COMBINING THE ANALYTIC HIERARCHY PROCESS WITH GIS FOR LANDFILL SITE SELECTION: THE CASE OF THE MUNICIPALITY OF M'SILA, ALGERIA

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Key-words: Landfill siting**,** Multi-criteria analysis, Analytic Hierarchy Process (AHP), GIS, M'Sila.

Abstract. In Algeria, the most used method for the disposal of municipal solid waste (MSW) is landfills. However, determining the location of landfill sites is a difficult and complex process relying on many criteria, such as technical, environmental and socio-economic parameters. The main objective of this study was to test a methodology, based on a multi-criteria analysis and geographic information systems, aimed at identifying areas potentially suitable for the landfill location of Municipal Solid Waste (MSW) for the municipality of M'sila. To choose the most appropriate landfill site, a geographic information system (GIS) was combined with an analytical hierarchy process (AHP) in order to analyse several criteria, such as land use, slope, distance from residential areas, settlements, surface waters, roads, and sensitive ecosystem areas. The analytical hierarchy process (AHP) was applied to identify the weights on each criterion. To assess the suitability for landfill siting, a simple additive weighting method was used. Each criterion was evaluated with the aid of AHP and mapped by GIS. The resulting land suitability was reported on a scale of 0 to 10, *i.e.*, from least suitable to most suitable sites. As a result, 0.5% of the study area is identified as the most suitable for landfill siting, 4.73% suitable and 7.73% moderately suitable, 14.27% less suitable and 72.93% was seen as being completely unsuitable areas to host sites for MSW landfill.

1. INTRODUCTION

Municipal solid waste (MSW) is generated by households, businesses, institutions and industry. MSW typically contains a wide variety of putrescible (packaging, food waste and paper products) and non-putrescible materials (construction materials). Solid waste has become a global environmental and health issue in today's world both in developing and developed countries (United Nations, 2017).

The increase in the quantity of generated waste arises from the effects of many factors, such as improvements in living standards, rapid population growth, economic growth etc. (Guerrero *et al.*, 2013; Minghua, 2009). For solid waste management, many effective techniques of disposal of municipal solid waste have been used, such as landfills, recycling, thermal treatment and biological treatment (Moeinaddini *et al.*, 2010; Kontos *et al.*, 2003).

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Although waste disposal in most towns and cities, especially those in underdeveloped countries, is done in the simple form of landfill deposition, less attention has been paid to the use of expert and engineering knowledge to find the most optimal waste disposal site in municipal solid waste management (MSWM). One of the most important aspects in well-engineered waste disposal siting is the identification of a long-term optimal waste depot location (Awomeso *et al.*, 2010).

Recently, due to the growing urgency of urban environmental problems, solid waste management in lower income countries has attracted much attention, with actions oriented toward landfills designed to increase environmental protection. Proper waste disposal, without compromising natural reserves and environmental quality, has become an absolute necessity in order to avoid environmental and public health risks (Pires *et al.*, 2011) and is one of the greatest endeavours of our times. Hence, it is necessary to devise suitable waste management and disposal methods (Gizachew *et al.*, 2012; Ebistu and Minale, 2013; Abedi-Varaki and Davtalab, 2016).

Algerian cities are experiencing an accelerated urbanization process (Nemouchi, 2005), high demographic growth and the economic, social and political upheavals have direct effects on the volume of household waste produced every day, which is constantly increasing (Safaa Monqid, 2012). These problems, common for all our cities and characterized by uncontrolled urbanization (Abdelli *et al.*, 2017), weaken the waste management systems in place.

Competent authorities have great difficulty in containing and eliminating them, as evidenced by the spectacle of solid waste indiscriminately discarded around the human environment, which also results in aesthetic problems and a general nuisance (Hafidi, 2015). According to a survey by the services of the Ministry of Land-use Planning and Environment, more than 3000 uncontrolled dumps have been identified. Waste management remains one of the weak links (Bendjoudi *et al.*, 2009) of urban management and urban services in Algeria, prior to the issuing of Law N° 01–19 of December 12, 2001 relating to the management, control and elimination of waste. Most solid waste disposal sites in M'sila were on the borders of urban areas, around water bodies, crop fields, settlements and on road sides (Bendjoudi *et al.*, 2009). Therefore, locating proper sites for dumping solid waste far from environmental resources, residential areas, water bodies, roads, faults and settlements is essential for the proper management of solid waste. (Miezah *et al.*, 2015). Over time, due to accelerated urbanization, many existing disposal sites have been very close to settlements and housing estates (Yousefi *et al.*, 2018). The environmental degradation associated with these dumps is likely to pose several health issues for the population (Nas *et al.*, 2008; Soroudi *et al.*, 2018; Yukalang *et al.*, 2017; Yan *et al.*, 2017), especially in summer, when the temperature is unbearable.

The socio-economic development and urban dynamic that Algeria has been experiencing have led to a series of strategic actions aiming to reform the waste management sector (PROGDEM "National Solid Municipal Waste-Management Programme", PNAGDES "National Special Waste-Management Plan", 2001). The problem of solid waste (about 34 million tons per year in Algeria, including 11 million tonnes of urban solid waste) (Aliouche *et al.*, 2017) arises from its collection, but also from the selection and management of dumps. Recognizing environmental risks related to poor waste management, several Algerian administrative regions envisaged the realization of inter municipal landfills. The information presented in this material forms part of this prospect and tries to suggest favourable sites for installing the controlled landfill in the municipality of M'sila.

Choosing an intelligent and integrated landfill site is considered a complex task for planners and authorities. It is a process that poses many difficulties for them, and which requires the evaluation of many different criteria (Chang *et al.*, 2008) as well as a considerable expertise in various social and environmental fields (Chang *et al.*, 2008; Rahman *et al.*, 2008; Lunkapis, 2010; Nishanth, 2010). Environmental factors are very important because the landfill may affect the biophysical environment and the ecology of the surrounding area (Siddiqui *et al.*, 1996; Kontos *et al.*, 2003; Erkut and Moran 1991). Economic factors must be taken into account in the siting of landfills, including the costs associated with the acquisition, development, and operation of the site (Delgado *et al.,* 2008; Erkut and Moran, 1991; Kontos *et al.,* 2003).

It is evident that many factors, with spatial dimensions, must be incorporated into landfill siting decisions, and geographic information systems (GIS) are useful for such studies due to their ability to manage (collect, store, manipulate, process and analyse) large volumes of spatial data from a variety of sources (Sener *et al.*, 2006). GIS is a very effective way of managing and integrating the necessary economic, environmental, social, technical, and political constraints.

Many attributes considered in the process of selecting technical landfill sites have a spatial representation, which in recent years has motivated researchers to use geographical approaches that allow for the integration of multiple attributes using geographic information systems (Kontos *et al.*, 2003; Sarptas *et al.*, 2005; Sener *et al.*, 2006; Gomez-Delgado and Tarantola, 2006; Delgado *et al.*, 2008; Chang *et al.*, 2008).

Site selection procedures can benefit from the appropriate use of GIS. A GIS is first and foremost an Information System: an organized set of elements which makes it possible to group, classify, process and disseminate information on any given phenomenon. It is capable of capturing, storing and managing spatially referenced data; provide massive amounts of spatially referenced input data and analyse it; easily perform a sensitivity and optimization analysis; and communicate the results of the model to be able to react quickly after events which have an impact on the territory (Vatalis and Manoliadis, 2002).

The multi-criteria method is used to deal with the problems encountered by decision-makers in the processing of large amounts of complex information. The principle of the method is to divide the decision problems into several smaller understandable parts, analyse each part separately, and then integrate the parts in a logical manner (Malczewski, 1997). To solve the problem of landfills, the integration of the Geographic Information System (GIS) and the Analytic Hierarchy Process (AHP) method were used because GIS provides an efficient manipulation and presentation of spatial data and considers many factors from a variety of sources (Kontos *et al.*, 2003; El Alfy, 2010; Sener *et al.*, 2011), while MCE supplies a consistent ranking of the potential landfill areas based on a variety of criteria (Sener *et al.*, 2006).

Many studies have applied different methods for landfill site selection. Barakat *et al.* (2017) has used GIS-based multi-criteria evaluation techniques for evaluating the suitability for landfill site selection in the common of M'sila, Algeria. Eskandari *et al.* (2016) have used an integrated approach for landfill siting based on conflicting opinions among environmental, economic and social cultural experts. In Alanbari *et al.* (2014), a landfill site selection is performed by using Geographic Information Systems (GIS) and Multi-criteria Decision Analysis (MCDA) in Al-Hashimyah Qadaa. Khan *et al.* (2015) has applied a weighted linear combination (WLC) in GIS using a comparison matrix to aggregate different significant scenarios associated with environmental and economic objectives Dhanbad, India. Uyan (2014), Ramjeawon (2008), Kara (2012), Malczewski (1997), Alavi *et al.*, (2013) and Asif *et al.* (2019) used a combination of AHP, GIS and field analysis in order to find the best solid waste disposal sites.

Therefore, this paper aims to test a methodology based on the application of the Analytic Hierarchy Process (AHP) combined with Geographic Information System (GIS) in order to obtain a map of areas suitable for landfill sites in M'sila, Algeria. This association of MCDA and GIS not only permits us to manage the spatial reference information, but also to apply analysis methods allowing us to have the most pertinent and profitable information at spatial-temporal scales. The use of special tools, such as the GIS software, has enabled us to quickly manage and efficiently process large amounts of input data within a specific geodatabase (geology, geomorphology, hydrology, meteorological and climatic aspects, constraints imposed by regulations and legislation both national and regional, etc. (Mussa *et al.*, 2019).

2. STUDY AREA

The commune of M'sila is located in the plains of Hodna, Algeria. It lies about 35° 42′ 7″ north of the Equator and 4° 32′ 49″ east of the Greenwich Meridian, 250 km southeast of Algiers, the capital city of Algeria. It covers an area of 233.2 km^2, with an average elevation of 471 meters above sea level (Fig. 1). The monthly average temperatures are between -3°C and 40°C, the warmest months are June, July and August, and the coldest months are December, January and February. The main activity in the area is agropastoralism, dependent on low and irregular rainfall under 250 mm per year. The area had a population of 238,689 in 2017, with a density of 925 inhabitants per sqkm (Programming and budget monitoring department “DPAT”, 2017).

3. MATERIALS AND METHODS

3.1. Materials

Many available datasets, gathered from different sectors of the country, both digital and hard copies at different scales, were used in this study. The data used was based on its availability and suitability for the purpose of the study.

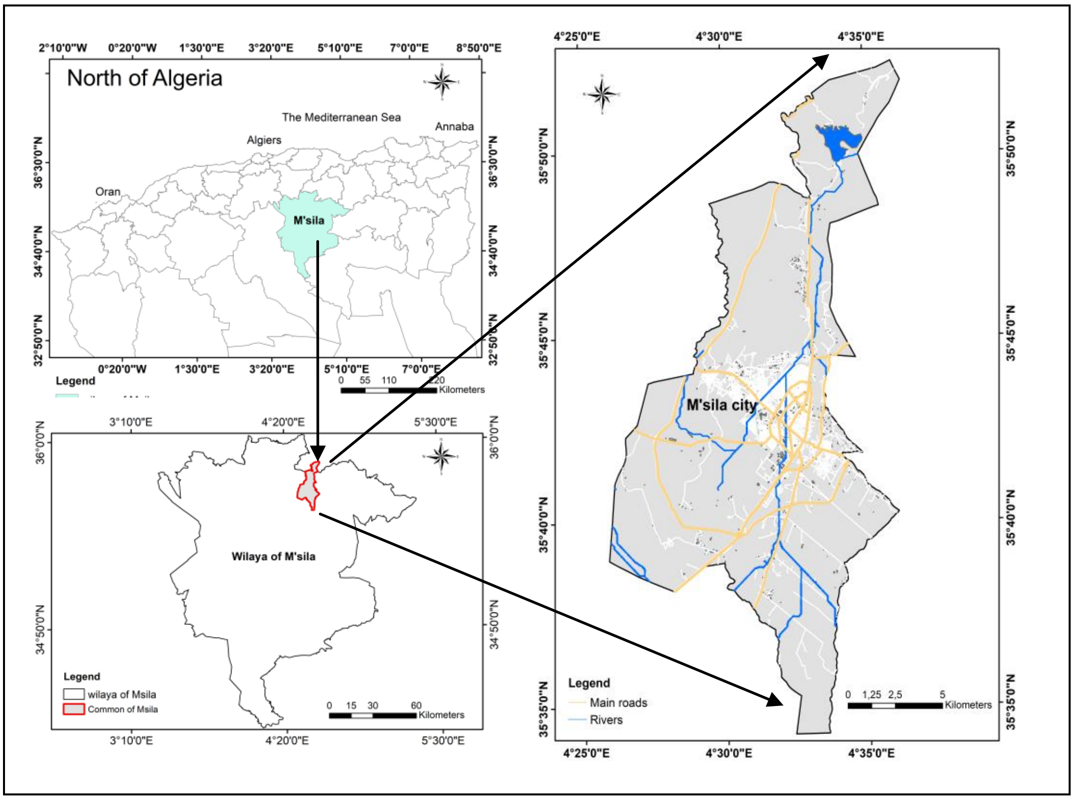

Fig. 1 – Study area – Commune of M’sila.

The Spot 5 imagery that covers M’sila was acquired from the University of Liège (ULg) in Belgium, following a program agreement between the University of M’sila and the University of Liège. The Spot imagery acquisition date was October 26, 2006. This imagery, with a resolution of

10m, was used to prepare primary input thematic maps, such as land-use and hydraulic networks, with the help of field investigations and secondary maps.

The Landsat 8 imagery that covers M'sila (path 195, row 035) was acquired from the United States Geological Survey (USGS) website. The Landsat imagery acquisition date was December 20, 2015. This imagery was used to generate the land use and land slopes.

The aerial photograph, zone F97 (Digital Mapping Camera) that covers M'sila City was acquired from the National Institute of Cartography and Remote Sensing (INCT), Algiers. The Aerial photograph acquisition date was 2011. This aerial photograph with a resolution of GSD-30cm (Ground Sampled Distance) was used to update thematic maps.

In this study, 7 (seven) input map layers, including settlements (urban centres and villages), roads (main roads and village roads), sensitive ecosystems, slope, land use, surface water and residential area were collected and prepared in a GIS environment. All layers were converted to the individual raster maps (Sener *et al.*, 2006; Sener *et al.*, 2011). All input datasets were georeferenced to WGS 1984 UTM Zone 31N coordinate system and reclassified by providing weights, while new maps were generated.

3.2. Methods

3.2.1. The Analytical Hierarchy Process (AHP) method

Currently, the most used methods for the identification of areas potentially suitable for landfills have been generally based on analytical hierarchical approaches (AHP) combined with geographic information systems (GIS), in order to examine various criteria (Kontos *et al.*, 2005; Chang *et al.*, 2008; Sharifi *et al.*, 2009; Carone and Sansò, 2010; Sener *et al.*, 2010; Gbanie *et al.*, 2013). Each criterion is evaluated according to a system based on scores and weights and mapped using GIS techniques. The AHP divides the decision problems into understandable parts; each of these parts is analysed separately and integrated in a logical manner (Demesouka *et al.*, 2013). Therefore, each criterion was allocated a score ranging from 0 to 10, where zero indicates that the area is unsuitable, while 10 describes the best condition.

For this study, we have selected seven criteria for the evaluation of landfill suitability. Establishing the weightings of the sub-criteria is based on the opinion of experts, literature, environmental and scientific requirements and governmental regulations (Table 2), as well as the pre-existing local level factors of M'sila area. The criteria were grouped according to their environmental or socio-economic importance and each criterion was assigned values from three to four classes with scores between 0 and 10.

After defining the importance of each criterion, the next step is to identify the relative importance of the criteria in relation to each other. AHP is one of the most common methods that have been used in recent years. It is a multi-attribute technique that has been integrated into GIS-based land use adequacy procedures.

After defining the importance of each criterion, the next step is to identify the relative importance of criteria to each other. AHP is one of the most common methods that have been used in recent years. It is a multi-attribute technique that has been integrated into GIS-based land use adequacy procedures (Saaty, 1980). It is a reliable decision support method which is widely used to define the relative importance of the different criteria in the landfill site selection (Kontos *et al.*, 2005; Moeinaddini *et al.*, 2010; Sener *et al.*, 2006; 2010; 2011; Sharifi *et al.*, 2009; Yesilnacar and Cetin, 2005). The AHP is based on pairwise comparisons and any criterion or sub-criterion is compared to another criterion at the same time. Decision makers can quantify their opinions about the criteria's magnitude.

The suitability of an area was then assessed by the use of Simple Additive Weighting (SAW) which is one method used to solve the problem of multi-attribute decision making. The basic concept of the SAW method is to find the sum of the weighted performance rating for each alternative to all attributes. This system is widely used for the calculation of final values in issues using several criteria according to the formula of the following equation (Yoon and Hwang, 1995; Khairul *et al.*, 2016):

$$V_i = \sum_{j=1}^{n} W_j V_{ij} \quad (1)$$

where V_i is the suitability index for the area i, Wj is the relative importance of the weight given to the criterion j, V_{ij} is the priority value of the area *i* with respect to the criterion j, n is the total number of criteria.

The end result of this methodology was the evaluation of the territory on the basis of suitability indices. In this study, the used scale for such indices ranged from 0 (less suitable area) to 10 (most suitable area).

We applied the pair-wise comparison method, which has the added advantages of providing an organized structure for group discussions and helping the decision maker when working with numerous and disputing evaluations, allowing them to obtain an agreement solution when setting criterion weights (Drobne and Lisec, 2009). The pair-wise comparison method in the context of the analytical hierarchy process (AHP) (Saaty, 1980) is now used in various application fields, such as finance, planning, telecommunications and ecology. This method is an effective method for the establishment of relative importance. It uses a ratio matrix to compare one criterion to another (Kontos and Halvadakis, 2002; Kontos *et al.*, 2003; Kontos *et al.*, 2005). Additionally, it uses a numerical scale with values ranging from 1 to 9, as shown in Table 1.

Table 1

The comparison scale in AHP (Saaty 1980)

Value	Intensity of importance
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Absolute importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments

The comparison was performed using an integer scale from 1 to 9, with each number having the interpretation shown in Table 1. This pair-wise comparison allowed for an independent evaluation of the contribution of each factor, thereby simplifying the decision-making process.

Table 2

Square matrix of the pair-wise comparisons of various criteria

Criteria	1	2	3	4	5	6	7	Weights	Rank
(1) Distance from water	**1.00**	5.00	5.00	7.00	1.00	1.00	3.00	0.258	2
(2) Distance from settlement	1/5	**1.00**	1.00	3.00	1.00	1/3	1/3	0.077	5
(3) Slope	1/5	1.00	**1.00**	3.00	1/3	1/5	1/3	0.057	6
(4) Distance from roads	1/7	1/3	1/3	**1.00**	1/7	1/9	1/5	0.026	7
(5) Land use	1.00	1.00	3.00	7.00	**1.00**	1/3	3.00	0.174	3
(6) Sensitive Ecosystems	1.00	3.00	5.00	9.00	3.00	**1.00**	3.00	0.288	1
(7) Residential area	1/3	3.00	3.00	5.00	1/3	1/3	**1.00**	0.120	4
								1.000	
Total	**3.88**	**14.33**	**18.33**	**35.00**	**6.81**	**3.31**	**10.87**		
	λ max = 7.444			CI= 0.074			C.R = 5,61 %		

Then, the obtained geometric means were normalized and the relative importance weights were extracted. For the decision-making problem mentioned earlier, a structural hierarchy is formed. Where CI is the consistency index, λmax is the largest or principal eigen value of the matrix, and n is the order of the matrix. This CI can be compared to that of a random matrix, the Random Consistency Index (RI), such that the ratio, CI/RI, is the consistency ratio, CR. As a general rule, for the matrix to be consistent we should have a value of CR ≤ 0.1. For this study, (RI = to 1.32) for n = 7 (Table 3), and calculated (λmax = 7.444), producing a value of Consistency Index (CI = 0.074). The consistency ratio CR was 0.0561 < 0.1, thus indicating that a consistent matrix was formed (Alonso and Lamata, 2006).

Table 3

Random inconsistency indices for different values of (n) (Saaty, A980)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

3.2.2. Description of site selection criteria

Generally, selecting a suitable landfill site would minimize the risk to human health as well as decrease the negative effects on the environment. Additionally, it would reduce the costs of waste disposal (Pinar and Akgun, 2014). The selected areas for landfilling should be close to the source of waste and far from protected areas (wildlife refuges, national parks, natural monuments, in addition to protected areas) (Mojtaba, 2019).

The assessment criteria used in this work were divided into two main categories: ecological criteria and socio-economic criteria. We assigned 3 to 4 classes of values to each factor, with a score between 0 and 10 (Table 3). Higher scores are representative of more favourable conditions of the location.

The ecological criteria included the three factors of distance from surface water, distance from residential area and sensitive ecosystems as shown in Table 3.

The socio-economic criteria included factors that affect the construction and the operations management of a landfill. The parameters here considered were land slopes, distance from roads, land use and distance from settlements.

Considering the criteria ascertained through different methods, as shown in Table 1, the information, digital maps, and data related to every criterion were acquired from relevant organizations, including the National Institute of Cartography and Remote Sensing (INCT), the Water Resources Department (DRE), and the Programming and Budget Monitoring Department (Ex DPAT). Since the data used in different organizations and companies are developed and compiled for particular applications, they have different formats and scales, and use different projection systems.

Considering the objective of the current study and the required accuracy, that data was converted into a homogeneous format, scale, and projection system so that all could be used in the defined conceptual model to obtain reliable results.

4. RESULTS AND DISCUSSION

Due to the high rate of population growth in M'sila, as is the case of other Algerian cities, the amount of MSW production is on the rise (Abdelli *et al.*, 2017). One of the major public health problems and environmental pollution factors in this region of Algeria is MSW dumping. MSW dumping in this area has caused environmental and health problems (Pires *et al.*, 2011), such as water and air pollution, disease-causing vectors and odour, especially during summer (Tchobanoglous *et al.*, 1993). Most of these dumps are temporary and are soon to be filled. Hence, it is necessary to look for other suitable sites to dispose of MSW.

GIS data sets of land use, rivers, roads, digital elevation models (DEMs), and slope were collected for this study from: the National Institute of Cartography and Remote Sensing, the Water

Resources Department, and the Programming and Budget Monitoring Department. The criteria for data selection were based on constraints and factors for an ideal landfill siting (Table 4), with terrain parameters, natural resources, and human infrastructure numbering among the broad criteria. The most significant criteria were selected according to landfill site selection regulations in Algeria and conditions of the study area in order to protect sensitive ecosystems, surface water, as well as urban and rural areas.

Table 4

Grading values and description of selected criteria

Criteria	Classes	Description	Scores
Ecological criteria			
Surface water (m)	d < 1000	Unsuitable	0
	1000 < d < 2000	Less-suitable	1
	2000 < d < 3000	Suitable	5
	3000 < d	Highly-suitable	10
Residential area (m)	0 < d < 1000	Less-suitable	1
	1000 < d < 2000	Suitable	5
	2000 < d	Highly-suitable	10
Sensitive ecosystems (m)	d < 500	Unsuitable	0
	500 < d < 1500	Less-suitable	1
	1500 < d < 3000	Suitable	5
	3000 < d	Highly-suitable	10
Socio-economic criteria			
Distance from roads (m)	0 < d < 500	Highly-suitable	10
	500 < d < 1000	Suitable	5
	1000 < d	Less-suitable	1
Slope (degree)	0° < α < 10°	Highly-suitable	10
	10° < α < 25°	Suitable	5
	25° < α < 45	Less-suitable	1
	45° < α	Unsuitable	0
Settlement (m)	0 < d < 1000	Less-suitable	1
	1000 < d < 2000	Suitable	5
	2000 < d	Highly-suitable	10
Land use			
	Barren land	Highly-suitable	10
	Pastures & agricultural area	Suitable	5
	Orchards	Less-suitable	1
	Built up (urbanized & industrial area)	Unsuitable	0

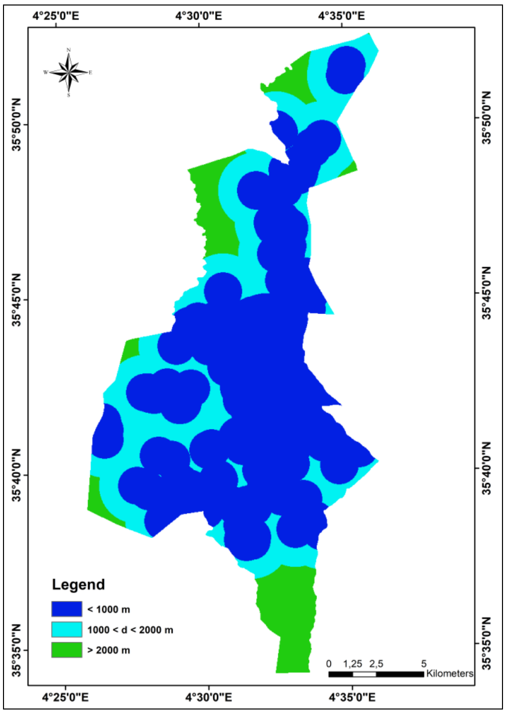

Fig. 2 – Map of distance to residential area.

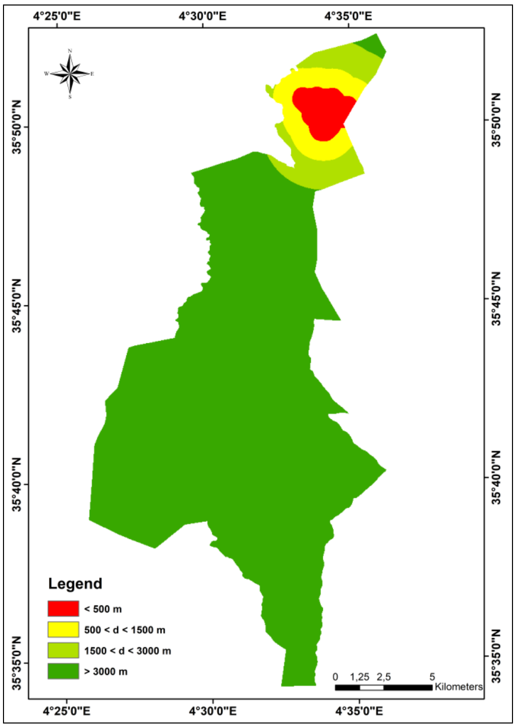

Fig. 3 – Map of sensitive ecosystems.

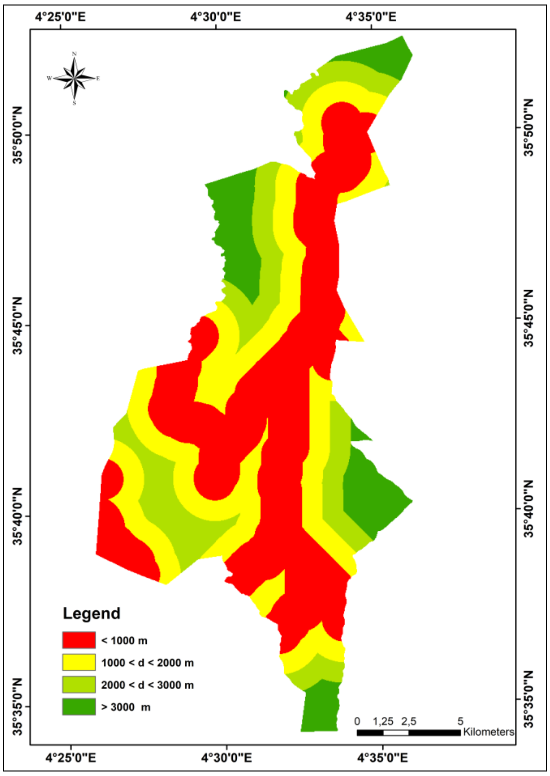

Fig. 4 – Map of distance to surface water.

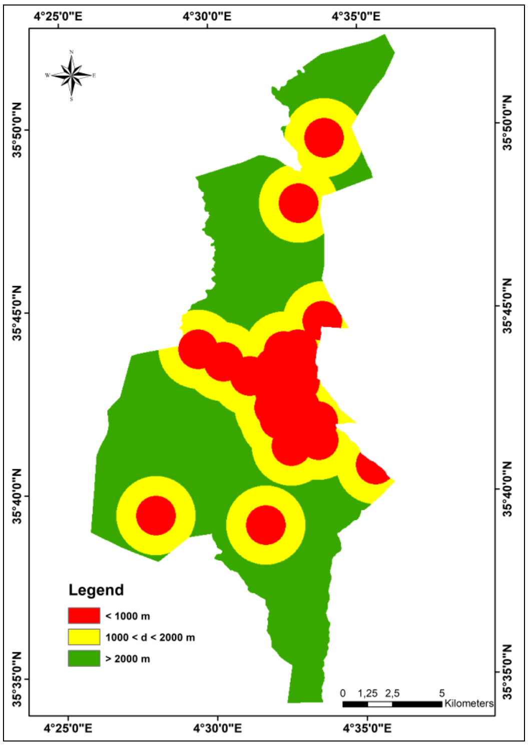

Fig. 5 – Map of distance to settlement.

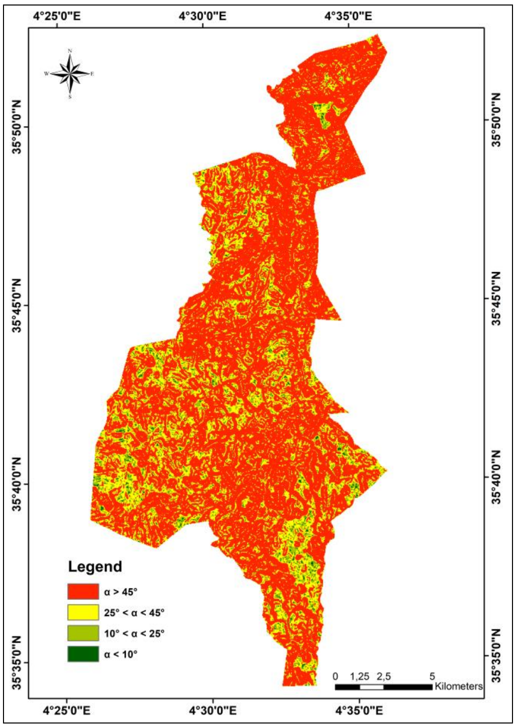

Fig. 6 – Map of slope.

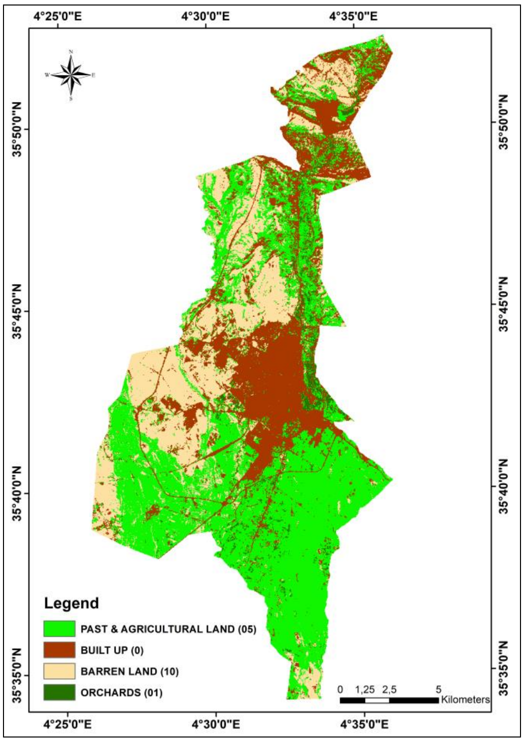

Fig. 7 – Map of land use.

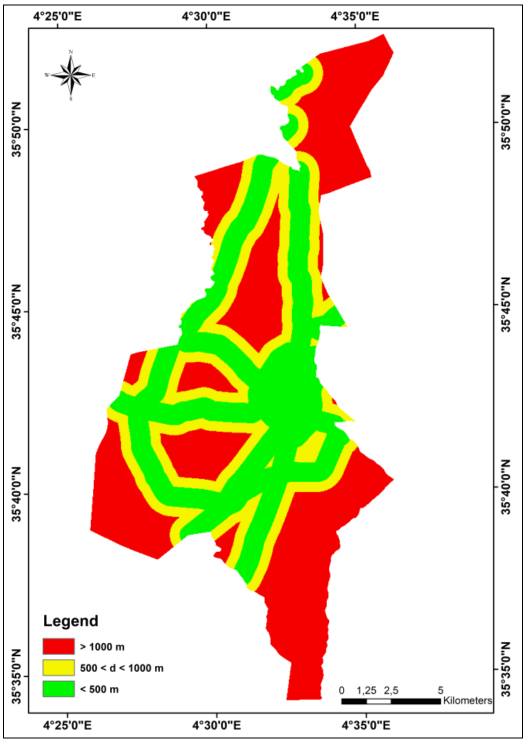

Fig. 8 – Map of distance to roads.

Table 5

Areas of selected priorities according to the index overlay method.

Selected Priorities	Highly Suitable	Suitable	Moderately Suitable	Less Suitable	Unsuitable	Sum of suitability
Area (km^2)	1.16	11.03	17.65	33.28	170.08	233.2
Area (%)	0.50	4.73	7.73	14.27	72.93	100

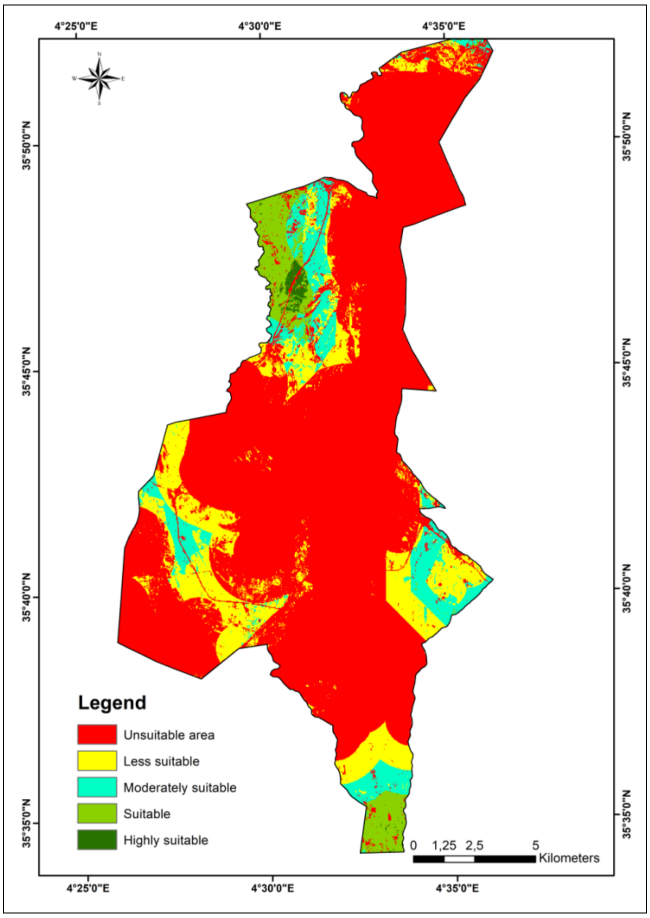

Fig. 9 – Landfill suitability map and area recommended for siting.

4.1. Ecological criteria

4.1.1. Surface Waters

Surface water is an important parameter to consider when setting up landfills. To avoid surface water pollution by landfill leachate[1], one should consider the minimum distance from surface water (Sener *et al.*, 2010). Oued K'sob is the main river that provides water for agricultural land irrigation in the study area. In this research, we have suggested bands at a gradually increasing distance and with a deviation of 1000 m (Fig. 2). For distances under the legal limits (1000 m), we assigned a score of zero, while areas over 3000 m were scored as 10 (Alavi *et al.*, 2013). The score was incrementally

[1] It has an adverse impact on groundwater quality, as well as on living beings. It contains high levels of organic, inorganic, heavy metal, and xenobiotic matter, which percolates through the subsoil and contaminates the groundwater.

increased as distance from the buffer zone increased as well (Table 4); the results presented in Fig. 4 show that surface waters must be 1000 m away from the selected landfill. Places that are at distances under 1000 m are unsuitable, places that are between 1000 m–2000 m away are less suitable, places between 2000 m–3000 m away are moderately suitable and places 3000 m away are highly suitable.

4.1.2. Sensitive Ecosystems

A landfill should not be located near any sensitive ecosystem such as lakes, dams, or wetlands (Alavi *et al.*, 2013; Sener *et al.*, 2010). M'sila is located near some sensitive areas, such as Ksob dam (With a capacity of 50 million cubic meters of water intended for the irrigation of 13,000 ha). For this reason, a 500 m buffer was placed around all sensitive ecosystems. Therefore, a score of 0 was assigned when the distance to a sensitive ecosystem was under 500 m. However, when the distance from the boundary was increased, the score rose accordingly, based on the expert opinion judgement. Therefore, if the distance to a sensitive ecosystem was over 3000 m, a score of 10 was allocated (Table 4); thus, the areas will be highly suitable for landfill sites (Fig. 3).

4.1.3. Residential area

Because of odour, dust and noise, the landfill sites' proximity to urban and rural areas can have an impact on the population and the landscape (Uyan, 2014; Tchobanoglous *et al.*, 1993). For that, the landfill site should not be placed near a residential or urban area, so as to avoid adversely affecting land value and future development, and to protect the general public from possible environmental hazards stemming from landfill sites. In this study, scores of 0 and 10 were given respectively to a distance under 1000 m and over 2000 m to a residential area. The results presented in Fig. 2 show areas that are at distances under 1000 m to residences to be unsuitable (Nas *et al.*, 2010), areas at between 1000 m–2000 m away to be less suitable, and areas that over 2000 m away – highly suitable.

4.2. SOCIO-ECONOMIC CRITERIA

4.2.1. Land Uses

Due to its reliance on an understanding both of the natural environment and the kinds of land uses envisaged, land use planning when performing site selection is an important criterion; therefore, based on the general land uses in this area, land uses were divided into the residential, agricultural, industrial, activity-dedicated and unused lands. Disposal of MSW onto built-up lands is strictly forbidden; consequently, built-up lands were deemed unsuitable for landfill sites and received a score of 0.

The unused lands, with a score of 10, were ranked highly suitable because of the easy clearing, good terrain and low economic values. Pastures and agricultural lands were ranked moderately suitable, barren land was ranked highly suitable because of the light vegetation and orchards were ranked unsuitable as they are not suitable for siting landfills (Fig. 7).

4.2.2. Distance to Roads

Distance to roads is an important criterion; hence, closer distances to main roads received higher scores. According to environmental experts, the distance between a landfill and a main road should be under 500 m. To assess this criterion, 500 m buffer zones were established around all roads. Distances of 500–1000 m received scores of 5. The highest score, that of 10, was assigned to a distance under 500 m (Table 4). The results shown in Fig. 8 indicate that distances greater than 1000 m from roads are less suitable, a distance between 500 m and 1000 m may be considered suitable, which corresponds to the study of Allen *et al.* (2002) who affirmed that a distance over 1 km away from main roads should be avoided. The most suitable distance from the road is under 500 m for easy accessibility.

4.2.3. Slope

Land slope is a basic parameter for the construction and operation of a landfill site. Sites with steep slopes are usually not technically suitable for landfill construction. The values of the slope distribution in M'sila range between 0 and over 45°, as demonstrated in Fig. 6.

The very steep areas (>45%), the steep areas (25 – 45%), the inclined planes areas (10 – 25%) and the slightly sloping areas (<10%) received scores of 0, 1, 5, and 10, respectively (Table 4). The most suitable areas were considered to be the inclined planes (10 – 25%) with a score of 5, while the slightly sloping areas (<10%), with a score of 10 (Kontos *et al.*, 2005), may be regarded as most appropriate areas. Those areas exceeding a 45° – slope were deemed not appropriate for a landfill site, which is accordance with the study of Guiqin *et al.* (2009) who affirmed that a slope greater than 40° is not suitable as a landfill site.

4.2.4. Distance from settlements

Locating a landfill near urban centres and villages can cause a negative environmental impact including odour, noise caused by vehicles and mechanical equipment, traffic, and dust. According to environmental experts, landfills at a distance of under 1000 m from population centres are not allowed, whereas those situated more than 2000 m away are highly suitable.

5. CONCLUSIONS

Disposing municipal solid waste to open dumps leads to many environmental and public health concerns in M'sila. In order to consider all criteria for landfill site identification within this extended area, we have applied a combined methodology of GIS and AHP. The landfill site selection criteria taken into consideration include proximity to major roads, built-up areas, land use, sensitive ecosystems, slope and water bodies. GIS was employed to digitize all the spatial features related to suitably siting landfill areas.

In this study, different data from various parameters were obtained and prepared in a GIS environment. Then, we used AHP to establish the relative importance of criteria to each other, and the SAW method to evaluate land suitability. The results showed that among the studied criteria, sensitive ecosystems and surface waters were the most important ones. The sensitive ecosystems were the major criteria in this case study, while the least important criterion was proximity to roads.

The purpose of this study was to pursue an appropriate selection process by taking into account environmental issues, and to suggest an appropriate site for landfills using GIS and multi-criteria decision-making techniques (AHP) so as to facilitate the choice of a suitable location.

As a result, approximately 0.5% of the entire study region was highly suitable for landfilling, while 4.73% was only suitable. These sites are easy to access for the disposal of solid waste. They are located in the northern and southern part of the study area. These are the most suitable classes, which could be suitable from an environmental, transport and socio-economic point of view.

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