An Integrated Multicriteria and Fuzzy Logic Approach for Municipal Solid Waste Landfill Siting

Abdelwaheb Aydi

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.75161

Abstract

Landfill site selection should take into account a wide range of alternative and evaluation criteria in order to reduce negative impacts on the environment. This study presents a geographic information systems-based multicriteria site selection of municipal solid waste (MSW) landfill in Ariana Region, Tunisia. The multicriteria decision integrates constraints and factors to select MSW landfill suitability. The methodology is used for ranking the best suitable landfill sites by the integration of fuzzy logic and analytic hierarchy process (AHP). The fuzzy set theory is used to standardize criteria using different fuzzy membership functions while the AHP is used to establish the relative importance of the criteria. The AHP makes pairwise comparisons of relative importance between hierarchy elements assembled by environmental and socio-economic decision criteria. The landfill suitability is accomplished by applying weighted linear combination (WLC) that uses a comparison matrix to aggregate different importance scenarios associated with environmental and socio-economic objectives. Data were assorted into five suitability classes within the study area, i.e., high, suitable, moderate, low and very low suitability areas, which represented 5.4, 0.5, 12.5, 3.9 and 2.5%, of the study area, respectively. Additionally, 75.2% was considered to be completely unsuitable for a landfill site. As a result, two candidate landfill sites are suggested.

Keywords: MSW landfill, GIS, multicriteria, analytical hierarchy process

1. Introduction

The construction of sanitary landfills that comply with environmental legislation and that reduce the undesired effects of current practices is one of the main municipal solid wastes (MSW) management priorities in Tunisia. The first and most important step in planning solid waste landfill is the site selection for solid waste disposal [1]. Landfill site selection is a complicated, complex, monotonous, requiring evaluation of various criteria. Among those criteria economic, environmental and social property are often considered for attractive the scheduling process and for setting guidelines that reduce public health risks, impact to the environment, cost to facility users and inefficiencies connected with other services [2–4]. As such, it evidently requires the processing of a massive amount of spatial data [5]. Various landfill siting techniques have been developed for this purpose. In the last few years, geographic information systems (GIS) have been increasingly used to facilitate and lower the cost of the process of selecting sites for sanitary landfills [6]. A number of GIS methods and techniques have been proposed to evaluate suitable landfill locations [1, 2, 7–9]. Some of those techniques take advantage of GIS-based multicriteria evaluation (MCE) [1, 2, 7, 8, 5, 10] and fuzzy set theory [2, 4, 11]. In MCE, the weighted linear combination (WLC) is one of the most popular methods because of its simplicity [12]. Several WLC-based approaches for landfill siting can be found in the literature [5, 11, 13]. In the WLC procedure, analytical hierarchy process (AHP) [14] is often applied to elicit criteria weights and to enhanced represent interaction between criteria and alternatives [6]. In AHP, weights are computed based on pairwise judgments and checked for consistency. Because pairwise judgments are often biased and inconsistent, acceptable consistency ratio (CR) often requires iterative revisions of the pairwise judgments before the final weights are computed.

The purpose of this paper is to evaluate the suitability of the study region to optimally site a landfill for MSW Ariana using AHP and WLC in a GIS environment.

2. Materials and methods

2.1. Study area

The study area is the Ariana Region, located in the north-eastern part of the Republic of Tunisia (**Figure 1**). The region occupies 482 km^2 and borders Bizerte government to the north, Tunisia government to the south, Manouba government to the West and Mediterranean Sea to the East. This is the fastest growing region in the country that has experienced a significant population growth especially in the past few decades. This densely populated region (876 people per km2) includes 90.8% of its area being urban and the remaining 9.2% being rural with a total population that exceeds 510,500 people or 4.8% of the total country’s population [15].

The climate is Mediterranean, characterized by dry and warm summers, and cool, wet winters. The average annual precipitation is 450 mm/year and much of the precipitation falls in late autumn and early winter where the month of November has the highest precipitation while August has the lowest. The annual predominant wind direction in Ariana region is northward with an annual average wind speed of 1.5 m/s.

Currently, the MSW disposal in the region is based on landfilling in the sanitary landfill of Jebel Chakir, located 15 km to the south of Ariana city. The Jebel Chakir landfill will be closed in the near future and is too far from waste production centers in Ariana region, which increase

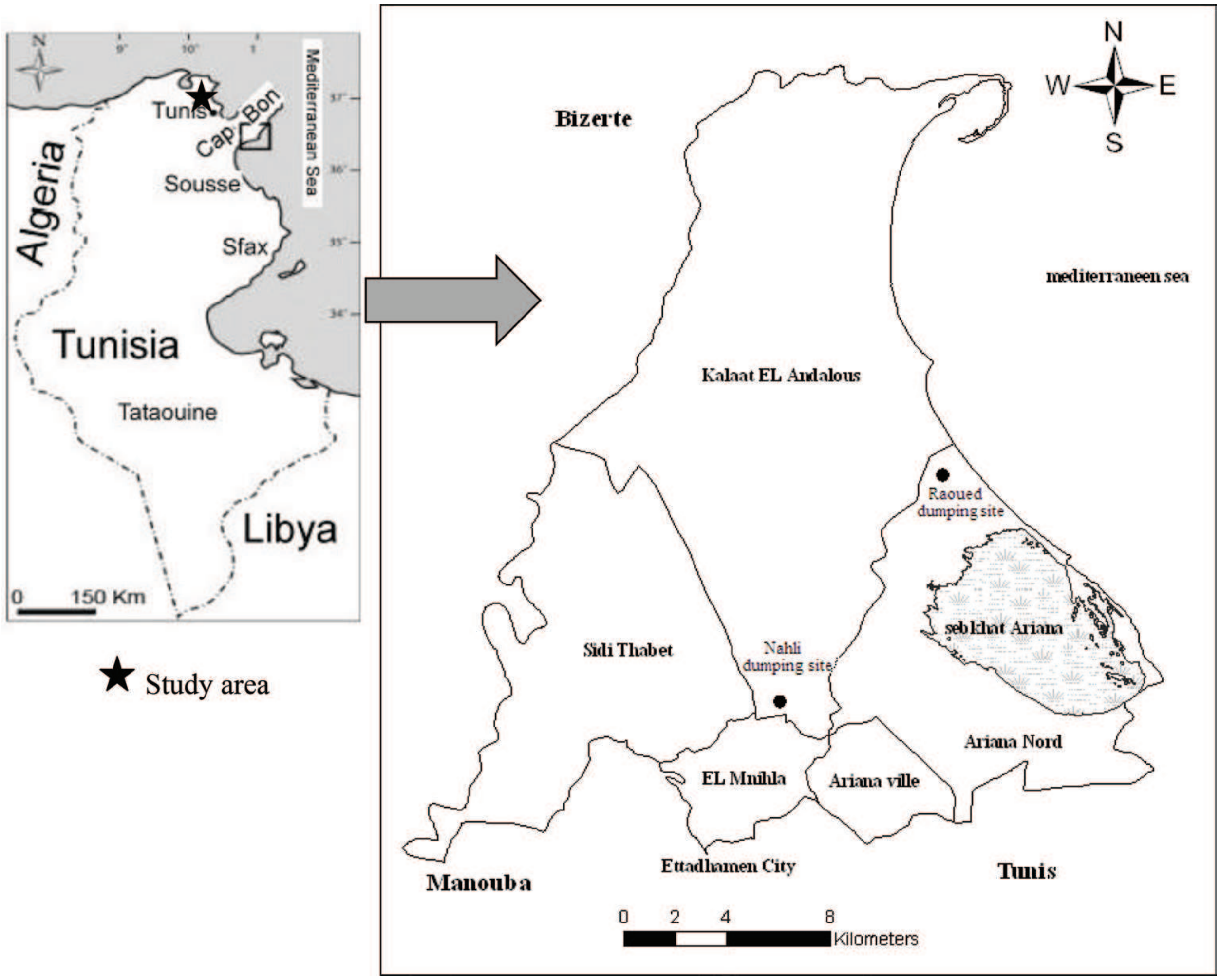

Figure 1. Location of the study area.

the transportation cost and need additional investments in the infrastructure of roads, hence intensify the financial problems of the responsible authorities. The estimated solid waste for the Ariana Region is 4,251,783 tons for exploitation period of 20 years. The estimate is quantified on the basis of average rate of daily waste production of 0.6 kg per capita [16]. The estimate assumes an efficiency of collecting waste of 95, and 1% of annual increase of waste production per capita per year. The estimated capacity needed for landfill area is 28 ha using average compacted waste density of 950 kg/m^3 and cover material [17].

2.2. Methodology

Hierarchical organization of the constraints and criteria considered for the landfill suitability is shown in **Table 1**. The top of the hierarchy is the goal while subsequent levels describe the decision or analysis criteria, the constraints and factors in increasing detail. The goal is to identify the areas that are most suitable for landfill siting.

In this work, the environmental, social, economic and geological information are considered to be pertinent in defining the potential sites to create a MSW landfill. In the ArcView GIS,

Level 1 **Goal**	**Level 2** **Decision factors**	**Level 3** **Subfactors**	**Exclusion criteria**	**Appreciation criteria**
Landfill suitability	Geology	Soil permeability	*	
		Elevation	*	
		Slope	*	
		Distance from coastal zone	*	
	Hydro/Hydrogeology	Depth to ground water table	*	
		Distance from water supply (reservoirs, wells, boreholes, springs)	*	
		Distance from wetlands	*	
		Distance from rivers	*	
		Distance from irrigation canals	*	
	Environment	Land use	*	*
		Olfactory and sonorous impacts		*
		Distance from protected areas	*	
	Social	Proximity to dense population		*
		Distance from residential areas	*	
	Economic	Proximity to roads	*	*
		Proximity to building materials	*	

Table 1. Hierarchical structure for the selection of the MSW landfill site.

all the thematic maps were transformed on raster grid to be used by Idrisi software. A raster grid cell of 100 × 100 m^2 was generated. Each cell is considered as a homogenous unit for any given factor. All the factors influenced were standardized and weighed and then combined using the AHP methods.

The site selection process is implemented in the following steps:

- The Exclusion of restricted areas for landfill siting. The constraints based on the Boolean criteria were used to differentiate areas that can be considered suitable for a waste disposal site from those that cannot be considered suitable under any conditions
- The factors were standardized to a continuous scale of suitability from 0 (least suitable) to 10 (most suitable) in a GIS environment by fuzzy membership functions, then weighted and combined using the AHP methods.

- The WLC aggregation method was applied for preparing the suitability maps. Suitability maps for each set of factors were combined to create three scenarios to allow determination of the most suitable sites.
- The landfill suitability is classified in five equally scored classes: high, suitable, moderate, low and very low suitability areas

3. Classification of exclusion criteria (constraints).

The exclusion criteria are constraints having for objective to limit research of suitable sites which do not tolerate any competition [10].

The classification consists in selecting various areas that represents a new plan of information for a required condition. Maps were classified into two categories: 1 was ranked to zones verifying the condition and 0 was ranked to the other zones. The resulting image is a Boolean image.

The last step consisted in combining, by superposition, the information contained in Boolean layers relative to the exclusion criteria mentioned above. The logical operator "AND" has been used in this part; it translates the intersection between conditions that must be absolutely satisfied.

4. Standardization of appreciation criteria

MCE requires that the values contained in the different criterion map layers be transformed to similar units [11]. A number of approaches can be used to make criterion map layers comparable. The fuzzy membership approach is one of the standardization methods that have been proposed [10]. For this reason, fuzzy sets were used in this study. To apply fuzzy functions in the GIS environment in this case study, all the map layers are transformed to a raster format with 100 m pixel size. Four fuzzy set membership functions are provided in IDRISI: Sigmoidal, J-Shaped, Linear and User-defined. Our choice has been made relying on two types of factors (environmental and socio-economic) that have been standardized in one common interval from ranging from 0 to 10.

5. Weighting factors for aggregation

The purpose of criterion weighting is to express the importance of each criterion relative to other criteria. One of the techniques that can be used in assigning weights is Pairwise Comparisons (that characterizes analytic hierarchy process: AHP, developed by Saaty [18]; it determines accurate relative weights of indicators by allowing to divide the complex decision problem into a series of one-on-one judgments regarding the significance of each criterion relative to the others.

Intensity of importance	**Definition**
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2,4,6,8	Intermediate values between adjacent judgments the two
Reciprocals of above non zero	If activity (i) has one of the above nonzero numbers assigned to it when compared with activity (j), then (j)has the reciprocal value when compared with (i)

Table 2. The comparison scale in AHP Saaty [14].

The pairwise comparison involves three tasks: (1) developing a comparison matrix at each level of the hierarchy initial from the second level and functioning down, (2) computing the relative weights for each element of the hierarchy and (3) estimating the consistency ratio to check the consistency of the judgment [19]. In the AHP weight can be derived by taking the principal eigenvector of a square reciprocal matrix of pair-wise comparisons between the criteria. The method uses a scale with values range from 1 to 9, illustrated in **Table 2**.

The consistency ratio is one of the very important aspects of the AHP theory. It allows us to assess the overall consistency of all pairwise comparison judgments provided by the decision makers in the form of pairwise comparison judgment matrices. More formally, the consistency ratio (CR) is calculated through dividing the consistency index (CI) by the randomized index (RI).

The consistency index (CI) for each matrix can be expressed as:$CI = (\lambda_{max} \text{-n})/(n - 1)$; Where $\lambda_{max}$is the principal eigenvalue of the judgment matrix and n is its order Saaty [18].

Then, the consistency ratio (CR) is defined as follows: CR = CI/RI; Where RI is the random index and depends on the number of elements being compared Saaty [18]. If CR < 0.10, the ratio indicates a reasonable level of consistency in the pairwise comparison; however, if CR ≥ 0.10, it indicates inconsistent judgments [18]. Once the satisfactory CR is obtained, the resultant weights are applied.

6. MCE using WLC method

A multicriteria evaluation consists of combining a set of criteria (constraints and factors) to build a single suitability map according to a specific category (set of factors). One of the most common procedures for aggregating data is the weighted linear combination (WLC) [19].

WLC is a technique based on the concept of a weighted average in which continuous criteria are standardized to a common numeric range, and then combined by means of a weighted average to produce a continuous mapping of suitability [13].

The suitability index for a site is the sum of the products of the standardized score for each criterion multiplied by the weight of each criterion, the following equation is given by Eastman [20]:

$$S = \sum_{i=1}^{n} w_i x_i$$

where S is the suitability index for area i; w_1, w_2,…,w_n are the weights of the criteria constrained to sum to 1; x_1, x_2,…,x_n are the standardized scores of the criteria i and n is the total number of criteria. As the sum of the weights is constrained to one, the final combined estimate is presented on the same scale.

7. Results and discussions

7.1. Criteria description and application

In Tunisia, there is not a Solid Waste Control Regulations for disposal site. Hence, criteria were selected according the MSW landfill siting guidelines of the countries legislation, extensive literature review, [1–4, 7, 9, 11, 13] assessment via questionnaire; availability of the data and local expert.

7.1.1. Exclusive criteria (constraints)

In this study, 13 constraints criteria such as: (1) Soil permeability, (2) Elevation, (3) Slope, (4) Distance from coastal zone,(5) Depth to ground water table, (6) Distance from water supply (reservoirs, wells, boreholes, springs), (7) Distance from wetlands, (8) Distance from rivers, (9) Distance from irrigation canals, (10) Land use, (11) Proximity to roads, (12) Distance from protected areas, and (13) Distance from residential areas were selected for the computation process. The buffer zones in the different constraint layers are listed in **Table 3**.

Figure 2 shows the maps layers of all the constraints criteria after buffering and restriction.

7.1.2. Appreciation criteria (factors)

The next process is to further examine the suitable areas for landfill. Factor criteria were used in order to further evaluate those areas.

7.1.3. Environmental factor

7.1.3.1. Land use

Land use is important for resolving public conflicts over the acceptance of unwanted facility siting [4]. **Table 4** shows the membership values assigned to all categories used in the analysis based on results of investigations with experts (agronomist, environmentalists…).

Constraints	**Buffering**
Soil permeability	Exclude soils having high rate of permeability
Elevation	Exclude areas over 200 m
Slope	Exclude areas over 5%
Distance from coastal zone	3 km buffer zone
Depth to ground water table	Exclude depth less than 14 m
Distance from water supply (reservoirs, wells, boreholes, springs)	3 km buffer zone
Distance from wetlands	1 km buffer zone
Distance from rivers	200 m buffer zone
Distance from irrigation canals	200 m buffer zone
Land use	Exclude arable lands and area with high economic advantages
Distance from protected areas	300 m buffer zone
Distance from residential areas	2 km buffer zone
Proximity to roads	200 m buffer zone

Table 3. Buffer zones for the generation of constraint map.

Figure 2. Boolean images of constraints maps a) Soil permeability, b) Elevation, c) Slope, d) Distance from coastal Zone, g) Depth to ground water Table, h) Distance from water supply, i) Distance from wetlands, j) Distance from rivers, k) Distance from irrigation canals, l) Land use, m) Distance from roads, n) Distance from protected areas, o) Distance from residential areas.

Factors	Sub-factors	Standardization of factors	
		Control point	**Fuzzy function/membership**
Environmental	Land use (no units)		
	Urban areas		0
	Protected area		0
	Wetlands		0
	Water		0
	Vine		2
	Mariachi culture		2
	Cereals		3
	Olive trees		3
	Forager culture		4
	Course		6
	Naked soil		10
	Olfactory and sonorous impacts	200 and 3000 m	Linear, increasing
Socio-economic	Proximity to dense population	200 and 1000 inhabitants/km^2	Sigmoidal, decreasing
	Proximity to buildings materials	5000 and 15,000 m	J-shaped, decreasing
	Proximity to roads	200 and 3000 m	J-shaped, decreasing

Table 4. Fuzzy set memberships and membership functions with control points used for MSW landfill site selection.

7.1.3.2. Olfactory and sonorous impacts

Concerning the olfactory and sonorous impacts factors, a simple linear distance decay function is appropriate for these criteria, in which a cost distance from the main roads increases, its suitability increases. To rescale the cost distance factor, a monotonically increasing linear fuzzy membership function was used. The first control point (a = 200 m) indicates the least suitable distance for siting a landfill while the second control point (b = 3000 m) and indicates the best fitted distance for siting a landfill (**Figure 3**).

7.1.4. Socio-economic factors

The socio-economic factors comprises three sub-factors namely proximity to dense population, distance from road and proximity to building materials.

7.1.5. Proximity to dense population

Proximity to the waste generation centers generate most of the waste quantity is a very significant factor because it defines the working costs for the landfill. The closer to the dense population settlements, the lower the operation cost will be. The population density map was standardized by sigmoid decreasing fuzzy function controlled by two points (c = 200 hab/ km^2, d = 1000 hab/km^2).

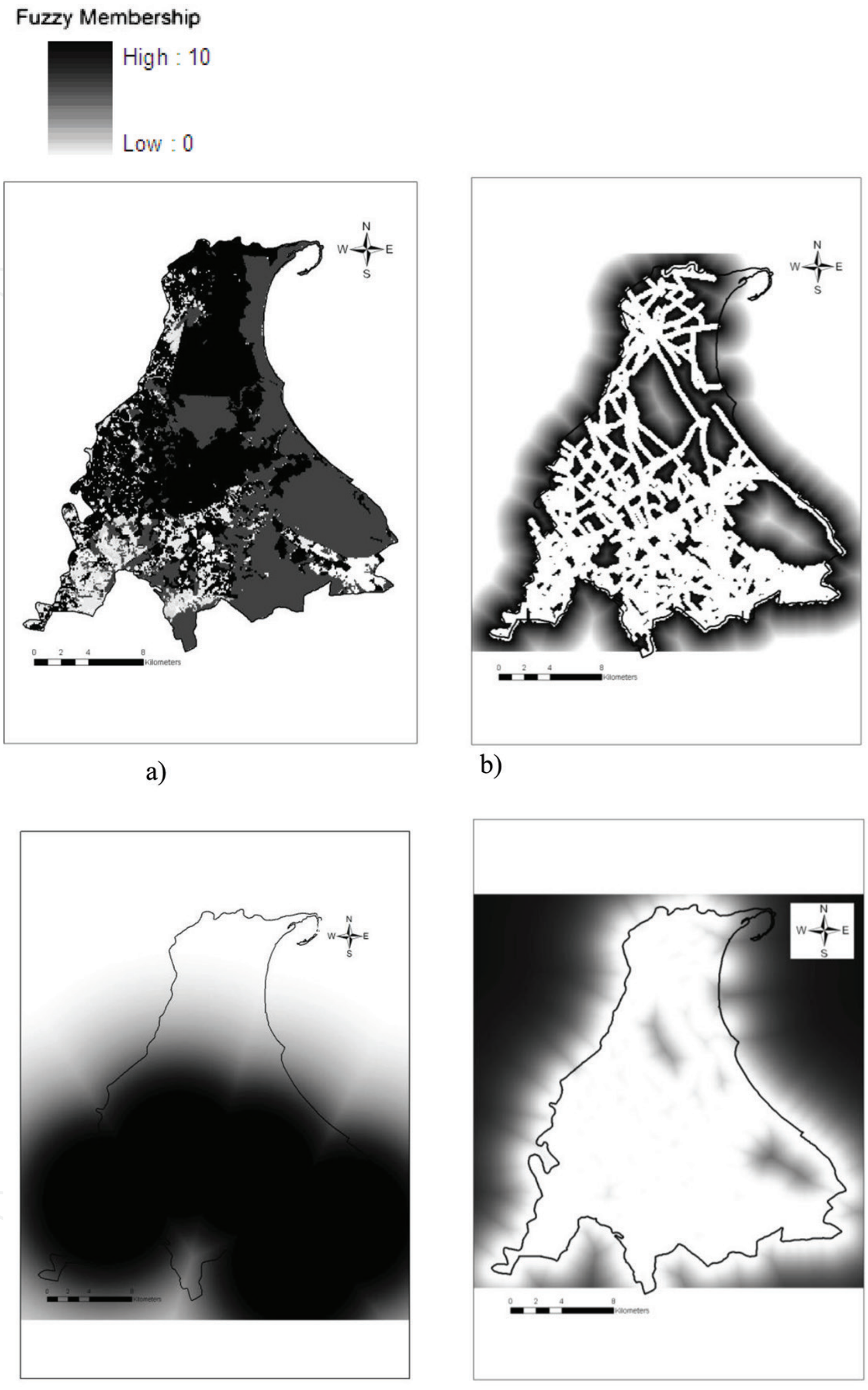

Figure 3. Examples of spatial evaluation maps of factors a) Land use, b) Olfactory and sonorous impacts, c) proximity to buildings materials, d) Distance from roads.

7.1.6. Proximity to roads

Proximity to roads considers the construction costs for building new road infrastructure between the settlements and potential landfill. A j-shaped decreasing fuzzy membership function was used for standardization controlled by two points (c = 200 m, d = 3000).

7.1.7. Proximity to building materials

Proximity to building materials is used for comparing the costs for building materials during landfill construction (impermeable soil for the bottom liner) and landfill operation (daily and final cover material). For sanitary landfills, such materials also minimize the propagation of various vectors (i.e., insects, rodents, birds and air contaminants) that may affect public health and well-being [4]. Again, a j-shaped decreasing function was used with two control points (c = 5000 m, d = 15,000).

The next step was implementation of the AHP to calculate the relative weights of the criteria. This step involved construction of comparison matrix where weights are determined through the pairwise comparison method. Pairwise comparison method was used only to assign weights and establish importance of environmental criteria using experience of experts and characteristics of the region (**Tables 5** and **6**).

The final stage is to calculate a CR to measure how consistent the judgments have been relative to large samples of purely random judgments. For the case study the CR was 0, indicating construction of a trustworthy matrix.

7.1.8. Scenario creation

WLC is displayed to compute the possible landfill areas for both of the environmental and socio-economic set of criteria, using the assigning weight to each of the criteria. Intermediate fitness maps were created for the environmental and socio-economic group of criteria, respectively. Final aggregation of the two intermediate suitability maps was implemented for three scenarios to demonstrate the importance of the weights associated with the environmental and

	Land use	**Olfactory and sonorous impacts**	**Eigenvector**	**Weight**
Land use	1	5	2.23	2.23/(2.23 + 0.45) = 0.83
Olfactory and sonorous impacts	1/5	1	0.45	0.45/(2.23 + 0.45) = 0.17

λ max=2, CI = 0.00, CR = 0.00 (consistency is acceptable).

Table 5. Pair-wise comparison matrix for assessing the weights of environmental factors.

	Proximity to buildings materials	**Proximity to dense population**	**Proximity to roads**	**Eigenvector**	**Weight**
Proximity to buildings materials	1	1/5	1/3	0.44	0.11
Proximity to dense population	5	1	3	2.44	0.63
Proximity to roads	3	1/3	1	1	0.26

λ max=3.038, CI = 0.019, RI = 0.58, CR = 0.03 < <0.1 (consistency is acceptable).

Table 6. Pair-wise comparison matrix for assessing the weights of socio-economic factors.

the socio-economic objectives. The WLC was used to create three final landfill suitability maps using different weights applied to the objectives. The scenario (a) allots a weight of 0.75 to the environmental and 0.25 to the socio-economic objective; for scenario (b) both objectives have the same weights and for scenario (c) weights of 0.25 and 0.75 are used for the environmental and the socio-economic objectives, respectively. It should be mentioned that we select the sustainable development scenario which assigned the equal weight to the environmental and socio-economical factors (0.5 for each factor). The final suitability map for the mentioned scenario is shown in **Figure 4**. Using an equal interval classification method, landfill suitability values of the Ariana region were classified into five groups: high suitability (8–10), suitable (8–6), moderate suitability (6–4) and low suitability (4–2) and very low suitable (2–0). This method divides the range of attribute values into equal-sized sub-ranges. This creates an easy to

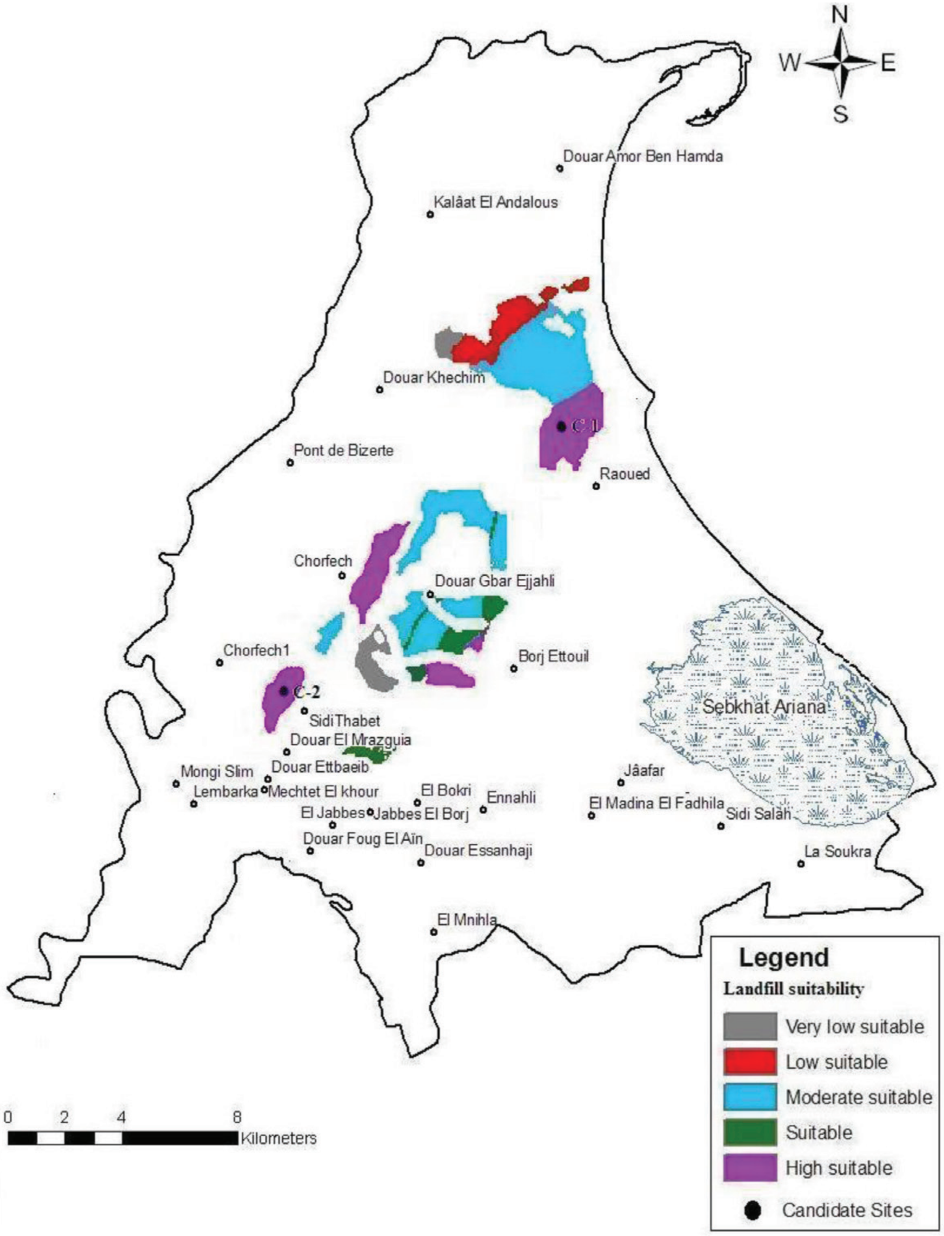

Figure 4. Landfill suitability map.

understand legend and works best with continuously distributed data. Then, we grouped similar and adjoining pixels to keep sites having an area of greater than 28 ha, roughly 28 cells (100 × 100). The results indicate that 2.5%, of the study area has very low suitability, 3.9% has low suitability, 12.5% has moderate suitability, 0.5% has suitable and 5.4% has high suitability for a landfill site. The other 75.20% of the study area is not suitable for a landfill site. The results of the AHP and weighted linear combination methods are compatible with our field observations.

Two candidate sites (C1 and C2) were recommended for landfill siting because these regions were determined to be high suitability regions by the AHP and GIS techniques (**Figure 4**). These two candidate sites are away from the Sebkhat Ariana. C1 is located north of the Sebkhat Ariana around Raoued district. The wastes of Kalaat El Andalous and the surrounding vicinity can be collected at this site. The other candidate site (C2) is situated western of the Sebkhat Ariana, near the Sidi Thabet district, where it can collect waste from areas such as Ennahli and the villages between them.

8. Conclusions

Although it is very difficult and expensive to include geological, hydrological and hydrogeological, social, environmental and economical parameters, studies for selecting the sites for solid waste disposal should be performed for every city in Tunisia. To determine an appropriate landfill site, GIS is a very powerful tool that can provide a rapid assessment of the study area. The selection of suitable landfill sites is very decisive for Tunisia. Ariana region was selected as the study area because it is the fast growing and urban in greater Tunis. Initially, landfill site selection criteria were determined depending on the applicable international literature. Thirteen criteria were evaluated in the present study. The areas that were inappropriate for MSW landfill site were at first determined and covered. Thus, these areas were not considered. Each criterion was evaluated and converted into arithmetical values by AHP. The criteria maps were mapped by GIS using the calculated numerical values. Using the same interval classification method, the study area was classified into four groups of high, moderate, low and very low suitability, which covered 3.24, 7.55, 12.70 and 2.81% of the study area, respectively. The results of the analysis were compared with field studies, and two candidate landfill sites (C1 and C2) were selected from the high suitability regions. These sites are also close to highly populated settlements. Finally, it is recommended that the methodology adopted in this research to be developed through integrating the indigenous data which might lead to better site selection.

Author details

Abdelwaheb Aydi

Address all correspondence to: abdelwaheb_2000@yahoo.fr

Department of Earth Sciences, Faculty of Science of Bizerte, Carthage University, Bizerte, Tunisia

References

[1] Şener Ş, Sener E, Karagüzel R. Solid waste disposal site selection with GIS and AHP methodology: A case study in Senirkent–Uluborlu (Isparta) basin, Turkey. Environmental Monitoring and Assessment. 2011;**173**(1-4):533-554

[2] Chang N-B, Parvathinathan G, Breeden JB. Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region. Journal of Environmental Management. 2008;**87**(1):139-153

[3] Wang G et al. Landfill site selection using spatial information technologies and AHP: A case study in Beijing, China. Journal of Environmental Management. 2009;**90**(8):2414-2421

[4] Gorsevski PV et al. Integrating multi-criteria evaluation techniques with geographic information systems for landfill site selection: A case study using ordered weighted average. Waste Management. 2012;**32**(2):287-296

[5] Zamorano M et al. Evaluation of a municipal landfill site in southern Spain with GIS-aided methodology. Journal of Hazardous Materials. 2008;**160**(2-3):473-481

[6] Donevska KR et al. Regional non-hazardous landfill site selection by integrating fuzzy logic, AHP and geographic information systems. Environmental Earth Sciences. 2012;**67**(1):121-131

[7] Sharifi M et al. Integrating multi-criteria decision analysis for a GIS-based hazardous waste landfill sitting in Kurdistan Province, western Iran. Waste Management. 2009;**29**(10):2740-2758

[8] Khamehchiyan M, Nikoudel MR, Boroumandi M. Identification of hazardous waste landfill site: A case study from Zanjan province, Iran. Environmental Earth Sciences. 2011;**64**(7):1763-1776

[9] Nazari A, Salarirad MM, Bazzazi AA. Landfill site selection by decision-making tools based on fuzzy multi-attribute decision-making method. Environmental Earth Sciences. 2012;**65**(6):1631-1642

[10] Sahnoun H et al. GIS and multi-criteria analysis to select potential sites of agro-industrial complex. Environmental Earth Sciences. 2012;**66**(8):2477-2489

[11] Moeinaddini M et al. Siting MSW landfill using weighted linear combination and analytical hierarchy process (AHP) methodology in GIS environment (case study: Karaj). Waste Management. 2010;**30**(5):912-920

[12] Voogd H. Multicriteria Evaluation for Urban and Regional Planning. Vol. 207. London: Pion; 1983

[13] Mahini AS, Gholamalifard M. Siting MSW landfills with a weighted linear combination methodology in a GIS environment. International Journal of Environmental Science & Technology. 2006;**3**(4):435-445

[14] Saaty T. The Analytic Hierarchy Process. New York Google Scholar: McGraw-Hill; 1980

[15] Statistique, I.I.N.d.l., Données générales sur la population. données démographiques et sociales, 2011. **< http://www.ins.nat.tn>**

[16] Aouadhi H, B.S.M., Modes et Plans de Gestion des Déchets Ménagers dans le Grand Tunis. Institut Supérieur des Technologies de l'Environnement de l'Urbanisme & du Bâtiment, Projet de Fin d'étude, 2006

[17] Aydi A, Zairi M, Dhia HB. Minimization of environmental risk of landfill site using fuzzy logic, analytical hierarchy process, and weighted linear combination methodology in a geographic information system environment. Environmental Earth Sciences. 2013;**68**(5):1375-1389

[18] Saaty TL. A scaling method for priorities in hierarchical structures. Journal of Mathematical Psychology. 1977;**15**(3):234-281

[19] Eastman JR, Kyem PA, Toledano J. A procedure for multi-objective decision making in GIS under conditions of conflicting objectives. In: Proceedings of the Fourth European Conference on Geographic Information Systems. 1993

[20] Eastman JR. IDRISI 32 release 2. Guide to GIS and Image Processing, 2001. **2**:p. 01610-1477