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Comparative study on efficiency of ANP and PROMETHEE methods in locating MSW landfill sites

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ABSTRACT: For the municipal managers in the country the importance of locating suitable MSW landfill sites is twofold: firstly, to win the heart and mind of the people; secondly, to minimize the environmental impact of the landfill sites. AHP and Fuzzy methods are among the numerous methods that so far have been used together with GIS to locate and prioritize municipal solid waste (MSW) landfill sites. In the present study, after overlaying the maps in the GIS software and selecting the most suitable sites, Analytic Network Process (ANP) and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) were used to rank the selected sites. For this end, various information layers that contribute to the process of locating MSW landfill site including distance from rivers, distance from residential area, distance from faults etc. were evaluated by using ANP and PROMETHEE methods and based on some criteria and sub-criteria. Then, the evaluated layers were analyzed by GIS software in order to find the most suitable landfill sites and rank them. Results suggested that ANP + GIS was not only more accurate than PROMETHEE + GIS, but also it involves a user-friendly procedure in scoring the criteria and sub-criteria.
Keywords: locating landfill site, GIS, PROMETHEE, ANP, municipal solid waste, Sarein Town.

INTRODUCTION

Uncontrolled urban development and subsequently the ever increasing urban population in Iran has led to massive increase in consumption of food and other items and consequently in generation of various types of municipal waste materials (Abdoli., 2007). Although, new municipal waste disposal systems have recently been developed and recycling tops the agenda in every municipal waste management system, it appears that sanitary landfilling is the most prospective method of waste disposal in the developing countries in terms of efficiency and cost-effectiveness (Mrayyana *et al., 2005*).

Air, water and soil pollutions which are mainly the result of poor urban management and failure to locate suitable landfill sites, pose some problems to the living environment of the citizens. Any landfill site should have enough area that allows for landfill facilities to be operational for at least 20 to 40 years. Sanitation and cost are the two main factors dictating the selection of a suitable landfill site. Any process of locating a landfill site should be initiated by understanding the topography of the region. This should be followed by understanding the geology, hydrogeology, natural drainage, topsoil, accessibility, meteorology and prevailing winds of the area. Furthermore, factors such as costs, future land use of the site, public acceptance, sanitary issues and number of the landfill facilities in the site must be studied in details before taking any actions to prepare the selected landfill site (Mikko *et al., 2000*). For these reasons, it is vitally important to use appropriate tools and technologies to minimize the negative outcomes of improper locating of landfill site. However, it is impossible to overcome this challenge without using a powerful system that is capable of utilizing and analyzing multiple information layers (Wang *et al*., 2005).

The most important methods that are used for location include fuzzy logic, Boolean logic, multi-criteria decision analysis / multi-attribute decision analysis (MCDA/MADA), ANP, PROMETHEE, among others (Saaty *et al*., 1996). These methods vary in terms of their information source and background. Over the last decades, multi-criteria decision making methods have been used prolifically in different scientific fields in the decision making processes that involve using a large set of criteria. This in part is due to the high capability of these methods in modeling the real issues, and partially because they are simple and easy-to-understand for their users (Yuksel *et al*., 2007). In the present study, ANP and PROMETHEE methods have been used to identify the most suitable landfill sites.

The touristic Sarein Town is located in between 48.04° East Longitude and 38.09° North Latitude, some 28Km to the west of Ardabil City in northwestern Iran, covering an area of over 1,280,000m2. Elevation of the town is 1650m above sea level. Based on the last census, the town had a population of 6121 in year 2012. According to the organization of cultural heritages and tourism of Ardabil Province, the town receives more than 5,200,000 domestic and foreign tourists annually. A record 85000 tourists visit the town every day in the peak season that is during summer months. The per capita garbage generation in the town stands at 0.930Kg/day. In total, up to 6453 tons of garbage is generated yearly in the town. Currently there is no recycling and separation-at-source being done in the town and all the process of garbage disposal from collection through transportation to landfill site is performed in a semi-mechanized way.

MATERIALS AND METHODS

In order to fulfill the goal of the study, which was the location of landfill site for Sarein Town, all the required information layers including geological maps, land type, geographic directions, land use, slope of the area, topography, situation of the villages, town limits, surface water, roads and faults were obtained and then analyzed by GIS9.3 software based on criteria set by Iran's Environmental Protection Organization. More specifically, the weighted layers were entered in the GIS software as raster layers so that each of them with their specific weighted values can be used in selection of the suitable landfill site.

As many as 6 sites were selected from the landfill sites identified for Sarein Town based on the highest scores of the obtained polygons. Since there was an individual variation among the identified sites in terms of topographical, geological, land use, hydrological and other features; in the next stage, ANP and PROMETHEE methods were used to prioritize the selected sites and to improve the accuracy of the selection. Curiously, data gathering in these two methods is done by developing and completing of questionnaires. In the present study, a questionnaire was developed that covered the economical, social and environmental criteria, which was completed by as many as 30 experts. ANP and PROMETHEE methods involve the following procedures:

Analytic Network Process (ANP)

ANP is the generalized form of the analytic hierarchy process (AHP). ANP is one of the most integrated models of multi-criteria decision analysis (MCDA) and so far has been used by scientists in different research areas . Algorithm of this process is based on a mathematical logic which gives it a very high efficiency in solving decision making problems. This method is a flexible and powerful, yet simple method that is used in situations where existence of contradictory decision making criteria makes the task of selection from the alternatives ever harder. If there are interdependences between the weight of criteria and weight of alternatives, hierarchy can no longer exist in the decision problem, rather it forms a "network" or non-linear system or a system with feedback. Here, laws and formula of hierarchy cannot be used to calculate the weight of elements, while theory of networks can provide the solution. Furthermore, not only the importance of the criteria represents the importance of the alternatives, importance of the alternatives may also influence the importance of the criteria. ANP prioritizes the criteria based on their importance in the alternatives. Here, availability of the real alternative makes the result more easily achievable (Yuksel *et al*., 2007). In general, ANP consists of two parts including control hierarchy (relation between goals, criteria and sub-criteria) and network connection (interdependence between elements and clusters).

Steps of problem-solving by ANP

1 – Outline of the problem: problem-solving by this method primarily involves drawing a network by using goal, criteria, sub-criteria and alternatives of the problem, based on their relations to each other.

2 – Pairwise comparison matrix and priority vector: in this step pairwise comparisons are conducted. The criterion against which or based on which the pairwise comparisons are conducted is referred to as control criterion.

Table 1. *degrees of importance for pairwise comparison*

Preference (qualitative concept of privileges)	Quantity
Extremely Preferred	9
Very strongly Preferred	7
Strongly Preferred	5
Moderately to strongly	3
Equally Preferred	1
Preferences among above intervals	8,6,4,2

3 – Construction of super matrix: once the goal is set, the calculations begin by constructing pair matrices. Then the pairwise comparisons are conducted by using a large-scale matrix named super matrix, which consists of the following components:

Cn represents n category

eNn represents n element in the n category

Block Wij including priority vectors (w)

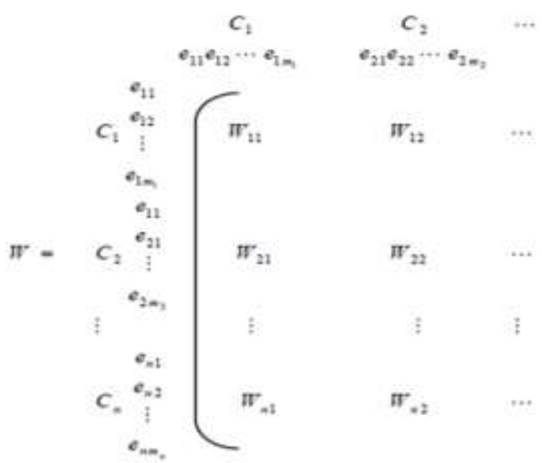

Figure 1. *Structure of Super Matrix*

If category i had no effect on category j, then Wij = 0.

4 – Selection of the best alternative based on the obtained weight: the highest final weight obtained from calculating the weights of criteria and of alternatives in Super Matrices, reveals the best alternative.

Logic of the Super Decisions software is based on ANP method. It’s worth mentioning that ANP is a very flexible technique. In fact, it is mainly its flexibility and simplicity that have made it popular among the researchers.

Preference ranking organization method for enrichment evaluations (PROMETHEE)

PROMETHEE is one of the compensation methods of MADM model. In the present paper it has been used for locating purposes. Curiously, with the compensation methods exchange between the criteria is not allowed. PROMETHEE I which provides partial ranking and PROMETHEE II which provides complete ranking, were both developed by Professor Brans in 1982 and as of the very early years of its introduction had a wide range of applications. Some years later, with the help of Professor Mareschal, Professor Brans developed two new versions of PROMETHEE. They were PROMETHEE III which did the ranking based on ranges and PROMETHEE IV which was used in continuous entities. The two researchers later proposed another two more interesting versions of this methodology under the name PROMETHEE V (1992) which involves procedure for multiple selection of alternatives under constraints and PROMETHEE VI (1994) which involves sensitivity analysis procedure (human brain). In general, PROMETHEE method involves the ranking of alternatives based on pairwise comparisons (Kao *et all.,* 1996).

Furthermore, PROMETHEE method is one of the most novel form of the MADM methods that has been used in different areas including banking, industrial locating, workforce planning, water resource management, investment, medicine, chemistry, healthcare, tourism, dynamic management etc. Essentially, the success of PROMETHEE methodology has been due to its mathematical properties and user friendliness (Majlesi *et all.*,2009). In year 1998, the two researchers developed the descriptive complement module for PROMETHEE that is known as geometrical analysis for interactive aid (Gaia). This module provides an interesting graphical representation that backs up the PROMETHEE method. More specifically, Gaia method involves constructing decision matrix after determining the criteria and alternatives. Here, criteria fall into two qualitative and quantitative categories. Quantitative criteria are extracted from data available in industrial towns; whereas, qualitative criteria are quantified form of the data extracted by using bipolar spectrum. Then, Shannon entropy method is used to allocate weight to the criteria. Decision matrix and criteria weights are two inputs for PROMETHEE method (Majlesi *et all.*,1998).

Steps of problem-solving by PROMETHEE

Let’s assume that A is a set of alternatives, out of which the selection will take place. If K is effective criterion in decision making, for each A□a alternative the fj(a) value represents the value of jth criterion in alternative a. Here, the ranking involves three steps:

Step 1: a preference function Pj is assigned for each criterion j. Pj (a,b) is calculated for each pair of alternatives. The value varies between zero and one. If fj(a) = fj(b), the value of Pj(a, b) becomes zero, and as the value of fj(a)-fj(b) increases so does the value of Pj(a, b), until the former increases to the point that the latter equals one. Various shapes can be assumed for Pj function, depending on the modeling resulted by criterion j. PROMETHEE method provides the decision maker with 6 generalized criteria for the preference function including usual, U-shape, V-shape, level, V-shape with indifference and Gaussian. Last but not least, a weight factor wj is also assigned for each criterion fj.

Step 2: global preference value л(a, b) is calculated for each alternative a over alternative b. The more is the value of л(a, b), the higher is the preference of alternative a. л(a, b) is calculated as follow:

[1] $$\pi(a,b) = \sum_{j=1}^{k} wjpj(a,b), (\sum_{j=1}^{k} wj = 1$$

Step 3: л(a, b) represents the preference degree of alternative a over alternative b. In order to calculate the global preference of alternative a over other alternatives, the output flow is calculated:

Positive preference flow or output flow:

[2] $$\varphi + \frac{1}{n-1} \sum_{x \in A} \pi(a,x)(a)$$

This flow represents preference of alternative a over other alternatives. Actually, this flow indicates the power of alternative a. The highest value of φ+(a) is indicative of the best alternative. Preference rate of other alternatives over alternative a, which is termed the input flow, is obtained from the following calculation:

Negative preference flow or input flow:

[3] $$\varphi - (a) = \frac{1}{n-1} \sum_{x \in A} \pi(a,x)$$

This flow represents the preference of other alternatives over alternative a. Actually, this flow indicates the weakness of alternative a. The lowest value of φ-(a) is indicative of the best alternative. Thus, by using φ+ and φ-, if any, it is possible to accomplish a partial ranking (PROMETHEE I). However, in order to accomplish a complete ranking of alternatives (PROMETHEE II), first the net preference flow for each alternative has to be defined:

[4] $$\varphi\ (a) = \varphi + (a) - \varphi - (a)$$

The net preference flow is the aggregate of the positive and negative preference flows. The higher is the net preference flow, the superior is the alternative.

One of the most important merits of the PROMETHEE method is the simplicity, clarity and reliability of the results that it provides. It is capable of providing either a partial or a complete ranking of a limited set of alternatives.

RESULTS AND DISCUSSION

After locating the most suitable MSW landfill sites for Sarein Town, they were analyzed by GIS software (Fig. 2) and as many as 6 sites were selected based on the scores. Then, ANP and PROMETHEE methods were used to rank the selected sites. The ranking process was initiated by identifying the environmental features of the 6 sites by using information layers obtained during the locating process (Table 2).

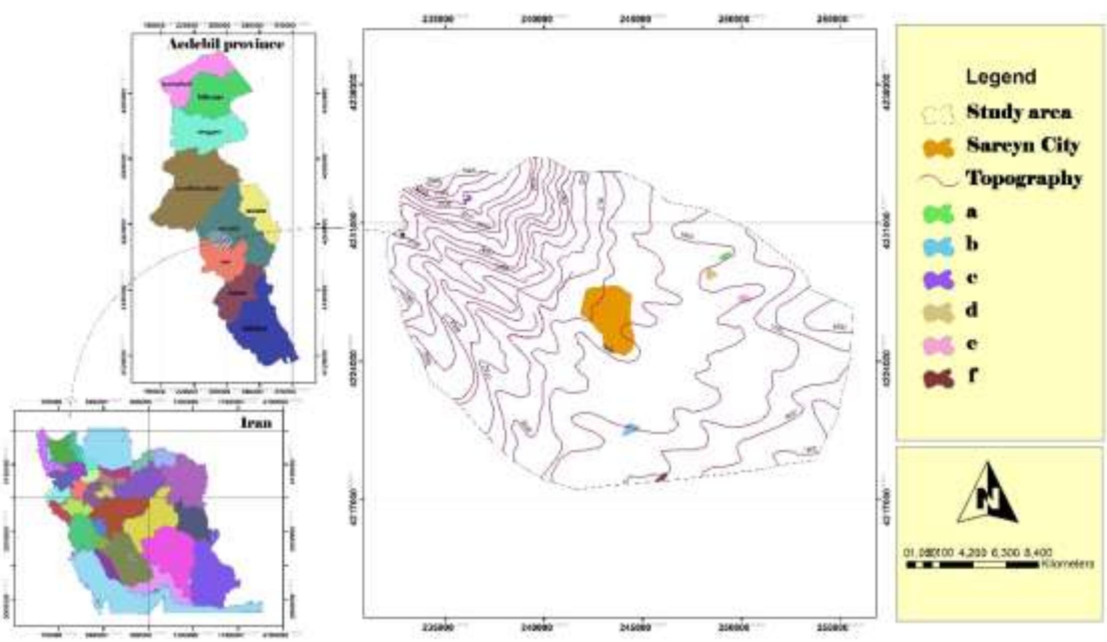

Figure 2. *Areas suitable for building landfill sites for Sarein Town (primary output of GIS software)*

Features of the 6 landfill sites selected based on criteria set by Iran's Environmental Protection Organization are given in Table 2.

Table 2. Features of the selected sites

	Site (a)	Site (b)	Site (c)	Site (d)	Site (e)	Site (f)	Environmental criteria
Complications	Hill - Mount	Mountain-Valley	Hill - Mount	Hills - valley	Hills - valley	Valley - rocky	Hill - Mount
Lithology	Permeable	Older eroded surfaces	Conglomerate, sandstone	Clayey silt-Impervious	Clayey silt-Impervious	Clayey silt-Impervious	Impenetrable and igneous
Slope (%)	15-24	35-45	25-45	5-20	11-24	35-45	Less than 40%
Land use	Agriculture	Meadow	Agriculture	Meadow	Meadow	Agriculture	Meadow
Distance to fault (meters)	7970	11834	870	903	3163	12084	200
distance from the main road (meters)	6390	1479	315	911	2045	3493	300
Distance from the city (meters)	17014	7600	10250	1990	9673	12093	1000
The distance from the village (meters)	1686	1577	2125	1133	1110	1836	500
distance from the river (meters)	2017	2761	1637	2160	470	3868	1000
Access	Mountainous - Valley	Rocky mountain	Mountainous - Valley	Relatively flat	flat	Rocky	Relatively flat
wind direction	northeast	northeast	northeast	northeast	northeast	northeast	In contrast to the wind direction to city

Scores for each of the selected landfill sites were determined based on the results from evaluation of the criteria by each of the mentioned methods (Tables 3 and 4).

Table 3. *Scoring of the selected landfill sites by ANP method*

Site	Score	Priority
A	0.048	6
B	0.102	3
C	0.099	4
D	0.358	1
E	0.308	2
F	0.085	5

Table 4. *Scoring of the selected landfill sites by PROMETHEE method*

Site	Score	Priority
A	0.124	5
B	0.128	4
C	0.139	3
D	0.224	2
E	0.269	1
F	0.116	6

DISCUSSION

Results from evaluation of the selected landfill sites by using ANP showed that site D ranks first in terms of suitability. Whereas, results from evaluation of the selected landfill sites by using PROMETHEE method revealed that site E shows highest suitability. Comparing the two D and E sites revealed that criteria such as hydrology, slope, and distance from town/city were more desirable in site D than in site E. This, in turn, shows that ANP method is comparatively more efficient in locating suitable landfill site.

The second preference specified by ANP was site E, and by PROMETHEE was site D. These are exactly the reverse of the first preferences by the two methods. Examining the evaluated criteria of each mentioned sites revealed that the accuracy of ANP method was higher in second preference as well.

Furthermore, third preferences provided by the ANP and PROMETHEE methods were site B and site C, respectively. As the site C is close to agricultural lands and fault and is located far distant from the town, we can conclude that the third preference should be site B, which was the preference of ANP method.

By comparing the remaining preferences provided by the two methods based on the features of the sites (Table 2) we can see that ANP preferences are of much higher accuracy.

CONCLUSION

The bleak prospect of overpopulation in urban areas both in developed and developing countries and subsequently the massive increase in generation of MSW has prompted the authorities to seek various engineering methods for locating MSW landfill sites. Currently, methods such as TOPSIS, AHP, ANP, among others, play a key role in locating suitable landfill sites. A great number of authors such as Pears, Khodabakhshi, Zareie, Saaty and others have used decision making methods in their works and reported both the weaknesses and strengths of the methods. The present study focused on comparing the efficiency of ANP and PROMETHEE methods.

In conclusion, ANP method was found to be more accurate than PROMETHEE method in ranking the sites identified as suitable by overlaying the weighted layers in GIS environment, while scores obtained from ANP method were more realistic.

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