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Suitability analysis for siting MSW landfills and its multicriteria spatial decision support system: Method, implementation and case study

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

Dept. Production Engineering and Management, Democritus University of Thrace, Vas. Sofias 12, 671 00 Xanthi, Greece

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ABSTRACT

Multicriteria spatial decision support systems (MC-SDSS) have emerged as an integration of geographical information systems (GIS) and multiple criteria decision analysis (MCDA) methods for incorporating conflicting objectives and decision makers' (DMs') preferences into spatial decision models. This article presents a raster-based MC-SDSS that combines the analytic hierarchy process (AHP) and compromise programming methods, such as TOPSIS (technique for order preference by similarity to the ideal solution) and Ideal Point Methods. To the best of our knowledge it is the first time that a synergy of AHP and compromise programming methods is implemented in raster-driven GIS-based landfill suitability analysis. This procedure is supported by a spatial decision support system (SDSS) that was developed within a widely used commercial GIS software package. A real case study in the Thrace region in northeast Greece serves as a guide on how to conduct a suitability analysis for a MSW landfill site with the proposed MC-SDSS. Moreover, the procedure for identifying MSW disposal sites is accomplished by performing four computational models for synthesizing the DMs per criterion preferential system. Based on the case study results, a comparison analysis is performed according to suitability index estimations. According to them Euclidean distance metric and TOPSIS present strong similarities. When compared with Euclidean distance metric, TOPSIS seems to generate results closer to that derived by Manhattan distance metric. The comparison of Chebychev distance metric with all the other approaches revealed the greatest deviations.

1. Introduction

One of the major problems facing developed countries is the inefficiency of municipal solid waste management (MSWM) systems, which cannot fulfill their needs due to a lack of appropriate infrastructures and the uncontrollable rise in world population rates (Tchobanoglous et al., 1993). Consequently, this rise in world population rates also causes an increase in the national average production of municipal solid waste (MSW), regarding to Greece MSW production was estimated to be approximately 4,000,000 tons for the year 2000. Per capita production rates rose approximately 0.7% between the years 1997 and 2010, resulting in an average increase in 0.43 kg per capita due to the 0.4% growth of the national population rate per year. Moreover, according to the official records until 1994, 4850 dumpsites within the Greek MSWM system were in use (70% of which were uncontrolled), while 1420 dumpsites were semi-controlled (Mavropoulos, 2000).

For this reason, regional authorities and the central government have devoted significant effort to recovering currently used MSWM systems and either identifying new potential waste disposal sites or restoring old ones. However, people's nescience of the health and social benefits derived from landfill siting can obstruct MSW disposal siting near residential areas, thereby amplifying the problem (Noble, 1992; McBean et al., 1995; Siddiqui et al., 1996). This attitude is widely known as the NIMBY (Never In My Back Yard) syndrome, which implies the citizens' opposition to waste disposal siting next to densely populated areas (Erkut and Moran, 1991; Lober and Green, 1994).

In addition to confrontations with stakeholders, decision makers (DMs) have to take into consideration numerous technical, environmental and social factors during the landfill site screening process to minimize as far as possible environmental and social consequences resulting from an inappropriate landfill site selection (Tchobanoglous and Kreith, 2002). In Greece, the guidelines for appropriate site selection are provided through national (Greek Governmental Ministry Decision 114218/97) and international (EU directive 99/31/EC) legislations. The institutional framework aims to protect environmentally sensitive areas and ensure development prospects and citizens' prosperity. The area demanded for locating landfills in Greece was shown to be 0.145 m^2/year per capita by Kallergis (2000b). As a result, appropriate landfill site selection is a challenging task in which conflicting objectives,

* Corresponding author. Tel.: +30 6932571309; fax: +30 2541074111.
E-mail addresses: odemesou@pme.duth.gr (O.E. Demesouka), avavatsi@pme.duth.gr (A.P. Vavatsikos), kanagn@civil.duth.gr (K.P. Anagnostopoulos).

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exclusionary criteria and citizens' skepticism should be sufficiently balanced during the site selection process.

Given the spatial nature of the site selection process, an intensive effort has been made during the last 30 years to build into the analysis sophisticated tools and techniques that allow efficient handling of both datasets and DMs' preferences. As a result, the development of the so-called multicriteria spatial decision support systems (MC-SDSS) aims to rank the alternatives according to the DMs' preferences in conjunction with the study area's characteristics. Finally, the use of MC-SDSS facilitates the estimation of the suitability index, for every candidate location, and increases the accuracy of the final result, thereby simplifying the siting procedure.

To rank the acceptable locations according to their relative importance in satisfying the analysis objectives, the MC-SDSS aims to develop methodologies, rules and software tools that support the spatial distribution of the DMs' preferences and the estimation of the suitability of alternatives. In this study, a new MC-SDSS for landfill siting suitability analysis is proposed that supports synergies between the analytic hierarchy process (AHP) and compromise programming methods. The spatial decision support system (SDSS) was developed using a widely used commercial geographical information systems (GIS) software package. Furthermore, a real case study in the Thrace region demonstrates the combined use of AHP and compromise programming methods regarding the landfill site selection problem. The above combination was selected because AHP is a well-known method of criterion weights elicitation and up to now was implemented to a variety of GIS-based suitability analysis studies, mostly in combination with weighted summation or ordered weighted average decision rules. The discussed in the present study synergy with compromise programming methods allows the implementation of a variety of decision rules for aggregating the per criterion DMs preferences. As a result alternative locations are ranked according to a selected distance metric from a hypothetical ideal and/or anti-ideal solution. The approach provides DMs with the capability of handling the levels of compensation among the decision criteria enhancing the flexibility of the decision analysis. Recently, Onut and Soner (2008) implemented AHP and Fuzzy TOPSIS, for ranking alternative waste transshipment locations, in a non GIS environment. Given that, to the best of our knowledge it is the first time that the above combination is performed to rank alternative locations in landfill GIS-based site screening suitability analysis. Finally, a comprehensive discussion of site selection criteria is provided.

2. Spatial multicriteria decision making

The landfill site selection process is one of the most critical tasks related to the numerous factors that DMs should take into consideration to avoid both public obstruction and environmental deterioration in the study area. Renowned for their ability to address spatially related problems, commercial GIS software packages have proven to be valuable tools for conducting landfill site screening processes (Vatalis and Manoliadis, 2002; Nas et al., 2009). The ability of GIS software packages to support geoprocessing tools such as overlay procedures led both scientists and practitioners to often refer to them as SDSS. However, Boolean overlays do not provide procedures to evaluate the suitability of sites falling within the feasible areas (Carver, 1991).

Despite the indisputable contribution of GIS to decision making, their application as SDSS meet several limitations. In short, the supported procedures are incapable of (a) building DM preferences into the analysis, (b) evaluating alternatives given the fact that each one satisfying the analysis constraints is considered an acceptable solution, (c) including evaluation criteria with respect to the analysis goal and (d) providing frameworks for the spatial distribution of the decision analysis goal satisfaction (Laaribi et al., 1996; Chakhar and Martel, 2003).

Recent evolutions in computer science allowed the development of synergies and tools among GIS technology and multiple criteria decision analysis (MCDA) methods to reduce previous disadvantages. Based on McHargs' (1992) seminal work and land use planning models proposed by Voogd (1983), spatial multicriteria decision analysis provides the framework for alternative site evaluation according to DM preferences (Laaribi et al., 1996). The synergy of MCDA models with GIS is a powerful tool for handling structured or semi-structured site selection decision problems and therefore allowing the suitability index estimation of alternatives. This usefulness is owed mainly to their ability to identify and rank potential landfill sites based on several social, environmental and technical criteria, hence maximizing analysis efficiency. At the most rudimentary level, the GIS-based multicriteria decision analysis can be thought of as a procedure for combining geographical data and value judgments (the DM's preferences) to obtain information for decision making.

During the last three decades, many articles have been published concerning the integration of GIS and multicriteria evaluation methods to locate both hazardous (e.g. Carver, 1991; Minor and Jacobs, 1994; Dorhofer and Siebert, 1998; Yesilnacar and Cetin, 2005) and solid (e.g. Lober and Green, 1994; Kao and Lin, 1996; Muttiah et al., 1996; Siddiqui et al., 1996; Lin and Kao, 2005; Tavares et al., 2011) waste disposal sites.

The indisputable benefits derived from the GIS-MCDA methods synergy revealed a well-established body of literature of 35 journal articles since 1983. Common practice among them is the development of approaches to identify the most suitable sites for locating MSW landfills. In particular, the 60% of them had been released after 2006 a fact that reflects the growing interest for this research area (Fig. 1). As it derives from Table 1, in the early years the analysis criteria were considered of equal importance (e.g. Lane and McDonald, 1983; Jensen and Christensen, 1986) or were derived based on their participation in satisfying analysis aspects (Halvadakis, 1993) The study by Siddiqui et al. (1996) pioneered GIS-based landfill siting analysis using the AHP as a criterion weights elicitation method, forming matrices of pairwise comparisons of the analysis objectives. Since then AHP was performed to a variety of case studies (e.g. Delgado et al., 2008), the most recent among them being the work presented by Gbanie et al. (2013). Given that commercial GIS software, such as the IDRISI (Eastman, 2003), facilitate ordered weighted average (OWA) approach, the method was applied in landfill siting analysis in several studies (Table 1). Regarding the applied decision rules, the weighted linear combination (WLC) approach was introduced by Lane and McDonald (1983), whereas multi-attribute utility theory (MAUT) was first applied by Leao et al. (2001). The use of utility functions remains a popular approach among researchers until now (Sharifi and Retsios, 2004; Geneletti, 2010). Recently, Chang et al. (2008)

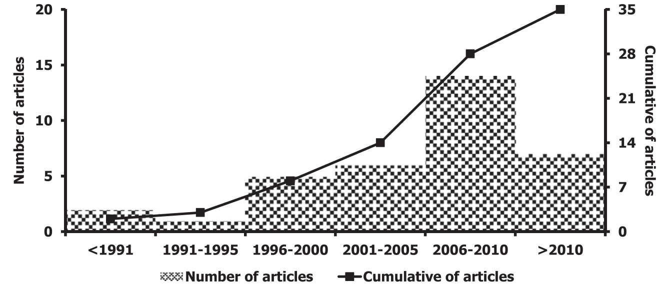

Fig. 1. Research area's development over the years.