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Landfill Site Selection by Combining GIS and Fuzzy Multi Criteria Decision Analysis, Case Study: Bandar Abbas, Iran

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Abstract: Landfill selection in an urban area is a critical issue in the urban planning process because of its enormous impact on the economy, ecology and the environmental health of the region. With the growth of urbanization as well as the desire to live in cities, lager amount of wastes are produced and unfortunately the problem gets bigger everyday. With the development of Geographic Information System (GIS), the landfill sitting process is increasingly based on more difficult spatial analysis and modeling. In this paper, GIS and fuzzy multi criteria decision analysis (FMCDA) are integrated to solve the landfill site selection problem and to develop a ranking of the potential landfill areas based on a variety of criteria. Two stages of analyses are considered to form a spatial decision support system (SDSS) for waste management in urban region, Bandar Abbas. In the first stage, in order to find the suitable sites, GIS digital map overlay techniques are used. A proper waste disposal area is a function of many parameters including distance to urban and rural areas, distance to industrial and agricultural areas, distance to permanent and seasonal rivers, distance to faults, terrain slope, underground water level, transportation network, soil type, geology and both present and future land use of the area. The second-stage analysis uses fuzzy multi criteria decision-making (FMCDM) to rank different landfill sites for Bandar Abbas based on decisions given by a group of experts.

Key words: Fuzzy · GIS · Landfill sitting · Multi criteria decision Analysis · Spatial decision support system

INTRODUCTION

The process of waste disposal management mainly consists of collection, processing, recycling and disposing. At present, waste disposal in most of cities is done in simple form of landfill deposing. Unfortunately, less attention has been paid to use engineering knowledge to find a good waste disposal area. Implementing engineering knowledge seems to be an important and efficient stage in the management of waste disposal and the reduction of hazardous effect of wastes on the environment. One of the most important aspects in this respect is finding a proper depot area for the wastes [1]. Therefore, landfill selection is a critical issue in the urban planning process because of its enormous impact on the economy, ecology and the environmental health of the region [2].

A good waste disposal area has few characteristics. This area should be away from the regions in which there is a history of flooding. Otherwise, the wastes can be a serious source of water pollution which in turn threatens the environment and lives. Moreover, the underground water level data should be used to avoid underground water pollution.

Another constrain for a proper waste disposal area is to have a specific distance from the faults in the region. The geological maps can be used for the purpose of identifying faults and locations where the structure of crust is weak. Landuse maps, road maps and other environmental factors should also be considered in locating a safe and environmental friendly waste disposal area [3].

These factors have been considered in selecting a waste disposal area for Bandar Abbas, Iran. With the development of Geospatial Information System (GIS), the landfill siting process is increasingly based on more sophisticated spatial analysis and modeling. Keir *et al*. [4] discussed the use of both raster-based and vector-based GIS to identify potential waste sites based on suitability of topography and proximity with respect to key

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geographic features. Sener *et al*. [5] used GIS for multi-criteria decision analysis (MCDA) to help the landfill site selection problem and developed a ranking of the potential landfill areas based on a variety of criteria.

In the past, analytic hierarchy process (AHP) introduced by Saaty [6], was one of the useful methodologies, which plays an important role in selecting alternatives [7,8]. The AHP allows group decision-making, where group members can use their experience, values and knowledge to break down a problem into a hierarchy and solve it by the AHP steps. 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 [9-11]. To overcome the shortcomings of the AHP, fuzzy set principle is used to integrate AHP to determine the best alternative [9,10]. However, the main source of uncertainties involving in a large-scale complex decision making process may be properly described via fuzzy membership functions. Therefore, the integration of fuzzy set and AHP gives a much better and more exact representation of relationship between criteria and alternatives [12-14].

This paper presents an integrated approach to construct a spatial decision support system (SDSS) for the selection of landfill sites via a two-stage analysis. In The first-stage analysis, in order to find the suitable sites, GIS digital map overlay techniques are used leading to support the second-stage analysis using FMCDM as a tool. Different siting constraints are considered and numerical and qualitative criteria are applied. In this stage, the geographical data were analyzed using GIS and a data matrix was created that combines the environmental, transportation, public health, social and economic criteria for the selection of four-candidate sites. GIS offers the spatial analysis capabilities to quickly eliminate parcels of land unsuitable for landfill site [2]. The second-stage analysis using FMCDM was applied to rank the proposed candidate sites and summarize the final selection.

MATERIALS AND METHODS

Area of Study: Bandar Abbas is a 27,316 sq. mm wide city in Iran located in the north of Hurmoz channel between Persian Gulf and Oman Sea. This city is surrounded from North by Hadji Abad, from east by Minab and Roodan, from West by Bandar Lengeh and from south by Persian Gulf and Gheshm Island. The city is about 10 m above the sea level and has a warm and humid weather. The summer for this city goes on for about 9 months. It has two main areas of urban and rural regions and has a population of 100,000 families. The closest city to Bandar Abbas is Gheshm Island with a distance of 28 km and far from distance to the capital, Tehran of about 1300 km.

Locating a Proper Waste Disposal Area: A waste disposal area is a matter of public health concern. Considering the high rate of urbanization, one should take the long term landuse planning of suburbs into consideration to locate the disposal area. Moreover, the present and future of garbage trucks traffic should be taken into account.

There are many factors which should be considered in locating a waste disposal area. Obviously, the type of ground selected for this purpose directly affects the design, usage and the tools needed for the effective operation. These factors mainly consist of: public health, extend and topography of the area, hydrology, geology drainage system and weather of the area, the availability of landfills in the area to cover the wastes, proximity to the residential and industrial areas, the distance to and from the city, the weather of the area, the drainage system of the area, cost and last but not least, the future landuse of the area.

Data Collection: The 1:25,000 national topographic maps as well as 1:250,000 geological maps are used to extract the following information layers of the region: the digital Terrain Model (DTM), geology and location of faults, road network, urban and rural areas, permanent and temporally rivers, the location of wells, agricultural and industrial areas and coastal zone limits. Geographical features required for the first-stage analysis could be extracted by using ArcGISs software. For example, the land in the Bandar Abbas region was classified by creating buffer zones around geographic features to be protected using literature values widely used in landfill selection process. The buffer maps were then converted into raster maps of uniform grid sizes and the raster calculator available in spatial analyst tool in ArcGISs was utilized to eliminate unsuitable land parcels based on the different criteria leading to identification of four potential landfill sites in the first stage [2].

The Spatial Decision Support System (SDSS) Model: After collecting the above mentioned information and specifying the criteria and standards, one can summarize the following stages for locating the waste disposal area: 1. First stage: Application of GIS in landfill candidate site selection 2. Second stage: Fuzzy multicriteria decision-making.

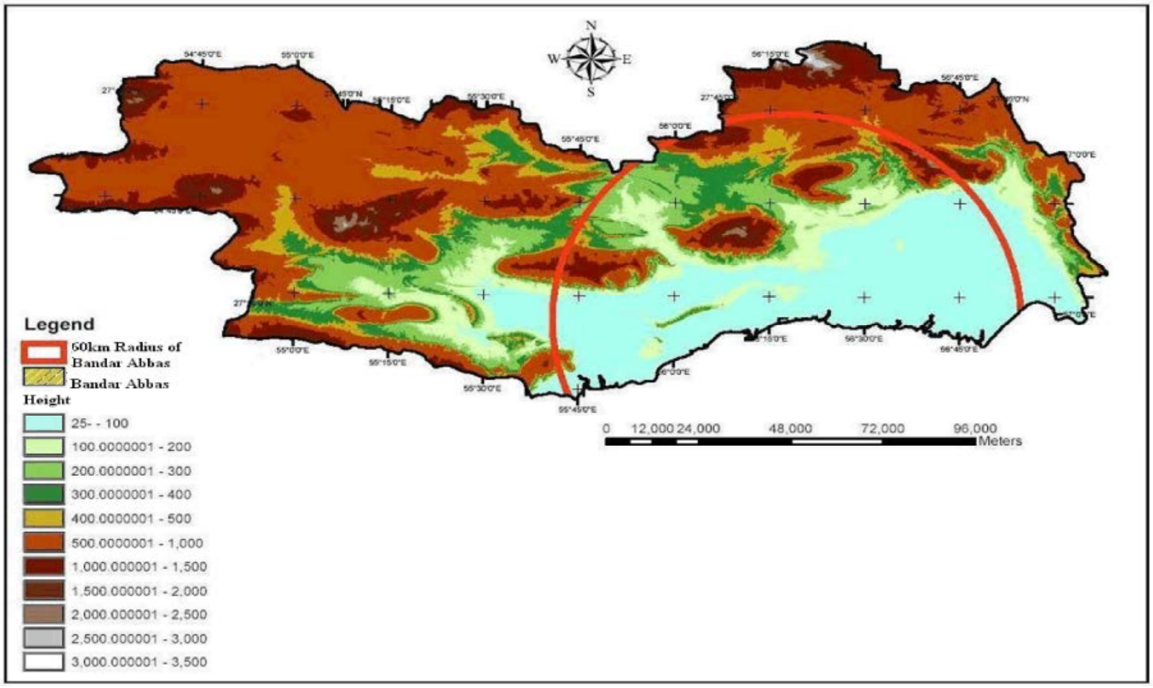

Fig. 1: The 100x100 m DTM of the region

First Stage: Application of Gis in Landfill Candidate Site Selection: The landfill site selection process was completed in two stages where the first stage utilizing GIS to identify a few candidate sites that were later ranked using FMCDM method in the second stage. Finding out where the unacceptable areas are, one should study the remaining areas.

Determining Unacceptable Areas: The unacceptable areas are locations where due to environmental concerns and/or high cost is rejected for the purpose of waste disposal [15]. To determine these areas, one should enter the collected data into the GIS system and use geo-processing techniques like buffering. Most of the available data to this project are in analogue format. Therefore, they were first digitized into vector format and then introduced to the GIS system. The criteria and standards used for defining the unacceptable areas are those specified by the Iranian Management and Planning Organization, the Iranian Environment Protection Organization, the Environment Protection Agency of British Columbia, Canada and the Environment Organization of Ireland. Based on the above mentioned criteria the unacceptable areas of different data layers are determined in GIS environment as following:

Proper Height and Slope: The areas which have high altitude or high slope are not proper for waste disposal. Moreover, the flat areas are not good either [16]. The best places for waste disposal areas are the ones with medium altitude surrounded by hills with no more than 20% slope. Using the 1:25,000 national maps, the 100 m by 100 m DTM of the region is extracted and the slope map is calculated. Figure 1 shows the DTM of the region.

Faults: Waste disposal areas should be away from faults otherwise in case of earthquake the wastes can pollute the underground water or damage the nearby engineering structures [17]. Figure 2 shows the geological map of the region on which the faults are marked. This map is digitized and a buffering zone of 100 m is applied around the faults.

Surface Water Sources: The waste disposal areas should not be in the vicinity of rivers, lakes, or swamps where the underground water level is high. Buffers of 200 m and 100 m for permanent and temporary rivers are applied respectively.

Water Wells: The waste disposal areas should be away from water wells otherwise it can have irretrievable human and environmental effects. All of the water wells in the region are entered into GIS system and a buffer of 400 m is considered for them.

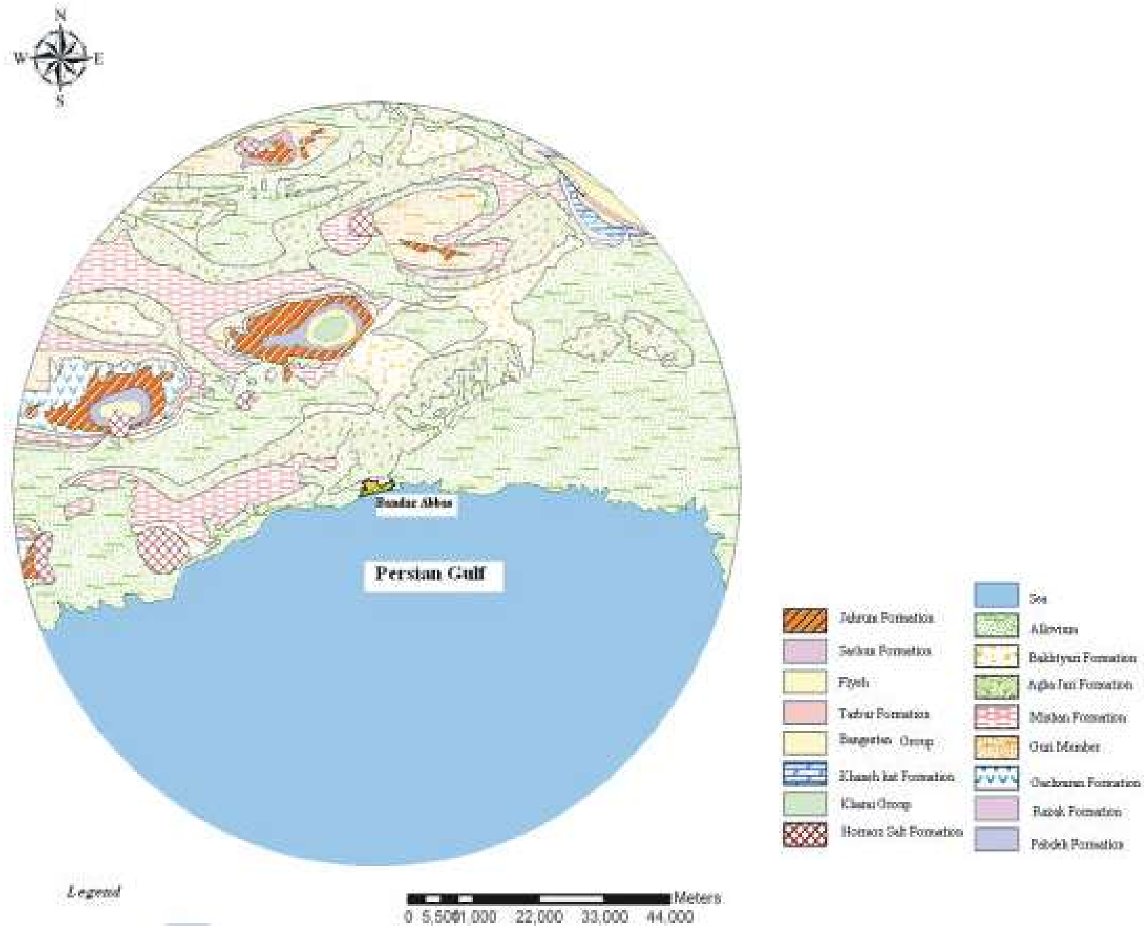

Fig. 2: Digitized geological map of the region

Urban and Rural Areas: The waste disposal areas should not be in the vicinity of the populated urban or rural areas. For this purpose a buffer of 300 m around these areas are considered.

Agricultural and Industrial Centers: The data layer for agricultural and industrial centers is entered into the GIS system and a buffer of 300 m is applied around these areas.

Road Network: The road network in the region consists of highways, main roads, secondary roads and tracks and railways. The waste disposal areas should not be too close to the road networks. Therefore a 300 m buffer is applied to these networks.

Coastal Zone: The coastal zone is the area where the underground water level is high. Moreover, the possibility of existing residential and sight seeing areas in coastal zones is high. Therefore a buffer of 5 km is applied around the coastal zone.

Weighting the Remaining Area: After finding out where the unacceptable areas are, the remaining areas should be classified into classes of high and low priority for being used as waste disposal areas. This is done through two steps of weighting process. In the first step, each layer is internally weighted based on the minimum and maximum distances. In the second step, each layer is externally weighted based on the fact that how critical and important the data layer is to the waste disposal problem [18]. The following subsections discuss these two steps in detail.

The Internal Weighting: In this part, each data layer is studied individually. The locations of each data layer can take a weight between zero to nine based on their direct distance to the features, implementation as well as engineering judgment. As an example, considering the road networks, the locations which are close to the roads have higher weight than the ones far away from the road network. Similarly, from the geological aspect, the locations are weighted based on the facts if the soils have a low penetration factor or is hard to dig or is close to clay

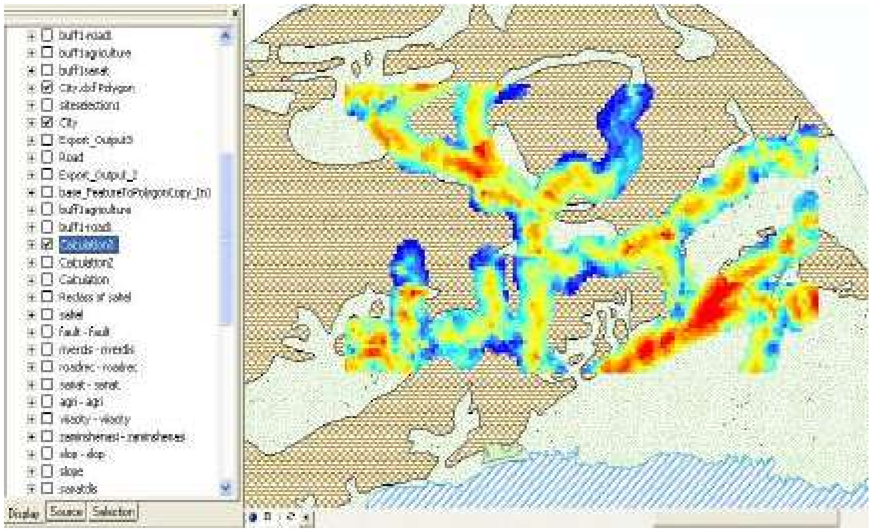

Fig. 3: The potential areas for waste disposal

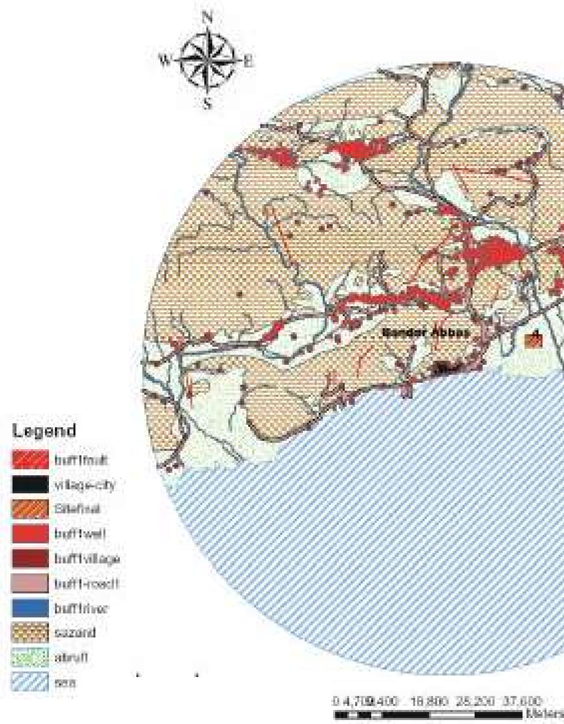

Fig. 4: The candidate sites for landfill with different constraints

Table 1: External weighting schema

Data Layer	Weight
Costline zone	0.20
Transportation Network	0.90
Surface Water Sources	0.65
Faults	0.35
Urban and Rural Areas	0.75
Industrial Centers	0.45
Agricultural Centers	0.35
Geology	0.55
Slop	0.80

area (which can be used to cover the surface of wastes) or not. For the river, water well and fault layers, the locations which are far from them have high weight and vice versa.

For urban and rural areas the locations are weighted based on their distance to these centers. The distance should not be so far that the transportation becomes a problem and not so close that provides an unpleasant appearance to the sight seeing, parks and recreational facilities which are mostly in the suburbs of cities. For agricultural and industrial centers, the highest weight is given to locations with a distance of two to five km. In respect of slope, the highest weight is given to the slopes between zero to two percent and the lowest weight is given to the slopes over 20%. This is due to the fact that waste disposal trucks have difficulty with to move on roads with slopes over 20%.

The External Weighting: In the previous subsection the locations are weighted within each data layer internally. However, it is obvious that the data layers themselves do not have equal weight for the problem in hand. Therefore, each data layer is weighted based on the technical, implementation, safety, environmental, economical and other factors. Table 1 shows the external weighting schema used in this study which itself is based on the ideas of three group of experts, i.e., civil engineers, GIS specialists and environmentalists [19].

All of this is implemented using Raster Map Calculator in ArcGIS. Figure 3 shows the output of overlaying process. The red spots show the potential areas for waste disposal.

Figure 4 shows the unacceptable areas after putting all of the above mentioned criteria together and also the four-candidate sites in GIS, which are subject to advanced assessment in the second-stage analysis.

RESULTS AND DISCUSSION

Second Stage: Fuzzy Multicriteria Decision-Making: The initial publication of fuzzy set theory was by Zadeh [20]. It can also be considered as a modeling language that is well suited for situations that contains fuzzy relations, criteria and phenomena. The second-stage analysis for landfill site selection requires having a careful evaluation of the pros and cons of different candidate sites with respect to different predetermined criteria. FMCDM method is therefore chosen for ranking different landfill sites for Bandar Abbas city based on decisions given by a group of experts [2]. Then, a stepwise ranking procedure is proposed to determine the ranking order of all candidate locations. When conducting the inference, triangular fuzzy numbers (TFN) are commonly used by the experts to describe vagueness and ambiguity in the real-world system. Triangular fuzzy number of is expressed as:

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x \le a \\ \dfrac{x-a}{b-a} & a \le x \le b \\ \dfrac{c-x}{c-b} & b \le x \le c \\ 0, & c \le x \end{cases} \qquad (1)$$

Where the parameters a and c locate the "feet" of the triangle and the parameter b locates the peak. Many methods, such as max, min, median, addition, multiplication and mixed operators, are available to aggregate TFNs.

The experts can employ an assumed weighting set W = {Very poor, Poor, Fair, Good and Very good} to evaluate the appropriateness of the alternatives versus various criteria. The membership functions of the linguistic values in the weighting set W represented by the approximate reasoning of triangular fuzzy numbers are shown in Figure. 5 [2].

The different criteria that were selected for evaluating the merits of the different landfill sites are: (1) Protection from strong winds, (2) Transportation Issues, (3) Altitude, (4) Size and shape of Landfill, (5) Public health, safety nuisance.

The decision objective is to select the most appropriate landfill from four different candidate sites. The different alternatives are defined as A= {A1, A2, A3, A4} and the decision criteria are defined as C= {SW, AR, AL, SS, PS}, where {SW= Protection from strong winds, AR= Transportation Issues, AL= Altitude, SS = size and shape of Landfill, PS= Public health, safety nuisance}. There is a committee of two experts (E1 and E2) who are called on for assessing the appropriateness of 'm' alternatives ({A1, A2, A3, A4}) under each of 'k' criteria ({SW, AR, AL, SS, PS}) as well as the importance weight of the criteria [2].

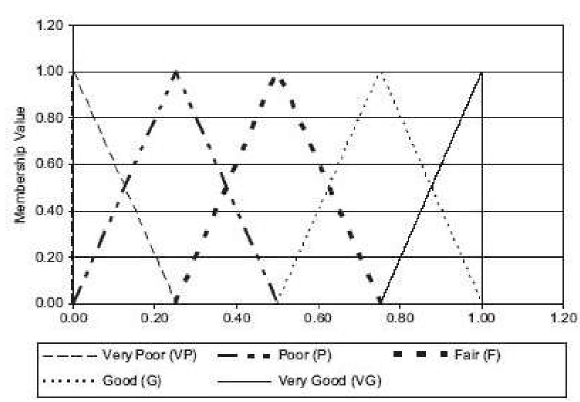

Fig. 5: Fuzzy membership functions

Table 2: Evaluation of different alternative against all criteria by expert E1

	Alternatives			
Criteria	Site 1	Site 2	Site 3	Site 4
Protection from strong winds	(0.6, 0.7, 0.8)	(0.6, 07, 0.8)	(0.6, 0.7, 0.8)	(0.6, 0.7, 0.8)
Transportation Issues	(0.45, 0.5, 0.6)	(0.7, 0.75, 0.8)	(0.8, 0.85, 0.9)	(0.5, 0.55, 0.6)
Altitude	(0.7, 0.75, 0.8)	(0.7, 0.75, 0.8)	(0.7, 0.75, 0.8)	(0.7, 0.75, 0.8)
size and shape of Landfill	(0.45, 0.5, 0.6)	(0.9, 0.95, 1)	(0.6, 0.65, 0.7)	(0.7, 0.80, 0.85)
Public health, safety nuisan,	(0.45, 0.55, 0.65)	(0.7, 0.8, 0.9)	(0.45, 0.55, 0.65)	(0.7, 0.8, 0.9)

Table 3: Evaluation of different alternative against all criteria by expert E1

	Alternatives			
Criteria	Site 1	Site 2	Site 3	Site 4
Protection from strong winds	(0.5, 0.7, 0.9)	(0.4, 0.5, 0.6)	(0.3, 0.4, 0.5)	(0.6, 0.7, 0.8)
Transportation Issues	(0.4, 0.5, 0.6)	(0.6, 0.75, 0.9)	(0.8, 0.85, 0.9)	(0.4, 0.6, 0.75)
Altitude	(0.6, 0.7, 0.8)	(0.6, 0.7, 0.8)	(0.6, 0.7, 0.8)	(0.6, 0.7, 0.8)
size and shape of Landfill	(0.3, 0.4, 0.55)	(0.6, 0.7, 0.8)	(0.4, 0.55, 0.65)	(0.6, 0.75, 0.9)
Public health, safety nuisan,	(0.3, 0.5, 0.7)	(0.5, 0.6, 0.7)	(0.3, 0.55, 0.65)	(0.7, 0.8, 0.95)

Table 4: Weights of different criteria by two experts

Criteria	Expert 1	Expert 2
Protection from strong winds	(0.6, 0.65, 0.7)	(0.45, 0.55, 0.65)
Transportation Issues	(0.8, 0.9, 0.95)	(0.8, 0.9, 0.95)
Altitude	(0.55, 0.6, 0.65)	(0.5, 0.6, 0.7)
size and shape of Landfill	(0.7, 0.8, 0.9)	(0.6, 0.75, 0.85)
Public health, safety nuisan,	(0.65, 0.7, 0.8)	(0.55, 0.65, 0.75)

Table 5: Fuzzy appropriateness indices for the seven alternatives

Alternatives	Fuzzy appropriateness index
Site 1	(0.28775, 0.401625, 0.542)
Site 2	(0.39425, 0.516375, 0.6455)
Site 3	(0.3535, 0.47325, 0.585625)
Site 4	(0.37175, 0.502625, 0.64075)

Let Sitj (i = 1, 2,…,m; t = 1, 2,…,k; j = 1, 2,…,n) be the rating assigned to alternative Ai by expert Ej under criterion Ct. Let Wtj be the weight given to Ct by decision maker Ej. The rating Sitj of n experts for each alternative vs. each criterion is aggregated. Then the final score Fi, fuzzy appropriate index, of alternative Ai is obtained by aggregating Sitj and Wt, which is finally ranked to obtain the most suitable alternative [2,9]. The experts give their own preference rating for the different alternatives and weights for different criteria by using the triangular fuzzy numbers. Tables 2 and 3 present the rating done by the two experts comparing the four alternatives (i.e., candidate sites) against the five criteria. The weights assigned to the different criteria for decision-making are presented in Table 4.

Based on the aggregation functions, the fuzzy appropriate ndices re obtained and presented in Table 5. This information may help justify the final ranking among these four-candidate sites. Therefore, the ranking values of fuzzy appropriate indices for the alternatives were computed based on the method developed in [2, 9, 20-21].

Let Sitj (qitj, oitj, pitj) and Witj = (ctj, atj, btj) be triangular fuzzy numbers. Then Fi can be expressed as Fi = (Yi, Qi, Zi). Thus, If Fi (i = 1, 2,…, m) is the fuzzy appropriate indices of m alternatives. The maximizing set with

$$f_m(x) = \begin{cases} (x - x_1)/(x_2 - x_1), & x_1 < x \leq x_2 \\ 0 & otherwise \end{cases} \quad (2)$$

And minimizing set $G = \{(x, f_g(x)) | x \in R\}$ with

$$f_m(x) = \begin{cases} (x - x_2)/(x_1 - x_{21}), & x_1 \leq x < x_2 \\ 0 & otherwise \end{cases} \quad (3)$$

Where, for i=1, 2,…, m. Let B ¼ (c, a, b) be a normal triangular fuzzy number. The index of rating attitude of an individual expert is defined as Y = (a-c)/ (b-c) [2,9]. If Y= 0.5, it implies that the expert is a risk lover. If Y>0.5, the expert is a risk averter. If Y < 0.5, the attitude of expert is neutral to the risk. Thus, the total index of rating attitude, R, with the evaluation data of individuals can is shown as

Table 6: Ranking values of the different alternatives

Alternatives	Ranking values
Site 1	0.267812
Site 2	0.722563
Site 3	0.556421
Site 4	0.665241

$$R=\left\{\sum_{t=1}^{k}\sum_{j=1}^{n}(a_{tj}-c_{tj})/(b_{tj}-c_{tj})+\sum_{i=1}^{m}\sum_{t=1}^{k}\sum_{j=1}^{n}(o_{itj}-q_{itj})\right\}/(kn+mk) \quad (4)$$

Ranking values $U_T(F_i)$ of fuzzy appropriate indices can be approximately expressed as:

$$U_T(F_i) \cong R[(Z_i - x_l)/x_2 - x_1 - Q_i + Z_i)]+(1-R)[1-(x_2 - Y_i)/(x_2-x_1+Q_1+Y_1)]$$

and the ranking values of the fuzzy appropriateness indices for alternatives are presented in Table 6. Site 2 exhibits the highest potential in this site selection process and site 1 is lowest.

CONCLUSIONS

This paper presented the features of a Fuzzy DSS for urban waste management. In order to gain an all-inclusive perspective, the process of decision-making consisted of a two-stage analysis, beginning with an initial site screening followed by a detailed assessment of the suitability of the candidate sites using a FMCDM approach guided by a panel of experts in the site selection process. The first-stage analysis was successful in preliminary landfill site screening leading to exclude the sensitive areas while retaining sufficient areas for further evaluation at the same time. Within the recovered fuzzy region in the second-stage analysis, MCDM method smoothly incorporated the information provided by two experts leading to fulfill the ranking of the four alternatives with respect to five different criteria. All the criteria were eventually aggregated to select the most suitable site in terms of ratings given the fact that fuzzy set theory may aid in justification of the uncertainty in decision-making. In consequence, a SDSS may strengthen the generation and evaluation of alternatives by providing an insight of the problem among the varied objectives and granting essential support to the process of decision-making under uncertainty.

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