickBird satellite imagery of the site was used as a base map. In the mountainous part of the study area, forests of various types (e.g., woodland, scattered trees, shrubs, etc.) are present, whereas in the coastal part diverse agricultural land uses (e.g., cropland, orchard, nursery, greenhouses, etc.) prevail (see Güler 2009; Güler et al. 2012, 2013). In this study, two discrete types of land use were distinguished, namely: (a) usable areas and (b) forest and agricultural areas. This vector layer was then converted into a raster grid format, in which areas covered with forest and agricultural areas were not excluded from consideration, although they were assigned lower rating and weight values (Fig. 3e; Table 3). In this way, the probability of siting a MSWDS in an area with forest cover or agricultural land use is minimized. The remaining "usable areas" consisting of barren and sparsely vegetated land were deemed suitable for siting of MSWDSs and they were assigned higher rating and weight values (Table 3).

MSWDSs should be located at a reasonable distance from settlement areas (>1000 m according to Turkish Solid Waste Control Regulation) since they can be a source of major nuisance to nearby residents and facilities through litter, dust, odor and noxious/toxic gas emissions, noise generation, and vector attraction (e.g., rats, flies, insects, birds, etc.) (Aragonés-Beltrán et al. 2010). In this study, polygons representing the settlement areas were delineated in GIS environment by visual interpretation of the high-resolution multispectral QuickBird satellite imagery and then distances from settlement areas were calculated using the Euclidean distance operator. Distances from settlements were buffered and categorized into five discrete classes as shown in Table 3. This vector layer was then converted into a raster grid format, in which ratings and weights (Fig. 3f; Table 3) assigned for buffer zones increase with increasing distance.

Distance from roads is a very important socioeconomic factor to be considered in the MSWDS selection. MSWDSs should be located far enough from the existing road network because of esthetic concerns, but should not be too far because of high project development and construction costs (Nas et al. 2010). In the present study, roads found within the study area have been digitized from the high-resolution multispectral QuickBird satellite imagery. Distances from roads were calculated using the Euclidean distance operator around the road network. In this study, distances from existing roads were buffered and categorized into six discrete classes as shown in Table 3. This vector layer was then converted into a raster grid format, in which ratings and weights (Fig. 3g; Table 3) assigned for buffer zones between 100 and 1000 m increases with increasing distance, whereas for the buffer zone >1000 m, a lower rating and weight were assigned.

MSWDSs are considered as a pollution source for both surface water and groundwater resources. For that reason, both Turkish Solid Waste Control Regulation and Turkish Water Pollution Control Regulation prohibit siting of MSWDSs in close proximity to the surface water bodies (e.g., lakes, reservoirs, perennial and intermittent rivers). In the present study, all surface water bodies, including irrigation and drainage canals, have been digitized in GIS environment from the high-resolution multispectral QuickBird satellite imagery. Distances from surface water bodies were calculated using the Euclidean distance operator. In this study, all surface water bodies were buffered and categorized into five discrete classes as shown in Table 3. Sites within a distance of 200 m from the surface water bodies are excluded to protect water resources in the region. This vector layer was then converted into a raster grid format, in which ratings and weights (Fig. 3h; Table 3) assigned for each buffer zone increase with increasing distance.

According to the Turkish Water Pollution Control Regulation, MSWDSs cannot be located within 50 m of springs, wells, and infiltration galleries supplying water for drinking purposes. In the present study, locations of springs and wells have been compiled from diverse sources (Table 1). Distances from springs and wells were calculated using the Euclidean distance operator. In this study, all water points were buffered and categorized into four discrete classes as shown in Table 3. Sites within a distance of 50 m from the springs and wells are excluded to protect drinking water sources in the region. This vector layer was then converted into a raster grid format, in which ratings and weights (Fig. 3i; Table 3) assigned for each buffer zone increase with increasing distance.

Siting a MSWDS in a mountainous terrain with high elevations is not feasible on economic grounds because of high construction and waste transportation costs. In this study, elevation layer was created by digitizing contour lines and spot heights from the 1:25,000-scale topographic map sheets ($n = 23$) published by Turkish Ministry of National Defense, General Command of Mapping. Subsequently, a raster-based digital elevation model (DEM) was created from this vector data using the tools available within the ArcGIS Spatial Analyst extension (ESRI, 2009). Elevation values in the DEM were categorized into five discrete classes as shown in Table 3. In this study, each elevation category was assigned rating and weight values (Fig. 3j; Table 3), where high elevations received lower ratings and weights compared to low elevations.

Aspect is an important factor when siting a MSWDS, because downwind areas may be exposed to unpleasant dust, odor, noxious/toxic gases and flying litter which can be a source of major nuisance to nearby communities. Aspect quantifies the direction that each grid cell in a DEM faces in 3D space and here it is recorded in degrees relative to the true north. In this study, aspect layer is used as a proxy for wind direction. As stated in the Turkish Solid Waste Control Regulation, necessary measures should be taken against airborne pollutants that will adversely affect the surrounding environment. The aspect map layer was derived from the DEM of the study area using ArcGIS Spatial Analyst extension (ESRI 2009). In this study, eight discrete aspect classes were defined as shown in Table 3. According to meteorological data obtained from the Turkish State Meteorological Service (2014), two dominant wind directions prevail in the study area, i.e., N9W and S4W, with frequencies of 52.2 and 26.5 %, respectively. Therefore, north and south facing slopes were assigned lower ratings and weights (Fig. 3k; Table 3).

Slope plays a critical role in the MSWDS selection, not only for the higher costs associated with construction and management of these facilities on steep slopes (Wang et al. 2009), but also for impeding natural flow of water in the areas with flat topography that increase vulnerability of water resources to land-based pollutants (Babiker et al. 2005). In addition, areas with steep slopes are more susceptible to mass wasting (Ercanoglu et al. 2004). The slope map was derived on a per-pixel basis from the DEM of the study area, where slope gradation was given in degrees. In this study, raster-based slope map was categorized into five classes as shown in Table 3. Slopes with values between 5° and 10° were identified as the most suitable areas for MSWDS siting, hence these areas were assigned higher rating and weight (Fig. 3l; Table 3) values.

Standardization of decision criteria

The purpose of data standardization in GIS-based decision-making is to provide a common scale of measurement for all the criteria considered in the suitability assessment. Given that the final ranking of the candidate sites is achieved by means of the WLC aggregation method, raster GIS-based decision criteria need to be standardized to a uniform suitability rating scale by transforming or rescaling the original data (i.e., grid cell values). In the present study, the criteria used for the GIS-based suitability analysis can be distinguished as "decision criteria" and "decision criteria with constraints". The difference between those two types of criteria is that the latter type aim at excluding specific geographic areas where siting of MSWDSs is strictly prohibited by national legislations. Therefore, in this study restricted areas (if present) were assigned a rating value of 0 and rest of the area were assigned rating values ranging from 1 to 5 (from least suitable to most suitable) to standardize each raster GIS-based criterion map (see Fig. 3a–l). In addition, a GIS-based constraint map was developed using Boolean logic to eliminate "restricted areas" in the final suitability map. To prepare this map, grid cells in each of the six "decision criterion with constraints" was assigned either a value of 1 (indicating that grid cell will be further evaluated as a MSWDS) or 0 (indicating that grid cell will be excluded from further consideration). Final binary constraint map (not shown), obtained using Eq. (1) (Gemitzi et al. 2007), consists of two classes of grid cells, i.e., suitable ($CSI = 1$) and unsuitable ($CSI = 0$).

$$CSI = \prod_{j=1}^{k} b_j \tag{1}$$

where CSI is the overall suitability index (SI) value (0 or 1) of the constraint map; b_j is SI value for each constraining criterion (0 or 1); and k is the number of constraining criteria. The list of site selection criteria, classes or buffers within each criterion and their corresponding rating values (r_i) are shown in Table 3.

Criteria weight assignment using AHP

AHP, developed by Saaty (1980) is a structured technique that can be used when dealing with complex decisions involving multiple and conflicting criteria that may be both qualitative and quantitative in nature. AHP can effectively deal with a complex decision-making problem by decomposing the problem into a hierarchic structure (Bathrellos et al. 2012; Youssef et al. 2014) (e.g., from top to bottom: overall goal, criteria, sub-criteria and alternatives) and by reducing complex decisions to a series of pairwise comparisons (Saaty 1990). In this method, decision-making process starts with choosing the criteria that are important for that decision (Saaty 1990). Then, based on expert opinions or judgments, matrix-based pairwise comparisons are made to determine the relative importance of one criterion over another by assigning numerical values taken from the Saaty's 1-to-9 scale (Table 4). Let us consider n

Table 4 The fundamental scale of absolute numbers for pairwise comparisons (Saaty 1980, 1990)

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one factor over another
5	Strong importance	Experience and judgment strongly favor one factor over another
7	Very strong importance	Experience and judgment very strongly favor one factor over another
9	Extreme importance	The evidence favoring one factor over another is of the highest possible validity
2,4,6,8	Intermediate values	When compromise is needed

Reciprocals are used for inverse comparisons

criteria to be compared (i.e., C_1, …, C_n) and denote the relative weight of C_j with respect to C_k by a_{jk} and form a square matrix $A = [a_{jk}]_{n \times n}$ with the constraints that $a_{jj} = 1$ and $a_{jk} = 1/a_{kj}$ for j, $k = 1, \ldots, n$. Then find a vector w of order n such that $A \times w = \lambda \times w$. For such a matrix, w is called the eigenvector (i.e., weight vector) and λ is the eigenvalue. For a consistent matrix, λ should be equal to n; however, for matrices formed by personal judgments, inconsistencies may arise. In such a case, the w vector satisfies Eq. (2):

$$A \times w = \lambda_{\max} \times w \tag{2}$$

where $\lambda_{max} \geq n$ and λ_{max} is the principal eigenvalue of the matrix. Therefore, the difference between λ_{max} and n reflects the inconsistency of the judgments. The method calculates a consistency index (CI) using Eq. (3) to check the overall consistency of the pairwise comparison matrix:

$$CI = (\lambda_{\max} - n) / (n - 1) \tag{3}$$

A true consistency ratio (CR) is calculated by dividing the CI for the set of judgments by the random consistency index (RI) values given by Saaty (1980). The pairwise comparison is deemed acceptable if the CR have a value of less than 0.1 (Saaty 1990). However, if the CR > 0.1, the results may be inconsistent and the preferences should be re-evaluated. Finally, overall weights of each criteria and sub-criteria are calculated for evaluation at the bottom level.

Calculation of relative weights (w_i) of each criteria and sub-criteria by implementing the AHP technique (Saaty 1980) involves in construction of a series of pairwise comparison matrices using the Saaty's 1-to-9 scale (Table 4). For this study, the pairwise comparison matrices for site selection criteria and sub-criteria are presented in Table 3, where main diagonals are always equal to 1. Here, only the lower left triangular halves of the pairwise comparison matrices are provided, since the upper right triangular halves are equal to the reciprocal of the corresponding entries in the lower left. Entries in each cell indicate the relative importance of the row variable to its corresponding column variable. The relative weights (w_i) of each site selection criteria (or sub-criteria) were then derived by taking the principal eigenvector of the square reciprocal matrix of pairwise comparisons between the criteria (or sub-criteria). The relative weights (w_i) satisfy the following conditions, such that $0 \leq w_i \leq 1$ and $\sum_{i=1}^{n} w_i = 1$.

The final stage in AHP technique is the calculation of the CR to verify reliability of pairwise comparison matrices formed by personal judgments (i.e., experts' choices). As defined previously, CR is a ratio between the preference matrix's CI and RI, value of which ranges from 0 to 1. Table 5 shows that all CR values are less than 0.1, proving the consistency of the preferences used to produce the pairwise comparison matrices. In other words, relative weights (w_i) computed using the AHP technique can be deemed valid (Saaty 1980, 1990) and they indicate the importance of a decision criteria or sub-criteria. For instance, the relative weights corresponding to both distance from surface waters and distance from springs and wells ($w_i = 0.1629$) are highest, whereas aspect is lowest ($w_i = 0.0191$) (Table 3).

Weighted linear combination (WLC) aggregation method

After checking the reliability of the pairwise comparisons, the WLC aggregation method was used to prepare a MSWDS suitability map for the Metropolitan Mersin (SE Turkey). The final *SI* score was obtained for each raster cell as a sum of the products of ratings and weights assigned for classes or buffers of each criterion (Table 3) and the constraint suitability index values ($CSI = 0$ or 1) of the constraint map as given in Eq. (4) (Gemitzi et al. 2007; Voogd 1983):

$$SI = \sum_{i=1}^{n} r_i \times w_i \times CSI \tag{4}$$

where *SI* is the total suitability index, n is the number of decision criteria, r_i is the standardized rating of the criterion i, w_i is the relative weight of criterion i, and *CSI* is the constraint suitability index values obtained using Eq. (1).

Table 5 Criteria and sub-criteria number (n), largest eigenvalue (λ_{max}) of the preference matrix, consistency index (CI), random consistency index (RI), and consistency ratio (CR) for the site selection criteria utilized in this study

Criteria	N	λ_{max}	CI	RI*	CR
All	12	13.119	0.1017	1.53	0.069
Lithology	5	5.0851	0.0212	1.12	0.019
Aquifer type	4	4.1041	0.0347	0.90	0.039
Distance from lineaments	6	6.2666	0.0533	1.24	0.043
Distance from landslides	6	6.1426	0.0285	1.24	0.023
Land use	2	–	–	0.00	0.000
Distance from settlements	5	5.0896	0.0224	1.12	0.020
Distance from roads	6	6.1488	0.0297	1.24	0.024
Distance from surface waters	5	5.1702	0.0425	1.12	0.038
Distance from springs and wells	4	4.2002	0.0667	0.90	0.075
Elevation	5	5.0985	0.0246	1.12	0.022
Aspect (Wind direction)	8	8.6218	0.0888	1.41	0.063
Slope	5	5.2508	0.0627	1.12	0.056

* RI values are taken from Saaty (1980, 2000)

CSI values (0 or 1) always act as Boolean masks and they do not involve in any weight assignment process. In this study, this masking layer was employed to exclude the "restricted areas", where siting of MSWDSs is strictly prohibited by the relevant national legislations.

Results and discussion

Final MSWDS suitability map

In this study, each one of the 12 input layers representing the site selection (i.e., decision) criteria were separately rated (Fig. 3), multiplied by the AHP-derived criteria weights (Table 3) and constrain map (not shown), then summed up on a cell-by-cell basis to create the final suitability map for a MSWDS for the Metropolitan Mersin (SE Turkey). The total *SI* values obtained from the WLC method range from 0 to 1.861, where a value of zero represents restricted areas that are completely unsuitable for siting of MSWDSs. For values above zero, the higher the total *SI* value, the most suitable is the area for siting of MSWDSs. In this study, the resulting suitability map was then reclassified into six discrete categories of relative suitability using the natural breaks (Jenks) algorithm to determine class intervals representing suitability of the area for siting MSWDSs. The classified suitability map depicting the distribution patterns of the different suitability categories over the study area and locations of candidate sites (i.e., C1, C2, and C3) is presented in Fig. 4.

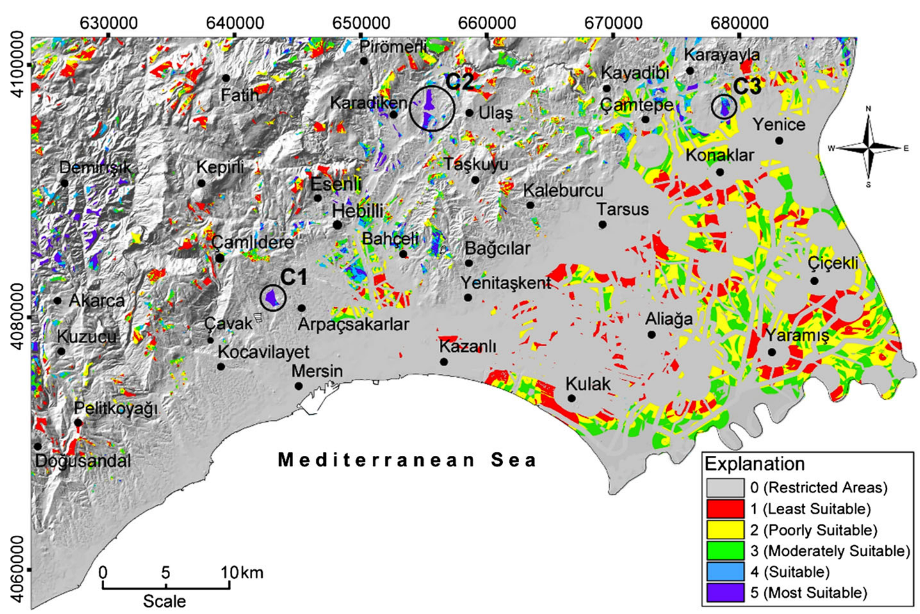

Fig. 4 Map showing suitability for municipal solid waste disposal site (MSWDS), where suitability scores are grouped into six classes: *0* restricted areas, *1* least suitable, *2* poorly suitable, *3* moderately suitable, *4* suitable, and *5* most suitable (C1, C2, and C3 are the candidate sites)

According to this figure, 84.89 % of the study area is classified as completely unsuitable (class 0), 3.47 % is least suitable (class 1), 4.77 % is poorly suitable (class 2), 3.39 % is moderately suitable (class 3), 2.75 % is suitable (class 4), and 0.73 % is most suitable (class 5).

Assessment of suitability of the candidate sites

Currently operating Bağcılar MSWDS, if not expanded, is expected to reach its full capacity around the year 2021. Therefore, new projections for population and waste generation rates were made for the years covering the period from 2020 to 2040 to determine the capacity of the future MSWDS suitable for allocation of municipal solid waste for a 20-year period. Population projection for the area covered by the Metropolitan Mersin was made using historical (1965–2010) data obtained from various governmental sources. According to population projections made in this study, the population of Metropolitan Mersin is expected to increase 45.5 %—from 1,142,363 to 1,662,429—between the years 2020 and 2040. There are many different factors affecting solid waste generation rates such as economic development, degree of urbanization and industrialization, public habits, and local climate. In this study, projections for solid waste produced were made considering the expected growth in population and estimated per capita waste generation (assuming that the generation rate is constant over each year, but varies from year to year). Based on the average waste generation rate of 1.95 % between 1998 and 2012 and average daily waste generation of 1.05 kg per capita in 2012 (Turkish Statistical Institute 2014b), the amount of solid waste that would be accumulated in 20 years (between 2020 and 2040) was estimated as 16.2 million tons for the Metropolitan Mersin. According to this figure, the estimated capacity and area required for a new MSWDS for the period between 2020 and 2040 are 27.1 million m^3 and 67.7 ha, respectively (using an average landfill height of 40 m and average on-site compacted solid waste density of 600 kg/m^3).

Candidate sites (i.e., C1, C2, and C3) found in this study is located in areas classified as the most suitable (Fig. 4), where total surface area of polygonal patches forming them range from 48.6 to 120.4 ha. Polygonal patches with an area smaller than 40 ha were not taken into consideration during the candidate site selection process. First candidate site (C1), located NW of the Arpaçsakarlar settlement, takes a high priority among the other two alternatives because it is the closest (~8 km) to the Metropolitan area of Mersin (Fig. 4). Covering an area of 68.1 ha, the site has an adequate space to serve as a MSWDS for the 20-year period between 2020 and 2040. The candidate site C1 has also safe distance from the settlement areas (>1132 m) and it is located outside environmentally sensitive zones (e.g., surface waters, spring, and wells) and geo-hazard risk zones (e.g., faults and landslides). This site can be characterized by fairly low values of topographic gradient (~4.2°) and elevation (~153 m amsl), and a favorable landuse (100 % usable area). Second candidate site (C2) is located 2.5 km east of Karadiken settlement at the northern part of the study area and has a straight distance of about 23 km to the Metropolitan area of Mersin (Fig. 4). The site is actually composed of two separate, slightly N–S elongated polygonal patches covering 76 and 44.3 ha. Covering a total area of ~120 ha, this site has enough space to serve as a MSWDS for more than 20-years. The candidate site C2 has also safe distance from the settlement areas (>1490 m), surface waters (>2275 m), springs and wells (>973 m), faults (>1651 m) and landslides (>3113 m). The average topographic gradients and elevations for the two separate patches are 4.5°–9.0° and 215–208 m, respectively. A small portion (~5 ha) of the candidate site C2 is comprised a landuse type of "forest and agricultural areas", where the remaining part is favorable for siting of MSWDSs. Third candidate site (C3) has a straight distance of about >40 km to the Metropolitan area of Mersin, however, it is closer to the Tarsus municipality and other population centers around it (Fig. 4) where the total population was 321,403 in 2013. This site, covering an area of 48.6 ha, is therefore suggested as an alternative MSWDS for the above-mentioned settlements, rather than the Metropolitan area of Mersin. The candidate site C3 has also safe distance from the settlement areas (>1310 m) and it is located far from environmentally sensitive zones (e.g., surface waters, spring, and wells) and geo-hazard risk zones (e.g., faults and landslides). This site is characterized by fairly low values of topographic gradient (~3.59°) and elevation (~72.8 m amsl). However, nearly 30 % of the area covered by the candidate site C3 is classified as "forest and agricultural areas", where the remaining 70 % is favorable for siting of MSWDSs.

Obviously, there is not much land available for siting MSWDSs in the Metropolitan area of the Mersin and therefore waste reduction/reuse policies and alternative waste management systems should be adopted in the forthcoming years to increase the projected life span of the MSWDSs. Finally, it is suggested that detailed geotechnical, engineering geological and hydrogeological investigations must be carried out on the identified candidate sites to protect water resources and land. The findings of this study are believed to yield important information for local authorities for future planning, allocation, and development of MSWDSs in the Metropolitan Mersin (SE Turkey).

Conclusions

This paper presented a methodology integrating AHP and GIS techniques to identify suitable MSWDSs for the Metropolitan Mersin (SE Turkey). In order to tackle this complex decision-making problem, 12 site selection criteria were identified and vector- and raster-based GIS tools were used for creating, analyzing, standardizing, and displaying these spatially referenced data. In the present work, AHP technique was employed to assign weights to decision criteria and classes within each criterion. WLC aggregation method was used to derive the final suitability map within a GIS-based framework. In this map, three candidate sites (i.e., C1, C2 and C3) were identified which satisfy the minimum requirements for MSWDSs. According to results of this study, C1 site (68.1 ha in area) was identified as an environmentally and economically superior alternative among the other two alternatives because it satisfies all decision criteria and it is closest ($\sim$8 km) to the Metropolitan area of Mersin. It has to be emphasized that GIS-based MCDA analyses provide a regional scale suitability assessment aiming to identify the best locations for MSWDSs, where further field investigations need to be conducted before the final decision is made. In addition, such suitability assessments can be improved by revising the data and methodology when more detailed and reliable data and more robust and powerful methods become available in the future.

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