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ORIGINAL ARTICLE

Choosing a municipal landfill site by analytic network process

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Abstract In this study, analytic network process (ANP), one of the multi-criteria decision making (MCDM) tools has been used to choose one of the four alternative landfill sites for the city of Eskisehir, Turkey. For this purpose, Super Decision Software has been used and benefit opportunity cost and risk (BOCR) analysis has been done to apply ANP. In BOCR analysis, each alternative site has been evaluated in terms of its benefits, costs and risks; the opportunity cluster has been examined under the benefit cluster. In this context, technical, economical and social assessments have been done for the site selection of sanitary landfill. Also, results have been compared with analytic hierarchy process (AHP) which is another MCDM technique used in the study conducted before. Finally, the current site has been determined as the most appropriate site in both methods. These methods have not been commonly used in the discipline of environmental engineering but it is believed to be an important contribution for decision makers.

Keywords Solid waste · Landfill site selection · Multi-criteria decision making (MCDM) · Analytic network process (ANP)

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Introduction

Deciding where to locate a municipal sanitary landfill is a difficult problem in which qualitative criteria compete with quantitative, economic and engineering criteria in a process that is highly political and emotional. The landfill site selection is a step-by-step process in which environmental, engineering and economic criteria are applied successively and often satisfies a set of goals which include (1) minimization of the risk to public health (public health and safety considerations); (2) minimization of the impact on the natural environment (environmental consideration); (3) maximization of the level of services of the site to the facility users (social considerations); and (4) minimization of the cost of the usage of the facility (economic considerations) (Anwar et al. 2002).

In addition to determining the suitability of a site, legislative restrictions also must be considered. At that point, the conditions in the Turkish Regulations of the Control of Solid Wastes in the Official Gazzette published on March 14, 1991 and published after revision on April 05, 2005 states that:

- Sanitary landfills cannot be located at the protection zones of the water catchment areas.

- The minimum distance between a sanitary landfill and a residential area should be at least 1,000 m. Only if natural barriers like trees, small hills, etc. are available around the landfill, this distance may be decreased with the permission of the appropriate authorities.
- No sanitary landfill can be constructed at places where the danger of flooding exists.
- The sanitary landfill should be located at a place where it can be reached by alternative roads under all weather conditions.
- A minimum distance of 1 m should exist between the ground water table and the bottom of the landfill (Ministry of Environment and Forestry of Turkey 1991).

In this study, ANP, one of the MCDM tools has been used to choose the most suitable landfill site among the alternatives. ANP is the general form of AHP and expresses the relationships between components like networks by describing the directions of the components. AHP is a method that obtains the relative significance of decision alternatives by pairwise comparisons in multi-criteria decision problems. By means of this structure, the indirect interactions between the components, which are not connected directly and the feedbacks are considered. ANP ranks the alternatives from the most important one to the less depending on decision maker's individual judgments and evaluations. In addition, ANP points out whether the alternatives are closer or farther to each other and how an alternative ensures the determined goal by relative significance of alternatives. While the basic ANP structure consists of only one network, the most complex one can analyze the benefit, opportunity, cost and risk that each alternative can cause together. The important issue is that benefit, opportunity, cost and risk may have different significance degrees according to the problem. This weighting procedure is called benefit opportunity cost risk (BOCR) analysis (Saaty 1994).

In this paper, a decision-making procedure was developed, based on the ANP method and legal restrictions that can be used by public sector decision makers to locate obnoxious facilities. The applicability of this procedure was demonstrated to locate a landfill for the city of Eskisehir, Turkey.

Municipal solid waste management in the city of Eskisehir

Eskisehir is located in the northwest of the central Anatolia region in Turkey and the city has an area of 13,652 km^2. According to the census of 2000, population of the city is 557,028 and projected population of centrum is 1,146,638 for the year 2025. The average daily municipal solid waste (MSW) production rate in Eskisehir is 600 tons and so, a projected cumulative volume of solid waste is ca. 9 million m^3 at an average height of 25 m in the landfill site.

Current landfill site is located in the southeast of the city center and has an area of approximately 8 ha. This area is filled by waste materials at an average height of 50 m. There is a small lake, a number of small wells and spring water with low flow in the close vicinity of the area. Landfill is not excavated or waste has not been dumped in natural depressions. Waste has been dumped, unregulated since 1986 on the surface of the natural valley by Metropolitan Municipality of Eskisehir. The two district municipalities and vehicles of the two private companies are working to collect municipal wastes as well as health care and industrial wastes from hospitals and industrial areas. The wastes are transported to the site and dumped for 24 h every day in an uncontrolled way. This unregulated dumping site is an open area where the wastes are partially classified and recycled under unhygienic conditions (Documents of Metropolitan Municipality of Eskisehir 2003).

Pre-assessments

The pre-assessment of alternative sites is the first phase while selecting a sanitary landfill site in any residential area. According to the data which were obtained from pre-researches conducted by Metropolitan Municipality of Eskisehir and in this study, site selection studies were performed for four alternative sites (Fig. 1):

Site 1 (Cavlum site): It takes attention with the proper topographic and geological structures. However, this site is in the east of the city center and therefore, it is exposed to the secondary wind direction. This situation will affect the city center negatively. Moreover, a haul distance of 25 km and the existence of the Curuksu Stream near this site are the disadvantages of the site.

Site 2 (Sultandere site): This site is only 500 and 800 m far from Sultandere village and Mamuca village, respectively, whereas, sanitary landfill site should be at least 1,000 m away from the nearest residential area according to Turkish Regulations of the Control of Solid Wastes. Only if natural barriers like trees, small hills, etc. are available around the landfill, this distance may be decreased with the permission of the appropriate authorities. In addition, the wind blowing from the west which is the primary dominant wind

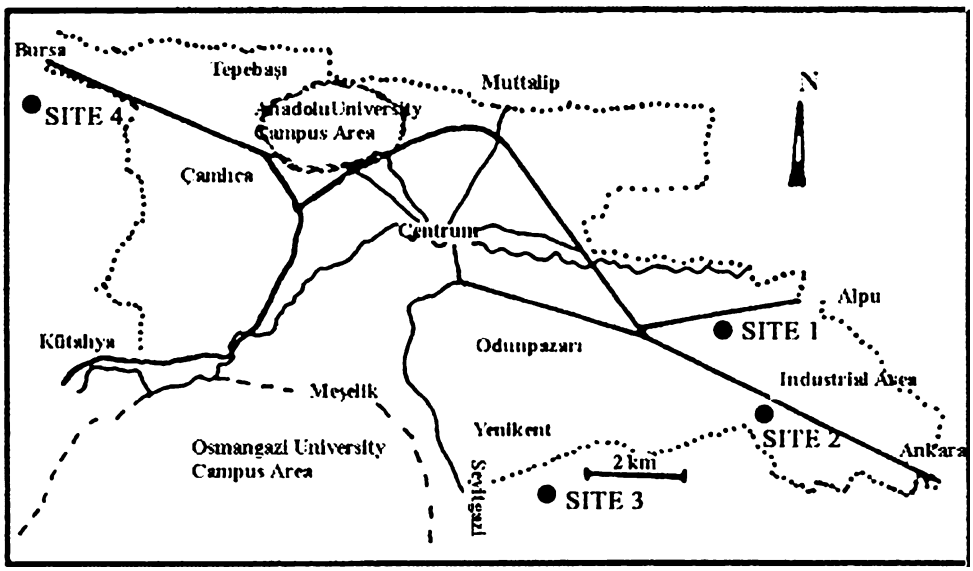

Fig. 1 Map of Eskisehir and alternative landfill sites

direction is affecting Sultandere village, negatively. Adding to all the negative properties is the slope of the site which is more than 20%, and there are a lot of primary agricultural areas around this site. Due to all the above mentioned properties, Site 2 has negative effects more than the other alternatives.

Site 3 (Current site): It draws attention to having the useful life (30 years) which is more than other alternative sites and has a shorter haul distance (10 km) than the others. Also, this site is not affecting the city with respect to the primary wind direction, negatively. But, the wind blowing from the east and southeast through the west in winter and autumn months causes the movement of polluted air from the current uncontrolled landfill site to the city center. Moreover, there is a small agricultural land and distance between the graveyard and the site is only 500 m (Kose et. al. 2005).

Site 4 (Satilmisoglu site): This site will affect the city center from primary and third wind direction, negatively. In addition to this disadvantage, it also has a longer haul distance (20 km) and a 5 km road should be constructed to enter the site (Kose and Yilmaz 2003).

Application of ANP

After the pre-assessment phase, where the alternative sites have been introduced briefly, Super Decision Software has been used and BOCR analysis has been conducted to apply ANP for the site selection. In BOCR analysis, each alternative site has been evaluated in terms of its benefits, costs and risks; the opportunity cluster has been examined under the benefit cluster.

In ANP, significance and impact weighting between each criterion might be done according to the decision maker. In this study, the significance of the weightage of chosen criteria have been formulated in the program as;

Risk: 1/2
Cost: 1/3
Benefit: 1/6

$$\text{Formula} = \text{benefit} + \frac{1}{\text{cost}} + \frac{1}{\text{risk}}$$

Evaluation of criteria

According to the criteria and the formula above, the appropriate order of alternative sites has been evaluated and presented in Fig. 2. Also, as mentioned before, comparison has been done between ANP and AHP methods given in Table 1. By using Super Decision Software, evaluation of each alternative site has been explained as follows.

Benefits

Capacity and useful life In this criterion, evaluation has been done according to the volume of alternative sites and indirectly useful life. According to the calculations, Site 3 having approximately 30 years of useful life has been ranked as the most advantageous

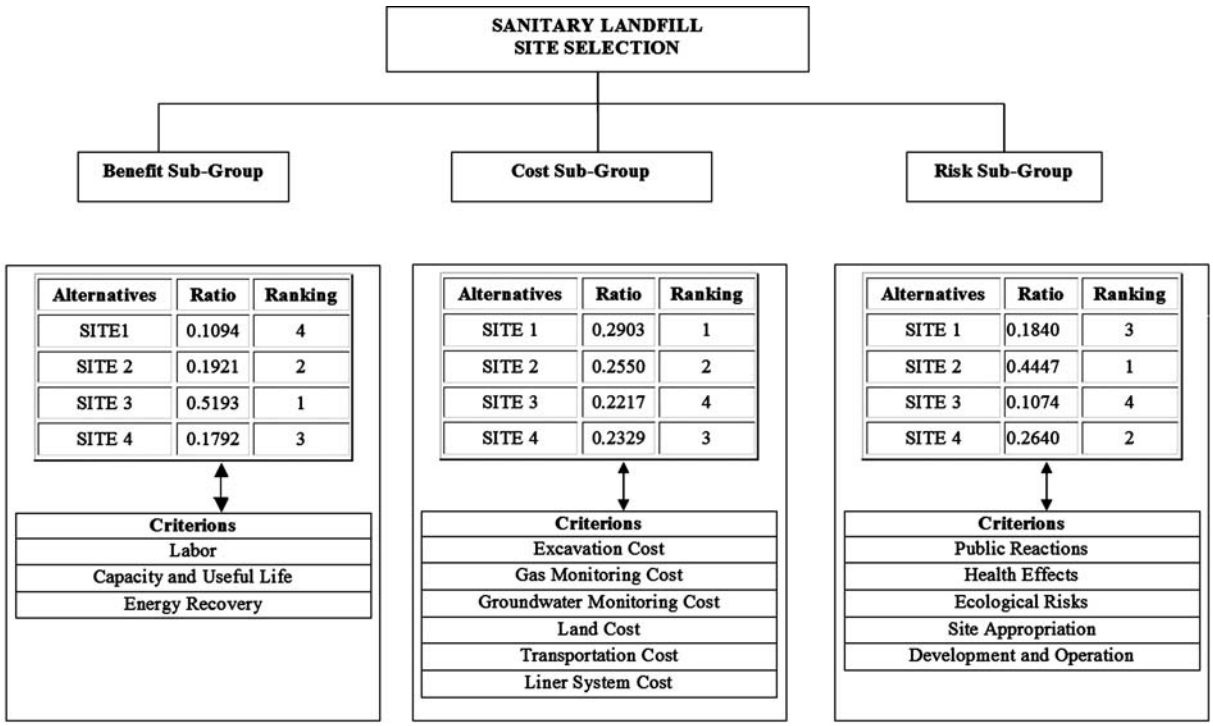

Fig. 2 Flow chart of analytic network process for the results of evaluation of the alternative sanitary landfill sites

Table 1 Comparison results of AHP and ANP applications

Alternatives	AHP property (%)	ANP property (%)
SITE 1	34.10	21.95
SITE 2	10.80	19.11
SITE 3	43.60	36.12
SITE 4	11.50	22.82

site followed by Site 4 and Site 2, having approximately 15 years of useful life. Site 1 which has 10 years of useful life has been ranked as the last alternative.

Energy recovery In this criterion, the amount and structure of the current solid waste are the characteristic factors. Even though all of the sites nearly have equal capacity from the point of providing benefit, useful life has been considered in terms of the duration of the providing energy and it has been put in the order as: Site 3, Site 4, Site 2 and Site 1.

Labor In the phase of the establishment and administration of the sanitary landfill plants, an important employment opportunity can be provided for residents. For that reason, the distance of the sites from the nearest locating area and the useful life have been considered in this criterion. According to this, while Site 3 and Site 4 have the most advantageous position based on employment opportunity, alternative sites Site 1 and Site 2 have less opportunity than the others.

Cost

Excavation In this criterion, the topography has been taken into consideration and slopes of the sites and soil profiles have been analyzed. According to this criterion, Site 2 which has more than 20% slope, has been determined as the costliest site because of the maximum slope rate. This site is followed by Site 4 which has very shallow solid profile and approximately 20% slope and Site 1 with 15% slope, respectively. In terms of cost, the most advantageous site, with 6–12% slope, is Site 3.

Gas monitoring In this criterion, the characteristic factor is volumes of the alternative sites; Site 3 which has the largest volume has been considered as the most expensive site. Then, it is followed by Site 4 and Site 2 which have approximately the same volumes. In comparison with the others, volume of Site 1 is quite less. So, according to this criterion, the most appropriate site in terms of economy is Site 1.

Groundwater monitoring Evaluation has been done according to the groundwater level in alternative sites. Hence, Site 3 whose groundwater level is 40–50 m in depth is the costliest. It is followed by Site 1 and Site 2 whose groundwater levels are 8 and 3.5 m, respectively. Even in this criterion, the most appropriate site in terms of cost of the monitoring of ground water has been defined as Site 4 whose groundwater level is 1.5 m.

Land Site 2 has been defined as the most expensive site because of having first degree agricultural areas. Because of the existing pastures, Site 4 and Site 1 have followed this site respectively. Site 3 used as current landfill site has been defined as the least costly alternative site in this criterion.

Transportation To define the distance of transportation, the distance of alternative sites to the city center has been taken into consideration in this criterion. Site 3 is the nearest site, 10 km away from the city center, and it is in the most advantageous position in terms of cost. Site 2 (11 km), Site 4 (20 km) have followed this site according to their distances. Site 1 is the costliest site in terms of hauling distance of 25 km.

Liner system In this criterion, geological and hydrogeological structure of sites have been taken into consideration. Site 3, placed in severe erosion prone area and consisting of limestone layer, has been defined as the most expensive site in this criterion. Site 1 which is also placed in severe erosion area, has followed this site. Then, the next appropriate sites are Site 4 and Site 2.

Risk

Public reaction In this criterion, the distance of alternative sites to the nearest residential areas has been taken into consideration. The most risky site to the nearest residential area which is 500 m away is Site 2. Site 1 and Site 4 have followed Site 2. Site 3 having the farthest (5 km) distance to the nearest residential area is the least risky one.

Health effects In this criterion, the alternative sites' proximity to ground and surface water and also its distance to the nearest residential area have been considered. Depending on this criterion, Site 2 has been defined as the most risky site, followed by Site 4 and Site 1. Site 3 has been ranked as the least risky.

Ecological risks In this criterion, the utilization structure of the currently used site and the alternative sites and also the plant cover have been considered. The sites which have been ranked from the most to the least risky sites are Site 4, Site 2, Site 3 and Site 1, respectively.

Site appropriation This criterion has considered the existence of sensitive sites in terms of environmental aspects. For this reason, while Sites 2 and 3 are the most risky sites, Site 1 and Site 4 have been defined as less risky ones which have less environmentally sensitive structures.

Development and operation Even in this criterion, the distance of alternative sites to the residential areas and the opportunity of the land usage have been considered. Hence, the most risky site is Site 2; Site 3 and Site 1 have followed Site 2, respectively. Site 4 has been considered the least risky one with respect to this criterion.

Conclusion

In Turkey, 67% of generated MSW has been dumped at open dumps and there has not been any National Solid Waste Management Strategy. Establishment of a national strategy is very important both for the protection of natural resources and prevention of environmental pollution. In setting up this system, different instruments will be used to help the decision makers for the most appropriate solution.

In this paper, besides technical evaluations, economic and social factors have also been taken into consideration in ANP method differently from the AHP method. Also, results of the two methods have been compared and the ranking of the sites in the two methods was found to be different. But Site 3 (currently used site) was found as the best alternative in both methods. However, since uncontrolled dumping is still carried on, the most important step that should be immediately applied is the rehabilitation of this site.

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