KSCE Journal of Civil Engineering (0000) 00(0):1-11
DOI
Copyright ⓒ2016 Korean Society of Civil Engineers
Environmental Engineering
pISSN 1226-7988, eISSN 1976-3808
www.springer.com/12205

An Application of OLAP/GIS-Fuzzy AHP-TOPSIS Methodology for Decision Making: Location Selection for Landfill of Industrial Wastes as a Case Study

Hanine Mohamed*, Boutkhoum Omar, Tikniouine Abdessadek***, and Agouti Tarik******

Received February 7, 2015/Revised October 3, 2015/Accepted September 12, 2016/Published Online

Abstract

The location selection for Landfill of Industrial Wastes (LIW) is a very significant task in waste management studies, which has significant impacts on sustainable development of the region. Furthermore, the selection of the appropriate and efficient sites for LIWs is an important multi-criteria decision making problem. The present document suggests an OLAP/GIS-Fuzzy AHP-TOPSIS based methodology for evaluation and selection of best sites for LIWs. In this respect, the candidate locations are specified based on the combination of On-Line Analytical Processing and Geographic Information System (OLAP/GIS). The Fuzzy Analytical Hierarchy Process (Fuzzy-AHP), a multi-criteria decision-making method is applied to analyze the structure of the problem and obtain the weights of the qualitative and quantitative criteria, by incorporating the uncertainty values in decision-making. Then, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is taken into account to assess and rank the alternative locations. Finally, a hypothetical application of the proposed approach is illustrated by a case study of location selection for LIWs in Morocco. The results show that the proposed methodology can successfully achieve the aim of this work.

Keywords: *location selection, landfill of industrial wastes, OLAP, GIS, Fuzzy-AHP, TOPSIS*

1. Introduction

Nowadays, in wastes management, the problem of location selection for Landfill of Industrial Wastes (LIW) is among the most important strategic decisions as it depends on several conflicting factors (Beskese *et al.*, 2015). For an appropriate selection, a decision maker must raise the difficulties of the diversity of the criteria and factors regarding decisions, the importance of the number of possible solutions and the heterogeneity of socio-economic spaces. Multiple precision-based location selection techniques have been studied so far (Beskese *et al*., 2015; Gumus, 2009; Wang *et al*., 2009; Gemitzi *et al.*, 2007; Babalola and Busu, 2011; Mahini and Gholamalifard, 2006), and the importance of the location selection cannot be overlooked.

Geographic Information System (GIS) and Multi-Criteria Decision-Making (MCDM) methods have been applied to resolve the problems of location selection for landfill of wastes as an effective and successful tool, particularly during recent years. Wang *et al*. (2009), presents an approach that integrates Analytical Hierarchy Process (AHP) and GIS to select the most suitable site for landfill of solid wastes in Beijing, China. Gemitzi *et al.*, 2007 solved the problem of location siting Municipal Solid Waste (MSW) landfills using an MCDM model with GIS in Greece, where the assessments of different sites under various criteria and weights of criteria are assessed by fuzzy numbers. Babalola and Busu (2011) considered Analytical Network Processing (ANP) with GIS for solving landfill sites for solid wastes in Damaturu, Nigeria. Mahini and Gholamalifard, (2006), applied Weighted Linear Combination (WLC) in a GIS environment to evaluate the suitability of the study region for landfill. Also, Ekmekçioğlu *et al.* (2010), applied fuzzy AHP and fuzzy TOPSIS for the selection site for MSW in Turkey. Demesouka *et al.* (2013), developed an integrated MCDM model to Suitability analysis for siting Municipal Solid Waste (MSW) landfills, which was based on AHP and TOPSIS methods. Vego *et al.* (2008), considered a PROMETHEE II and GAIA methodology to find the most suitable site for MSW management in Dalmatia, Croatia.

The literature review shows that many approaches that combine GIS with MCDM techniques, (such as WLC, ANP, GAIA,

*Ph.D. Candidate, Dept of Computer Science, Laboratory of Engineering and Information Systems, Cadi Ayyad University, Marrakesh, Morocco (Corresponding Author, E-mail: m.hanine@uca.ma)
**Ph.D. Candidate, Dept of Computer Science, Laboratory of Engineering and Information Systems, Cadi Ayyad University, Marrakesh, Morocco (E-mail: o.boutkhoum@uca.ma)
***Professor, Dept of Computer Science, Laboratory of Engineering and Information Systems, Cadi Ayyad University, Marrakesh, Morocco (E-mail: tikniouine@uca.ma)
****Assistant Professor, Dept of Computer Science, Team of Telecommunications and Computer Networks, Cadi Ayyad University, Marrakesh, Morocco (E-mail: t.agouti@uca.ma)

PROMETHEE, AHP, Fuzzy ANP, TOPSIS and MACBETHEE) have been used for the localization of suitable site for landfill wastes. However, in these approaches, decision-makers have to deal with a huge amount of data including valuable information on characteristics of existing areas for development projects. This set of information is used to be managed in transactional (i.e. relational) databases that are hard to access for decision makers in usable forms and formats (Ahmad *et al.*, 2004). The most of database applied in these approaches are based on the concept of On-Line Transactional Processing (OLTP).

Despite the big influence of GIS with transactional database in the management of spatial data, this concept cannot offer the relevant information quickly and efficiently to decision-makers (Bédard *et al.*, 2006; Bédard *et al.*, 2001). Indeed, GIS cannot effectively be designed to support numerical and multidimensional data exploration. Hence, the new types of systems have been developed to precisely realize decisional requirements such as data warehousing, based on the idea of OLAP (On-Line Analytical Processing) as opposed to OLTP. Generally, this technology is based on the multidimensional database approach which introduces concepts that differ from the concepts found in the transactional database approach (Bédard *et al*., 2003; Kyung *et al.*, 2012). Table 1 summarizes a comparison between transactional OLTP and OLAP models (Rivest *et al.*, 2001; Watson and Gray, 1997).

Many approaches and tools deal with the combination of OLAP and GIS. The most important work in this field is Spatial OLAP (SOLAP) provided by Geomatics Center of Laval University in Canada, the essential features of which are quick and easy spatio-temporal analysis, exploration of multidimensional data and also provides a set of visualization techniques, such as diagrams, tables and maps (Bédard *et al*., 2001; Bédard *et al.*, 2003; Bédard *et al*., 2006). Another research axis proposed by Voss for combining the CubeView and Polaris to facilitate the observation of spatial patterns and temporal trends in huge volumes of data (Voss *et al.,* 2004). Some research works focalize on the combination of GIS and OLAP in a single tool named GOLAPA (*Geographic Online Analytic Processing Architecture*), proposed by Informatics Center of the Federal Pernambuco University in Brazil to provide users with an abstraction of the complexity implicated in querying both analytical and geographic data for decision-making (Fidalgo *et al.*, 2003; Fidalgo *et al*., 2004). Moreover, Biomonte *et al*. (2006) propose an extensible GIS-OLAP integrated solution supporting geographical dimensions and measures, based on a formal multidimensional model named GeoCube.

In this document, to resolve the problem of location selection for LIWs, a new decision-making framework that integrates the OLAP/GIS technology, Fuzzy-AHP and TOPSIS techniques is introduced. According to the literatures, the authors cannot find another approach that integrates these three techniques to resolve the problem of location selection for LIW. Each of these techniques has strong points and weaknesses. We aim at designing a new decision methodology that benefits from the advantages of the above-mentioned techniques and methods for solving the decision-making problem in practice. In this regard, the aim of using OLAP/GIS is to facilitate the decision-making process by determining the candidate locations. Fuzzy AHP is utilized to structure the problem and give the weights of various criteria by integrating the uncertainty values in the decision-making process. Then, TOPSIS is applied to rank the alternative locations.

The proposed hybrid framework has main advantages according to the previously proposed methodologies in the literature, as follows: (i) it is adapted for the selection of location for LIW to consider the decision-makers' preferences and judgements depending on their experiences and knowledge; (*ii*) it is suitable in supporting the multidimensional database and OLAP visualization; (*iii*) the powerful graphical visualization tool, called Geographic Information System (GIS), is offered for the spatial analysis of the localization of the candidate sites according to the spatial criteria defined by decision-makers, (*iv*) the weights of selected criteria and sub-criteria are calculated by using pairwise comparisons, with fuzzy-AHP method, and (*v*) the ranking of the alternative locations are provided with TOPSIS method.

Table 2 provides a synthesis of advantages and drawbacks of the MCDM methods to landfill location selection. This would be useful for understanding the necessity for a hybrid methodology, which has been proposed in this current study.

The remainder of this document is structured as follows. In the second section, the proposed integrated framework is concisely explained. For an easier understanding of the proposed framework, an empirical study is demonstrated in the next section. In the fourth section, the sensitivity analysis is highlighted. Finally, some perspectives and a conclusion are presented in the last section.

Table 1. Comparison of OLTP and OLAP Models (adapted form. Watson and Gray, 1997)

Criteria	OLTP	OLAP
– History Management	– By updating instances	– By adding new data (history conserved)
– Type of data	– Detailed	– Detailed and Aggregated
– Query execution Time	– Variable: depends on the complexity, the number of tables that are involved in joins	– Stable: regardless of the complexity due to the multidimensional Structure
– Size capacity	– Space minimized by the normalized Structure	– Large volume generated by the Storage aggregations
– Temporality	– Uni-time	– Multi-times
– Database	– Relational	– Relational or Multidimensional

Table 2. Comparison of Some Methods Applied to LIWs

MCDM methods	Advantages	Drawbacks
AHP	– Can be used for one or various problems, as it includes qualitative and quantitative attributes. – Easy to structure even complex decision problems. – The consistency index of the evaluation can be calculated and displayed for the decision-makers (Pohekar and Ramachandran, 2004). – It can be performed by using a simple spreadsheet.	– The number of pair-wise comparisons rise with more alternatives and criteria. – Needs very complex calculations (Chou *et al*., 2008). – Time-consuming.
TOPSIS	– Provision of an analytical framework for ranking of alternatives (Geng *et al.*, 2010). – Computing the distance of the alternatives from the ideal solution. – Very simple to apply and to understand. – Only needs a simple spreadsheet to be shown.	– Normalization is necessary to resolve multi-dimensional problems. – There is no way to check for Consistency.
Fuzzy set theory	– A suitable mathematical tool for the analysis of an imprecision and vagueness description of objects or ambiguity, which follows from information granulation.	– Impossible to process inconsistencies for MCDM problems, such as ranking, choosing or sorting.

2. Proposed Integrated Decision-making Methodology

Over the recent years, a number of researchers have devoted their efforts to develop the best approaches for decision-making. The proposed approach is applied in such a way that makes the combination of OLAP/GIS with MCDM methods as efficient as possible. It consists of using the functionalities of OLAP/GIS to prepare the inputs necessary for the multi-criteria methods. Operationally, the proposed system begins with the definition of the problem, where the analytical capabilities of OLAP/GIS are utilized to generate the set of candidate locations for LIW. In order to take into account the uncertainty in weight calculation of attributes, the present methodology introduces triangular fuzzy numbers into traditional AHP method. Finally, to classify the alternative locations, one of the most efficient MCDM methods like, TOPSIS is applied (Mousavi *et al.*, 2013).

A three steps approach has been applied for evaluating and selecting the most efficient site for LIWs (Fig. 1). The three steps of

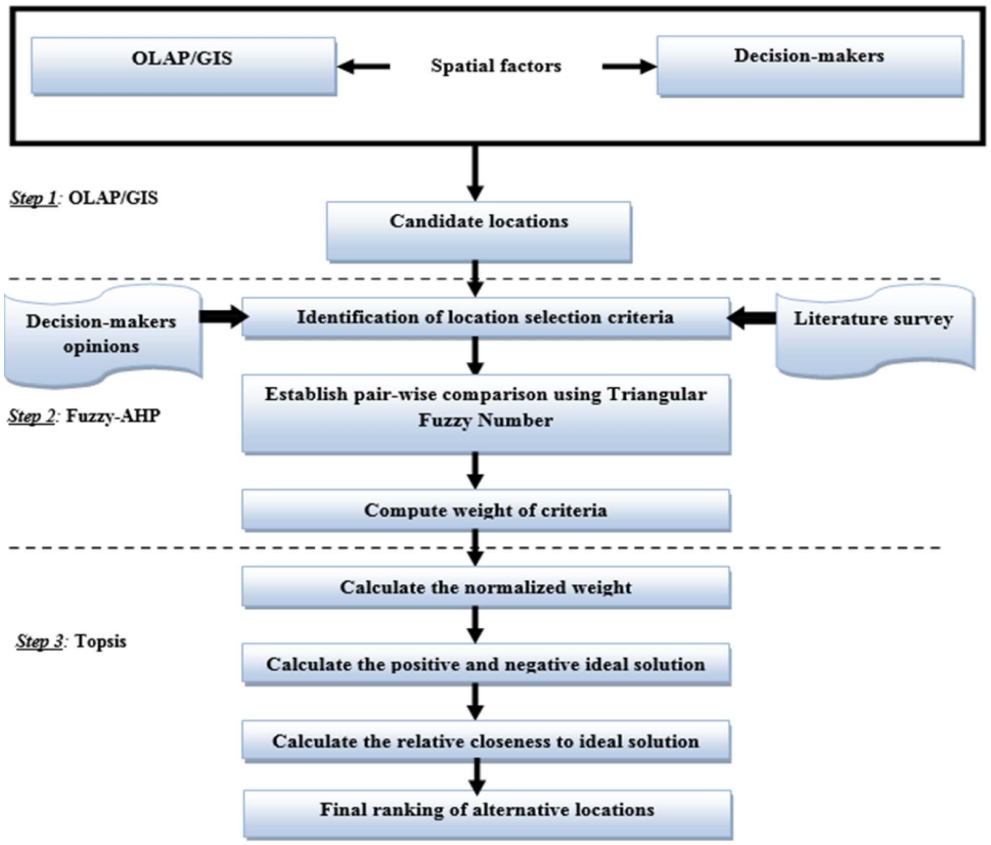


Fig. 1. The Three Steps Research Approach

the integrated approach are illustrated in the following subsections.

2.1 Step I-OLAP/GIS

In this step, the candidate feasible sites are specified based on the combination of OLAP and GIS. Firstly, decision-makers use ETL (Extract, Transform and Load) software for extracting data from several sources stored in decisional database (i.e. data warehouse). Additionally, they suggest to analyze data using online analytical techniques such as OLAP to provide strategic numerical information to improve the decision making process. Concerning spatial analysis, decision-makers use GIS application based on layer superposition techniques for building a map to reduce a vast list of available locations to a few potential locations for LIWs with respect to spatial factors.

2.2 Step II-Fuzzy-AHP

AHP is a MCDM technique that was introduced in the 1970s by Saaty (Saaty, 1980). It has been applied widely for analyzing difficult decisions by incorporating both qualitative and quantitative criteria in the decision-making process. However, it has been generally criticized because it made it impossible to reflect the decision-makers' uncertain preferences through crisp values (De, 1987).

Consequently, Fuzzy-AHP is proposed for this study to consider the linguistic imprecision in the decision-maker's mind. Recently, fuzzy-AHP has been applied to resolve multi-criteria decision-making problems in many areas, for example, selecting location for thermal power plant location (Choudhary and Shankar, 2012), selection site for landfill of wastes (Beskese *et al.*, 2015), selection of the suitable site of a bridge construction (Ardeshir *et al*., 2014) and selection of best data warehouse system (Lin *et al*., 2007).

There are many techniques that allow us to obtain the weights of factors in Fuzzy-AHP, the one mostly used is that of Buckley (1985). The latter is suitable in this present study to evaluate the criteria and sub-criteria.

Buckley's method is based on Triangular Fuzzy Numbers (TFN) to give the interval judgments for the preferences of each criterion over another, and then the synthetic value of the pair-wise comparison is calculated. In this method, the first step is to use TFN for pair-wise comparison by means of Fuzzy-AHP scale (Table 3-Fig. 2).

These pairwise comparisons are combined to form individual decision matrices as,

Table 3. Triangular Fuzzy Numbers of Linguistic Comparison Measures (Choudhary and Shankar, 2012)

Linguistic scale	Triangular fuzzy scale	Reciprocal
Equal	(1,1,1)	(1,1,1)
Important	(1,3,5)	(1/5,1/3,1)
Strongly important	(3,5,7)	(1/7,1/5,1/3)
Very strongly important	(5,7,9)	(1/9,1/7,1/5)
Extremely Preferred	(7,9,9)	(1/9,1/9,1/7)

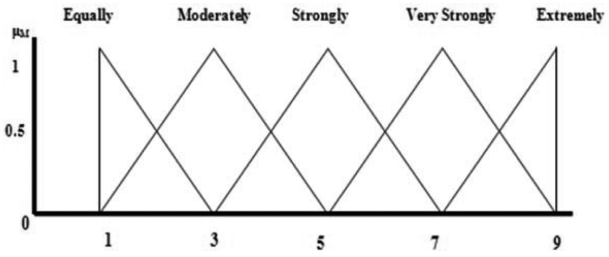


Fig. 2. Linguistic Variables for the Weight of Each Criteria

$$\tilde{D} = \begin{bmatrix} \tilde{d}_{11} & \tilde{d}_{12} & ..... & \tilde{d}_{1n} \\ \tilde{d}_{21} & \tilde{d}_{22} & ..... & \tilde{d}_{2n} \\ ..... & ..... & ..... & ..... \\ \tilde{d}_{m1} & \tilde{d}_{m2} & ..... & \tilde{d}_{mn} \end{bmatrix} \quad (1)$$

The fuzzy weight matrix is computed by using Buckley's method as adapted from Kahraman and Cebi (2009), as follows:

$$\tilde{g}_i = \sqrt[n]{\tilde{d}_{i1} \otimes \tilde{d}_{i2} \otimes ... \otimes \tilde{d}_{in}} \quad (2)$$

$$\tilde{p}_i = \tilde{g}_i \otimes (\tilde{g}_1 \oplus \tilde{g}_2 \oplus ... \oplus \tilde{g}_n)^{-1} \quad (3)$$

where $\tilde{d}_{ij}$ is the fuzzy comparison value of criterion i according to criterion j. $\tilde{g}_{ij}$ is the geometric mean of fuzzy comparison value of criterion i to each criterion. $\tilde{P}_{ij}$ is the weight of criterion i, and is the fuzzy addition sign. Once all of the fuzzy weights are computed, centroid technique is utilized to transform these fuzzy numbers to crisp values. In this technique, conversion process is performed using the center of the gravity. It is the technique mostly used for defuzzification (Beskese *et al.*, 2015; Opricovic and Tzeng, 2004). Once the defuzzification is finished, normalization follows. These two processes can be applied at the same time by using Eq. (4)

$$\tilde{p}_g = \frac{\tilde{P}_g}{\sum_{i=1}^{n} \tilde{p}_i} = \frac{\tilde{P}_{ga} + \tilde{P}_{gb} + \tilde{P}_{gc}}{\sum_{i=1}^{n} \tilde{p}_i} \quad (4)$$

Where the importance weight of g^{th} criterion, p_g, is a crisp number and n is the number of the criteria.

2.3 Step III-TOPSIS

In this phase, TOPSIS method has been applied to classify the alternative sites based on their overall performance. Hwang and Yoon (1981) develop this method, to resolve MCDM problems based on the concept that has been chosen as the best alternative, having the shortest distance from the Positive Ideal Solution (PIS) and the longest distance from the Negative Ideal Solution (NIS). For example, the PIS maximizes the criteria $C1$ and minimizes the criteria $C2$, whereas the NIS maximizes the criteria $C2$ and minimizes the criteria $C1$. In TOPSIS steps, the performance evaluation and the weights of the criteria are calculated as exact values (Ilangkumaran and Kumanan, 2009). This method is widely used in many sectors, including tourism destination evaluation, Location selection, financial performance evaluation, software selection, company evaluation, and ranking the carrier alternatives. Thereafter, the alternatives are classified

according to the relative closeness to the ideal solutions (Hwang and Yoon, 1981; Joshi *et al.*, 2011). The general TOPSIS steps have the following, (Choudhary and Shankar, 2012; Joshi *et al*., 2011):

Step 1: Construct normalized decision matrix. The normalized value e'_{ij} is computed using the following equation:

$$e'_{ij} = \frac{g_{ij}}{\sqrt{\sum_{i=1}^{m}\left[g_{ij}\right]^2}} \quad ; \mathrm{i} = 1, 2, .., \mathrm{m}; \mathrm{j} = 1, 2.., \mathrm{n} \tag{5}$$

Where g_{ij} is deterministic value of alternative *i* for each criterion *j*.

Step 2: Construct the weighted normalized decision matrix by multiplying the normalized decision matrix with its related weights. An element of the new matrix is:

$$v_{ij} = \pi_j \times e'_{ij} \quad ; \mathrm{i} = 1, 2, .., \mathrm{m}; \text{ and } \mathrm{j} = 1, 2.., \mathrm{n} \tag{6}$$

Where π_j is the weight of j^{th} criterion.

Step 3: Identify the PIS (A*) and NIS (A-).

PIS: (7)

$$A^* = \left\{v_1^+, ..., v_n^+\right\} \text{ Where,}$$

$$v_j^+ = \left\{\max(v_{ij}) \; if \; j \in J; \min(v_{ij}) \; if \; j \in J'\right\}, j = 1,...., n.$$

NIS: (8)

$$A^- = \left\{v_1^-, ..., v_n^-\right\} \text{ Where,}$$

$$v_j^- = \left\{\min(v_{ij}) \; if \; j \in J; \max(v_{ij}) \; if \; j \in J'\right\}, j = 1,...., n.$$

Step 4: Determine the Euclidean distance of each alternative from the PIS and NIS.

Positive ideal solution: (9)

$$D_i^* = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^+)^2}, \mathrm{i}=1,2,.....\mathrm{m}$$

Negative ideal solution: (10)

$$D_i^- = \sqrt{\sum_{j=1}^{n}(v_{ij} - v_j^-)^2}, \mathrm{i} = 1, 2, ..., \mathrm{m}$$

Step 5: Compute the relative closeness of the i^{th} alternative to ideal solution using the following equation:

$$CC_i = \frac{D_i^-}{D_i^* + D_i^-}, \quad \mathrm{i} = 1,2, ..., \mathrm{m} \tag{11}$$

With, $0 \le \mathrm{CC_i} \le 1$

Step 6: Classify the alternatives sites based on values o f CC_i and choosing the appropriate one.

3. Case Study

In this chapter, for an easier understanding of the proposed integrated approach, an application is provided. Casablanca Province being considered in this study is located in the west of Morocco. The study area also has many industrial zones with diversified industries: Energy, Aerospace, Shipbuilding, Electronics, Plastics, Steel, Pharmaceuticals, Foods, Textile, Metal furniture, Chemicals, Fertilizers and Phosphate derivatives, etc… All these industries produce wastes of various kinds, some of which are toxic and dangerous, menacing human health.

Decision making in location selection for LIW is very significant in the long-term development for the province policy. The decision is required based on many different reasons, like the increase in the production of industrial wastes. Hence, decision-makers should choose the location for a new site that not only works well, but also is sufficiently flexible to accommodate future needs in the province policy. Various important factors that can be classified as spatial (such as proximity to residential areas, geographical and geotechnical characteristics of sites, etc.) and non-spatial factors (such Available land area, soil conditions and topography, and Economics considerations), can be considered while selecting a better site location for LIW. The success or failure of the project depends on the consideration of those factors. In fact, conflicting criteria have high significant impacts on the process for solving the problem.

A location selection group of ten experts is assigned the task of selecting the best locations to construct new LIWs. The three-phase framework shown in Section 2 is adopted to select the best locations for LIWs as discussed in the following subsections.

In this respect, spatial factors are used in GIS for selecting the candidate locations, and non-spatial factors are used for ranking the alternatives from which the most suitable site is selected. The problem is then solved by using the proposed methodology demonstrated in section 2. The results display the productivity of the system in a real-life. This process of application is presented and discussed in the following steps:

3.1 Application of OLAP/GIS in the Identification of Candidate Locations

In this part, many technologies are used such as ETL (Extract, Transform, and Load), Data warehouse, OLAP, and GIS maps to identify candidate sites for LIW. Firstly, the aim of using ETL is to facilitate the extraction of data from several sources (i.e., file, transactional database...) and are stored in the data warehouse. This latter is a collection of data oriented by subject, non-volatile and variable in time for supporting decision-making process (Inmon *et al.*, 1996).

Deploying a data warehouse requires appropriate design process and data model. Concerning the design process, there are three concepts: Star schema, Snowflake schema and Hybrid schema. The snowflake schema is applied in this current research for rapid and easy migration of data from transactional database to data warehouse (Ahmad *et al.*, 2004). Concerning the data model, the multidimensional model is the most preferred one to capture all characteristics of data warehouse. This model is based on three concepts: Facts, dimensions and measures (Ahmad *et al.*, 2004). Fig. 3 presents the snowflake schema proposed for designing the data warehouse in this study.

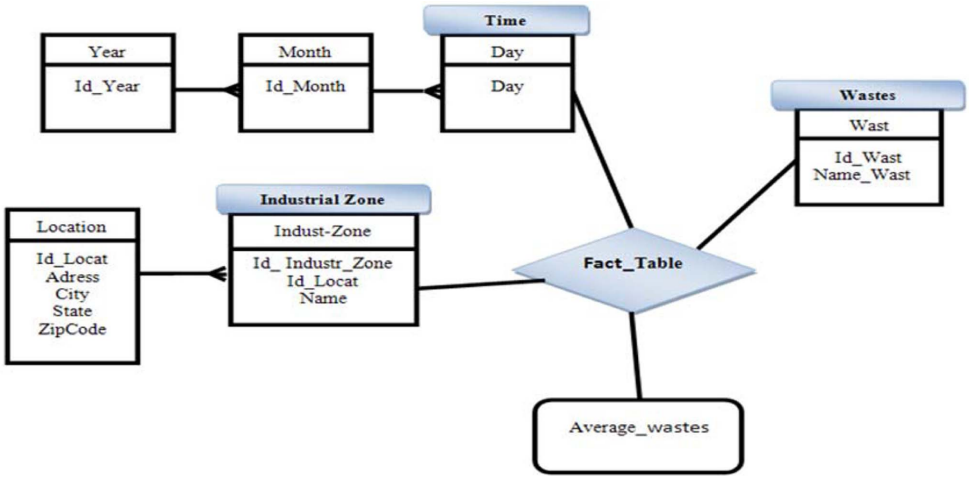
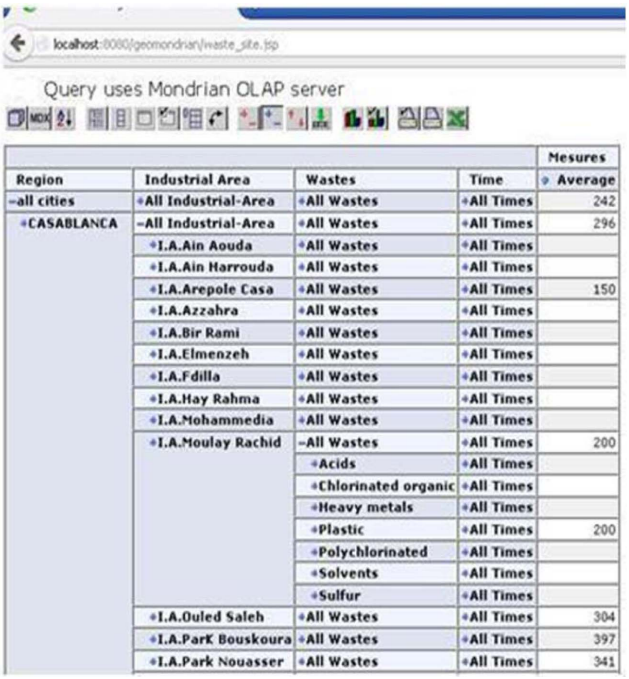


Fig. 3. The Snowflake Schema for Data Warehouse Model

In order to deploy the solution, the data warehouse is implemented in PostgreSQL, which supports the multidimensional concept that is well chosen in this work to offer a stable, fast and standards compliant database with a brilliant geospatial extension (PostGIS). Furthermore, our aim is not to develop a commercial software product. Hence, we use rather Pentaho Data Integration to extract and load data, Mondrian Server to provide OLAP numerical analysis, and MapInfo (GIS Software) for spatial analysis.

In application, firstly we have implemented an OLAP client under Mondrian server. The advantage of the use of OLAP Mondrian server is that the users can apply various graphical wizards to write their queries easily and show results in several graphical formats. A snapshot of this prototype tool used in this work which allows answering complex queries, is shown in Fig. 4. For example: "What is the average value for each type of waste for each industrial area and for Casablanca city in all times?".



				Mesures
Region	Industrial Area	Wastes	Time	Average
-all cities	+All Industrial-Area	+All Wastes	+All Times	242
+CASABLANCA	-All Industrial-Area	+All Wastes	+All Times	296
	+I.A.Ain Aouda	+All Wastes	+All Times	
	+I.A.Ain Harrouda	+All Wastes	+All Times	
	+I.A.Arepole Casa	+All Wastes	+All Times	150
	+I.A.Azzahra	+All Wastes	+All Times	
	+I.A.Bir Rami	+All Wastes	+All Times	
	+I.A.Elmenzeh	+All Wastes	+All Times	
	+I.A.Fdilla	+All Wastes	+All Times	
	+I.A.Hay Rahma	+All Wastes	+All Times	
	+I.A.Mohammedia	+All Wastes	+All Times	
	+I.A.Moulay Rachid	-All Wastes	+All Times	200
		+Acids	+All Times	
		+Chlorinated organic	+All Times	
		+Heavy metals	+All Times	
		+Plastic	+All Times	200
		+Polychlorinated	+All Times	
		+Solvents	+All Times	
		+Sulfur	+All Times	
	+I.A.Ouled Saleh	+All Wastes	+All Times	304
	+I.A.ParK Bouskoura	+All Wastes	+All Times	397
	+I.A.Park Nouasser	+All Wastes	+All Times	341

Fig. 4. Visual Interface of the Mondrian Server

Finally, for determining the candidate locations, the system was run to export data to MapInfo after performing the spatial analysis by using the layer superposition technique. The list of available locations was limited to a few potential locations that satisfy the following spatial factors: a) The grounds having good ability for agriculture are excluded; b) The coast with a protection zone around 5 km is excluded; c) the residential areas with a protection zone about 2 km are excluded; d) 1km about streams, rivers, streams and lagoons are excluded.

In this process, twelve candidate locations are specified based on OLAP/GIS. The location selection group visits these locations to collect socio-economic and other relevant information of each location. After these visits, four locations were removed from the list due to socio-economic reasons. Three more sites were further removed from the list after considering location selection guidelines of the Moroccan Ministry of Environment (Minenv, 2013). The remaining five candidate sites are as follows and shown in Fig. 5:

S1: Tit Mellil, Mediouna Province.
S2: Oulad Salah, Nouaceur Province.
S3: Lahraouyine, Mediouna Province.
S4: Dar Bouazza, Nouaceur Province.
S5: Bouskoura, Nouaceur Province.

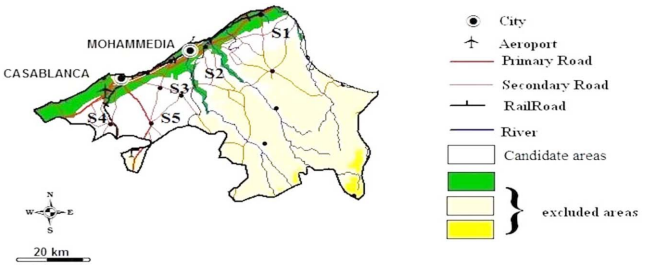


Fig. 5. Map of the Candidate Locations

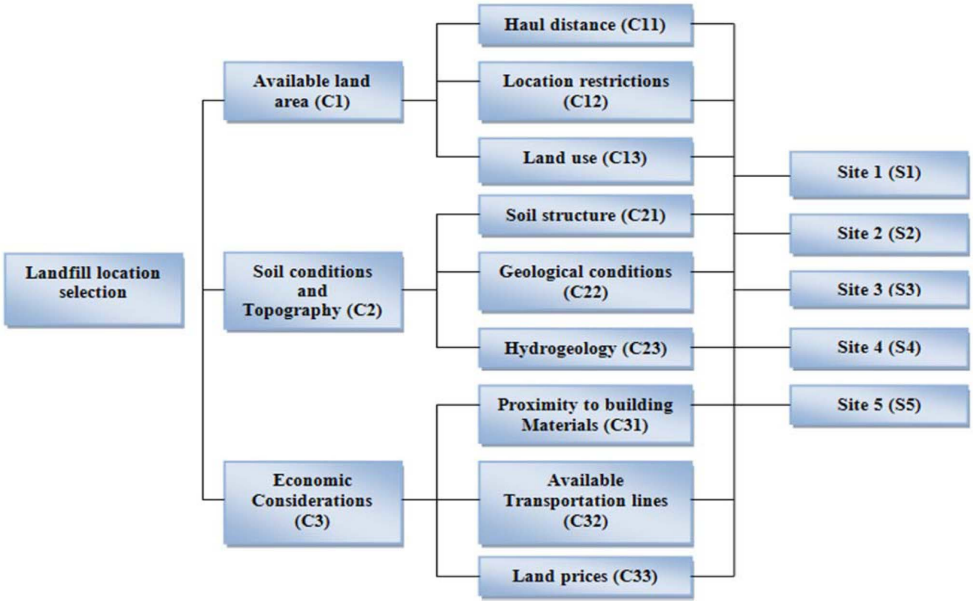


Fig. 6. Hierarchical Structure of the Criteria for Landfill Suitability

3.2 Application of fuzzy-AHP to Define the Importance Weights of Criteria

In Fuzzy-AHP, the first step is to determine the criteria for evaluation of possible sites. Hence, with the researching of literature review and recent opinions of some experts in order to determine some general decision-making attributes of location selection for LIW, the group of decision-makers identify three main criteria and nine sub-criteria having impacts in this study (Beskese *et al.*, 2015; Gumus, 2009; Gemitzi *et al*., 2007). These sub-criteria are further assembled into three criteria as Available land area, soil conditions and topography, and Economics considerations shown in Fig. 6, which present the hierarchy model of location selection for LIW. The highest level and the lowest level of the hierarchy denote the general objective (selecting the most suitable location for LIW) and the candidate locations (S1, S2, S3, S4, and S5) respectively. The three main criteria are included in the second level and are further broken down into sub-criteria in third level.

When all aspects of the criteria and sub-criteria are fixed, the next step is dedicated to obtain the priority weights of each attribute (criteria, sub-criteria and alternatives) using linguistic comparison terms and their equivalent Triangular Fuzzy Numbers (TFN) defined by Gumus, (2009) in Table 3. The fuzzy comparison matrices of criteria and sub-criteria along with computed weights are shown in Tables 4-6, and 7. An example of computations of the weights using Buckley's method for Table 4 is given below

Table 4. The Fuzzy Comparison Matrix of Criteria

	C1	C2	C3	Weight
C1	(1, 1, 1)	(1/7,1/5,1/3)	(1/5,1/3,1)	0.12
C2	(3,5,7)	(1, 1, 1)	(1,3,5)	0.61
C3	(1,3,5)	(1/5,1/3,1)	(1, 1, 1)	0.27

Table 5. The Fuzzy Comparison Matrix of Sub-criteria According to Criterion C1

	C11	C12	C13	Weight
C11	(1, 1, 1)	(1/7,1/5, 1/3)	(1, 3, 5)	0.27
C12	(3, 5, 7)	(1, 1, 1)	(1/9,1/7,1/5)	0.28
C13	(1/5,1/3, 1)	(5, 7, 9)	(1, 1, 1)	0.45

Table 6. The Fuzzy Comparison Matrix of Sub-criteria According to Criterion C2

	C21	C22	C23	Weight
C21	(1, 1, 1)	(1, 3, 5)	(1/7, 1/5, 1/3)	0.27
C22	(1/5,1/3,1)	(1, 1, 1)	(5, 7, 9)	0.46
C23	(3, 5, 7)	(1/9,1/7,1/5)	(1, 1, 1)	0.27

Table 7. The Fuzzy Comparison Matrix of Sub-criteria According to Criterion C3

	C31	C32	C33	Weight
C31	(1, 1, 1)	(1/7,1/5,1/3)	(1, 3, 5)	0.25
C32	(3, 5, 7)	(1, 1, 1)	(1/5,1/3,1)	0.40
C33	(1/5,1/3,1)	(1, 3, 5)	(1, 1, 1)	0.34

(Boutkhoum *et al.,* 2016).

These values has given the following $\tilde{g}_{ij}$ values:

$\tilde{g}_1$ = (0.30; 0.40; 0.70)

$\tilde{g}_2$ = (1.44; 2.47; 3.27)

$\tilde{g}_3$ = (0.58; 1; 1.71)

Where the values of i (i.e. 1, 2, and 3) represent the main criteria.

By using these values, the weights of the main criteria of the methodology were computed as:

$\tilde{p}_1$ = (0.13; 0.10; 0.12)

$\tilde{p}_2$ = (0.61; 0.64; 0.57)

$\tilde{p}_3$ = (0.25; 0.26; 0.30)

Table 8. Summary of the Evaluation Criteria Weights

Criteria	Local weight	Sub-criteria	Local weight	Overall weight
C1	0.12	C11	0.27	0.032
		C12	0.28	0.034
		C13	0.45	0.054
C2	0.61	C21	0.27	0.165
		C22	0.46	0.281
		C23	0.27	0.165
C3	0.29	C31	0.25	0.072
		C32	0.40	0.116
		C33	0.34	0.099

After defuzzification and normalization, the crisp values of the main criteria were found as p1 = 0.12;

$p_2 = 0.61$; and $p_3 = 0.27$.

For the rest of the computations of the weights are not shown here because they follow the same steps as discussed above. In the last step of fuzzy AHP, the results of overall weights for all the sub-criteria are calculated as an example Overall weight (C11) = Local weight (C1) * Local weight (C11) and shown in Table 8.

3.3 Application of TOPSIS in Ranking of Alternatives

In this part, TOPSIS technique is used to classify the alternative sites. The priority weights of each sub-criteria computed by fuzzy-AHP and presented in Table 8 can be used as input in TOPSIS. Then using the scale in Table 9, the decision-makers are asked to evaluate the alternative locations according to each sub-criterion (Table 10). Using Eqs. (5), (6), the weighted normalized decision matrix is obtained. This can be illustrated in Table 11.

Then, based on the calculation of the PIS and NIS for the alternative locations (i.e., A* and A-) as shown in the two last columns in Table 11 obtained by using Eqs. (7), (8), the decision-makers calculate the ranking of alternative sites. Table 12 shows the evaluation results and the final ranking of alternative locations for LIW. As a result, the best alternative is the one with the shortest distance to the PIS and with the longest distance to the NIS.

An example is applied in order to illustrate steps 5 and 6 for the computations of the alternative location (S1) as follows:

$$D_1^* = \sqrt{\begin{aligned}&(0.0232-0.0232)^2+(0.0035-0.0247)^2+(0.0241-0.0435)^2+\\&(0.0405-0.1216)^2+(0.1524-0.2133)^2+(0.0198-0.139)^2+\\&(0.0546-0.006)^2+(0.0632-0.009)^2+(0.0308-0.0103)^2\end{aligned}}$$

$$= 0.1762$$

$$D_1^- = \sqrt{\begin{aligned}&(0.0232-0.0033)^2+(0.0035-0.0035)^2+(0.0241-0.0049)^2+\\&(0.0405-0.0135)^2+(0.5124-0.0305)^2+(0.0198-0.0198)^2+\\&(0.0546-0.0546)^2+(0.0632-0.0813)^2+(0.0308-0.0719)^2\end{aligned}}$$

$$= 0.1356$$

Table 9. Scale of Pairwise Comparison

Relative importance	Definition
1	Equal importance
3	Weak importance
5	Strong importance
7	Demonstrated importance over the other
9	Absolute importance

Table 10. Input Values of the TOPSIS Analysis

	Weight	S1	S2	S3	S4	S5
C11	0.032	7	1	3	3	5
C12	0.034	1	3	5	7	3
C13	0.054	5	3	1	3	9
C21	0.165	3	1	9	3	7
C22	0.281	5	3	1	7	1
C23	0.165	1	3	3	1	7
C31	0.072	9	1	3	5	5
C32	0.116	7	3	5	9	1
C33	0.099	3	5	7	3	1

Table 12. The Final Evaluation and Ranking of Alternative

	D^*	D^-	CCi	Ranking
S1	0.1762	0.1356	0.4349	3
S2	0.1905	0.1056	0.3565	5
S3	0.2161	0.1271	0.3702	4
S4	0.1674	0.1924	0.5348	1
S5	0.1871	0.1792	0.4892	2

Table 11. The Weighted Normalized Decision Matrix

	S1	S2	S3	S4	S5		A+	A-
C11	0.02320	0.0033	0.0099	0.0099	0.0166	+	0.0232	0.0033
C12	0.00350	0.0106	0.0176	0.0247	0.0105	+	0.0247	0.00350
C13	0.02415	0.0145	0.0049	0.0145	0.0435	+	0.0435	0.0049
C21	0.04055	0.0135	0.1216	0.0405	0.0946	+	0.1216	0.0135
C22	0.15239	0.0914	0.0305	0.2133	0.0305	+	0.2133	0.0305
C23	0.01986	0.0596	0.0596	0.0199	0.1390	+	0.1390	0.01986
C31	0.05457	0.0061	0.0182	0.0303	0.0303	-	0.0061	0.05457
C32	0.06321	0.0271	0.0451	0.0813	0.0090	-	0.0090	0.0813
C33	0.03080	0.0513	0.0719	0.0308	0.0103	-	0.0103	0.0719

$CC1$ is calculated for this example as follows:

$$CC_1 = \frac{0.1356}{0.1356 + 0.1762} = 0.4349$$

4. Results and Discussion

4.1 Results Analysis

As cited in section 2.3, TOPSIS is chosen for use because of many reasons. However, in order to confirm the current ranking, the decision-makers propose to compare the current results with other techniques. Therefore, we use the other two known techniques like PROMETHEE II and TODIM. The details of PROMETHEE II and TODIM methods can be found in (Mousavi *et al*., 2013; Tosun *et al*., 2015; Peng *et al.*, 2014; Wei *et al*., 2015; Roshanaei *et al*., 2013). For importance weights, the similar assessment obtained results via fuzzy-AHP method are applied. Concerning the methodology, Fuzzy AHP-PROMETHEE II decision-makers decide to choose and use V-Shape preference function where the parameter value "p" of this function is set to two for all the criteria. The results calculated via fuzzy AHP-PROMETHEE II and fuzzy AHP-TODIM methodologies can be illustrated in Table 13. As can be seen from this Table, the optimal alternative does not change (S4) while the ranking of the alternatives changed. As a result, we can say that the final outranking of the proposed approach gives the very close solution to the fuzzy AHP-TODIM and fuzzy AHP-PROMETHEE II methods (Dağdeviren, 2008).

4.2 Sensitivity Analysis

The evaluation of location selection for LIWs alternatives is performed, and with respect to the *CCi* values, the ranking of the locations are S4–S5–S1–S3–S2 from the most to the least suitable. If the best location is required to be chosen, then the alternative S4 must be chosen because it has the highest *CCi* value.

A sensitivity analysis is performed to reveal the effect on the assessment process and ranking of alternatives by exchanging the priority weights of decision attributes. The results of the sensitivity analysis are presented in Table 14 and, graphically in Fig. 7. The principle of the sensitivity analysis is to exchange the weight gained from fuzzy-AHP among criterion, while the others are constant, and hence, five combinations of the three criteria are investigated (by adding the equal weight criterion). For each combination, the PIS, NIS and *CCi* value of the alternative locations are calculated to display the new results. Table 14 describes the calculation results, and Fig. 7 shows their graphical representation. The comparison of the main ranking with other combinations results illustrates that all alternatives are changing in ranking.

With respect to Table 14 and Fig. 7, it can be seen that the first combination describes the original results of the current work. In

Table 13. Ranks Compared with Other Methodologies

Alternatives	Fuzzy AHP-TOPSIS		Fuzzy AHP-PROMETHEE II		Fuzzy AHP-TODIM	
	Closeness coefficient (CCi)	Rank	Net Flow(Φ)	Rank	Total value δ(Aı)	Rank
S1	0.4349	3	-0.2877	5	0.852	2
S2	0.3565	5	-0.0113	3	0.532	4
S3	0.3702	4	-0.0500	4	0.00	5
S4	**0.5348**	1	**0.2991**	**1**	**1.00**	**1**
S5	0.4892	2	-0.0097	2	0.824	3

Table 14. The Sensitivity Analysis Results

Sensitivity analysis runs						
1	Wc	C1=**0.12**	C2=**0.61**	C3=**0.27**		
	CCi	S1=0.4349	S2=0.3565	S3=0.3702	S4=**0.5348**	S5=0.4892
	Ranking	**5**	**4**	**3**	**1**	**2**
2	Wc	C1=**0.61**	C2=**0.12**	C3=**0.27**		
	CCi	S1=0.4760	S2=0.3272	S3=0.2990	S4=0.4264	S5=**0.7226**
	Ranking	**2**	**4**	**5**	**3**	**1**
3	Wc	C1=**0.12**	C2=**0.27**	C3=**0.61**		
	CCi	S1=0.390	S2=0.5580	S3=0.4001	S4=0.4212	S5=**0.6918**
	Ranking	**5**	**2**	**4**	**3**	**1**
4	Wc	C1=**0.27**	C2=**0.61**	C3=**0.12**		
	CCi	S1=0.4505	S2=0.2936	S3=0.3547	S4=**0.5408**	S5=0.4837
	Ranking	**3**	**5**	**4**	**1**	**2**
5	Wc	C1=0.33	C2=0.33	C3=0.33		
	CCi	S1=0.4424	S2=0.3976	S3=0.3501	S4=0.4706	S5=**0.6130**
	Ranking	**3**	**5**	**4**	**2**	**1**

CCi: Value (CCi) of locations using TOPSIS
Wc: Weight of criteria

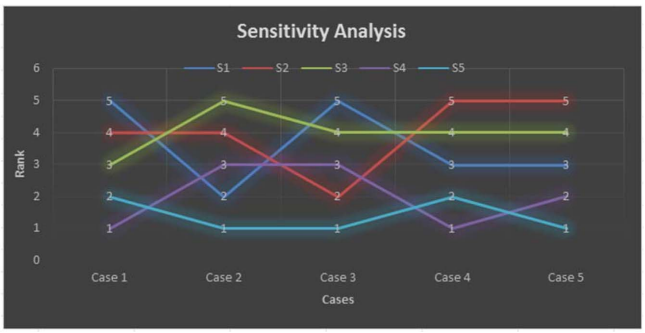


Fig. 7. Model Result Changes Caused by the Sensitivity Analysis

addition, out of five combinations, S2 has the lowest ranking when combinations are executed. In the second combination, the value *CCi* of S3 springs from 0.3702 to 0.2990, and ranking of S3 is changing from three to five. This also leads to change in ranking of S1 from five to two. S4 is ranked as first alternative in combinations one and four. Also S5 is selected as the first rank in combinations 2,3 and 5. Moreover, the results of the sensitivity analysis illustrate that the locations S5 and S4 are the most appropriate alternatives in all analyses for setting up new LIWs. The sensitivity analysis displays that the weights have effects on the alternatives' ranking. Additionally, this analysis makes the assessment process easier for the decision makers.

5. Conclusions

In this document, the methodology of OLAP/GIS-Fuzzy AHP-TOPSIS for assessing and selecting a suitable location for LIWs is handled. Firstly, the combination of OLAP and GIS is used to facilitate the decision-making process by providing candidate locations according to the spatial factors. Then, TOPSIS method uses Fuzzy-AHP result weights as input weights for determining the rank of alternative locations. In addition, an application example is illustrated to present the applicability and performance of the proposed approach through a case study of the location selection for LIW in Casablanca region. Also, the results obtained by the proposed methodology are compared with the results made by fuzzy AHP-TODIM and fuzzy AHP-PROMETHEE II approaches, for which the analysis of the results and sensitivity analysis are also presented. The proposed methodology is flexible to fit in with other sectors with some specific characteristic changes and to incorporate various factors in the assessment process.

As a future direction, a software can be prepared to accelerate and simplify the computations of both methods (Fuzzy-AHP and TOPSIS). As another direction, other methods can be included in the proposed methodology to ensure more reliability for decision-making process.

Acknowledgements

The authors are grateful to the referees for their pertinent remarks and suggestions as well as the Editor. They also wish to thank Prof. A. El Maknissi, for his suggestions and remarks. The authors also warmly thank Mr. Redouane Boulguid for noted out several English corrections that lead to the improvement of the document.

References

Ahmad, I., Azhar, S., and Lukauskis, P. (2004). "Development of a decision support system using data warehousing to assist builders/developers in site selection." *Automat Constr*, Vol. 13, No. 4, pp. 525-542, DOI: 10.1016/j.autcon.2004.03.001.

Ardeshir, A., Mohseni, N., Behzadian, K., and Errington, M. (2014). "Selection of a bridge construction site using fuzzy analytical hierarchy process in geographic information system." *Arab. J. Sci. Eng.*, Vol. 39, No. 6, pp. 4405-4420, DOI: 10.1007/s13369-014-1070-2.

Babalola, A. and Busu, I. (2011). "Selection of landfill sites for solid waste treatment in damaturu town-using GIS techniques." *Journal of Environmental Protection*, Vol. 2, No. 1, pp. 1-10, DOI: 10.4236/jep.2011.21001.

Beskese, A., Demir, H. H., Ozcan, H. K., Okten, H. E. (2015). "Landfill site selection using fuzzy AHP and fuzzy TOPSIS: A case study for Istanbul." *Environmental Earth Sciences*, Vol. 73, No. 7, pp. 3513-3521, DOI: 10.1007/s12665-014-3635-5.

Bédard, Y., Gosselin, P., Rivest, S., Proulx, M.-J., Nadeau, M., Lebel, G., and Gagnon, M.-F. (2003). "Integrating GIS components with knowledge discovery technology for environmental health decision support." *Int. J. Med Inform*, Vol. 70, No. 1, pp. 79-94, DOI: 10.1016/s1386-5056(02)00126-0.

Bédard, Y., Proulx, M. J., Rivest, S., and Badard, T. (2006). "Merging hypermedia GIS with spatial on-line analytical processing: Towards hypermedia SOLAP." *Lecture Notes in Geoinformation and Cartography*, pp. 167-187, DOI: 10.1007/978-3-540-34238-0_10.

Bédard, Y., Merrett, T., and Han, J. (2001). "Fundamentals of spatial data warehousing for geographic knowledge discovery." *Geographic Data Mining and Knowledge Discovery,* pp. 53-73, DOI: 10.4324/9780203468029_chapter_3.

Bimonte, S., Tchounikine, A., and Miquel, M. (2006). "GeoCube, a multidimensional model and navigation operators handling complex measures: Application in spatial OLAP." *Lect Notes Comput Sc*, pp. 100-109, DOI: 10.1007/11890393_11.

Boutkhoum, O., Hanine, M., Boukhriss, H., Agouti, T., and Tikniouine, A. (2016). "Multi-criteria decision support framework for sustainable implementation of effective green supply chain management practices." SpringerPlus, pp. 1-24, DOI: 10.1186/s40064-016-2233-2.

Buckley, J. J. (1985). "Fuzzy hierarchical analysis". Fuzzy Set Syst, 17, 233–247, DOI: 10.1016/0165-0114(85)90090-9.

Chou, S.-Y., Chang, Y.-H., and Shen, C.-Y. (2008). "A fuzzy simple additive weighting system under group decision-making for facility location selection with objective/subjective attributes." *Eur. J. Oper. Res.*, Vol. 189, No. 1, pp. 132-145, DOI: 10.1016/j.ejor.2007.05.006.

Choudhary, D. and Shankar, R. (2012). "An STEEP-fuzzy AHP-TOPSIS framework for evaluation and selection of thermal power plant location: A case study from India." *Energy*, Vol. 42, No. 1, pp. 510-521, DOI: 10.1016/j.energy.2012.03.010.

Dağdeviren, M. (2008). "Decision making in equipment selection: an integrated approach with AHP and PROMETHEE." *J. Intell Manuf*, Vol. 19, No. 4, pp. 397-406, DOI: 10.1007/s10845-008-0091-7.

Demesouka, O. E., Vavatsikos, A. P., and Anagnostopoulos, K. P.

(2013). "Suitability analysis for siting MSW landfills and its multicriteria spatial decision support system: Method, implementation and case study." *Waste Manage*, Vol. 33, No. 5, pp. 1190-1206, DOI: 10.1016/j.wasman.2013.01.030.

De, M. (1987). "A fuzzy multicriteria model for comparing energy projects." *Energy*, Vol. 12, No. 7, pp. 599-613, DOI: 10.1016/0360-5442(87)90101-0.

Ekmekçioğlu, M., Kaya, T., and Kahraman, C. (2010). "Fuzzy multicriteria disposal method and site selection for municipal solid waste." *Waste Manage*, Vol. 30, Nos. 8-9, pp. 1729-1736, DOI: 10.1016/j.wasman.2010.02.031.

Fidalgo, R., Silva, J., Times, V., Sousa, F., and Barros, R. (2003). "GMLA: A XML Schema for Integration and Exchange of Multidimensional Geographical Data." P*roc the 5th Annual Brazilian Symposium on GeoInformatics*, 2003.

Fidalgo, R. N., Times, V. C., Silva, J., Souza F., and Salgado, A. C. (2004). "Providing multidimensional and geographical integration based on a gdw and metamodels." *Proc. Brazilian Symposium on Databases (SBBD)*, 2004.

Gemitzi, A., Tsihrintzis, V. A., Voudrias, E., Petalas, C., and Stravodimos, G. (2007). "Combining geographic information system, multicriteria evaluation techniques and fuzzy logic in siting MSW landfills." *Environ Geol,* Vol. 51, No. 5, pp. 797-811, DOI: 10.1007/s00254-006-0359-1.

Geng, X., Chu, X., and Zhang, Z. (2010). "A new integrated design concept evaluation approach based on vague sets." *Expert Syst Appl*, Vol. 37, No. 9, pp. 6629-6638, DOI: 10.1016/j.eswa.2010.03.058.

Watson, H. J. and Gray, P. (1997). *Decision support in the data warehouse*, Prentice-Hall, New Jersey.

Gumus, A. T. (2009). "Evaluation of hazardous waste transportation firms by using a two step fuzzy-AHP and TOPSIS methodology." *Expert Syst Appl.,* Vol. 36, No. 2, pp. 4067-4074, DOI: 10.1016/j.eswa.2008.03.013.

Hwang, C. L. and Yoon, K. (1981). *Multiple attribute decision making: methods and applications*, New York: Springer-Verlag.

Ilangkumaran, M. and Kumanan, S. (2009). "Selection of maintenance policy for textile industry using hybrid multi-criteria decision making approach." *Jnl of Manu Tech Mnagmnt.,* Vol. 20, No. 7, pp. 1009-1022, DOI: 10.1108/17410380910984258.

Inmon, W. H. (1996). "The data warehouse and data mining." *Communication of the ACM*, Vol. 39, No. 11, November 1996.

Joshi, R., Banwet, D. K., and Shankar, R. (2011). "A Delphi-AHP-TOPSIS based benchmarking framework for performance improvement of a cold chain." *Expert Syst Appl*., Vol. 38, No. 8, pp. 10170-10182, DOI: 10.1016/j.eswa.2011.02.072.

Kahraman, C. and Çebı˙, S. (2009). "A new multi-attribute decision making method: Hierarchical fuzzy axiomatic design." *Expert Syst Appl,* Vol. 36, No. 3, pp. 4848-4861, DOI: 10.1016/j.eswa.2008.05.041.

Kyung, M. J., Yom, J. H., and Kim, (2012). "Spatial data warehouse design and spatial OLAP implementation for decision making of geospatial data update." *KSCE Journal of Civil Engineering*, Vol. 16, No. 6, pp. 1023-1031, DOI: 10.1007/s12205-012-1410.

Lin, H. Y., Hsu, P. Y., and Sheen, G.-J. (2007). "A fuzzy-based decision-making procedure for data warehouse system selection." *Expert Syst Appl.,* Vol. 32, No. 3, pp. 939-953, DOI: 10.1016/j.eswa.2006.01.031.

Mahini, A. S. and Gholamalifard, M. (2006). "Siting MSW landfills with a weighted linear combination methodology in a GIS environment." *Int. J. Environ. Sci. Technol.*, Vol. 3, No. 4, pp. 435-445, DOI: 10.1007/bf03325953.

Minenv (2013). Site of environmental ministry of Morocco (http://www.environnement.gov.ma/).

Mousavi, S. M., Tavakkoli-Moghaddam, R., Heydar, M., and Ebrahimnejad, S. (2013). "Multi-criteria decision making for plant location Selection: An integrated Delphi–AHP–PROMETHEE Methodology." *Arab J. Sci. Eng.*, Vol. 38, No. 5, pp. 1255-1268, DOI: 10.1007/s13369-012-0361-8.

Opricovic, S. and Tzeng, G.-H. (2004). "Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS." *Eur. J. Oper Res.*, Vol. 156, No. 2, pp. 445-455, DOI: 10.1016/s0377-2217(03)00020-1.

Pohekar, S. D. and Ramachandran, M. (2004). "Application of multi-criteria decision making to sustainable energy planning—A review." *Renew Sust. Energ. Rev.*, Vol. 8, No. 4, pp. 365-381, DOI: 10.1016/j.rser.2003.12.007.

Rivest, S., Bédard, Y., and Marchand, P. (2001). "Towards better support for spatial Decision making: Defining the Characteristics of spatial on-line Analytical processing (SOLAP)." *Geomatica*, Vol. 55, No. 4, 2001, pp. 539 to 555, 2001.

Roshanaei, V., Vahdani, B., Mousavi, S. M., Mousakhani, M., and Zhang, G. (2013). "CAD/CAM System Selection: A multi-component hybrid fuzzy MCDM model." *Arab J. Sci. Eng.*, Vol. 38, No. 9, pp. 2579-2594, DOI: 10.1007/s13369-012-0514-9.

Saaty, T. L. (1980). *The analytic hierarchy process,* New York (NY): McGraw-Hill.

Tosun, Ö. and Akyüz, G. (2015). "A fuzzy TODIM approach for the supplier selection problem." *International Journal of Computational Intelligence Systems*, Vol. 8, No. 2, pp. 317-329, DOI: 10.1080/18756891.2015.1001954.

Vego, G., Kučar-Dragičević, S., and Koprivanac, N. (2008). "Application of multi-criteria decision-making on strategic municipal solid waste management in Dalmatia, Croatia." *Waste Manage*, Vol. 28, No. 11, pp. 2192-2201, DOI: 10.1016/j.wasman.2007.10.002.

Voss, A., Hernandez, V., Voss, H., and Scheider, S. (2004). "Interactive visual exploration of multidimensional data: Requirements for CommonGIS with OLAP." *Proc. 15th International Workshop on Database and Expert Systems Applications*, 2004.

Wang, G., Qin, L., Li, G., and Chen, L. (2009). "Landfill site selection using spatial information technologies and AHP: A case study in Beijing, China." *J. Environ Manage*, Vol. 90, No. 8, pp. 2414-2421, DOI: 10.1016/j.jenvman.2008.12.008.

Wei, C., Ren, Z., and Rodríguez, R. M. (2015). "A hesitant fuzzy linguistic TODIM method based on a score function." *International Journal of Computational Intelligence Systems*, Vol. 8, No. 4, pp. 701-712, DOI: 10.1080/18756891.2015.1046329.