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ORIGINAL ARTICLE

# MSW landfill site selection by combining AHP with GIS for Konya, Turkey

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**Abstract** Landfill site selection is a critical issue in the urban planning process because of its enormous impact on the economy, ecology, and the environmental health of the region. Landfill site selection process aims to locate the areas that will minimize hazards to the environment and public health. Multi-criteria evaluation methods are often used for different site selection studies. The purpose of this study was to determine suitable landfill site selection by using the geographical information system and the analytic hierarchy process in the study area. The final index model was grouped into four categories as "low suitable", "moderate", "suitable" and "best suitable" with an equal interval classification method. As a result, 12.69 % of the study area was low suitable, 7.27 % was moderately suitable, 13.79 % was suitable, and 15.52 % was the best suitable for landfilling; 50.72 % of the study area is not suitable for a landfilling.

**Keywords** Municipal solid waste · Analytic hierarchy process · GIS · Site selection

## Introduction

Municipal solid waste (MSW) is waste that consists of daily items that are discarded by the public, and the composition of municipal waste varies greatly from country to country and changes significantly with time. Population growth is applying increased stress on natural resources and the health of ecosystems and enlarging in production and consumption. As cities grow economically, business activity and consumption patterns drive up solid waste quantities. Konya city is one of the most urbanized regions in Turkey with approximately 1.2 million populations, and with high population levels concentrated in this city waste management becomes a huge task. In almost all countries of the world, the responsibility for urban solid waste management services is municipal. This responsibility covers tasks related to regulating, financing, administering and operating these services. Unregulated disposal has negative impacts on all components of environmental and human health (Sener et al. 2010). Therefore, sanitary landfill involves well-designed engineering methods to protect different regions in the economic, ecological and environmental health sectors from contamination by solid wastes (Zamorano et al. 2008; Goorah et al. 2009; Gorsevski et al. 2012). In addition, landfill selection in an urban area is a critical issue in the urban planning process because of its enormous impact on the economy, ecology, and environmental health of the region (Chang et al. 2008). The evaluation of a new waste disposal site is a complicated process as it requires considerable expertise in diverse social and environmental fields, such as soil science, engineering, hydrogeology, topography, land use, sociology, and economics (Sumathi et al. 2008). During this process, the implementation of determined criteria and alternatives is achieved by mathematical formulations that are intended to capture all relevant aspects of the decision problem (Donevska et al. 2012).

Landfill site selection process aims to locate the areas that will minimize hazards to the environment and public health. Also, determined areas must be financially efficient (Kontos et al. 2005). Multi-criteria evaluation (MCE) methods are often used for different site selection studies (Pérez et al. 2003; Carrión et al. 2008; Longdill et al. 2008;

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Zucca et al. 2008; Farzanmanesh et al. 2010). MCE methods were developed in the 1960s to assist with decision-making. MCE is a concept which has wide usage in many fields, according to the literature. MCE is a device which enables the most appropriate choice to be made among a number, all depending on different criteria (Cay and Uyan 2013). Most of these studies used MCE with Geographical Information System (GIS).

GIS plays a significant role in landfill site selection. GIS has been increasingly used as an important spatial decision support system (SDSS) for evaluating suitable landfill locations. A number of GIS methods and techniques have been proposed to evaluate suitable landfill locations. The potential advantage of a GIS-based approach for landfill site selection arises from the fact that it not only reduces the time and cost of site selection but also provides a digital data bank for long-term monitoring of the site (Moeinaddini et al. 2010; Donevska et al. 2012; Eskandari et al. 2012). For optimal landfill site selection the combination of GIS and MCE techniques is most convenient (Eskandari et al. 2012).

The analytic hierarchy process (AHP) is one such multi-criteria decision-making method and can be used to analyze and support decisions which have multiple and even competing objectives (Guiqin et al. 2009; Cay and Uyan 2013). The integration of GIS and AHP is a powerful tool to solve the landfill site selection problem. AHP is a systematic decision approach first developed by Saaty (1980) and Siddiqui et al. (1996) who were among the first to combine GIS and AHP for landfill site selection (Sener et al. 2010; Donevska et al. 2012).

The landfill site selection issue is one of the problematic aspects of the disposal process of MSW. The frequently used method for solving the site selection problem is the decision-making process in which MCE methods are integrated with GIS (Korucu and Erdagi 2012). Several researchers have used combined GIS and AHP method for the landfill site selection process. For example, Donevska et al. (2012) and Gorsevski et al. (2012) evaluated the suitability to select landfill site using together fuzzy sets and AHP with GIS. Guiqin et al. (2009), Moeinaddini et al. (2010), Sener et al. (2010) and Eskandari et al. (2012) combined AHP with GIS for the same goal. This paper focuses on combining AHP with GIS for a new regional landfill site selection in the metropolitan municipality area of Konya city, Turkey, with modern EU standards.

## Modelling theory

### Analytic hierarchy process (AHP)

MCE is a device which enables people to make the most appropriate choice among many criteria, and it is a widely used concept (Jankowski 1995; Wu 1998; Murphy 2003; Eastman et al. 1995). AHP is one such multi-criteria decision-making method.

The AHP, which is used as a decision analysis device (Saaty 1980), is a mathematical method developed by Saaty in 1977 for analyzing complex decisions involving many criteria (Kurttila et al. 2000). It is widely used by decision-makers and researchers as an MCE device.

Pairwise comparison, which is applied within the scope of the AHP technique, provides a comparison of criteria which are used in decision analysis and determines values for each of these criteria (Vaidya and Kumar 2006). In AHP, a matrix is generated as a result of pairwise comparisons and criteria weights are reached as a result of these calculations. Also, it is possible to determine the consistency ratio (CR) of decisions in pairwise comparison. CR reveals the random probability of values being obtained in a pairwise comparison matrix (Yilmaz 1999).

If $n$ number criteria are determined for comparison, AHP performs the following process to ascertain the weight of these criteria (Chakraborty and Banik 2006; Cay and Uyan 2013):

(a) Create $(n \times n)$ pairwise comparison matrix $A$ for $n$ objectives such as (1).

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

where $a_{ij}$ indicates how much more important the $i$th objective is than the $j$th objective, while making a suitable material handling/equipment selection decision. For all $i$ and $j$, it is necessary that $a_{ii} = 1$ and $a_{ij} = 1/a_{ji}$. The possible assessment values of $a_{ij}$ in the pairwise comparison matrix, along with their corresponding interpretations, are shown in Table 1.

(b) Divide each value in column $j$ by the total of the values in column $j$. The total of the values in each column of the new $Aw$ matrix must be 1. Thus, a normalized pairwise comparison matrix is found.

**Table 1** AHP evaluation scale

| Numerical value of $a_{ij}$ | Definition |
|---|---|
| 1 | Equal importance of $i$ and $j$ |
| 3 | Moderate importance of $i$ over $j$ |
| 5 | Strong importance of $i$ over $j$ |
| 7 | Very strong importance of $i$ over $j$ |
| 9 | Extreme importance of $i$ over $j$ |
| 2, 4, 6, 8 | Intermediate values |

$$Aw = \begin{bmatrix} \frac{a_{11}}{\sum a_{i1}} & \frac{a_{12}}{\sum a_{i2}} & \cdots & \frac{a_{in}}{\sum a_{in}} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \frac{a_{n1}}{\sum a_{i1}} & \frac{a_{n2}}{\sum a_{i2}} & \cdots & \frac{a_{nn}}{\sum a_{in}} \end{bmatrix} \tag{2}$$

(c) In the AHP the $c_i$ is determined by finding the principal eigenvector of the matrix $A$. Here we used a simplified approach suitable for hand calculations with a first approximation to the eigenvector by calculating the $c_i$ as the average. Calculate $c_i$ as the average of the values in row $i$ of $Aw$ matrix to yield the column vector $C$, where $c_i$ value shows the relative degree of importance (weight) of the $i$th objective.

$$C = \begin{bmatrix} c_1 \\ c_2 \\ \cdot \\ \cdot \\ \vdots \\ \cdot \\ c_n \end{bmatrix} = \begin{bmatrix} \frac{\frac{a_{11}}{\sum a_{i1}}}{n} + & \frac{\frac{a_{12}}{\sum a_{i2}}}{n} + & \cdots & + \frac{\frac{a_{in}}{\sum a_{in}}}{n} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \frac{\frac{a_{n1}}{\sum a_{i1}}}{n} + & \frac{\frac{a_{n2}}{\sum a_{i2}}}{n} + & \cdots & + \frac{\frac{a_{nn}}{\sum a_{in}}}{n} \end{bmatrix} \tag{3}$$

(d) Control the consistency of the weight values ($c_i$). The procedure to be adopted in order to determine consistency is as follows:
First, calculate the $A \times C$ matrix (consistency vector).

$$A \times C = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \times \begin{bmatrix} c_1 \\ c_2 \\ \cdot \\ \cdot \\ \cdot \\ c_n \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ \cdot \\ \cdot \\ \cdot \\ x_n \end{bmatrix} \tag{4}$$

Second, calculate the $x_i$ by multiplying $A \times C$, which is a second, better, approximation to the eigenvector. We now estimate $\lambda_{\max}$ using the following formula:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{x_i}{c_i} \tag{5}$$

where $\lambda_{\max}$ is the eigenvalue of the pairwise comparison matrix.
Then, calculate an approximation to the consistency index (CI).

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{6}$$

Finally, to ensure the consistency of the pairwise comparison matrix, the consistency judgment must be checked for the appropriate value of $n$ by CR (Zou and Li 2008), that is,

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{7}$$

where RI is the random consistency index. The RI values for different numbers of $n$ are shown in Table 2.
If CR $\leq$0.10 the degree of consistency is satisfactory. If CR >0.10 there are serious inconsistencies. In this case, the AHP may not yield meaningful results (Chakraborty and Banik 2006).

**Table 2** RI table values (Saaty 1980)

| $n$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

## Materials and methods

### Study area

The field of the study includes borders of Konya Metropolitan Municipality in the city of Konya. The city of Konya is geographically situated between 36.5° and 39.5° north latitudes and 31.5°–34.5° east longitudes and it is the largest province of Turkey. Konya city's area is 38,257 $km^2$ and Konya Metropolitan Municipality's responsibility area (study area) is 2,100 $km^2$. It is located nearly in Central Anatolia, Turkey (Fig. 1). The population of the city is approximately 2,050,000 according to the 2011 census. The population in the study area (borders of Konya Metropolitan Municipality) is approximately 1,074,000 according to the


**Fig. 1** The geographical position of Konya Metropolitan Municipality's boundary

2011 census. The average height from the average sea level is about 1,016 m. Konya city is located in the part of the country with least rainfall, where the continental climate conditions prevail with summers that are hot and arid while winters are cold and snowy.

According to Turkish Statistical Institute's 2010 data (TURKSTAT 2008), in Turkey, total number of municipalities is 2,950, total municipal population is 61,571,332 and rate of population served by municipal waste services in total population is 83 %. Again for 2010, amount of municipal waste collected is 25,277 thousand tonnes/year and the average per capita solid waste production is approximately 1.14 kg/capita-day. In study area, amount of municipal waste collected is approximately 400 thousand tonnes/year. Konya Metropolitan Municipality has a controlled landfill site of 172 ha which has a pre-processing plant, a composting plant, a transfer station, a recovery facility, a leachate treatment plant and a landfill gas power plant.

## Methodology

GIS data sets of the study area (e.g., land use, roads, geology, airport, groundwater wells, slope) were collected for the Konya City from different sources such as Konya Metropolitan Municipality, Directorate of State Hydraulic Works, Selcuk University, Department of Geomatic Engineering. Geology, land use, and water supply sources maps were collected from departments of the scale 1:25,000 and subsequently digitized. Elevation maps were prepared based on the Shuttle Radar Topography Mission (SRTM) data. The digitization and analysis of the maps were performed using GIS software, ArcGIS Desktop 9.3. The AHP weights were calculated using Microsoft Excel.

Hierarchy model of landfill suitability is shown in Fig. 2. In this study, twelve criteria were selected for evaluating landfill suitability. Firstly, constraints were masked. Constraint values are shown in Table 3.

Determinates' criteria were divided into three main groups. The first group comprised environment factors. Environmental factors should be considered more sensitive than other factors. Because leachate generated from landfills can affect natural sources negatively (Sener et al. 2010). The second group comprised economic factors and the third group comprised social factors.

**Table 3** Different constraint areas

| Constraints |
|---|
| Buffer of groundwater wells distance = 100 m |
| Buffer of historical and tourism area distance = 1,000 m |
| Buffer of residential (urban and rural) and industrial areas distance = 1,000 m |
| Buffer of rivers, lakes, wetlands, coastal area and dam distance = 1,000 m |
| Buffer of protection areas distance = 1,000 m |
| Buffer of airports distance = 1,000 m |

Fifty-seven criteria were used in the computation process, which were divided into three main groups as shown in Table 4. The weight (*W*) of each criterion was calculated as described in the section "Modeling theory" (Table 4). The CR values of all comparisons were lower than 0.10. This means that the weights were suitable. As a result, the overall score of alternatives in the GIS environment and land suitability of the study area was determined by calculating the landfill suitability index (LSI) (Sener et al. 2010):

$$\begin{aligned}\mathrm{LSI} = {} & [A \times A_1\mathrm{c_{wi}} \times A_1\mathrm{sc_{wi}} + A_2\mathrm{c_{wi}} \times A_2\mathrm{sc_{wi}} \\ & + A_3\mathrm{c_{wi}} \times A_3\mathrm{sc_{wi}} + A_4\mathrm{c_{wi}} \times A_4\mathrm{sc_{wi}} \\ & + A_5\mathrm{c_{wi}} \times A_5\mathrm{sc_{wi}} + A_6\mathrm{c_{wi}} \times A_6\mathrm{sc_{WI}} \\ & + A_7\mathrm{c_{wi}} \times A_7\mathrm{sc_{wi}} + A_8\mathrm{c_{wi}} \times A_8\mathrm{sc_{wi}}] \\ & + [B \times B_1\mathrm{c_{wi}} \times B_1\mathrm{sc_{wi}} + B_2\mathrm{c_{wi}} \times B_2\mathrm{sc_{wi}}] \\ & + [C \times C_1\mathrm{c_{wi}} \times C_1\mathrm{sc_{wi}} + C_2\mathrm{c_{wi}} \times C_2\mathrm{sc_{wi}}]\end{aligned}$$

where, LSI, landfill suitability index; $A_1\mathrm{c_{wi}}$, weight index of distance from residential and industrial areas criteria; $A_1\mathrm{sc_{wi}}$, weight index of distance from residential and industrial areas sub-criteria; $A_2\mathrm{c_{wi}}$, weight index of distance from rivers, lakes, wetlands, coastal area and dam criteria; $A_2\mathrm{sc_{wi}}$, weight index of distance from rivers, lakes,

| Goal | Objectives | Criteria |
|---|---|---|
| Landfill Suitability | (A)Environment Factors | (A1) Distance from residential and industrial areas(m)<br>(A2) Distance from rivers, lakes, wetlands, coastal area and dam (m)<br>(A3) Distance from groundwater wells(m)<br>(A4) Distance from protection areas (m)<br>(A5) Distance from infrastructure (e.g. electrical supply lines, oil ducts and water pipelines)<br>(A6) Land use<br>(A7) Slope (%)<br>(A8) Geology |
| | (B) Economic Factors | (B1) Distance from roads and railway (m)<br>(B1) Elevation (m) |
| | (C ) Social Factors | (C1) Distance from tourism and historical sites (m)<br>(C2) Distance from airport (m) |

**Fig. 2** Hierarchy model of landfill suitability

**Table 4** Weights of all criteria used in landfill site selection

| Goal | Obj. | Weight | CR | Criteria | Weight | CR | Sub-criteria | Weight | CR | ∑Weight |
|---|---|---|---|---|---|---|---|---|---|---|
| Landfill suitability | Environment factors (*A*) | 0.777 | 0.071 | Distance from residential and industrial areas (m) | 0.107 | 0.086 | 1,000> | 0.033 | 0.055 | 0.003 |
| | | | | | | | 1,000–2,000 | 0.148 | | 0.012 |
| | | | | | | | 2,000–3,000 | 0.187 | | 0.016 |
| | | | | | | | 3000-4000 | 0.283 | | 0.024 |
| | | | | | | | 4000< | 0.348 | | 0.029 |
| | | | | Distance from rivers, lakes, wetlands, coastal area and dam (m) | 0.131 | | 500> | 0.027 | 0.045 | 0.003 |
| | | | | | | | 500–1,000 | 0.146 | | 0.015 |
| | | | | | | | 1,000–1,500 | 0.146 | | 0.015 |
| | | | | | | | 1,500–2,000 | 0.341 | | 0.035 |
| | | | | | | | 2,000< | 0.341 | | 0.035 |
| | | | | Distance from groundwater wells (m) | 0.14 | | 200> | 0.028 | 0.041 | 0.003 |
| | | | | | | | 200–300 | 0.072 | | 0.008 |
| | | | | | | | 300–400 | 0.287 | | 0.031 |
| | | | | | | | 400–500 | 0.307 | | 0.033 |
| | | | | | | | 500< | 0.307 | | 0.033 |
| | | | | Distance from protection areas (m) | 0.058 | | 500> | 0.030 | 0.062 | 0.001 |
| | | | | | | | 500–750 | 0.071 | | 0.003 |
| | | | | | | | 750–1,000 | 0.292 | | 0.013 |
| | | | | | | | 1,000–1,250 | 0.304 | | 0.014 |
| | | | | | | | 1,250< | 0.304 | | 0.014 |
| | | | | Distance from infrastructure (e.g. electrical supply lines, oil ducts and water pipelines) | 0.03 | | 250> | 0.092 | 0.037 | 0.002 |
| | | | | | | | 250–500 | 0.152 | | 0.004 |
| | | | | | | | 500–1,000 | 0.289 | | 0.007 |
| | | | | | | | 1,000< | 0.467 | | 0.011 |
| | | | | Land use | 0.44 | | Agriculture (irrigated) | 0.039 | 0.069 | 0.013 |
| | | | | | | | Agriculture (not irrigated) | 0.128 | | 0.044 |
| | | | | | | | Forest | 0.282 | | 0.096 |
| | | | | | | | Barren | 0.550 | | 0.188 |
| | | | | Slope (%) | 0.027 | | 0–10 | 0.669 | 0.025 | 0.014 |
| | | | | | | | 10–20 | 0.267 | | 0.006 |
| | | | | | | | 20< | 0.064 | | 0.001 |
| | | | | Geology | 0.066 | | Alluvium | 0.022 | 0.074 | 0.001 |
| | | | | | | | Dolomite | 0.044 | | 0.002 |
| | | | | | | | Limestone | 0.069 | | 0.004 |
| | | | | | | | Volcanic | 0.129 | | 0.007 |
| | | | | | | | Flysch | 0.135 | | 0.007 |
| | | | | | | | Ophiolite | 0.283 | | 0.015 |
| | | | | | | | Metamorphic | 0.317 | | 0.016 |
| | Economic factors (*B*) | 0.155 | | Distance from roads and railway (m) | 0.65 | 0 | 250> | 0.360 | 0.031 | 0.036 |
| | | | | | | | 250–500 | 0.360 | | 0.036 |
| | | | | | | | 500–750 | 0.162 | | 0.016 |
| | | | | | | | 750–1,000 | 0.079 | | 0.008 |
| | | | | | | | 1,000< | 0.040 | | 0.004 |

Table 4 continued

| Goal | Obj. | Weight | CR | Criteria | Weight | CR | Sub-criteria | Weight | CR | ∑Weight |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Elevation (m) | 0.35 | | 2,000< | 0.033 | 0.053 | 0.002 |
| | | | | | | | 1,750–2,000 | 0.066 | | 0.004 |
| | | | | | | | 1,500–1,750 | 0.131 | | 0.007 |
| | | | | | | | 1,250–1,500 | 0.271 | | 0.015 |
| | | | | | | | 1,250> | 0.498 | | 0.027 |
| | Social factors (*C*) | 0.068 | | Distance from tourism and historical sites (m) | 0.6 | 0 | 2,000> | 0.039 | 0.069 | 0.002 |
| | | | | | | | 2,000–4,000 | 0.070 | | 0.003 |
| | | | | | | | 4,000–6,000 | 0.137 | | 0.006 |
| | | | | | | | 6,000–8,000 | 0.264 | | 0.011 |
| | | | | | | | 8,000< | 0.490 | | 0.020 |
| | | | | Distance from airport (m) | 0.4 | | 3,000> | 0.092 | 0.037 | 0.003 |
| | | | | | | | 3,000–4,000 | 0.152 | | 0.004 |
| | | | | | | | 4,000–5,000 | 0.289 | | 0.008 |
| | | | | | | | 5,000< | 0.467 | | 0.013 |

wetlands, coastal area and dam sub-criteria; $A_3c_{wi}$, weight index of distance from groundwater wells criteria; $A_3sc_{wi}$, weight index of distance from groundwater wells sub-criteria; $A_4c_{wi}$, weight index of distance from protection areas criteria; $A_4sc_{wi}$, weight index of distance from protection areas sub-criteria; $A_5c_{wi}$, weight index of distance from infrastructure criteria; $A_5sc_{wi}$, weight index of distance from infrastructure sub-criteria; $A_6c_{wi}$, weight index of land use criteria; $A_6sc_{wi}$, weight index of land use sub-criteria; $A_7c_{wi}$, weight index of slope criteria; $A_7sc_{wi}$, weight index of slope sub-criteria; $A_8c_{wi}$, weight index of geology criteria; $A_8sc_{wi}$, weight index of geology sub-criteria; $B_1c_{wi}$, weight index of distance from roads and railway criteria; $B_1sc_{wi}$, weight index of distance from roads and railway sub-criteria; $B_2c_{wi}$, weight index of elevation criteria; $B_2sc_{wi}$, weight index of elevation sub-criteria; $C_1c_{wi}$, weight index of distance from tourism and historical sites criteria; $C_1sc_{wi}$, weight index of distance from tourism and historical sites sub-criteria; $C_2c_{wi}$, weight index of distance from airport criteria; $C_2sc_{wi}$, weight index of distance from airport sub-criteria.

In this study, landfill suitability map was prepared 12 map layers including distance from residential and industrial areas, distance from rivers, lakes, wetlands, coastal area and dam, distance from groundwater wells, distance from protection areas, distance from infrastructure, land use, slope, geology, distance from roads and railway, elevation, distance from tourism and historical sites and distance from airport. ArcGIS software was used this process for overlay analyses. Determined numerical values from LSI divided into four grades (low suitable, moderate, suitable and best suitable) according to criteria and buffer zones were built. The higher score is more suitable area for landfills.

## Criteria description

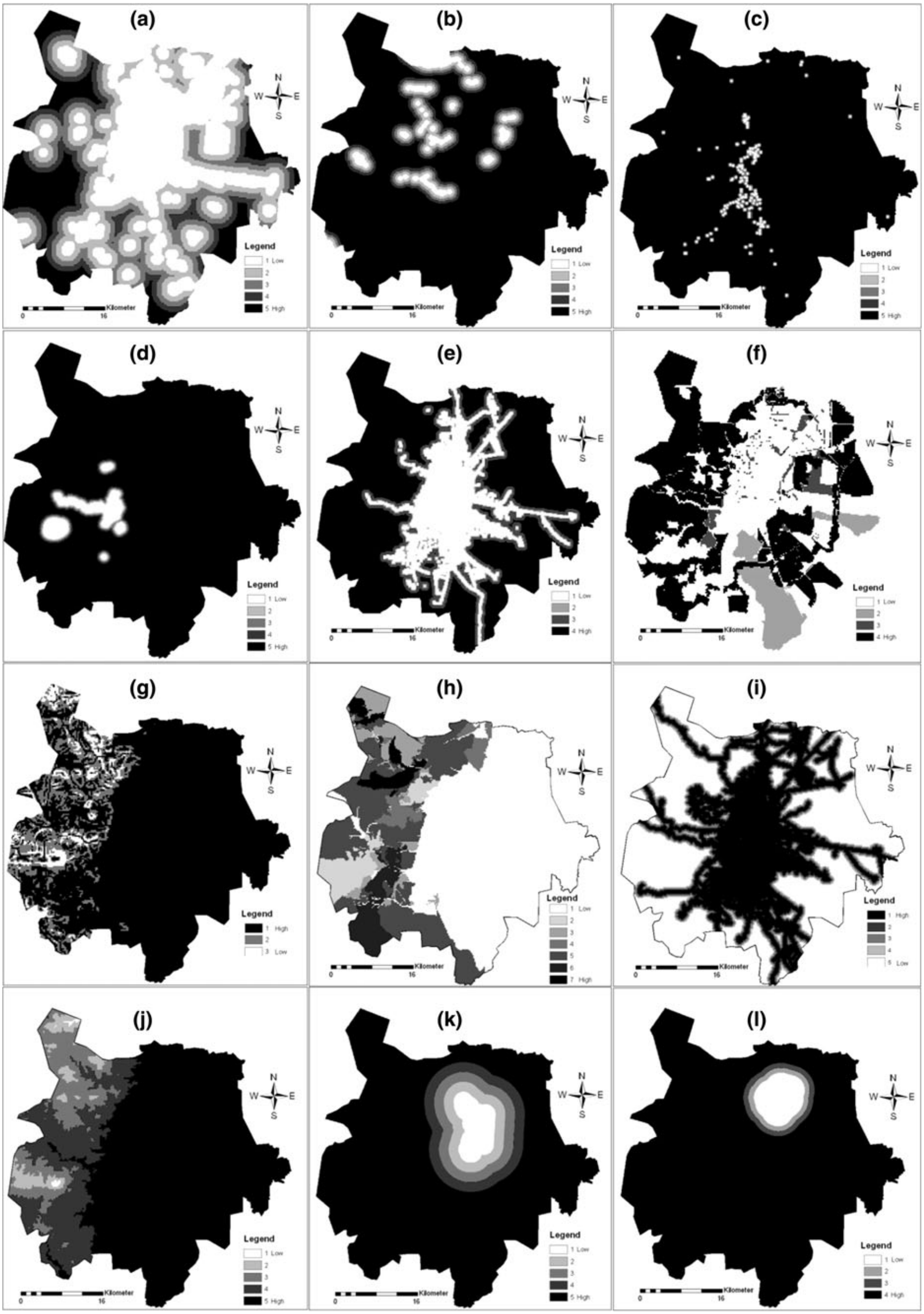
The following factors are considered in the landfill process for this study. Landfill site selection criteria may change from one region from another based on local conditions and circumstances (Sener et al. 2010). Twelve criteria were determined for landfill site selection process into borders of Konya Metropolitan Municipality. All of criteria and calculated weight by AHP of these criteria were summarized in Table 4. Each criterion is explained in below.

### Environment factors

#### *($A_1$) Distance from residential and industrial areas*

Sitting a landfill near rural and urban residential areas can cause negative environmental impacts on the population and the landscape because of odor, dust and noise (Donevska et al. 2012). Therefore, according to Turkish legislation, landfills at a distance less than 1,000 m from urban areas are not allowed. In this study, a 1,000 m buffer zone was masked for rural–urban residential and industrial areas. Residential and industrial areas with a <1,000 m buffer zone was scored as 1, 1,000–2,000 m buffer zone was scored as 2, 2,000–3,000 m buffer zone scored as 3, 3,000–4,000 m buffer zone scored as 4 and >4,000 m buffer zone scored as 5 (Fig. 3a). All buffer zones were separately weighted by AHP. The criterion map was

**Fig. 3** Suitability index of **a** residential and industrial areas, **b** rivers, lakes, wetlands, coastal area and dam, **c** groundwater wells, **d** protection areas, **e** infrastructure, **f** land use, **g** slope, **h** geology, **i** roads and railway, **j** elevation, **k** tourism and historical sites, **l** airport area ▶


(a)
(b)
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(j)
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N
W
E
S
Legend
1 Low
2
3
4
5 High
1 High
3 Low
6
7 High
5 Low
4 High
Kilometer
0
16

obtained by ArcGIS software with weighted value of each buffer zone in Table 4.

*($A_2$) Distance from rivers, lakes, wetlands, coastal area and dam*

According to Turkish Water Pollution Control Regulations, landfill sites should not be placed near any surface water bodies (Sener et al. 2010). Therefore, in this study buffer zones were selected at intervals of 500 m around all surface waters. <500 m buffer zone was scored as 1, 500–1,000 m buffer zone was scored as 2, 1,000–1,500 m buffer zone scored as 3, 1,500–2,000 m buffer zone scored as 4 and >2,000 m buffer zone scored as 5 (Fig. 3b). All buffer zones were separately weighted by AHP. The criterion map was obtained by ArcGIS software with weighted value of each buffer zone in Table 4.

*($A_3$) Distance from groundwater wells*

Groundwater wells should be at a distance from landfill site. In this study, <200 m buffer zone was scored as 1, 200–300 m buffer zone was scored as 2, 300–400 m buffer zone scored as 3, 400–500 m buffer zone scored as 4 and >500 m buffer zone scored as 5 (Fig. 3c). All buffer zones were separately weighted by AHP. The criterion map was obtained by ArcGIS software with weighted value of each buffer zone in Table 4.

*($A_4$) Distance from protection areas*

Konya city has some protection areas such as historical and archeological areas. Such areas are not suitable for landfill sites. In this study, <500 m buffer zone was scored as 1; 500–750 m buffer zone was scored as 2; 750–1,000 m buffer zone was scored as 3; 1,000–1,250 m buffer zone was scored as 4; and >1,250 m buffer zone was scored as 5 (Fig. 3d). All buffer zones were separately weighted by AHP. The criterion map was obtained by ArcGIS software with weighted value of each buffer zone in Table 4.

*($A_5$) Distance from infrastructure*

In study, in order to prevent damage to infrastructure systems, landfill site were selected a certain distance away from infrastructure systems; <250 m buffer zone was scored as 1; 250–500 m buffer zone was scored as 2; 500–1,000 m buffer zone was scored as 3; and >1,000 m buffer zone was scored as 4 (Fig. 3e). All buffer zones were separately weighted by AHP. The criterion map was obtained by ArcGIS software with weighted value of each buffer zone in Table 4.

*($A_6$) Land use*

The land use is considered an environmental factor in construction of a landfill. In this study, land use was evaluated for four criteria as irrigated agricultural areas, not irrigated agricultural areas, forest areas and barren areas. Irrigated agricultural areas was scored as 1, not irrigated agricultural areas was scored as 2, forest areas was scored as 3 and barren areas was scored as 4 (Fig. 3f). All buffer zones were separately weighted by AHP. The criterion map was obtained by ArcGIS software with weighted value of each buffer zone in Table 4.

*($A_7$) Slope*

The slope is a crucial factor for landfill site selection. For example, steep slopes will lead to higher excavation costs. The slope of the land surface was evaluated as 0–10 %, 10–20 % and >20 %. The 0–10 % buffer zone was scored as 1; 10–20 % buffer zone was scored as 2; and >20 % buffer zone was scored as 3 (Fig. 3g). All buffer zones were separately weighted by AHP. The criterion map was obtained by ArcGIS software with weighted value of each buffer zone in Table 4.

*($A_8$) Geology*

The geological map of the scale 1:25,000 was digitized using ArcGIS software and converted into a grid map. There were seven formations in the study area such as alluvium, dolomite, limestone, volcanic, flysch, ophiolite and metamorphic. Alluvium, dolomite and limestone have high potential for water adsorption and are not suitable for landfill sites. However, these areas covered for a large part of the study area. Therefore, it was not masked and was weighted. In this study, alluvium was scored as 1, dolomite as 2, limestone as 3, volcanic as 4, flysch as 5, ophiolite as 6, and metamorphic as 7 (Fig. 3h). All areas were separately weighted by AHP. The criterion map was obtained by ArcGIS software with weighted value of each buffer zone in Table 4.

(*B*) Economic factors

*($B_1$) Distance from roads and railway*

Proximity to roads is considered in the construction costs when building a new road infrastructure between the settlements and potential landfill (Donevska et al. 2012). In this study, <250 m buffer zone was scored as 1; 250–500 m buffer zone was scored as 2; 500–750 m buffer zone was scored as 3; 750–1,000 m buffer zone was scored as 4; and >1,000 m buffer zone was scored as 5 (Fig. 3i). All buffer zones were separately weighted by AHP. The criterion map was obtained by ArcGIS software with weighted value of each buffer zone in Table 4.

*($B_2$) Elevation (m)*

In the study area, elevation is between 1,000 and 2,000 m. This difference was divided into five equal parts, e.g., >2,000 m buffer zone was scored as 1; 1,750–2,000 m buffer zone was scored as 2; 1,500–1,750 m buffer zone was scored as 3; 1,250–1,500 m buffer zone was scored as 4; and <1,250 m buffer zone was scored as 5 (Fig. 3j). All buffer zones were separately weighted by AHP. The criterion map was obtained by ArcGIS software with weighted value of each buffer zone in Table 4.

(*C*) Social factors

*($C_1$) Distance from tourism and historical sites*

This criterion is important during the landfill siting process tourism. These criteria were divided into five parts, e.g., <2,000 m buffer zone was scored as 1; 2,000–4,000 m buffer zone was scored as 2; 4,000–6,000 m buffer zone was scored as 3; 6,000–8,000 m buffer zone was scored as 4; and <8,000 m buffer zone was scored as 5 (Fig. 3k). All buffer zones were separately weighted by AHP. The criterion map was obtained by ArcGIS software with weighted value of each buffer zone in Table 4.

*($C_2$) Distance from airport*

A four-part buffer zone was applied around airports, e.g., <3,000 m buffer zone was scored as 1; 3,000–4,000 m buffer zone was scored as 2; 4,000–5,000 m buffer zone was scored as 3; and >5,000 m buffer zone was scored as 4 (Fig. 3l). All buffer zones were separately weighted by AHP. The criterion map was obtained by ArcGIS software with weighted value of each buffer zone in Table 4.

## Results and discussion

A landfill suitability index map was determined by combining AHP with GIS for the logical location of a municipal landfill in Konya, Turkey in Fig. 4. In order to calculate the suitability indexes, the evaluation criteria

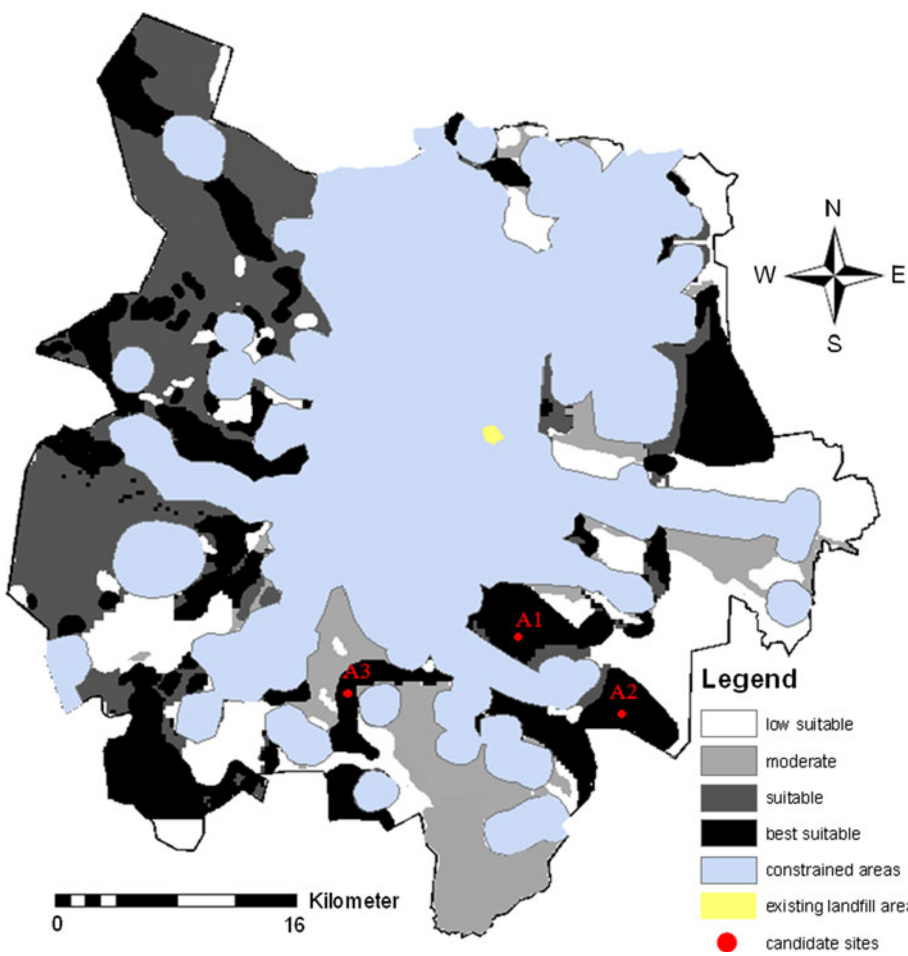


**Fig. 4** Landfill suitability index map in the study area

(Fig. 3) were used. Twelve landfill selection criteria were chosen according to attributes of study area. Each criterion map was prepared using ArcGIS with weight values obtained from AHP and combined for landfill suitability map by the LSI. The final index model was grouped into four categories as "low suitable", "moderate", "suitable" and "best suitable" with an equal interval classification method. As a result, 12.69 % of the study area was low suitable, 7.27 % was moderately suitable, 13.79 was suitable, and 15.52 % was best suitable for landfilling; 50.72 % of the study area is not suitable for a landfilling. In the study area, a lot of regions were determined to be high suitability. The prevailing wind direction in the city of Konya is north and northeast. One of the main reasons of air pollution is the wind as urban growth and industry are located the direction of the prevailing wind in the city of Konya. Therefore, determined best suitable regions for landfilling can be selected south regions. We suggested three candidate sites as $A_1$, $A_2$ and $A_3$ for landfill site selection due to transportation costs, direction of the prevailing wind in the Fig. 4.

The results of such study directly depend on the selected criteria. Therefore, selected criteria must be arranged for study area. In this study, based on the expertise and decision maker views, the evaluation criteria were determined and categorized.

## Conclusions

MSW management is one of the most important problems for all counties in the world. An inadequate waste management can cause serious problems for environmental quality and human health. One of the most important steps is landfill site selection for MSW management.

This paper presents an application of combining AHP with GIS for new regional landfill site selection in metropolitan municipality area of Konya, Turkey with modern EU standards. The AHP is used to evaluate the importance and determinate weights of criteria. The AHP methodology integrated with GIS are remarkably important for the effective and quick evaluation of the landfill site selection. Environmental, economic and social factors were all together considered in the computation process including 12 criteria categorized in three factors. Final suitability map was created for combined all criteria. This study can offers a methodology and decision support to the decision maker for solving the landfill site selection. However, the existing landfill is located near the residential area and airport and stayed in constrained areas according to Fig. 4. Some residential areas are affected negative due to reek. This condition might cause serious health hazards.

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