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OPTIMAL ALLOCATION OF LANDFILL DISPOSAL SITE: A FUZZY MULTI-CRITERIA APPROACH

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ABSTRACT

The arbitrary disposal through land-fill sites and also the unscientific management of solid wastes generated by domestic, commercial and industrial activities leading to serious problems of health, sanitation and environmental degradation in India demand an immediate proper solid waste disposal planning otherwise it may cause a serious problem, especially in small and medium-sized cities/towns if proper steps are not initiated now. The present paper aims to develop decision support systems to allocate the best landfill disposal site among the given alternative sites for Vidya Vihar, Pilani, Rajasthan, India. The technique is applied to determine the overall strategy for planning of solid waste disposal and management, while taking into account its environmental impact, as well as economical, technical and sustainable development issues. The model effectively reflects dynamic, interactive, and uncertain characteristics of the solid waste management system and provides decision-makers with a decision tool to make a better decision while choosing a municipal solid waste management strategy.

Key words: Decision making, solid waste management, landfill siting, planning

INTRODUCTION

Due to rapid population growth and economic development, there has been a significant increase in municipal solid waste (MSW) generation in India. The estimated solid waste generation in India ranges from 100g per capita per day in small towns, 300-400g per caipta per day in medium cities and about 500g per capita per day in large cities. As per the available trend the amount of waste generated per capita is estimated to increase at a rate of 1%–1.33% annually (Singhal and Pandey, 2001). Thus municipal solid waste is one of the largest mass of solid materials generated by humanity. This projection clearly shows the need of immediate handling of municipal solid waste (MSW) with appropriate strategic planning and management.

The principal means for managing the various materials contained in MSW are by proper collection from the sources, recycling and recovery of energy in waste-to-energy plants, anaerobic or aerobic bioconversion to compost material, and land-filling (Jain and Pant, 1994; Huang *et al*., 2001). However, municipal solid waste in India is generally disposed in landfill sites. These sites are generally low lying areas on the outskirts of the town/city and respective Municipal Corporation is generally responsible for collection of wastes from the sources and then its disposal to these landfills. The disposal of these wastes creates a problem primarily in highly populated areas. The more concentrated the population, the greater the problem becomes. Therefore to protect the environment, there is a need to identify and select a best landfill site for disposal of solid wastes because improper landfill sites are constant threat for water and air pollution (Hazardous, 2002; Hanrahan *et al*., 2006).

This study attempts to develop a decision support system to allocate the best landfill disposal site based on the study of the existing solid waste disposal practices and identification of possible sites. The developed decision support system

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allocates the best landfill disposal site among the given alternative sites so that the chosen site can minimize cost involved in the development, construction, operation and maintenance; reduce health risk and adverse environmental impact and maximize public acceptability. The specific objectives for selecting best site may be evaluated in terms of various attributes such as accessibility to the site, receptors like proximity of human habitation, agriculture value, land use designation and availability of drinking water sources, environmental conditions like quality of soil, water and air, climatological and geological conditions, socio-economic and cultural aspects like job opportunities and health, waste management practices like quantity of waste generation, collection techniques to be used, the level of service to be offered, and life of the site (Hazardous, 2002; Kurian *et al.*, 2005). These parameters involve uncertainty due to vagueness in the data at different stages of decision-making process which makes the formulation of the problem quite complex.

Moreover, no single site can satisfy all the selection objectives with complex interactions among various activities and conflicts among different experts and interest groups and hence, trade off between various factors is very obvious. Therefore most of the important factors for choosing the best alternative have been considered in the present case study and the uncertainty associated with specifying various attributes is incorporated using fuzzy approach of decision making. The process of decision making tries to involve the community as well as experts at each and every stage. Since some of the parameters are difficult to measure and qualitative in nature, the inputs both from the community and experts are of immense importance.

The formulation developed herein will then be used in a case study on the evaluation of best landfill disposal site for screening potential landfill sites for disposing off municipal solid waste for Pilani, a small town in Jhunjhunu district of the Rajasthan state of India. It is located at a distance of about 200kms from New Delhi, the Capital of India and has a population of over 60,000. This region is semi-desert in nature and annual rainfall is around 450mm. The temperatures during the year go to extremes like 50ºC in summer and 0ºC in winter. The case study will simulate the allocation of best disposal site with appropriate results to indicate usefulness of the formulation in managing more complex studies along with better flexible policies of solid waste management.

MATERIALS AND METHODS

Solid waste disposal creates a problem primarily in highly populated areas. The more concentrated the population, the greater the problem becomes. The first objective of solid waste management is to remove discarded materials from inhabited places in a timely manner to prevent the spread of disease, to minimize the likelihood of fires, and to reduce aesthetic insults arising from putrefying organic matter. The second objective, which is equally important, is to dispose off the discarded materials in a manner that is environmentally acceptable. Solid waste disposal in landfills is the most widely used method of disposing waste and about 80% of the wastes go to landfills. Though it has many disadvantages, it owes its wide acceptance to ease of maintenance and management. In India, the methods followed are not in keeping with the modern practices of sanitary filling. The collected wastes are mainly dumped in low lying areas which are prone to flood which finally result both surface and ground water contamination. In addition to this, birds foraging on garbage dumps cause substantial problems for aircrafts operating in the areas. Therefore, selected landfill site should not only minimize the impacts on air or water quality but also be consistent with local use conditions and zoning. It should assure that bird populations do not pose a hazard to aircraft and protect archeological, historical and other cultural sensitive areas (Hagemeister *et al.*, 1996).

These important aspects are to be incorporated while allocating an optimal landfill site and best practices should then be adopted for design, construction and operation of modern landfill in which refuse is spread in thin layers, each of which is compacted by a bulldozer before the next is spread. When about 3m of refuse has been laid down, it is covered by a thin layer of earth, which is also compacted. Pollution of surface and groundwater is minimized by lining and contouring the fill, compacting and planting the cover, selecting proper soil, diverting upland drainage and placing wastes in sites not subjected to water-logging or high ground water. In addition, there is a growing need to more effectively manage the process of waste collection, transportation and landfill itself for an efficient solid waste management (Cardinali, 2001; Rushbrook; 2001; Buteyn *et al*., 2005). At the municipal level, to develop a sustainable approach to waste management and to integrate strategies aiming at producing the best practicable, and environmentally sustainable option is not an easy task since it is necessary to take into account economic, technical, normative aspects, paying particular attention to environmental problems. Therefore, a systematic approach for selecting a suitable landfill site using the concepts of fuzzy set theory and multiple-criteria decision analysis is proposed in this paper.

In general, the selection of a best disposal site for solid waste management is performed based on the qualitative criteria which are often imprecisely defined for the decision-makers. It is therefore difficult to clearly identify the “best” among them. This uncertainty in the form of impreciseness in the solid waste management for site selection process, therefore, adopts a fuzzy decision-making method by deriving membership functions and fuzzy preference relation matrix, the details of which can be found elsewhere (Bellman and Zadeh, 1970; Klir and Yuan, 1995; Chen 2001). The main purpose of the site selection process is to make the best use of the land resources available based on economic, engineering and environmental suitability, and public approval process. A general listing of various factors to be considered for siting is presented below (Fatta *et al*., 1997; Hazardous, 2002; Kurian *et al*., 2005). The relative importance of these factors depends on the site consideration, opinion of the decision maker as well as the chosen method of disposal.

- Accessibility to the site
  Distance from the road
  Distance from the origin of waste

- Receptor related factors
  Proximity of human habitation/locality
  Drinking water sources
  Land use designation
  Agriculture value
  Public utility facility
  Historical/Archeological monuments
  Public accessibility

- Environmental related factors
  Hydro-geological investigation
  Distance to nearest surface water
  Air quality
  Soil quality
  Water quality
  Safety

- Socio-economic factors
  Job opportunity
  Health

- Geological Related factors
  Soil Permeability
  Depth to bedrock
  Seismicity

- Waste management practices related
  Waste quantity/day
  Life of site

These factors may be considered as different criteria to select best alternative among the given alternatives using fuzzy based multi-criteria analysis. The method is suitable for making decision under fuzzy environment. To deal with uncertainty in the form of fuzziness of the selection process of landfill, the importance weights of various criteria and the ratings of qualitative criteria are considered as linguistic variables in this paper. These linguistic variables can be expressed in triangular fuzzy numbers which is defined by a triplet (n_1, n_2, n_3). The membership function for such triangular fuzzy number has been calculated accordingly:

$$\mu_i(x)=\begin{cases}0 & \text{for } x < n_1 \\ \dfrac{x-n_1}{n_2-n_1} & \text{for } n_1 \le x \le n2 \\ 0 & \text{for } x > n_3\end{cases} \quad (1)$$

By expressing the importance weight and ratings of each criterion in terms of linguistic variables, different alternatives have been evaluated for different criteria depending on the choices of decision makers using fuzzy logic concepts. The series of steps are shown in Fig. 1. These steps are finally applied for three possible landfill sites available to dispose the solid wastes of Vidya Vihar, Pilani, Rajasthan, India, assuming that the authorities of *Nagarpalika* have these three alternatives namely A_1, A_2, and A_3 to dispose the solid wastes after its collection.

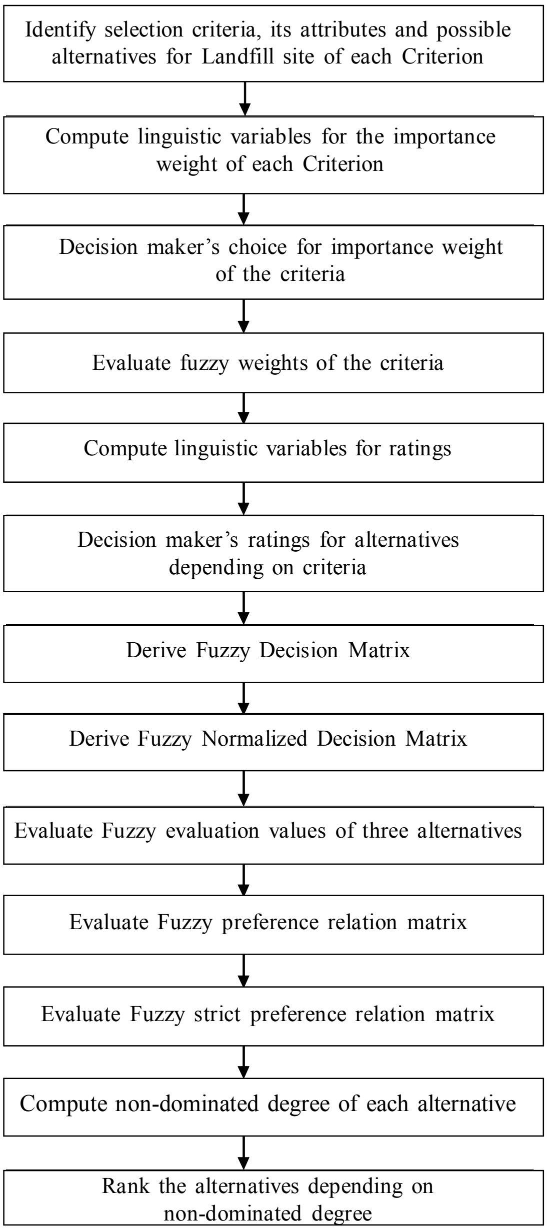

Fig. 1: Various steps of fuzzy-based site selection process for a landfill

As a policy maker *Nagarpalika* has to take the opinion of three experts of solid waste management namely DM_1, DM_2 and DM_3 for different factors to be considered for best siting depending upon the relative importance given by these experts. These factors are dependent on the specific site consideration such as depth to groundwater (C_1), life of site (C_2), soil permeability (C_3), distance to nearest drinking water (C_4), population within 500 meters (C_5), distance from collection point (C_6), air quality (C_7), health (C_8), land use zoning (C_9), type of Road (C_{10}), public acceptability (C_{11}), odor (C_{12}), public utility facility within 2km (C_{13}) etc.

RESULTS

Keeping with the various steps of fuzzy based selection process of a landfill described in Fig. 1, the evaluation was carried out to perform analysis for choosing the best site for disposal amongst the available alternatives for the case study. In this study a total of 13 important selection criteria, its attributes and all three possible alternatives for landfill site have been identified and the linguistic variables for assigning importance weights of each criterion (like very low, low, medium, high and very high) have been defined in the form of triplet of triangular fuzzy numbers. These variables are then used to assess the importance of each criteria by the experts DM_1, DM_2 and DM_3 and depicted in Table 1. The fuzzy weight of each criterion is then calculated using the assigned importance weight of the corresponding linguistic variable and Table 1 as given in Table 2. The fuzzy weight of any j^{th} criteria can be calculated as

$$w_{j\text{-fuzzy}} = \frac{w_j^1 + w_j^2 + w_j^3 + \ldots w_j^k}{k} \qquad (2)$$

where k is number of experts and w_j^k is the weight assigned by k^{th} expert for j^{th} criteria. For example, in Table 1, for the criterion related to depth to groundwater (C_1), there are different opinions of three experts i.e. VH, H and H which correspond to triangular membership value weight as (0.7, 0.9, 1.0), (0.5, 0.7, 0.9), and (0.5, 0.7, 0.9) respectively. Therefore the fuzzy weight of any j^{th} criteria (say related to depth to groundwater) can be calculated as:

$$\left(\frac{0.7+0.5+0.5}{3}, \frac{0.9+0.7+0.7}{3}, \frac{1.0+0.9+0.9}{3}\right)$$

i.e. $w_{1\text{-fuzzy}} = (0.56, 0.76, 0.93)$.

Table 1: Importance weight of each attributes

S. No.	Attributes	D_1	D_2	D_3
1	Depth to groundwater (C_1)	VH	H	H
2	Life of site (C_2)	H	VH	H
3	Soil permeability (C_3)	VH	H	VH
4	Distance to nearest drinking water (C_4)	VH	VH	VH
5	Population within 500 meters (C_5)	H	VH	M
6	Distance from collection point (C_6)	H	VH	H
7	Air quality (C_7)	H	VH	VH
8	Health (C_8)	VH	H	H
9	Land use zoning (C_9)	M	M	M
1	Type of road (C_{10})	M	M	H
1	Public acceptability (C_{11})	M	M	M
1	Odor (C_{12})	VH	H	H
1	Public utility facility within 2 km (C_{13})	H	VH	H

Similarly other values have been calculated and entered in Table 2. The linguistic variables for assigning ratings of each criterion (like very poor, poor, fair, good and very good) have also been classified in the form of triplet of triangular fuzzy numbers. These variables are then used to assess the ratings of each criterion by the experts DM_1, DM_2 and DM_3 for all three possible alternative sites and are presented in Table 3. The step by step procedure to evaluate local and normalized fuzzy decision matrix, fuzzy preference relation matrix and finally ranking of the possible alternatives is described below:

1) The fuzzy decision matrix is derived using the defined ratings of each criterion and Table 3 with respect to each of the possible alternatives. Each element of this matrix say r_{ij} is nothing but the fuzzy rating of any alternative A_i with respect to any j^{th} criteria assigned by the experts and can be calculated as:

$$r_{ij\text{-fuzzy}} = \frac{r_{ij}^1 + r_{ij}^2 + r_{ij}^3 + \ldots r_{ij}^k}{k} \qquad (3)$$

where k is number of experts and r_{ij}^k is the weight assigned by k^{th} expert for i^{th} alternative with respect to j^{th} criteria. For example, in Table 3, for fifth criteria related to population within 500m (C_5), there are different opinions of three experts i.e. poor, fair and poor for alternative 1 (i.e. for first site) which correspond to triangular membership value rating as (1.0, 3.0, 5.0), (3.0, 5.0, 7.0) and (1.0, 3.0, 5.0) respectively. Therefore the fuzzy rating of any j^{th} criteria (say related to population within 500m) can be calculated as

$$r_{ij\text{-fuzzy}} = r_{15-\text{fuzzy}} =$$

$$\left(\frac{1.0+3.0+1.0}{3}, \frac{3.0+5.0+3.0}{3}, \frac{5.0+7.0+5.0}{3}\right)$$

i.e. $= r_{15-\text{fuzzy}} = (1.6, 3.6, 5.6)$.

Similarly other entries of this matrix are evaluated.

2) For transforming all the criteria evaluation into a common scale, global or normalized fuzzy decision matrix is derived as calculated in Table 4. Any entry of this global matrix, say:

$g_{ij\text{-fuzzy}} = g_{15-\text{fuzzy}}$

will be equal to: $\left(\frac{1.6}{10}, \frac{3.6}{10}, \frac{5.6}{10}\right)$

where numerator values of this entry are taken from fuzzy decision matrix evaluated above (say 1.6, 3.6, 5.6) and denominator value is the maximum value available in fuzzy decision matrix derived in step (1) for any alternative with respect to any of the criteria. In this case it is given as 7.0, 9.0, 10.0 for first alternative site with respect to criteria 1 and hence denominator value will be 10. Similarly other entries of normalized fuzzy decision matrix are calculated and tabulated in Table 4.

3) Using the different importance levels of each criterion for given alternative and the elements of fuzzy global decision matrix, fuzzy evaluation value of each alternative is calculated for all criteria j = 1, 2, … n. It can be expressed as:

$$E_i = \sum_{j=1}^{n} g_{ij\text{-fuzzy}} (.)\, w_{j-\text{fuzzy}}.$$

Table 2: Fuzzy weights of the criteria

S. No.	Attributes	Weights
1.	Depth to groundwater (C_1)	(0.56, 0.76, 0.93)
2.	Life of site (C_2)	(0.56, 0.76, 0.93)
3.	Soil permeability (C_3)	(0.63, 0.83, 0.96)
4.	Distance to nearest drinking water (C_4)	(0.70, 0.90, 1.0)
5.	Population within 500 meters (C_5)	(0.50, 0.70, 0.86)
6.	Distance from collection point (C_6)	(0.56, 0.76, 0.93)
7.	Air quality (C_7)	(0.63, 0.83, 0.96)
8.	Health (C_8)	(0.56, 0.76, 0.93)
9.	Land use zoning (C_9)	(0.30, 0.50, 0.70)
10.	Type of Road (C_{10})	(0.36, 0.56, 0.76)
11.	Public acceptability (C_{11})	(0.30, 0.50, 0.70)
12.	Odor (C_{12})	(0.56, 0.76, 0.93)
13.	Public utility facility within 2 km (C_{13})	(0.56, 0.76, 0.93)

Table 3: Opinion of three decision makers for ratings of each site (alternative) with respect to each criteria/attributes

S. No.	Attributes	Site 1			Site 2			Site 3		
		DM_1	DM_2	DM_3	DM_1	DM_2	DM_3	DM_1	DM_2	DM_3
1.	Depth to groundwater (C_1)	VG	VG	VG	VG	VG	VG	VG	VG	VG
2.	Life of site (C_2)	G	G	G	F	G	G	G	G	G
3.	Soil permeability (C_3)	F	F	F	G	G	F	G	F	G
4.	Distance to nearest drinking water (C_4)	G	G	G	G	G	G	F	F	F
5.	Population within 500 meters (C_5)	P	F	P	VG	G	VG	P	P	VP
6.	Distance from collection point (C_6)	F	F	F	F	P	F	P	VP	P
7.	Air quality (C_7)	P	P	P	G	G	G	G	G	G
8.	Health (C_8)	P	F	P	VG	G	G	P	VP	P
9.	Land use zoning (C_9)	P	F	P	F	F	G	G	F	G
10.	Type of Road (C_{10})	G	G	G	F	F	F	P	P	VP
11.	Public acceptability (C_{11})	F	VP	VP	F	F	P	P	P	VP
12.	Odor (C_{12})	F	P	VP	G	G	G	VP	P	VP
13.	Public utility facility within 2 km (C_{13})	P	P	P	P	P	P	G	F	F

Table 4: Fuzzy normalized matrix for every criteria/attributes of each site/alternative

Attributes	Site 1 (A_1)	Site 2 (A_2)	Site 3 (A_3)
Depth to groundwater (C_1)	(0.7., 0.9, 1.0)	(0.7, 0.9, 1.0)	(0.7, 0.9, 1.0)
Life of site (C_2)	(0.5, 0.7, 0.9)	(0.43, 0.63, 0.83)	(0.5, 0.7, 0.9)
Soil permeability (C_3)	(0.3, 0.5, 0.7)	(0.43, 0.63, 0.83)	(0.43, 0.63, 0.83)
Distance to nearest drinking water (C_4)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)
Population within 500 meters (C_5)	(0.16, 0.36, 0.56)	(0.63, 0.76, 0.96)	(0.06, 0.23, 0.43)
Distance from collection point (C_6)	(0.3, 0.5, 0.7)	(0.23, 0.43, 0.63)	(0.06, 0.23, 0.43)
Air quality (C_7)	(0.1, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.5, 0.7, 0.9)
Health (C_8)	(0.16, 0.36, 0.56)	(0.56, 0.76, 0.93)	(0.06, 0.23, 0.43)
Land use zoning (C_9)	(0.16, 0.36, 0.56)	(0.43, 0.56, 0.76)	(0.43, 0.63, 0.83)
Type of road (C_{10})	(0.5, 0.7, 0.9)	(0.3, 0.5, 0.7)	(0.06, 0.23, 0.43)
Public acceptability (C_{11})	(0.1, 0.23, 0.43)	(0.23, 0.43, 0.63)	(0.06, 0.23, 0.43)
Odor (C_{12})	(0.13, 0.3, 0.5)	(0.5, 0.7, 0.9)	(0.06, 0.23, 0.43)
Public utility facility within 2 km (C_{13})	(0.1, 0.3, 0.5)	(0.1, 0.3, 0.5)	(0.36, 0.56, 0.76)

For example, final fuzzy evaluation value in terms of triangular membership function for alternative site 1, $E_1=(E_{11}, E_{12,} E_{13})$ where E_{11} is the value of final fuzzy evaluation for alternative 1 with respect to first value of triangular fuzzy number (i.e. value corresponding to membership function value of zero), E_{12} is the value of final fuzzy evaluation for alternative 1 with respect to second value of triangular fuzzy number (i.e. value corresponding to membership function value of 1), E_{13} is the value of final fuzzy evaluation for alternative 1 with respect to third value of triangular fuzzy number (i.e. value corresponding to membership function value of zero). The value of these fuzzy evaluation can be calculated as follows:

$$E_{11} = \sum_{j=1}^{n} g_{1j\text{-fuzzy}}(.)\, w_{j-\text{fuzzy}}$$
$$= (0.7\times 0.56)+(0.5\times 0.56)+(0.3\times 0.63)$$
$$+(0.5\times 0.7)+(0.16\times 0.5)+(0.3\times 0.56)$$
$$+(0.1\times 0.63)+(0.16\times 0.56)+(0.16\times 0.3)$$
$$+(0.5\times 0.36)+(0.1\times 0.3)+(0.13\times 0.56)$$
$$+(0.1\times 0.56)=1.99$$

Similarly, $E_{12} = 4.55$ and $E_{13} = 7.77$ and therefore, final fuzzy evaluation value for alternative site 1, $E_1 = (1.99, 4.55, 7.77)$. In the same way, final fuzzy evaluation value for alternative 2 and 3 are calculated respectively as:

$E_2 = (2.96, 5.86, 9.34)$

$E_3 = (1.96, 4.43, 7.61)$

4) The fuzzy differences between upper and lower values for all possibly occurring combinations have been calculated and presented below:

$$Z_{12l} = E_{1l} - E_{2u} = (1.99 - 9.34) = -7.35$$
$$Z_{12u} = E_{1u} - E_{2l} = (7.77 - 2.96) = 4.81$$
$$\therefore Z_{12} = [Z_{12l}, Z_{12u}] = [-7.35, 4.81]$$

Similarly,

$$Z_{13} = [Z_{13l}, Z_{13u}] = [-5.62, 5.81]$$

and

$$Z_{23} = [Z_{23l}, Z_{23u}] = [-4.65, 7.38]$$

5) The fuzzy preference relation matrix is calculated by following ways: The lower and upper values corresponding to zero membership function (i.e. Z_{ijl} and Z_{iju}) are already calculated in above step. Assuming triangular membership function with equilateral triangle, the value of z_{ij} corresponding to membership value of 1 can be calculated as:

$$z_{ij}^{1} = \frac{z_{ijl} + z_{iju}}{2}.$$

For example,

$$z_{12}^{1} = \frac{-7.35 + 4.81}{2} = -1.27.$$

Therefore the coordinates of vertices of triangular membership function curve corresponding z_{12} will be:

$$(z_{12l}, \mu(z_{12l}))_{\text{at vertix1}} = (-7.35, 0)$$

and

$$(z_{12}^{1}, \mu(z_{12}^{1}))_{\text{at vertix 2}} = (-1.27, 1)$$

$$(z_{12u}, \mu(z_{12u}))_{\text{at vertix3}} = (4.81, 0)$$

respectively. Now taking the region for S1 for $z_{12}>0$, value of membership function $\mu(z_{12})$ can be calculated corresponding to zero value of z_{12}. Using the linear interpolation, $\mu(z_{12})=0.79$ for $z_{12} = 0$. If $z_{ijl}>0$, then alternative A_i is absolutely preferred to A_j. If $z_{iju}< 0$, then alternative A_i is not absolutely preferred to A_j. If $z_{ijl}<0$ and $z_{iju}>0$, the degree of preference of alternative A_i over alternative A_j can be obtained by introducing a term pr_{ij}. This term pr_{ij} may be expressed as membership function $\mu_{z_{ij}}(x)$ and the fuzzy preference relation matrix (PR) may thus be expressed as:

$$PR = \begin{bmatrix} pr_{11} & pr_{12} & pr_{13} \\ pr_{21} & pr_{22} & pr_{23} \\ pr_{31} & pr_{32} & pr_{33} \end{bmatrix}$$

where $pr_{11} = pr_{22} = pr_{33} = 0.5$ and other entries of the matrix when $i \neq j$, are calculated as follows:

$$p_{ij} = \frac{\text{Area covered under the tringular membership function curve varying from 0 to } z_{iju}}{\text{Total area covered under the tringular membership function curve varying from } z_{ijl} \text{ to } z_{iju}}$$

The final value fuzzy preference relation matrix is given as:

$$PR = \begin{bmatrix} 0.50 & 0.30 & 0.38 \\ 0.70 & 0.50 & 0.85 \\ 0.62 & 0.15 & 0.50 \end{bmatrix}$$

6) To determine the most suitable alternative among the given alternatives, it is necessary to evaluate the degree of strict dominance of alternative A_i over alternative A_j and therefore the fuzzy strict preference relation matrix is calculated from final value fuzzy preference relation matrix as given below:

$$PRS = \begin{bmatrix} prs_{11} & prs_{12} & prs_{13} \\ prs_{21} & prs_{22} & prs_{23} \\ prs_{31} & prs_{32} & prs_{33} \end{bmatrix}$$

The calculated fuzzy strict preference relation matrix is as follows:

$$PRS = \begin{bmatrix} 0.00 & 0.00 & 0.00 \\ 0.40 & 0.00 & 0.70 \\ 0.24 & 0.00 & 0.00 \end{bmatrix}$$

7) The non-dominated degree (NDD) of each alternative A_i (for i = 1, 2, 3) is evaluated from fuzzy strict preference relation matrix derived above using the expression:

$$NDD(A_i) = 1 - \max_{j \in A_i \text{ and } j \neq i} (prs_{ji})$$

Therefore, the non-dominated degree (NDD) of each alternative A_1 would be equal to

$$1 - \max(0, 0.40, 0.24) = 0.60$$

Similarly, it would be calculated as 1.0 and 0.3 for alternative A_2 and A_3 respectively.

8) As per the above calculation, the alternative site A_2 has the highest non-dominated degree than other two alternative sites. Therefore alternative site A_2 has highest rank as $r(A_2)=1$.

9) Deleting the alternative A_2 from the fuzzy strict preference relation matrix by deleting the corresponding row and column from the matrix, the resulting fuzzy strict preference relation matrix will be given as:

$$PRS = \begin{bmatrix} 0.00 & 0.00 \\ 0.24 & 0.00 \end{bmatrix}$$

which further gives non-dominated degree of alternatives A_1 and A_3 as 0.76 and 1.0 respectively and therefore alternative site A_3 will have higher rank than alternative site A_1. Thus (A_2>A_3>A_1) and alternative site 2 is the best landfill site compared to 1 and 3 and alternative site 3 is better than the site A_1. The results obtained by the proposed method coincides with other similar studies presented in Hagemeister *et al.*, (1996), and Hazardous/23/2002-03. However, the fuzzy approach method presented here not only evaluates the ranking order of all possible disposal sites but also indicates the degree of preference of each alternative site under fuzzy environment which is lacking otherwise.

DISCUSSION

Solid waste management is the challenging task in today's world. Location of landfill sites for disposing off solid waste is important. Fuzzy logic concepts play an important role in evaluating different alternatives considering different criteria. Ranks are given for all the alternatives and the best one is chosen which depends upon several factors as mentioned in the results. The study demonstrates that alternative landfill site 2 is best among the available three sites for the disposal of solid wastes.

The presented method deals with the imprecision or vagueness nature of the linguistic assessment of decision maker in more effective way and the final numerical rating of a specific landfill site can be provided which is an indication to the feasibility of disposing of solid wastes at the site. A stepwise method is presented in this paper to determine the ranking order of fuzzy numbers which can help the decision maker to make a suitable decision under fuzzy environment.

The most suitable alternative among the given alternatives is obtained by evaluating the degree of strict dominance of alternative A_i over alternative A_j and by deriving the fuzzy strict preference relation matrix accordingly. The methodology can be extended to rank several sites relative to each other. The method presented in this method is comparatively easier and more comprehensive in comparison with conventional aggregation method where the scores of each attributes and then for all the categories of a particular site are added to calculate the total score on the basis of which results are interpreted. The case study clearly shows that there will not be significant impact on the environmental quality due to the disposal site and hence will be the most acceptable. As far as the environmental related attributes are concerned, the contaminated land, polluted air, water and soil parameters are preferred site for landfill.

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REFERENCES

Bellman, R. E. and Zadeh, L. A., (1970). Decision-Making in Fuzzy Environ. J. Manage. Sci., **17** (4): B-141-163.

Buteyn, D. Simmons, L. and Roberts, J., (2005). The Landfill Location Criteria Calculator: A Risk Based Approach to Solid Waste Management. Proc. 20th Int. Conference on Solid Waste Technology and Management – Philadelphia, April 3., **6**: 403 – 409.

Cardinali, R., (2001). Waste management: a missing element in strategic planning. Work Study, **50** (5): 197-201.

Chen, C. T., (2001). A fuzzy approach to select the location of the distribution center. J. Fuzzy Sets and Systems, **118**: 65-73.

Fatta, D., Voscos, C., Haralambous, A. J. and Loizidou, M., (1997). A study on groundwater quality in the surrounding of a landfill. J. Env. Sci. Health, **32** (8): 2275-2287.

Hagemeister, M. E., Jones, D. D., Woldt, W. E., (1996). Hazard Ranking of Landfills using fuzzy composite programming. J. Env. Engg., ASCE, **122** (4): 248-258.

Hanrahan, D., Srivastava, S., Ramakrishna, A. S., (2006). Improving Management of Municipal Solid Waste in India: Overview and Challenges. World Bank Report, South Asia Region, Environment and Social Development Unit.

Hazardous/23/2002-03, Guidelines for the Selection of Site for Landfilling. Hazardous Waste Management Series, Central Pollution Control Board, New Delhi.

Huang, G. H., Sae-Lim, N., Liu, L. and Chen, Z., (2001). An Interval-parameter fuzzy-stochastic programming approach for municipal solid waste management and planning. J. Env. Model. Assess. **6**: 271-283.

Jain, A. P. and Pant, G. B. (1994). Solid Waste Management in India, 20th WEDC Conference, Colombo, Sri Lanka.

Klir, G. J., and Yuan, B., (1995). Fuzzy Sets and Fuzzy Logic: Theory and Applications. Prentice-Hall Inc., Englewood Cliffs, N. J., *pp*.1-94, 390-416.

Kurian, J., Esakku, S., Nagendran, R., and Visvanathan, C., (2005). A Decision Making tool for dumpsite rehabilitation in Developing Countries. Proc. Sardinia, Tenth International Waste Management and Landfill Symposium, S. Margherita di Pula, Cagliari, Italy; 3-7 October.

Rushbrook, P., (2001). Guidance on Minimum Approaches for Improvements to Existing Municipal Waste Dumpsites. WHO Regional Office for Europe, Copenhagen, Denmark.

Singhal, S. and Pandey, S., (2001). Solid Waste Management in India: status and future directions. TERI Info. Monitor on Env. Science, **6** (1): 1-4.