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A Decision Support Approach For Optimized Siting Of Municipal Solid Waste Landfill Case Study Tangier Morocco

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Summary

The selection of a landfill site is a strategic decision and complicated process in the management of solid waste. The objective of this paper is to identify the best municipal solid waste (MSW) facility sites with the combination of Geographic Information Systems (GIS), Remote Sensing and a fuzzy optimization model to solve multicriteria decision making (MCDM) systems based on a fuzzy analytic hierarchy process (fuzzy AHP. The case study was made for the city of Tangier in North Morocco, which is rapidly evolving into a large urban area.

The study employs a two-stage analysis to deal with the imprecise judgments of decision makers. The first stage makes use of a geographic information system (GIS) to provide a global visual representation of multi-efficient solutions which have been translated into multi-scale maps, multi-themes and representing homogeneous free waste landfill areas.

The second stage makes uses of the process of fuzzy AHP hierarchical analysis to evaluate and reconsider homogeneous free aereas of waste landfill determined by the process of spatial analysis, and to identify the most suitable site.

Our work offers a siting methodology and provides essential support for decision-makers in the assessment of waste management problems in Tangier.

***Keywords*: Landfill, GIS, AHP, Fuzzy, Remote sensing.**

1. INTRODUCTION

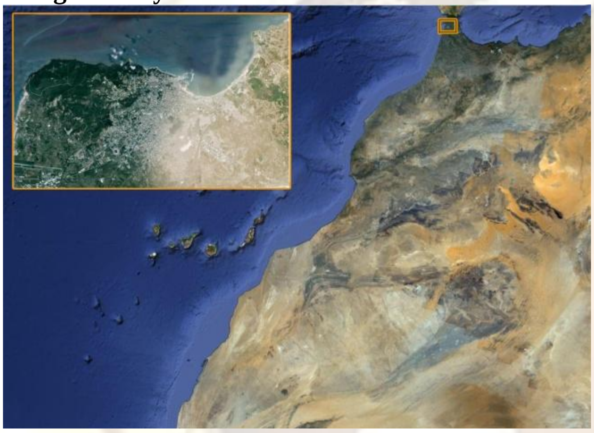
A provident, sustainable environmental policy depends on efficient solid waste management. It becomes necessary to have a waste management scheme that is comprehensive and consistent across an urban area in which the division of responsibility is clarified, recognized and accepted by all [1]. The components of municipal solid waste (MSW) management include reducing the waste, re-using, recycling, energy recovery, incineration and landfilling [2]. Even if policies of waste reduction and reuse are applied, still the existence of a sanitary landfill is necessary to a MSW management system [3]. Landfill siting is a difficult, complex, tedious, and protracted process requiring evaluation of many different criteria [4].

An MSW siting landfill is a spatial multi-criteria decision analysis (SMCDA) for which both Geographical Information System (GIS) and MCDA methods should be used [5]. GIS may also play a key role in maintaining data to facilitate collection operations, customer service, the analysis of optimal locations for transferring stations, the planning of road for waste transportation to transfer stations and from transfering stations to landfills, and the long-term monitoring of landfills [6]. There have been different methods on MCDM and the most known is Analytical Hierarchy Process (AHP) which based especially on pairwise comparisons on a ratio scale [7]. However, the AHP is criticized for its inability to accommodate uncertainty in the decision making process. The main difficulty arises the estimation of required input data that express qualitative observations and preferences. The AHP is mainly used in nearly crisp decision applications. It does not take into account the uncertainty associated with the mapping of people's judgment to an evaluation scale. In order to overcome the shortcomings of the AHP, fuzzy set principle is used to integrate AHP to determine the best alternative [8]. The present study's purpose is to develop a methodology to locate a new MSW by using fuzzy AHP combined with GIS for Tangier, Morocco.

2. Background Information

Tangier is located in the northwest of Africa between the parallels 35 ° 47 'north and meridian 5 ° 48' west of Greenwich. It's located on the Strait of Gibraltar which delimits the Mediterranean Sea to the west. The width of the strait varies from 44 km west to 15 km east. The study area is related to the Rif's chain which forms a distinct entity that runs along the Mediterranean coast curving northward. The topography shows large areas dominated by hills and basins where the altitude does not exceed 400 m. Regionally, the four main structural morphologic units (massive primary limestone ridge, and the layers of flysch-Rif area) are oriented towards the Mediterranean and a concentric concave. The study area is generally sub-dominant sandstone facies flysch (Oligocene Numidian of the water, Oligocene of the Beni-Idère, the Lower Cretaceous of Tizirène). According to the classification of bioclimatic of Morocco, Tangier is localized in the "wetland" with a Mediterranean climate with oceanic influence. The Annual rainfall varies between 600 and 700 mm. The wettest months are between the months of November and March. In general, temperatures remain clement in winter and mild in summer on both coasts and altitude. They rarely reach 5°C in January and the most common maxima of this month range from 14°C to 18°C. In summer, the atmosphere heats up significantly, the maximum temperatures most frequent in July range from 16 ° C to 23.1 ° C. Peaks of 30 ° C to 34 ° C can be reached a few days a year, but their frequency remains outstanding. Evapotranspiration is important, but still lower than the cumulative annual rainfall (evaporation> 450 mm / year calculated as a Turk).The study area enjoys very favorable air flow conditions and it's located in a very windy zone. It also benefits from thermal contrasts due to the proximity to cold sea areas (Mediterranean) and hot land masses (Morocco, Spain and the Sahara).Winds in the region are very frequent, moderate to severe.

Fig. 1 Study area



According to the High Planning Commission of the Kingdom of Morocco, the total population of Tangier's Prefecture increased from 859,878 inhabitants in 2004 to 971,000 inhabitants in 2010. The majority and the largest portion of solid waste which are brought to the landfill are household waste (about 83%). The percentage of solid waste undergoing treatment is very low (9%).The current dump raises many problems inherent in its location within the new urban area and the pollution it generates.

3. Methodologie

3.1. Data Used

In this work, satellite data was used for the latest situation on the land, we will use the latest data from the Landsat satellite. These images were taken between January and June 2011 from the ETM + (Enhanced Thematic Mapper Plus) data from Landsat. These images are multispectral mode with a spatial resolution of 30m with the possibility of improving the resolution after merging of multispectral bands with the panchromatic channel with 15m spatial resolution Images that were originally defined in WGS84 UTM projection system. Geological maps: apart from land map, it was very appropriate to trace the lineaments (faults, fractures) as complementary data and that for having an overview of the study field. The treatment of directional filters is applied to data to enhance Landsat7 preferred directions namely North 0 °, 45 ° North, 90 ° North and 135 ° North. Geological maps used at 1/50 000 (including Al-Manzla, Tangier, Ksar Es Sghir, Asilah) will serve to control the delay faults on different filters. In general, the classification of satellite imagery aims to produce thematic images, that is to say, images whose content does not represent a measurement but interpretation and categorization of the object's nature associated with the pixels. The use of ASTER images Gdem with 30m resolution allowed us to develop a Digital Terrain Model (DTM) which served as a basis for mapping the slopes and the exposure map.

The following table shows the different spectral bands of ETM + Landsat 7 satellite.

Table 1 Spectral bands of ETM + Landsat 7 satellite

Spectral bands	Wavelength interval µm	Resolution
Band1 (blue)	0,45 – 0,52	30 m
Band 2 (green)	0,52 – 0,60	30 m
Band 3 (red)	0,63 – 0,69	30 m
Band 4(near infrared)	0,76 – 0,90	30 m
Band 5 (shortwave infrared)	1,55 – 1,75	30 m
Band 6 (thermal infrared)	10.4 – 12.5	60 m
Band 7 (shortwave infrared)	2,08 – 2,35	30 m
Band 8 (Visible + near infrared)	0,52 – 0,9	15 m

The table below shows the scene Landsat7 used in this work with the technical characteristics:

Table 2 Specifications of the scene Landsat7

Scene Path-Row	Date of acquisition	Capteur	Level of treatment	Location
201/035	18 juin 2011	ETM+	L1G	Tanger

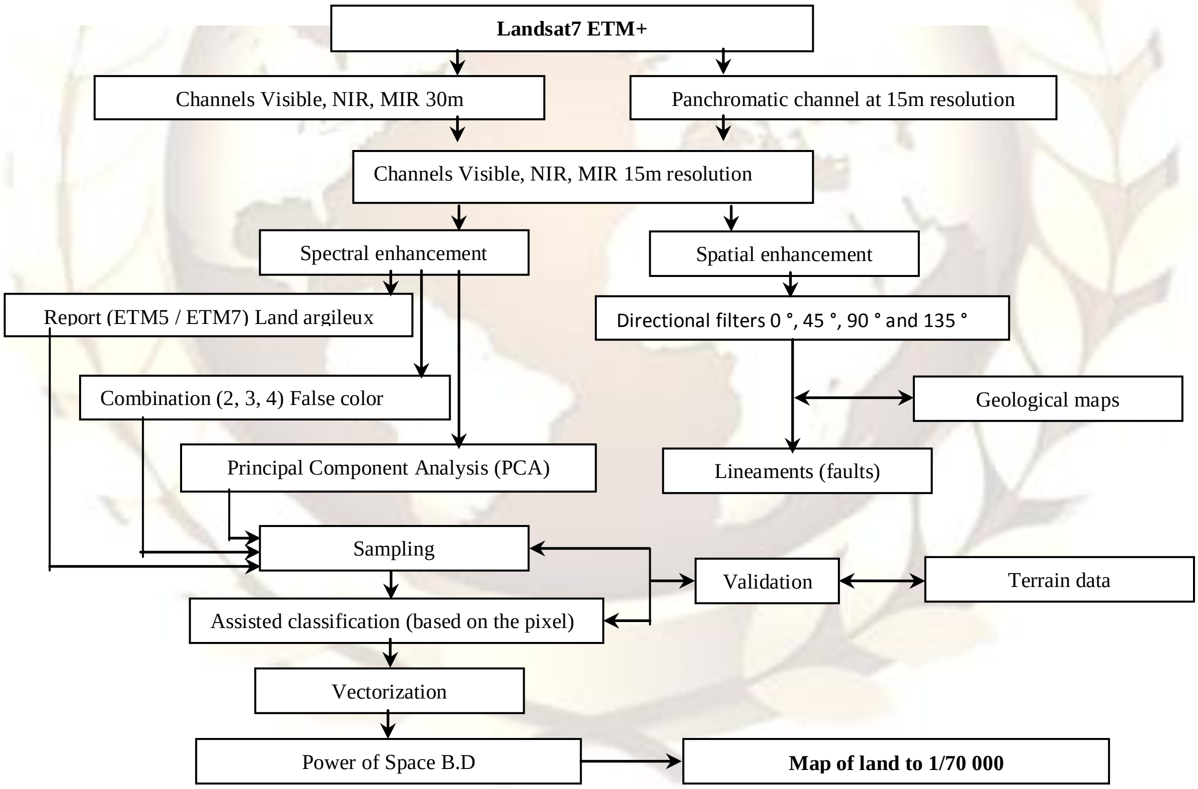
The methodological approach proposed is to establish a supervised classification of satellite images on the theme of land by the method of maximum likelihood (Maximum Likelihood).

This is a parametric method that is based on a normal distribution of data and that takes into account the variance of the data. In general, the classification of satellite imagery aims to produce thematic images, that is to say, images whose

content is no longer a measure but an interpretation and categorization of the nature of the objects associated with the pixels
The following chart summarizes the main steps in this part of the supervised classification of images and the interpretation of apparent flaws. The rest of the criteria was done through digitizing the maps at different scales. The river system was extracted by digitizing topographic map at 1/50000. The lithostratigraphy was obtained from the digitization of the geological map at 1/1000000. Roads, highways, railways and airports have been obtained from digitizing map at 1/500000 issued by the National Agency of the Land Registry and Cadastral Mapping Direction of Mapping. The location of sites with biological interest has been provided by Tangier Delegation of the Waters and Forest as a form of a map at 1/50000. The delineation of archaeological sites was carried out by the Delegation of Cultural Ministry.

geology, topography, hydrological, climatology, land uses and socio-cultural. Among many aspects which have to be considered in site selection, it is important to take into account most of these criteria and to weight them objectively. In this study, sub-criteria were standardized in a common interval of 0 to 10. These weights are based on the results of a questionnaire of professionals as well as data reproduced in the literature.
Geology: this criterion was presented by soil permeability and faults. The faults have great importance because of their influence on groundwater [9]. A score of 10 was attributed to the faults of 200 m or more, while a ranking value of 0 was assigned to the faults of 100 m or less. The criteria used are classified into six main categories, as shown in Figure 2: the geology, topography, hydrological, climatology, land uses and socio-cultural. Among many aspects which have to be considered in site selection, it is important to take into account most of these criteria and to weight them objectively.

Fig.2 Methodology used in the supervised classification of satellite images



3.2. Evaluation Criteria

In the case study and as mentioned earlier, there are no specific criteria for selecting landfill sites. The criteria used in this study were based on criteria derived from literature review with some adjustments to locally desired priorities and requirements. The criteria used are classified into six main categories, as shown in Figure 2: the

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Geology: this criterion was presented by soil permeability and faults. The faults have great importance because of their influence on groundwater [10], [11]. A score of 10 was attributed to the faults of 200 m or more, while a ranking value of 0 was assigned to the faults of 100 m or less.

Soil permeability: the karst formations and sandy soils were considered unwanted areas for the implementation of a landfill, so we assigned a rank value of 0. Clay and shale were considered optimal for location implantation of a landfill, with a ranking value of 10.

Topography: the slope is one of the first criteria conditioning the location of a landfill [12]. Very steep slopes will lead to higher costs of excavation [13]. A value of 0 was assigned to a slope greater than 45% while the value of 10 was attributed to land with slopes less than 5%.

Hydrology: in this study, hydrology was presented by the proximity to groundwater, the drainage and proximity to surface water. The value 0 was assigned a distance less than 300 m while the value 10 was assigned at a distance greater than 500 m.

Climatology: it was made based on the implantation sites that landfill shouldn't be exposed to wind [14]. The morphology of the site and frequency of wind direction in Tangier were taken into account.

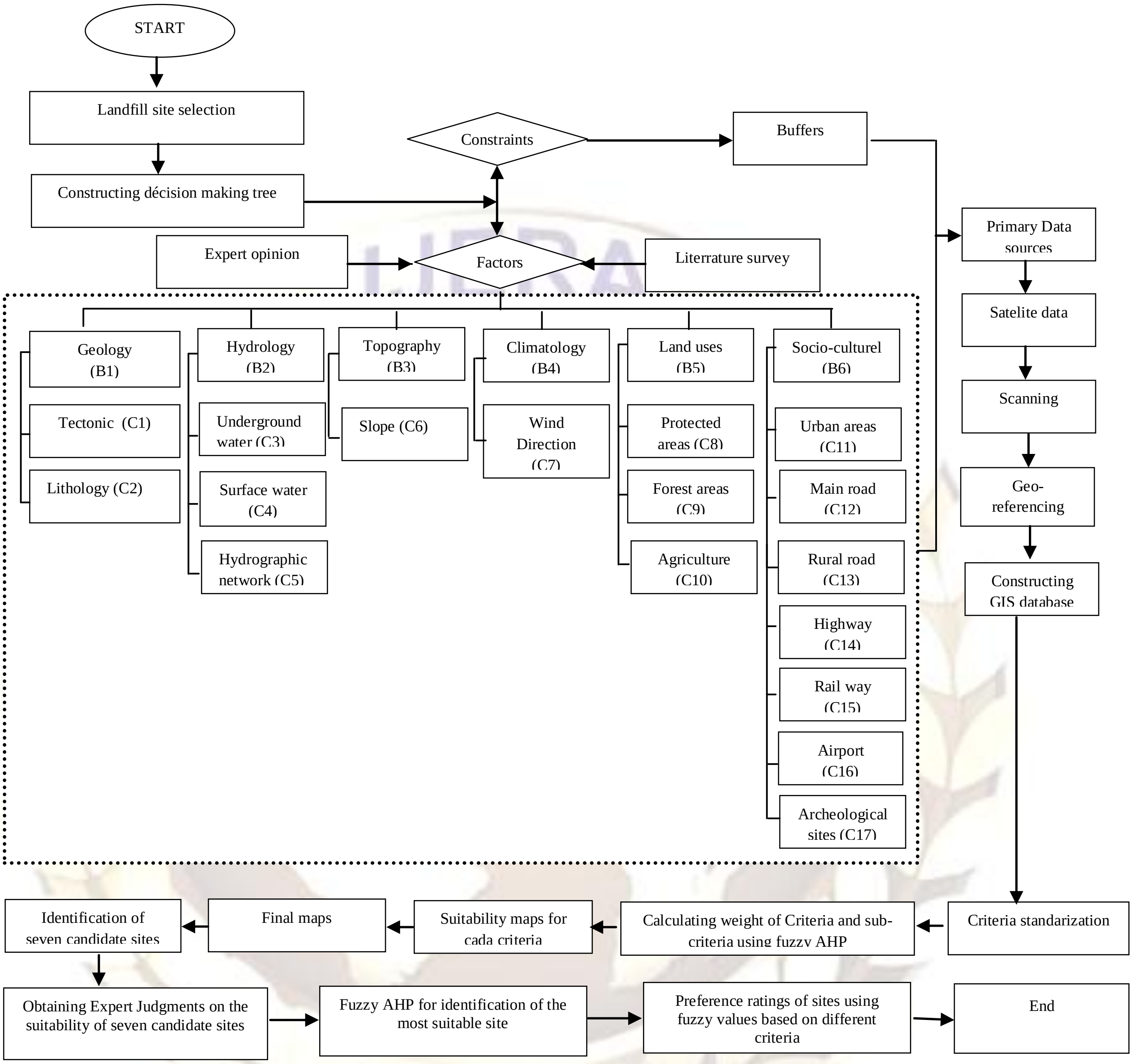
Land Uses: the adopted criteria for spaces reserved for agriculture, forest areas and protected areas of rank values ranging from 0 to 10 see table 1.

Socio-cultural: seven sub criteria selected are current and projected urban areas, main roads, rural roads, airports, railways and archaeological sites.

Table 3 Summary ranking values of the sub-criteria used in GIS

Sub-criteria	Unit	0	1	2	3	4	5	6	7	8	9	10
Lithologie	-	Sand Gravel	-	Fin Sand	-	Clay	-	Sand Stone	-	Limestone	-	Schist
Tectonique	M	100	110	120	130	140	150	160	170	180	190	200
Land slope	M	>45	45-50	40-45	35-40	30-35	25-30	20-25	15-20	10-15	15-5	<5
Ground water	M	<300	320	340	360	380	400	420	440	460	480	>500
Surface water	M	<300	320	340	360	380	400	420	440	460	480	>500
Wind direction	-	P	P	N	NE	E	SE	S	SO	O	NO	N
Protected areas	M	<500	550	600	650	700	750	800	850	900	950	>1000
Agriculture areas	M	<300	320	340	360	380	400	420	440	460	480	>500
Forest areas	M	<300	320	340	360	380	400	420	440	460	480	>500
Urbain settlements	M	<500	550	600	650	700	750	800	850	900	950	>1000
Main road	M	300	400	500	600	700	800	900	1000	1100	1200	1300
Rural road	M	100	200	300	400	500	600	700	800	1000	1100	1200
Highway	M	500	600	700	800	900	1000	1100	1200	1300	1400	1500
Aerport	M	<3000	3200	3400	3600	3800	4000	4200	4400	4600	4800	>5000
Railroad	M	<300	320	340	360	380	400	420	440	460	480	>500
Archeological sites	M	<500	550	600	650	700	750	800	850	900	950	>1000

Fig.3 Schematic diagram for modeling the siting of a landfill in Tangier



4. FUZZY AHP FOR LANDFILL SITING

Uncertainty is a major concept in our daily life. Fuzzy sets and fuzzy logic can provide an approach to address this concept. In recent years, fuzzy logic has been successfully applied in a variety of disciplines, including weather forecasting, image processing, nuclear reactor control, process control, biomedical, synchronization and automatic in many areas research [13], [14]. Fuzzy sets have been applied as an important tool for representing and handling uncertainty in various situations [15]. A fuzzy set is a class of objects with a continuum of degrees of membership. In the literature, the triangular and trapezoidal fuzzy numbers are generally more used to capture the imprecision of the parameters. In this work, we use triangular fuzzy numbers to represent a fuzzy number such that F = {X, μ_F (x), X ∈ R}, where X takes its value in R, -∞ ≤ x ≤ + ∞ and μ_F (x) ∈ [0,1]. A fuzzy number is denoted by M = (a, b, c).
With a ≤ b ≤ c, the triangular membership functions:

$$\mu_{F(x)} = \begin{cases} 0 & x < a \\ \dfrac{x-a}{b-a} & a < x < b \\ \dfrac{c-x}{c-b} & b < x < c \\ 0 & x > c \end{cases}$$

By defining the confidence interval of level α, which is a reliable interval, a triangular fuzzy number is characterized as follows: ∀ α ∈ [0,1]

$$\widetilde{M}_{\alpha}=[a^{\alpha},c^{\alpha}] = [(b-a)\alpha + a, -(c-b)\alpha + c]$$

The procedure of fuzzy AHP is presented as follows [16], [17], [18], [19].
Step 1: Compare the scores of performance by using fuzzy numbers $(\breve{1},\breve{3},\breve{5},\breve{7},\breve{9})$
Step 2: Construct the fuzzy comparison matrix $\breve{A}\,(a_{ij})$ as follows:

$$\tilde{A} = \begin{bmatrix} 1 & \breve{a}_{12} & \dots & \breve{a}_{1n} \\ \breve{a}_{21} & 1 & \dots & \breve{a}_{2n} \\ \dots & & & \dots \\ \breve{a}_{n1} & \breve{a}_{n2} & \dots & 1 \end{bmatrix}$$

$$a_{ij} \begin{cases} 1 & i = j \\ \breve{1},\breve{3},\breve{5},\breve{7},\breve{9} \; or \; \breve{1}^{-1},\breve{3}^{-1},\breve{5}^{-1},\breve{7}^{-1},\breve{9}^{-1} & i \neq j \end{cases}$$

Step 3: find the eigenvalues. An eigenvalue λ is a fuzzy number found from $\breve{A}\breve{x} = \breve{\lambda}\breve{x}$ (1)
$\breve{A}$ matrix with fuzzy n × n containing fuzzy numbers has $\breve{a}_{ij}$ *and* $\breve{x}$ is an eigenvector containing fuzzy numbers $\breve{x}_i$. Referring to the cut α, Equation 1 is equivalent to :

$$[\breve{a}_{i1l}{}^{\alpha}\breve{x}_{1l}{}^{\alpha}, \breve{a}_{lu}{}^{\alpha}\breve{x}_{1u}{}^{\alpha}] + \cdots + [\breve{a}_{inl}{}^{\alpha}\breve{x}_{nl}{}^{\alpha}] = [\lambda\breve{x}_{il}{}^{\alpha}, \lambda\breve{x}_{iu}{}^{\alpha}]$$ With $\breve{A} = [\breve{a}_{ij}]$; $\breve{x} = (\breve{x}_1, \dots, \breve{x}_n)$

$\breve{a}_{ij}{}^{\alpha} = [\breve{a}_{ijl}{}^{\alpha}, \breve{a}_{iju}{}^{\alpha}]$; $\breve{x}_i{}^{\alpha} = [\breve{x}_{il}{}^{\alpha}, \breve{x}_{iu}{}^{\alpha}]$;
$\breve{\lambda}^{\alpha} = [\lambda_l{}^{\alpha}, \lambda_u{}^{\alpha}]$ (2)
For 0 ≤ α ≤ 1 and for all i, j, i = 1,2, ..., n, j = 1,2, ..., n.
The index of optimism μ is a convex combination (Lee et al, 1999) defines as follows:
$\breve{a}_{ij}{}^{\alpha} = \mu a_{iju}{}^{\alpha} + (1-\mu)\, a_{ijl}{}^{\alpha} \quad \forall \mu \in [0,1]$ (3)
As α is fixed, the following matrix is obtained

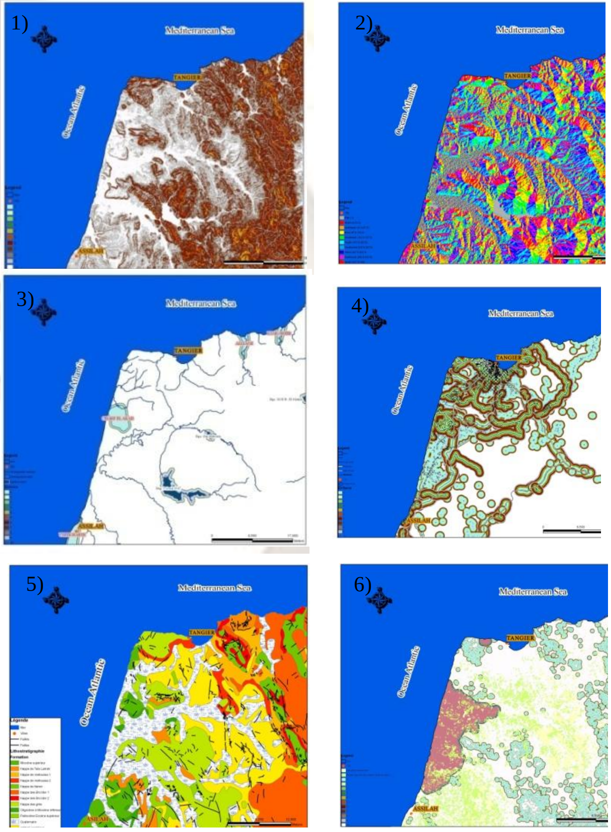
$$\tilde{A} = \begin{bmatrix} 1 & \breve{a}_{12} & \dots & \breve{a}_{1n} \\ \breve{a}_{21} & 1 & \dots & \breve{a}_{2n} \\ \dots & & & \dots \\ \breve{a}_{n1} & \breve{a}_{n2} & \dots & 1 \end{bmatrix}$$

The eigenvector is calculated by fixing the value of μ and by identifying the maximum eigenvalue
Step 4: determine all weights.

5. RESULTS AND DISCUSSION

GIS-based approach provides a digital data bank for long-term monitoring of the site and reduces the time and cost of site selection. ARCGIS 9.3 was used for the preparation of thematic maps [20]. The resulting maps are shown in Figure 4.

Fig.4 thematic maps obtained (1) Topography (2) Climatology (3) Hydrology (4) Socio-cultural (5) Geology (6) Land uses



The overlay of thematic maps allowed us to select 41 potential sites that meet the diverse geological, topographical, hydrological, climatological, land use and socio-cultural criteria.

Fig.5 sites suitables for landfill siting

For landfill site implementation in Tangier and for a period of 20 years, only suitable sites with a score of

10 and a minimum area of 50 hectares were selected, this choice is based on the quantity of waste generated, the height of landfill and compaction rates. The quantity of waste is closely linked to population ratio and the production of waste. The calculation result gave an area of about 35,5 ha, This area has been increased by over 30% to cover the infrastructure needs annexes for the landfill areas. We will retain a total area of 50ha. These sites, despite their selection in the same category (sites appropriate), have different characteristics. The classification of these sites, the better to less favorable will be performed by the Fuzzy AHP. We selected seven sites suitable that will undergo a multi-criteria analysis based on the FUZZY AHP. For the description of each of these areas, we used information extracted from the GIS, The lower and upper bounds of fuzzy numbers while respecting the value of α is defined from equation (2).

For α = 0.5 and μ = 0.5 the results of this analysis are summarized in the following tables [19]:

Table 4 The fuzzy comparison matrix of criteria with respect to the overall objective

	B1	B2	B3	B4	B5	B6	Eigenvecto	Weig
B	$\check{1}$	$\check{9}^{-1}$	$\check{5}$	$\check{7}^{-1}$	$\check{9}^{-1}$	$\check{5}$	0,041	0,025
B	$\check{9}$	$\check{1}$	$\check{9}$	$\check{9}$	$\check{9}$	$\check{9}$	0,704	0,445
B	$\check{5}^{-1}$	$\check{9}^{-1}$	$\check{1}$	$\check{7}^{-1}$	$\check{9}^{-1}$	$\check{5}$	0,017	0,011
B	$\check{7}$	$\check{9}^{-1}$	$\check{7}$	$\check{1}$	$\check{9}^{-1}$	$\check{7}$	0,075	0,048
B	$\check{9}$	$\check{9}$	$\check{9}$	$\check{9}$	$\check{1}$	$\check{9}$	0,704	0,445
B	$\check{5}$	$\check{9}^{-1}$	$\check{5}$	$\check{7}^{-1}$	$\check{9}^{-1}$	$\check{1}$	0,041	0,026

The fuzzy comparison matrices sub criteria C1 to C17 against the criteria B1, B2, B3, B4, B5, B6 are represented by the tables of 4 to 7.

Table 5 The fuzzy comparison matrix of the sub-criteria with respect to criterion B1

B1	C1	C2	Eigenvector	Weight
C1	$\check{1}$	$\check{7}$	0,990	0,874
C2	$\check{7}^{-1}$	$\check{1}$	0,143	0,126

Table 6 The fuzzy comparison matrix of the sub-criteria with respect to criterion B2

B2	C3	C4	C5	Eigenvector	Weight
C3	$\check{1}$	$\check{9}^{-1}$	$\check{7}^{-1}$	0,057	0,046
C4	$\check{9}$	$\check{1}$	$\check{9}$	0,976	0,786
C5	$\check{7}$	$\check{9}^{-1}$	$\check{1}$	0,209	0,168

Table 7 The fuzzy comparison matrix of the sub-criteria with respect to criterion B5

B5	C8	C9	C10	Eigenvector	Weight
C8	$\check{1}$	$\check{9}$	$\check{9}$	0,795	0,480
C9	$\check{9}^{-1}$	$\check{1}$	$\check{7}$	0,429	0,260
C10	$\check{9}^{-1}$	$\check{7}$	$\check{1}$	0,429	0,260

Table 8 The fuzzy comparison matrix of the sub-criteria with respect to criterion B6

B6	C11	C12	C13	C14	C15	C16	C17	Eigenvector	Weight
C11	$\check{1}$	$\check{9}$	$\check{9}$	$\check{9}$	$\check{9}$	$\check{9}$	$\check{9}$	0,763	0,257
C12	$\check{9}^{-1}$	$\check{1}$	$\check{5}$	$\check{5}$	$\check{7}^{-1}$	$\check{7}^{-1}$	$\check{7}^{-1}$	0,149	0,051
C13	$\check{9}^{-1}$	$\check{5}$	$\check{1}$	$\check{5}$	$\check{5}$	$\check{7}^{-1}$	$\check{7}^{-1}$	0,747	0,252
C14	$\check{9}^{-1}$	$\check{5}$	$\check{5}$	$\check{1}$	$\check{7}$	$\check{7}^{-1}$	$\check{7}^{-1}$	0 ,315	0,106
C15	$\check{9}^{-1}$	$\check{1}$	$\check{7}$	$\check{9}^{-1}$	$\check{1}$	$\check{7}$	$\check{7}$	0,087	0,029
C16	$\check{9}^{-1}$	$\check{7}$	$\check{1}$	$\check{9}^{-1}$	$\check{7}$	$\check{1}$	$\check{7}$	0 ,423	0,142
C17	$\check{9}^{-1}$	$\check{7}$	$\check{7}$	$\check{7}$	$\check{7}$	$\check{7}$	$\check{1}$	0,485	0,163

The fuzzy comparison matrices of alternatives with respect to seven criteria under C1 to C17 were performed, only one example of the 17 tables is given in Table 9.

Table 9 The fuzzy comparison matrix of the decision alternatives with respect to sub-criterionC1

C1	S1	S2	S3	S4	S5	S6	S7	Eigenvector	Weight
S1	$\check{1}$	$\check{5}^{-1}$	$\check{7}^{-1}$	$\check{7}$	$\check{3}$	$\check{5}^{-1}$	$\check{9}^{-1}$	0,045	0,022
S2	$\check{5}$	$\check{1}$	$\check{7}^{-1}$	$\check{7}^{-1}$	$\check{9}^{-1}$	$\check{5}^{-1}$	$\check{5}^{-1}$	0,560	0,269
S3	$\check{7}$	$\check{7}$	$\check{1}$	$\check{7}$	$\check{9}^{-1}$	$\check{7}$	$\check{9}^{-1}$	0,560	0,269
S4	$\check{7}$	$\check{7}$	$\check{7}$	$\check{1}$	$\check{9}^{-1}$	$\check{7}$	$\check{9}^{-1}$	0,221	0,106
S5	$\check{3}^{-1}$	$\check{5}^{-1}$	$\check{7}^{-1}$	$\check{7}^{-1}$	$\check{1}$	$\check{9}$	$\check{9}$	0,560	0,269
S6	$\check{7}$	$\check{7}$	$\check{7}$	$\check{7}$	$\check{5}$	$\check{1}$	$\check{9}^{-1}$	0,089	0,043
S7	$\check{5}$	$\check{5}$	$\check{7}$	$\check{7}^{-1}$	$\check{9}$	$\check{9}$	$\check{1}$	0,045	0,022

Table 10 Summary combination of priority weights: Sub-criteria of criterion B1

B1	C1	C2	Weight
Weight alternatives	0,874	0,126	
S1	0,022	0,297	0,057
S2	0,269	0,297	0,273
S3	0,269	0,166	0,256
S4	0,106	0,098	0,105
S5	0,269	0,015	0,237
S6	0,043	0,098	0,050
S7	0,022	0,029	0,023

Table 11 Summary combination of priority weights: Sub-criteria of criterion B2

B2	C3	C4	C5	Weight
Weight alternatives	0,046	0,786	0,168	
S1	0,009	0,018	0,018	0,018
S2	0,009	0,027	0,027	0,026
S3	0,451	0,037	0,037	0,056
S4	0,045	0,037	0,037	0,037
S5	0,017	0,405	0,405	0,387
S6	0,451	0,070	0,070	0,088
S7	0,017	0,406	0,406	0,388

Table 12 Summary combination of priority weights: Sub-criteria of criterion B5

B5	C8	C9	C10	Weight
Weight alternatives	0,480	0,260	0,260	
S1	0,244	0,011	0,023	0,126
S2	0,244	0,010	0,019	0,125
S3	0,244	0,312	0,315	0,280
S4	0,244	0,312	0,315	0,280
S5	0,007	0,022	0,007	0,011
S6	0,01	0,312	0,315	0,168
S7	0,007	0,021	0,006	0,010

Table 13 The fuzzy comparison matrix of the sub-criteria with respect to criterion B6

B6	C11	C12	C13	C14	C15	C16	C17	Weight
S1	0,432	0,241	0,244	0,008	0,04	0,244	0,31	0,217
S2	0,432	0,241	0,244	0,008	0,04	0,244	0,31	0,217
S3	0,044	0,007	0,008	0,01	0,04	0,244	0,024	0,054
S4	0,023	0,006	0,007	0,244	0,04	0,244	0,024	0,084
S5	0,023	0,241	0,009	0,244	0,28	0,008	0,012	0,117
S6	0,023	0,241	0,244	0,244	0,28	0,01	0,31	0,193
S7	0,023	0,024	0,244	0,244	0,28	0,008	0,012	0,119

Table 14 Summary combination of priority weights:

	B1	B2	B3	B4	B5	B6	Weight
Weight alternatives	0,025	0,445	0,011	0,048	0,445	0,026	
S1	0,057	0,018	0.143	0.244	0,126	0,272	0,086
S2	0,273	0,026	0.101	0.189	0,125	0,272	0,091
S3	0,256	0,056	0.184	0.081	0,28	0,054	0,163
S4	0,105	0,037	0.143	0.081	0,28	0,074	0,151
S5	0,236	0,387	0.143	0.135	0,011	0,057	0,193
S6	0,05	0,088	0.184	0.135	0,168	0,166	0,128
S7	0,023	0,388	0.102	0.135	0,01	0,105	0,188

Main criteria of the overall objective

The calculation of eigenvectors and eigenvalues was done using Matlab7.10.0.499 (R2010A). The results show that site 5 is the first rank with a weight of 19% followed by Site 7 with a weight of 18%. Sites 3 and 4 respectively have a weight of 16% and 15%.

The Sites 1 and 2 have similar weights 9%.

CONCLUSION

The present study offered a new siting methodology combining the fuzzy AHP with GIS and remote sensing. The methodology outlined based on geology, hydrology, sociocultural, topography, climatology and land uses criteria can be used as an efficient spatial decision supporting tool to provide politicians, planners and decision makers. A scoring system was employed to represent the severity of these factors. The proposed system ranks sites using a scale that ranges from 0 to 10, with 10 representing the optimal choice. The GIS analysis requires collecting data from different sources with different formats to create a complete uniform database. Thus, the GIS data should be updated regularly in order to reflect the current situation of an area under investigation. Remote sensing data can assist in providing updated information of the study area. Also, it can support the decision makers to monitor the investigated area by using different dates of satellite images. The planners and the decision-makers can get useful information about the possible locations of landfill sites using this methodology. It is especially useful that the site ranking process allows for easy readjustment of the criteria weights. Overall, GIS offered adequate means to identify seven candidate sites based on this methodology and available data applied in this research; These data were later ranked using intelligent system approach (fuzzy AHP) for selecting a solid waste landfill site. The disadvantage of this method is that the selection of the best candidate site is depends on the experts judgments to defin the factor weights and the grading values.

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