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LANDFILL SITTING USING MCDM in TEHRAN METROPOLITAN

Bahram Abediniangerabi* and Shirin Kamalirad

Department of Urban Planning, Islamic Azad University, Robat Karim Branch, Robat Karim, Iran

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Abstract: Managing Municipal Solid Waste in order to control waste materials in Tehran Metropolitan with a population of over 8.5 million persons and daily production of 7500 tons of trash seems an evitable necessity. Daily production of such amount of trash and accumulation of them in the southern part of Tehran (Kahrizak) due to lack of proper and standard methods of landfilling have caused severe problems by creating a latex lake of twelve hectares. Among these problems, penetration of infection and contamination to underground waters, causing excessive problems for soil and agricultural lands can be mentioned. In such conditions caused for Tehran, lack of solution finding for the issue would bring heavy outcomes for the Tehran Metropolitan in terms of environmental and economic issues. In this paper, efforts are taken to find a new place as a landfill by applying sustainable development approach. For this, in order to use the criteria propounded in sustainable development, multi-criteria decision making methods has been applied for weighing and spatial analysis has been used to combining them for indicating the most appropriate site. In this way, the new site would be selected by observance of sustainable development would be a place with the least environmental and social damages while being economically affordable.

Keywords: Landfill Sitting, Sustainable Development, Tehran Metropolitan, Multi-Criteria Decision Making Methods, Spatial Analysis, Weighted Linear Combination

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* Correspondence to: Bahram Abediniangerabi, Tel.: +98 21 22595180 Cell phone: +98 9372915005.
E-mail: abedini.bahram@gmail.com

INTRODUCTION

According to the European Commission in the Waste Framework Directives of 1975, Municipal Solid Waste (MSW)—more commonly known as trash or garbage—is any substance that an individual throws or intends to throw away (Gbanie, 2012), such as product packaging, grass clippings, furniture, clothing, bottles, food scraps, newspapers, appliances, paint, and batteries. This comes from our homes, schools, hospitals, and businesses. According to the Environmental Protection Agency (EPA), the average person dumps almost 2 kg of waste into landfills every single day. This average for Tehran with 8.5 billion persons (Statistical Center Of IRAN, 2011) is about 1 kg per resident. It means that about 8000 tons waste is daily produced in Tehran (Sarmaye, 2010).

Although this per capita is lower than the world average but paying no attention to correct principles and standard methods in land filling in Arad Kuuh-e-Kahrizak district (Tehran Waste Management Organization, 2012) caused many dangerous problems to the residents' health and also to agricultural lands quality. The most important feature of this problem is unsuitable landfill site that it has low distance to residential areas and surface waters. It can be concluded that solving this problem is the most important issue and has first priority for decision makers.

The components of municipal solid waste management include reducing the waste, re-using, energy recovery, incineration and landfill (Abdoli, 2005; Kontos et al, 2005). Landfill as described by Sumathi *et al.*, (2008) is a waste disposal method in which key engineering principles are applied. This is achieved by spreading waste into thin cells, compressing it into small volumes and, finally, covering it with a soil layer. Landfill, although found at the bottom of waste management hierarchy (waste reduction, reuse, recycling, composting and land filling), is an integral component of the waste management chain and requires greater attention to reduce its environmental impact (Mahini & Gholamalifard, 2006; Rahman et al, 2008). Landfill sitting in an urban area 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 (Chang *et al.*, 2007).

It is less expensive than other forms of waste treatment but has, nonetheless, created and continues to create environmental problems. But inasmuch as in developing countries such as Iran, it is impossible to focusing on these methods simultaneously because of lack of technology and financial issues. So, it seems the most appropriate method in these countries is locating appropriate landfill sites to minimizing hazards to the public health as well as to the environment and will be financially efficient (Bagchi,1990).

The identification of suitable municipal landfill as outlined in the literature is a complex and multidisciplinary process which requires environmental, ecological, social, economic and technical or engineering considerations (Gbanie, 2012). This complexity will be more when the process needs to use spatial data (GeoDa). The criteria that are used in landfill sitting such as soil type, slope, wind direction, land price, distance to residential areas and etc., have geographical features. The important matter is a required technique to be used in sitting process with these criteria and their importance coefficients.

Several techniques for landfill sitting can be found in the literature (Halvadakis, 1993; Bonham-Carter, 1994; Ehler *et al.*, 1995; Balis *et al.*, 1998; Dorhofer & Siebert, 1998; Yagoub & Buyong, 1998; Herzog, 1999; Lukasheh *et al.*, 2001; Guiqin *et al.*, 2009). Moeinaddini *et al.*, (2010) proffered an approach that combined AHP with WLC in a GIS environment. Their model is useful for landfill site selection in arid and semiarid areas. Geneletti (2010) proposed and implemented an approach by combining stakeholders view with spatial multi criteria evaluation approach in the sitting and ranking of inert landfill site in south-western Trentino, Italy. Their approach used seven criteria (distance from settlement, elevation, slope, distance from water bodies, soil permeability, major farmlands and ecological values) to construct land suitability map (Gbanie, 2012). In similar studies, GIS-based approach was adopted in selecting municipal solid waste landfill sites by combining spatial information techniques and AHP for Isparta Basin, Turkey; Beijing, China; and Lemons Island, Greece respectively (Guiqin *et al.*, 2009; Kontos *et al.*, 2005; Sener *et al.*, 2006). Although, the same approach was used, different criteria were considered in their models. In most of these studies, because of existence of multi criteria and using spatial data for sitting, they used a mixture of MCDM and GIS.

Geographic information system (GIS) is a digital database management system designed to manage large volumes of spatially distributed data from a variety of sources (Guiqin et al., 2009). The GIS can store, retrieve, analyze, and display spatial information according to user-defined specifications. The GIS has been extensively used to facilitate and lower the cost of the landfill site-selection process (Charnpratheep *et al.*, 1997; Kao *et al.*, 1997; Sener *et al.*, 2006).

The analytic hierarchy process (AHP) has the special advantage in multi-criteria evaluation and combining it with GIS provides an effective means for studies of regional eco-environmental evaluation (Ying *et al.*, 2007). This combination can utilize and convert spatial and non-spatial data into valuable information which in addition to the judgment of the decision maker can be used to make critical decision. GIS-based MCDM has been used in many researches (Minor & Jacobs, 1994; Kao & Lin, 1996; Lin & Kao, 1998; Allen *et al.*, 2002;

Kontos & Halvadakis, 2002). In GIS-based MCD, geographical data are combined, processed and transform into a decision (Sharifi *et al.*, 2009).

The main goal of this paper is locating landfill for Tehran metropolitan, using AHP and GIS. According to the above-mentioned facts about landfill sitting process, we used the similar process for landfill sitting, in this paper. For this, the criteria are converted to useful spatial data by GIS and then mixed each other per importance coefficients of criteria, calculated by AHP and finally the appropriate places according to their priorities are indicated. It is needed to explain, in sitting process the triple indexes of sustainable development (Economic, Social and Environmental) (Haughton *et al.*, 2004) have been used as main criteria for achieving to adequate sustainability.

STUDY AREA

Tehran province, shown in **Fig. 1** as a political and economic centre of Iran, has 12.5 million inhabitants (Statistical Center Of IRAN, 2011). Tehran metropolitan is a big region with 33 municipalities (Kamrava, 2005) and Tehran city as capital of Iran and center of this region, has 8.5 million inhabitants (Statistical Center Of IRAN, 2011). This city located in latitude between 34°52′E and 36°21′E and in longitude between 50°10′N and 53°10′N (Broujeni, 2001) (**Fig. 1**)

Tehran region has two landfills that one of them is in eastern area of Tehran city that it used only for construction trash and another is located in southern area of Tehran, Arad Kouh (Tehran Waste Management Organization, 2012). As it has been mentioned in above, Tehran region faced to environmental and hygienic problems by producing approximately 7500 tons trash per day. Because of unhygienic and inappropriate landfilling, Tehran region faces to crucial problems such as latex lake about 12 hectares and 250 million tons Methane gas produced by trash (**Fig. 2**). According to the Raja News Agency, the smell of this gas and other unpleasant gases pervaded in entire of the region and caused many skin and respiratory diseases and Cancer among the inhabitants of the areas near to the landfill, especially in Kahrizak.

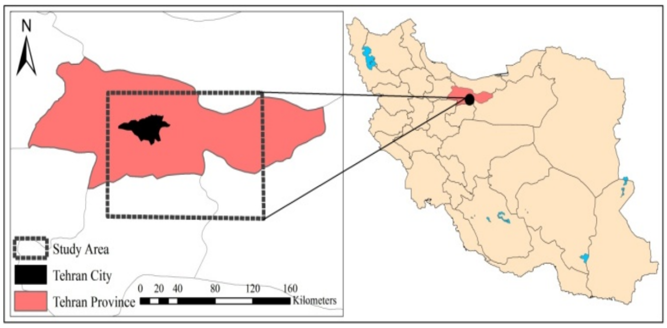

Fig. 1 location of study area in Iran.

Fig. 2 Latex Lake produced by Trash in Kahrizak region.

The study area for new landfill sitting is around the Tehran city with the radius of 40 to 74 km. This study area has three different climate regimes including humid, semi humid and cold, semi dry and dry (Iran Meteorological Organization). Also, according to the wind figure of MehrAbad airport meteorological station, dominant wind direction is west and north-west with the speed of 22 m/s. The average depth of underground water is 184.9 m in Tehran province (Heidarzadeh, 2001).

METHOD AND MATERIALS

Sitting procedure

In this paper, because of high sensibility of landfill in ecological and economical points of view, sustainable development pillars have been used as main policies in sitting procedure. For this, sitting criteria have been classified according to three main pillars of sustainable development (Economical, Environmental and Socio-cultural) and their subcriteria have been extracted from sustainable development literature. In the next step, information data are converted to data layers in GIS. Because the majority of criteria and subcriteria include spatial and fuzzy data, raster data set has been used for data analysis. As an illustration, distance from roads raster layer is one of the economical subcriteria in this procedure. Every cell in this layer indicates a unique data. In this layer, every cell that has lowest distance (Euclidean distance) to roads is more valuable for sitting and with reduction of the distance, its value for selecting as appropriate place for landfill is decreased. It is needed to explain, efficacy of every criteria can has different effect on procedure. Some criteria have positive effect and others have negative effect. For example, distance can has both positive and negative effects. Areas with more distance from cultural heritage are appropriate but in contrast, areas with more distance to roads are not appropriate for landfill sitting. For solving this problem, every data layer is reclassified using GIS, according to their efficacy in sitting procedure.

Mixing the data in GIS with equal importance coefficient is possible. But it should be concerned that layers have different effect on procedure. Some of the data layers strongly affect sitting and others have low effects. Because landfills sitting are so sensible to environmental criteria, environmental criteria are more effective than others. For achieving to appropriate importance coefficients, the Analytical Hierarchy Process is used.

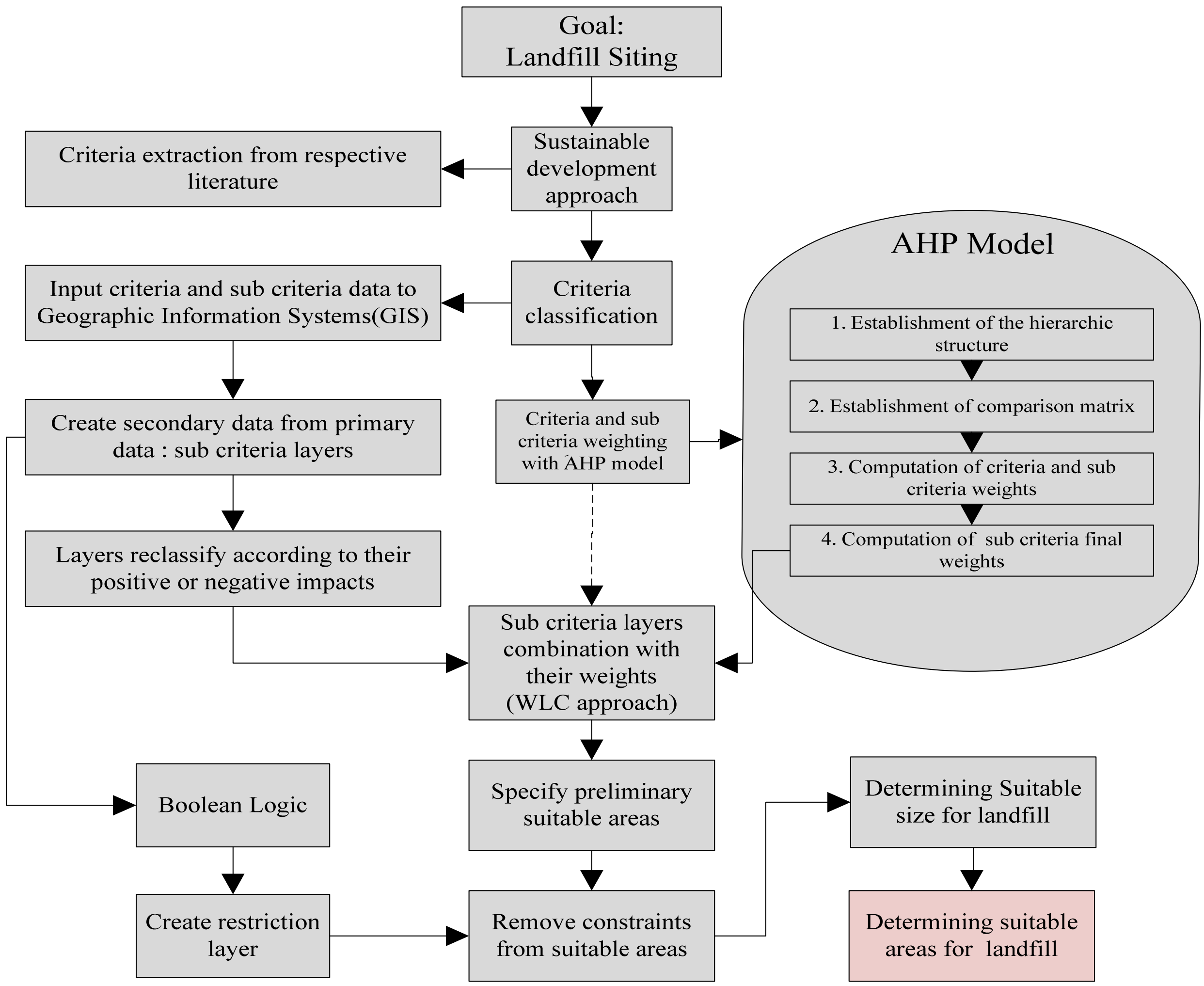

Fig. 3 Landfill sitting procedure.

After delineating of criteria and subcriteria hierarchical tree, their pairwise comparisons are done by 8 questionnaires (8 interviews have been done with related academics and professionals and their data converted to AHP pairwise comparison tables). For criteria and sub criteria importance coefficients calculation, the Expert Choice software (Version 9.48S25) is used and in data layers combination according to their calculated coefficients, Weighed Linear Combination (WLC) approach is used in GIS environment (ArcGIS, Version 9.3).

In the next step, some areas with restrictions such as residential areas, some land uses, protection areas, etc., according to Boolean logic is removed from whole considered area. Finally, the remained appropriate areas for landfill, classified according to their preference records. By calculating needed land area for Tehran region, the most appropriate areas are indicated. **Figure 3** shows the landfill sitting process.

Criteria and subcriteria description

In this paper, three main criteria of landfill sitting procedure are Economical, Environmental and Socio-Cultural criteria. The economic criteria includes land possession, land price, proximity to waste production centers (cities, factories, rural areas, etc.) and proximity to substructures such as power lines, water networks and roads. Environmental criteria include land use, hydrology, geology and meteorology subcriteria and finally, Socio-cultural criteria include proximity to cultural heritages, proximity to public view and proximity to airports subcriteria.

Economic Criteria

Economical criterion is one of the most important criteria in sustainable development. In landfill sitting, this goal is achievable with accurate planning. Because of high expense of land filling including trash and garbage transfer to landfill, energy consumption, land possession; economic criteria should be used effectively for being economy. For this, land price, land possession, proximity to infrastructures are the most important sub criteria used in sitting process. These subcriteria and their effects on sitting explained in below:

(a) Land possession: the possession of public lands is easier and cheaper than private lands (Heidarzadeh, 2001).

(b) Land price: the main part of landfill charge is possession of indicated place (Heidarzadeh, 2001). So low price lands are in first priorities.
(c) Proximity to power lines: access to power in landfill sites is important (Heidarzadeh, 2001) so the areas with low distance to power lines are so economical and appropriate.
(d) Proximity to main roads: distance from existing roads is always viewed as a very important economic factor to be considered in the location of a landfill site (Gbanie, 2012).
(e) Proximity to waste production centre: when considering economic feasibility of a candidate landfill site, the proximity to waste production sources is an important factor; landfill sites close to the waste production centres will decrease transportation costs (Guiqin *et al.*, 2009).

Table 1 shows economic criteria and subcriteria and their relevant maps have been shown in **Fig. 4**.

Table 1. Economic criteria and subcriteria and their classification patterns

Row	Economical Criterions	Classification Pattern	References	Map Source	Map Scale
1	Land Possession	1. National possession is ideal: scored 3 2. Governance possession is ideal: scored 2 2. Private possession is not ideal: scored 1	(Heidarzadeh, 2001)	Iran Ministry of Economic & Property of Iran	1:100000
2	Land Prize	1.Very low prize is ideal: scored 5 2.Low prize is ideal: scored 4 3. Medium prize is moderate: scored 3 4. High prize is not ideal: scored 2 5. Very high prize is not ideal: scored 1 (In regional scale)	(Heidarzadeh, 2001)	Iran Ministry of Economic & Property Iran	1:100000
3	Proximity to Power Lines	1. less than 500 m is suitable: scored 2 2. 500 - 2000 m is moderate: scored 1 3. more than 2000 m is unsuitable: scored 0	(Heidarzadeh, 2001)	NICO (National Iranian Cartography Organization)	1:100000
4	Proximity to main roads	1.Less than 100 m is unsuitable: scored 0 2.100-1000 m is suitable: scored 2 3. more than 1000 m is moderate: scored 1	(Christian, 2003 and Malczewski, 2004)	NICO (National Iranian Cartography Organization)	1:100000
5	Proximity to waste production center	1. Less than 2000 m is unsuitable: scored 0 2.2000-3000 m is suitable: scored 2 3. 3000 - 5000m is moderate: scored 1 4. more than 5000m is unsuitable: scored 0	(Heidarzadeh, 2001)	National Geographic Center (NGC)	1:100000

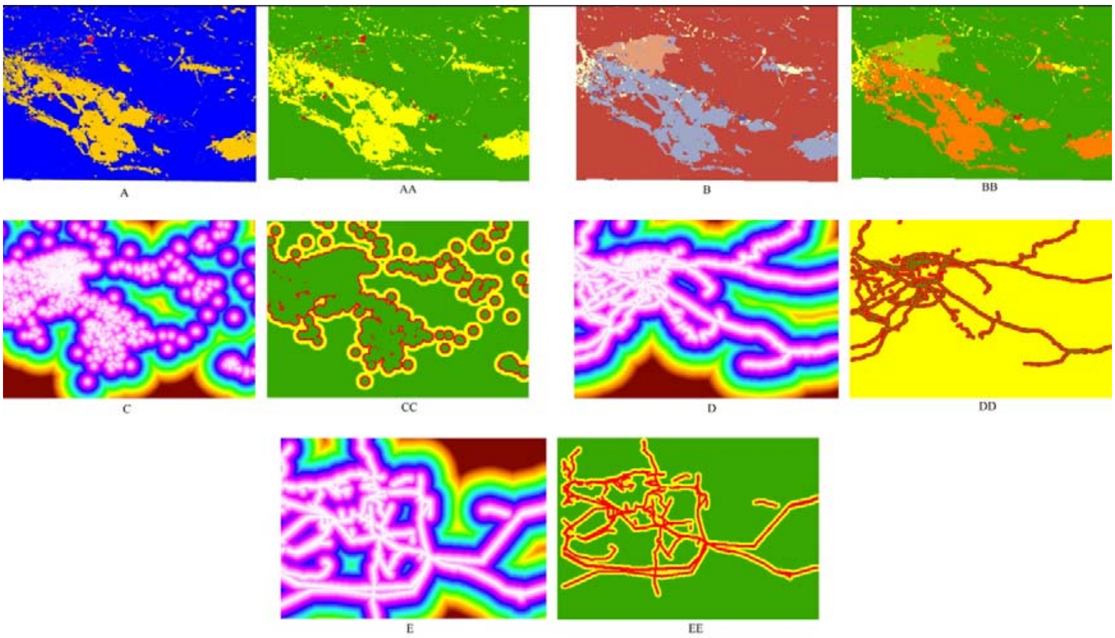

Fig. 4 Maps of economic criteria with their reclassified maps: (A) Land possession, (AA) Reclassify of land possession, (B) Land prize, (BB) Reclassify of land prize, (C) Proximity to waste production centres, (CC) Reclassify of Proximity to waste production centres, (D) Proximity to major roads, (DD) reclassify of Proximity to major roads, (E) Proximity to power lines, (EE) Reclassify of proximity to power lines.

Table 2. Environmental criteria and subcriteria and their classifiction patterns

row	Environmental Criterions	Classification pattern	References	Map Source	Map Scale
1	Land uses	1.Arid lands is the most ideal: scored 2 2.Degraded land is ideal(pasture, dry farming, woods): scored 1 3.arable land (included: cultivation lands, orchards, vineyards): scored 0	(Guiqin et al., 2009)	Hydro graphic and coastal survey department	1:100000
2	Distance from Surface Waters, Rivers, Lakes, Wells, Springs, Kanats	1. less than 300 m is unsuitable: scored 1 2. 300-1000 m is moderate: scored 2 3. more than 1000 in suitable: scored 3	(Monavvari *et al.*, 2012)	National Geographic Center (NGC)	1:100000
3	Distance from Streams	1. less than 1000 m is unsuitable: scored 1 2. more than 1000 in suitable: scored 2	(Sharifi *et al.*, 2009)	National Geographic Center (NGC)	1:100000
4	Slope	1. 0-10% is suitable: scored 3 2. 10-20% is moderate: scored 2 3. more than 20 % is unsuitable: scored 1	(Korucu, 2011)	National Geographic Center (NGC)	1:100000
5	Elevation	1. less than 1000 m is the most suitable: scored 3 2. 1000-1500m is suitable: scored 2 3. 1500-2100m is unsuitable suitable: scored 1 4. more than 2100 m is the most unsuitable: scored 0	(Korucu, 2011), (Sharifi *et al.*, 2009)	National Geographic Center (NGC)	1:100000
6	Distance from Faults	1. less than 100 m is unsuitable: scored 0 2. 100-1000m is suitable: scored 1 3. more than 1000m is the most suitable: scored 2	(Sharifi and et al, 2009), (Delgado *et al.*, 2008)	Geological Survey of Iran	1:100000
7	Soil type	1.silt or clay-silt is suitable: scored 3 2.Clay and mixture is moderate: scored 2 3. Gravel, sand and limestone is unsuitable: scored 1	(Monavvari *et al.*, 2012)	Soil Researches Institute	1:250000
8	Climate regimes	1. Moderate dry desert is suitable: scored 5 2. Cold semi dry is suitable: scored 4 3. Mediterranean super cold is moderate: scored 3 4. Wet and cold is unsuitable: scored 2 5. Very wet and cold: scored 1	(Sharifi *et al.*, 2009)	Iran Meteorological Organization	1:100000
9	Dominant wind direction	1. Areas with west and northwest wind direction is unsuitable: scored 1 2. Areas with other wind direction is suitable: scored 2 3. Flat area is worst: scored 0	(Moeinaddini *et al.*, 2010)	Iran Meteorological Organization	Wind direction figure
10	Rainfall rate	1. Less than 300mm is the most suitable: scored 4 2. 300-500m is suitable: scored 3 3. 500-650m is moderate: scored 2 4. 650-750m is unsuitable: scored 1 5. more than 750m is the most unsuitable: scored 0	(Sharifi *et al.*, 2009)	Iran Meteorological Organization	1:100000

Environmental Criteria

In the sustainable development principles, the main goal of environmental consideration is less pollution with desirable and minimum use of resources that its consequence is perfect output with more production and less waste (United Nations, 1997).

Using these kind of criteria and subcriteria will reduce occurrence of environmental problems in landfilling. These environmental criteria divided to four subcriteria including Land use (in regional scale, this subcriteria is land cover according to agriculture category), Hydrology (Distance form groundwater), Geology (including Slope, Height, Distance form Faults and soil type) and Climatology (including climate regimes, dominant wind direction and rainfall rate). These subcriteria have been explained in below:

(a) Land uses: Land use is one of the most important subcriteria in environmental assessment. The agriculture lands and pastures control and preservation are the goal of this subcriteria. According to sustainable development, it should be tried to

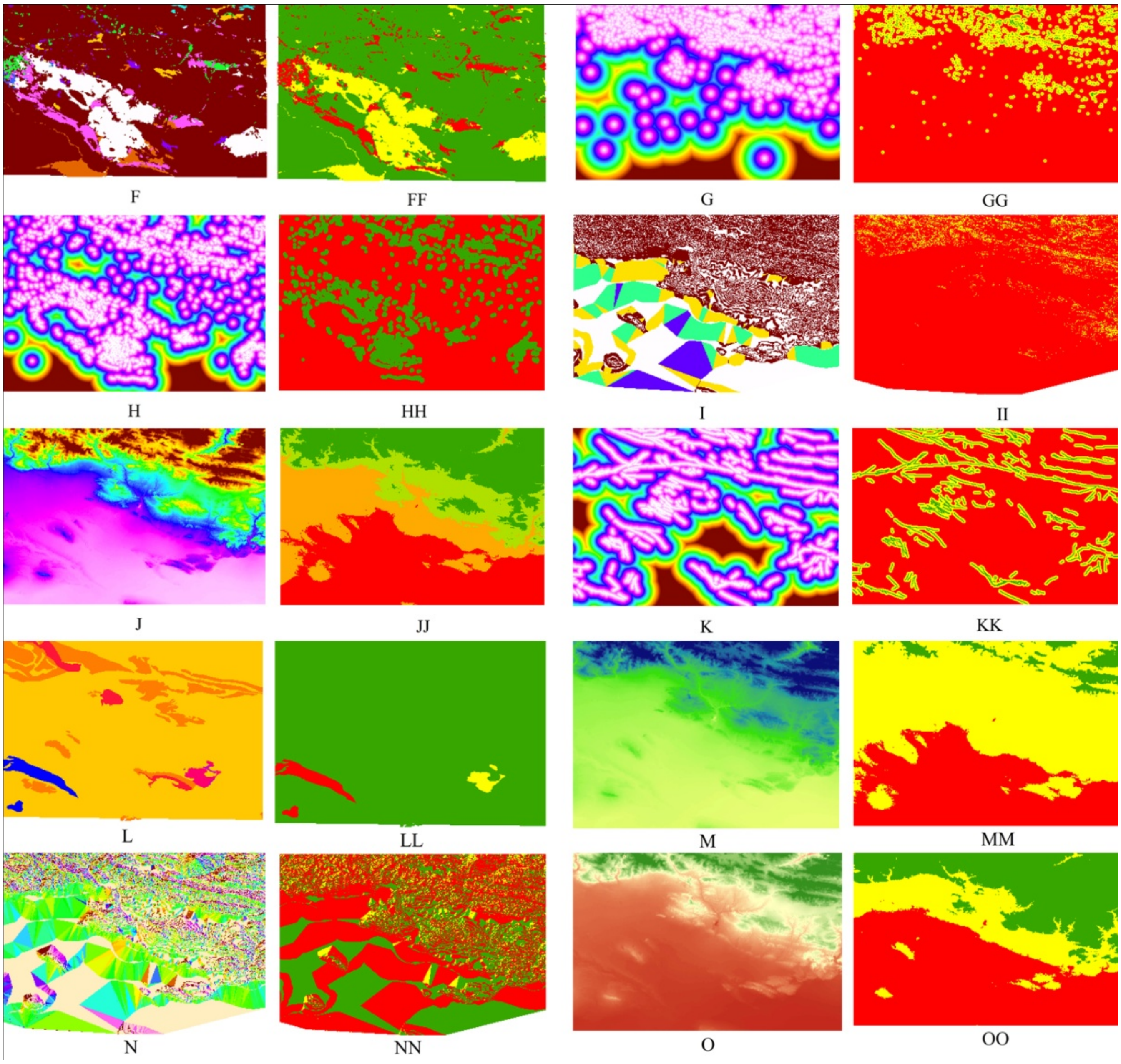

Fig. 5 Maps of environmental criteria with their reclassified maps: (F) Land uses, (FF) Reclassify of land uses, (G) Distance from surface waters(springs, rivers, wells, kanats), (GG) Reclassify of distance from surface waters(springs, rivers, wells, kanats), (H) Distance from streams, (HH) Reclassify of distance from streams, (I) Slope, (II) reclassify of slope, (J) Elevation, (JJ) Reclassify of elevation, (K) Distance from faults, (KK) Reclassify of distance from faults, (L) Soil styles, (LL) Reclassify of soil styles, (M) Climate regimes, (MM) Reclassify of climate regimes, (N) Wind direction, (NN) Reclassify of wind direction, (O) Rainfall rate, (OO) Reclassify of rainfall rate.

use arid and less potential agriculture lands for landfilling.

(b) Distance from ground waters including Rivers, Lakes, Wells, Springs, Kanats: According to present legislations in Iran, entering disposal of solid or liquid waste to any surface water such as sea, lakes and rivers is not allowed. Also according to the EU directives, a landfill should not be close to any source of water (Sharifi *et al.*, 2009).

(c) Distance from Streams: Because near the streams, there is potential threat of stream occurrence that its consequences are facilities destruction and transmission of waste and latex, so it is better landfills are located in places without flooding records (at least 100 years) (Heidarzadeh, 2001).

(d) Slope: The slope of the land surface is a crucial factor as far as construction costs are concerned, such as very steep slopes will lead to higher excavation costs (Guiqin *et al.*, 2009).

(e) Elevation: Landfill sitting in places with high elevation because of transmission of soft trash such as plastic bags by wind and environmental pollution is not appropriate.

(f) Distance from Faults: Areas without faults and also with safe distance from them are appropriate, faults increase permeability of rocks so water ground may be polluted with leachate of landfill. (Moeinaddini *et al.*, 2010)

(g)Soil type: Soil must be impervious and capable of removing pollutants (cation exchange rate < 30 meq/100 g of soil) (Delgado and et al, 2008). The areas with high sensitive soils like limestone or the collapsible soils are not suitable for construction of landfill (Monavvari *et al.*, 2012). The areas in which the supply of heavy clay fine-grained soil for creating and using the coating layers is difficult or impossible are not suitable for constructing waste landfill.

(h) Climate regimes: The most appropriate climate regime for landfilling is Hot and Dry regime (Sharifi, 2009). In general, less humidity with hot temperature is appropriate for landfilling.

(i) Dominant wind direction: This criterion is not based on any legal restrictions but on the fact that a landfill site should not be exposed to wind (Moeinaddini *et al.*, 2010). The wind frequency percentages in study area were based on records from the Mehrabad meteorological station. According to these records, in Tehran metropolitan, dominant wind direction is west and northwest with frequency more than 32% and others such as north wind has frequency less than 10%. Therefore, the areas with west and northwest wind direction were given the lowest grades and sites with others wind direction were given a high grade. Flat areas were assigned the worst grade of 0, because these areas are exposed to wind from all directions.

(j) Rainfall rate: Places with high rainfall rate is less appropriate for landfilling (Sharifi *et al.*, 2009). According to Iran meteorological organization, in Tehran province, with decreasing the height, the rainfall rate is decreased. As in the height from 800 to 1100, the rate is 330 mm, 1100 to 1800 the rate is 840 mm, 1800 to 2200 the rate is 1140 mm and from 2200 to 5600 the rate is 1560 mm.

Socio-Cultural Criteria

The preservation and promotion of social and cultural indexes are the goal of sustainable development (United Nations, 1997). In landfill sitting, it is necessary to consider these indexes. The preservation of cultural and ancient heritages and distance from airports has been included in this process. Also, one of the considered social subcriteria is invisibility of landfill site. These subcriteria have been explained in below:

(a) Distance from cultural heritages: For preservation of cultural and ancient heritages, it is needed to consider appropriate distance from them (Heidarzadeh, 2001).

(b) Distance from visible locations: Selecting sites should be invisible from roads and residential areas for reducing visual pollution (Heidarzadeh, 2001).

(c) Distance from Airports: Areas must be in safe distance from airport because of preventing the events occur for pilots by attracting birds and rising dust in landfill. (Monavvari *et al.*, 2012)

Table 3. Socio-cultural criteria and sub criteria and their classifiction patterns

row	Socio-cultural Criterions	Classification pattern	References	Source map	Map Scale
1	Distance from cultural heritages	1.Less than 500m in the most unsuitable: scored 0 2. 500-1000m is unsuitable: scored 1 3. 1000-1500m is suitable: scored 2 4. More than 1500 m is suitable: scored 3	(Sharifi *et al.*, 2009)	NICO (National Iranian Cartography Organization)	1:100000
2	Distance from visible locations	1.Visable land from settlement is unsuitable : scored 1 2. Invisible land form settlement is suitable: scored 2	(Heidarzadeh, 2001)	GIS raster map	1:100000
3	Distance from Airports	1. More than 3000 m is suitable: scored 2 2. Less than 3000 m is unsuitable: scored 1	(Heidarzadeh, 2001), (Bagchi,1990; Kontos *et al.*, 20032	NICO (National Iranian Cartography Organization)	1:100000

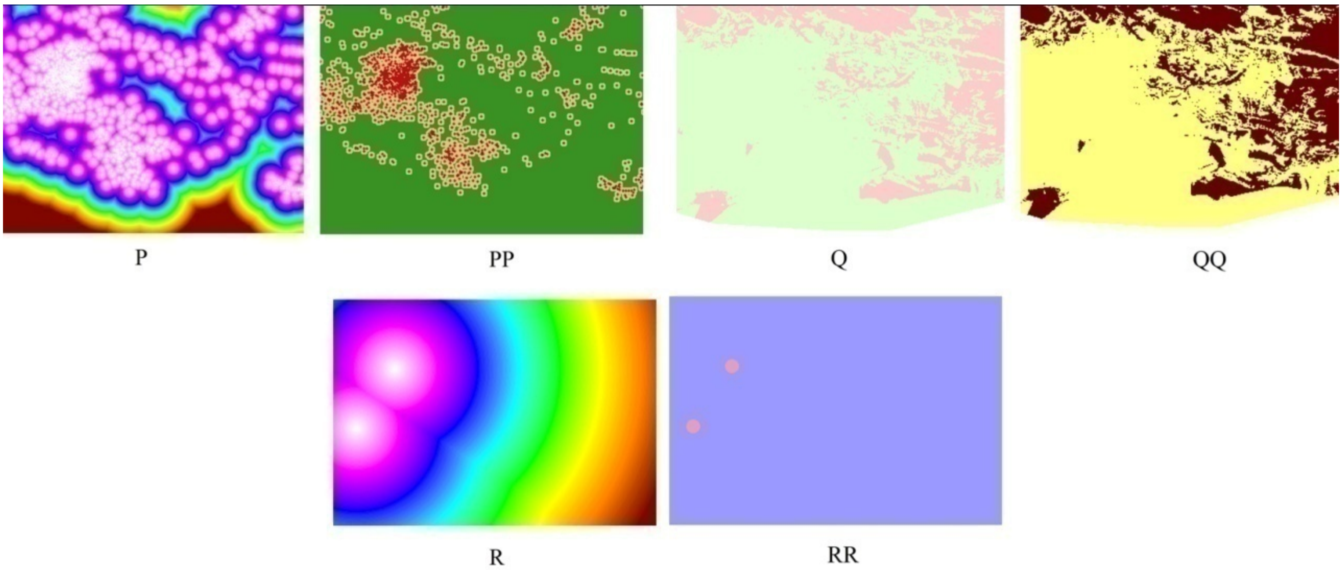

Fig. 6 Maps of socio-cultural criteria with their reclassified maps: (P) Distance from cultural heritages, (PP) Reclassify of distance from cultural heritages, (Q) visible locations, (GG) Reclassify of visible locations (R) Distance from airports, (RR) Reclassify of distance from airports.

AHP Model

Analytical hierarchy process (AHP) is a decision-making technique which can be used to analyse and support decisions which have multiple and even competing objectives. To do this, a complex problem is divided into a number of simpler problems in the form of a decision hierarchy (Erkut & Moran, 1991). Once the hierarchy has been established, a pairwise comparison matrix of each element within each level is constructed. Participants can weigh each element against each other within each level, which is related to the levels above and below it, and mathematically tie the entire scheme together. AHP is often used to compare the relative suitability of a small number of alternatives concerning the overall goal. A single numerical value, the consistency ratio (CR), which measures the level of inconsistency of the pair wise comparison matrix (i.e. the likelihood whether factor weights were randomly assigned), was calculated using the mathematical relation.

$$CR=\frac{CI}{RI} \qquad (1)$$

where CR = consistency ratio; CI = consistency index; RI= mean/average consistency index.

$$CI=\frac{\lambda max - n}{n-1} \qquad (2)$$

and CI = consistency index; greatest eigenvalue of preference matrix; n = order of matrix.

Saaty (2008) recommended that a revision of the preference matrix should be made if and only if CR > 0.1.

In this study, the most appropriate site is selecting for landfill using relevant criteria and its subcriteria. For this, it is necessary to determining coefficient of these criteria and subcriteria in AHP model.

Hierarchy structure establishment

The hierarchy of landfill sitting was establishing and **Fig. 7** is the decision hierarchy structure of landfill sitting in this case. We used three main criteria in the computation process, which each of them were divided into several subcriteria. Economic criteria were included four subcriteria that one of them was divided into two sub subcriteria. Environmental criteria were included four main subcriteria that three of them were divided to several sub subcriteria and finally, Socio-Cultural criteria were divided to three subcriteria.

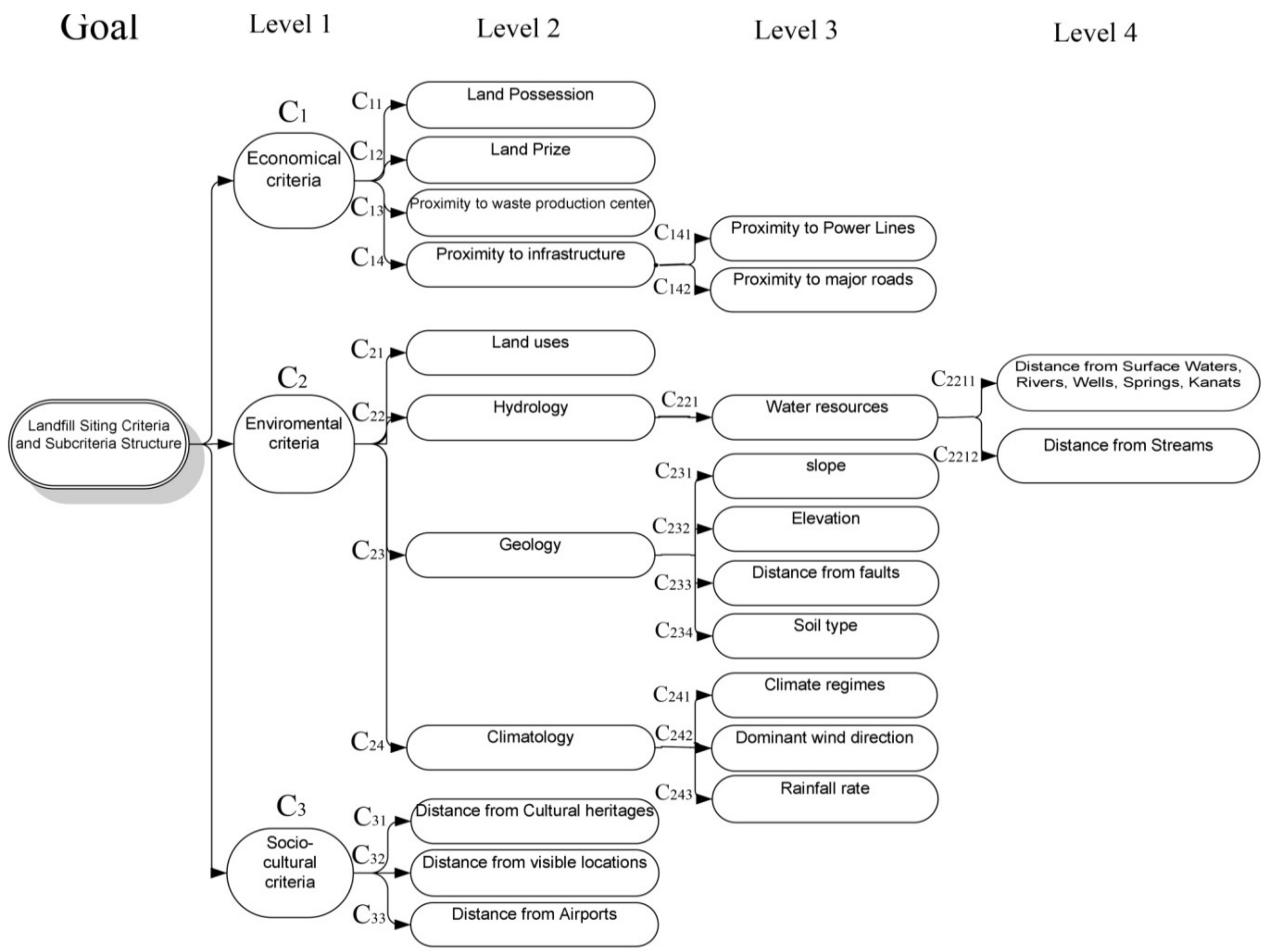

Fig. 7 Hierarchy structure of landfill sitting AHP model.

Pairwise comparison and weighting

A pair wise comparison is a numerical representation of the relationship between two elements that discerns which element is more important, according to a higher criterion. Saaty (1980; 1994) proposed a scale of 1–9, where 1 represents equal importance; that is, the two elements contribute equally to the objective, while 9 represents extreme importance that is favours one element (row component) over another (column component). If the element has a weaker impact than its comparison element, the score range varies from 1, indicating indifference, to 1/9, an over whelming dominance by a column element over the row element. For reverse comparison of the elements, the corresponding reciprocal value is assigned, so that the matrix $a_{ij}a_{ji} = 1$.

In the presented model there are about 8 pair wise matrices. In order to perform the pair wise comparisons, eight face to face interviews were held with the experts in environmental agencies, municipality and urban planning by making use a

Table 4. Saaty's 1-9 scale for AHP preference (Saaty, 1996)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one over another
5	Strong importance	Experience and judgment strongly favour one over another
7	Very strong importance	Activity is strongly favoured and its dominance is demonstrated in practice
9	Absolute importance	Importance of one over another affirmed on the highest possible order
2, 4, 6, 8	Intermediate values	Used to represent compromise between the priorities listed above
Reciprocal of above non-zero numbers	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then j has the reciprocal value when compared with *i*	

comprehensive questionnaire. As a result of these interviews and judgments, weights of the criteria, subcriteria and sub subcriteria were determined using Expert Choice software (Version 9.48s25). After carrying out all the comparisons, consistency ratio of all the pair wise comparisons matrices and those of the judgments were calculated. The consistency measure is very useful for identifying possible errors in judgments. If the inconsistency ratios of all the pair wise comparisons matrices are less than 0.1, all comparisons matrices are consistent and judgments are reliable. In this study, the inconsistency ratios (CR) of all the comparisons matrices were less than 0.1 and so all of the judgments were accepted as reliable. **Table 5** showed pairwise comparison among criteria and subcriteria and theirs weights. **Table 6** showed comparison among sub subcriteria and theirs weights.

The last step is determining the global weight of subcriteria and sub subcriteria. For this, the local weight of every subcriteria and sub subcriteria is multiplying to relating criteria, subcriteria (in related place on hierarchy tree) weights for achieving to global weight.

The equation in below shows how the global weight is calculated:

$$GWi=\sum_{j} wj*wij \qquad (3)$$

where GWi: global weight of the criteria i, w_{ij}: local weight of criteria ij, wj: weight of the main criteria j. **Table 7** showed global weights of criteria, subcriteria and sub subcriteria that calculated by Expert choice software.

Table 5. Pairwise comparison among criteria and subcriteria and their local weights in related level

	C_1	C_2	C_3	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	Wi
C_1	1	0.36	2.1												0.241
C_2	2.8	1	4.9												0.636
C_3	0.47	0.2	1												0.123
C_{11}				1	1.7	0.9	0.53								0.215
C_{12}				0.59	1	0.43	0.36								0.126
C_{13}				1.1	2.3	1	0.48								0.240
C_{14}				1.9	2.8	2.1	1								0.419
C_{21}								1	0.48	0.67	2.9				0.216
C_{22}								2.1	1	1.3	3.8				0.394
C_{23}								1.5	0.77	1	2.9				0.297
C_{24}								0.34	0.26	0.34	1				0.093
C_{31}												1	3.2	1.9	0.399
C_{32}												0.31	1	0.48	0.196
C_{33}												0.53	2.1	1	0.405
IR		0.0				0.01			0.01				0.0		-

Table 6. Pairwise comparison among sub subcriteria and their weights in related level

	C_{141}	C_{142}	C_{221}	C_{2211}	C_{2212}	C_{231}	C_{232}	C_{233}	C_{234}	C_{241}	C_{242}	C_{243}	Wi
C_{141}	1	0.5											0.333
C_{142}	2	1											0.667
C_{2211}			1										1
C_{2211}				1	3								0.750
C_{2212}				0.33	1								0.250
C_{231}						1	1	0.9	0.5				0.197
C_{232}						1	1	0.9	0.55				0.202
C_{233}						1.1	1.1	1	0.55				0.217
C_{234}						2	1.8	1.8	1				0.383
C_{241}										1	2	1	0.400
C_{242}										0.5	1	2	0.200
C_{243}										1	0.5	1	0.400
CR		0	0		0		0				0		-

Table 7. Global weights of criterions

Row	Criterion	Global Weights
1	Distance from Surface waters	0.138
2	Soil style	0.104
3	Land use	0.101
4	Distance from airports	0.067
5	Distance from cultural heritages	0.066
6	Distance from faults	0.059
7	Proximity to major roads	0.055
8	Elevation	0.055
9	Slope	0.053
10	Proximity to waste production centers	0.048
11	Distance from streams	0.046
12	Land possession	0.043
13	Invisible land	0.032
14	Rainfall rate	0.032
15	Climate regimes	0.032
16	Proximity to power lines	0.028
17	Land price	0.025
18	Dominant wind direction	0.016
Overall inconsistency ratio		0.0

Layers combination and determining suitable sites with WLC method

In this step, each of criterion layers (subcriteria and sub subcriteria) that has been prepared and reclassified in ArcGIS, combining with their importance coefficients. For this WLC method is used. The WLC combination technique is the sum of the product of each standardized criterion map and their weights Eq.4 (Eastman, 2006).

$$Si=\sum_{i,j=1}^{n} WjXi \qquad \textbf{(4)}$$

where Si =Suitability index for area i (raster grid); Wj ($\sum W_j = 1$) is the relative importance weight of criterion j, Xij is the standardizing value of area i under criterion j and n is the number of criterion. Eighteen reclassified raster layers are combined and preliminary suitable areas are produced by aggregation procedure based on WLC approach. **Figure 8** showed preliminary raster map of suitable sites for landfill. This map shows suitable sites as a raster view and indicated High to Low.

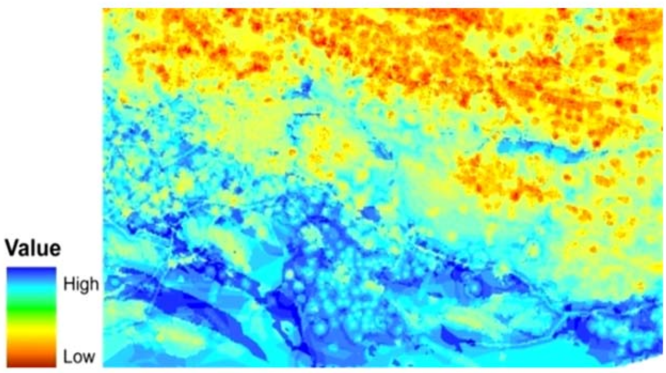

Fig. 8 Preliminary raster map of suitable sites for landfill.

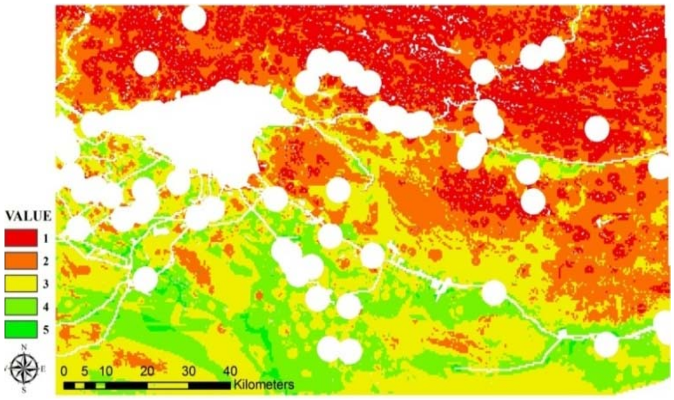

Fig. 9 Scoring suitable lands for landfill map.

But this map involved restriction districts such as cities, villages, roads and boundaries too. For removing these boundaries, Boolean logic is used. Restriction layer includes cities, villages, roads, rivers, wells, springs, kanats, airports and urban land uses. This layer scored 0 and other lands scored 1 in Boolean logic. Produced layer that is result of erasing restriction layer from preliminary suitable layer scored by suitability index from 1 to 5 where 1 is the worst lands and 5 is the best lands for landfill. **Figure 9** Showed scoring suitable lands map.

Landfill sizing procedure

In scoring suitable lands map, there are 23 highly suitable lands that their areas are between 22 to 670 hectares. To determining suitable area for Tehran landfill, the methodology described by Aivaliotis *et al.* (2004) was adopted. The following assumptions were made: the landfill is equably connected with

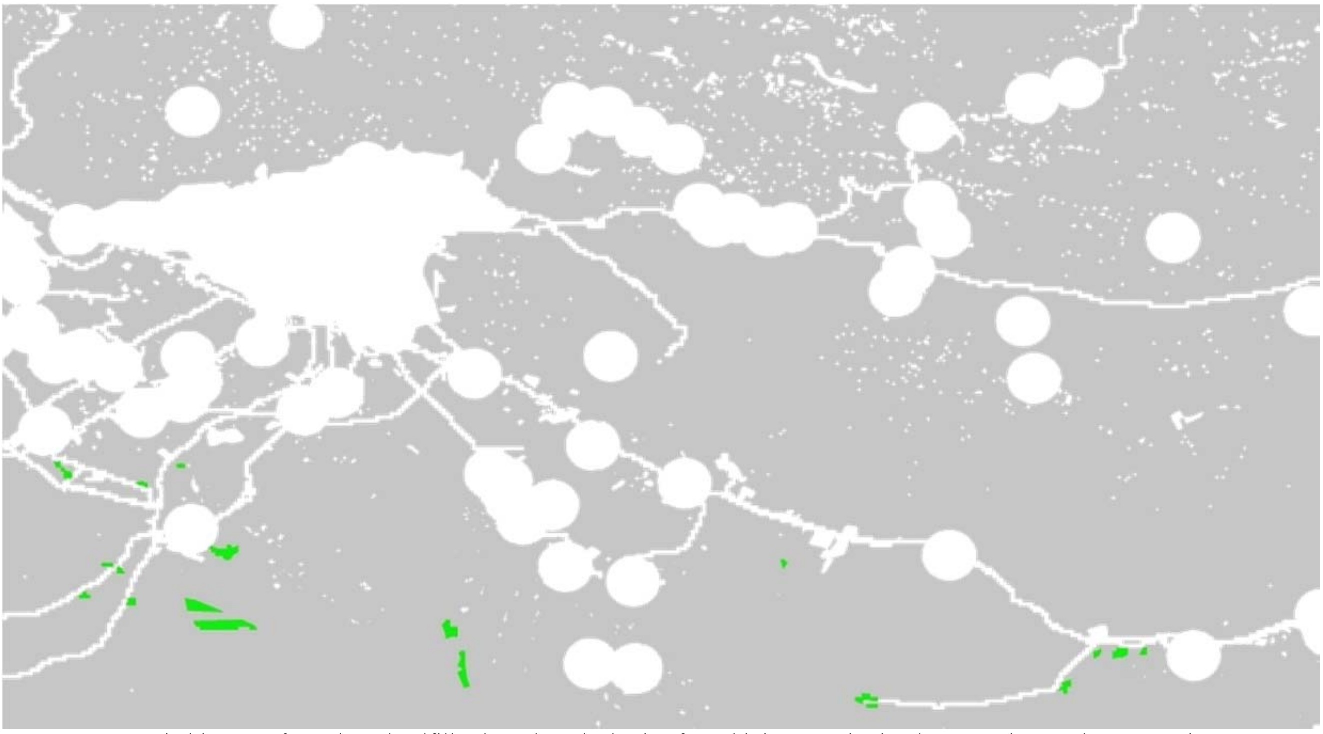

Fig. 10 Suitable areas for Tehran landfill selected on the basis of combining 18 criterion layers and removing constraints.

its base in two shapes, square and orthogonal. The average daily solid waste production per capita in Tehran in 2011 was reported about 0.88 kg/capita/day (Sarmaye, 2010) and the average density in a landfill after compaction is between 500 and 800 kg/m3 (Aivaliotis *et al.*, 2004). For the study area, the estimated solid waste quantity M is 64110000 ton for a 20-year operation period, assuming a 1.1% growth rate for population growth in 20-year and a constant average waste production per capita per year. According to Aivaliotis *et al.*, (2004), size A of the required surface area of the landfill, for waste quantity M (in tons) to be placed, will range from $A = (M/1.76)^{0.725}$ to $A = (M/2.55)^{0.725}$. Thus the required landfill area ranges from 232 000 to 303 000 m^2, for the two mentioned shapes. The higher value, i.e., 30 ha, has been used during sitting calculation conservatively.

According to these measurements, twenty one areas are indicated to highly suitable areas for landfill in Tehran region. **Figure 10** showed final highly suitable areas for Tehran landfill.

Conclusion

This research presents a GIS-based MCDM approach to determining suitability index for landfills sitting at a regional level in Tehran metropolitan. Two main spatial models were applied in sitting: Overlapping index of multiple class maps model for maps combination and Boolean logic model for removing restricted lands. Sustainable development criteria were extracted from literature and were calibration with existing regulations that were applied as three pillars of landfill sitting and then their subcriteria and sub subcriteria have indicated in AHP structure for weighting. With criterions weights provided in AHP model, multiple class maps were combined to suitability index map with WLC method. Then restricted lands have been removed from suitability index map by Boolean logic model and suitable areas have been determinate. The suitability index map provided in this study can be used by governmental authorities for reducing environmental damages.

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