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Municipal solid waste management using Geographical Information System aided methods: A mini review

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Abstract

Municipal Solid Waste Management (MSWM) is one of the major environmental challenges in developing countries. Many efforts to reduce and recover the wastes have been made, but still land disposal of solid wastes is the most popular one. Finding an environmentally sound landfill site is a challenging task. This paper addresses a mini review on various aspects of MSWM (suitable landfill site selection, route optimization and public acceptance) using the Geographical Information System (GIS) coupled with other tools. The salient features of each of the integrated tools with GIS are discussed in this paper. It is also addressed how GIS can help in optimizing routes for collection of solid wastes from transfer stations to disposal sites to reduce the overall cost of solid waste management. A detailed approach on performing a public acceptance study of a proposed landfill site is presented in this study. The study will help municipal authorities to identify the most effective method of MSWM.

Keywords

Geographical Information System, municipal solid waste management, public acceptance, route optimization, selection of landfill site

Introduction

Solid waste generation has become an important issue in recent years due to the uncontrolled growth of the urban population and industrialization. The amount of municipal solid waste (MSW) generated per capita in developing countries such as India is estimated to increase at a rate of 1–1.33% annually and most of the MSW is directly disposed of on land in an unscientific manner (Bhide and Shekdar, 1998; Das et al., 1998; Pappu et al., 2007; Shekdar, 1999). One of the most serious and growing potential problems of Solid Waste Management (SWM) is the shortage of land for disposal (El-Fadel et al., 1997). An efficient SWM system has to be designed wherein decision makers and waste management planners can deal with the increase in complexity, uncertainty, multi-objectivity and subjectivity associated with this problem (Sumathi et al., 2008).

The solid waste dumping sites are the sources of leachate and believed to be one of the main reasons for groundwater contamination near the dumping sites. The disposal of hazardous waste materials in landfills without proper pre-treatment may also lead to the emissions of toxic substances and, hence, these landfills are reported as a potential source of nitrate contamination and heavy metals in groundwater (Kumar et al., 2006; Singh et al., 2008; Velis and Brunner, 2013; Yang et al., 2008). Gharaibeh and Masad (1989) reported that the dissolution of solid wastes combined with rainfall produces a large quantity of polluted water in the form of leachate. Surface water near the landfill sites exhibits high toxicity as the plume of toxicants move from the landfill and meet the nearby streams. The surface water may also receive contamination from the shallow groundwater near the landfill (Ahel et al., 1998; Bruner et al., 1998; El-Fadel et al., 1997; UNEP et al., 1996). Landfill gases generated due to the decomposition of organic waste, which contributes greenhouse gases, are emitted into the atmosphere. It is also responsible for causing landfill fires, and explosions if trapped in buildings (Khalil, 1999; Macleod et al., 2006; Maillefer et al., 2003; Palmer et al., 2005; Sharholy et al., 2007).

The main functional elements of Municipal Solid Waste Management (MSWM) are waste generation, storage, collection, transportation, processing, recycling and disposal in a suitable landfill. The functional elements of MSWM are depicted in Figure 1.

In the domain of SWM components, identification of landfill sites for solid waste disposal remains a critical management issue. The selection of landfill sites should be based on a number

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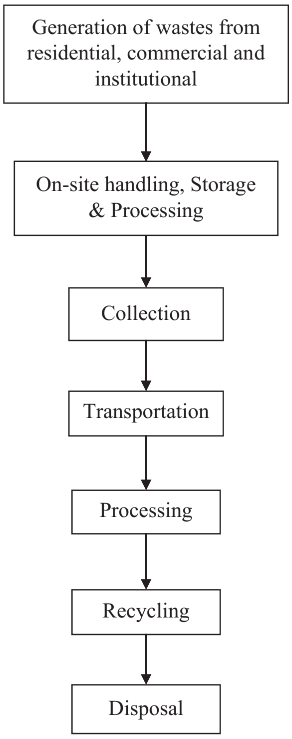

Figure 1. Functional elements of municipal solid waste management.

of parameters, such as the pre-existing land use pattern, location of sensitive sites, infiltration, water bodies, water supply sources, groundwater quality, air quality, geology and the socio-economic parameters of the area (Central Pollution Control Board, 1999; Dipanjan et al., 1997; Sumathi et al., 2008). The Geographical Information System (GIS) helps to quantify the relationship between the demands and supply of suitable land for waste disposal over time and plays a significant role in decision making for planning and management of solid wastes (Leao et al., 2001). It is a great tool for handling physical suitability analysis but has limited capabilities of incorporating the decision maker's preferences and heuristics into the problem-solving process; whereas an expert system is capable of addressing heuristic analysis, it lacks the capabilities of handling spatial data that are crucial to spatial analysis (Eldrandaly, 2007). Optimization of the MSW collection system using GIS involves the planning of bins, vehicles and optimal routing that can reduce the effective cost of management and impacts on the environment (Ghose et al., 2006). The transfer and transport element is a two-step process: (i) the transfer of wastes from the smaller collection vehicle to the larger transport equipment and (ii) the subsequent transport of the wastes, usually over long distance, to a processing or disposal site. The vehicle types and the road networks are taken as the basis for finding the optimal route for collection of wastes. The order in which the bins are visited is calculated based on the proximity of the bins and the optimal path generated for each vehicle (Ghose et al., 2006). The challenge for successfully locating waste disposal facilities is the social and political acceptance of the proposed landfill. In most of the cases the areas near landfill sites are adversely affected and hence the acceptance by public plays an essential role. The main focus of this paper is to address the landfill site selection process using GIS-aided tools, route optimization to reduce the overall cost of SWM and an approach of getting public acceptance after the site selection with the help of GIS.

Landfill site selection

Siting a location for landfill requires a wide and vigorous evaluation process in order to identify the best available disposal location that must follow the governing regulations and at the same time must consider economic, environmental, health and social impacts (Al Sabbagh et al., 2012; Brunner, 2013; Wilson et al., 2007). It requires processing and evaluation of a significant amount of spatial data related to various parameters governing the suitability of a site (Ojha et al., 2007). The environmental factors play a very important role in selecting the landfill site, as the landfill may affect the biophysical environment and ecology of surrounding area (Erkut and Moran, 1991; Lober, 1995; Siddiqui et al., 1996; Su et al., 2010). Areas having flat and gently rolling hills that are not subjected to flooding are the best sites for area and trench-type landfills (Sener et al., 2006; Şener et al., 2010). Slope is another important factor; areas with slopes greater than 15% should be considered unsuitable for waste disposal sites (Bagchi, 1994). Landfill site suitability is assessed on a scale based on territorial indices that measure the risk contamination for the following five environmental components: surface water, groundwater, atmosphere, soil and human health. This facilitates in establishing the general indices to quantify overall environmental impact as well as individual indices for these specific environmental components. Baban and Flannagan (1998) discussed the importance of two major issues for landfill site selection: (1) approval of the local population, which is driven by social and political considerations and economic incentives, and (2) engineering and technical protocols for planning and protection of the physical environment. Landfill should be located at a certain distance from human settlements and from airports. As a safety measure a maximum 5 km buffer zone has also been considered safe for big cities and smaller buffer zones for smaller cities and villages (Sharifi et al., 2009). This distance factor differs from country to country. For example, as per China Solid Waste Management Law and Waste Landfill Criterion, a sanitary landfill cannot be located within 500 m of a residential area and so it is implemented for the present urban and industrial areas of China (Wang et al., 2009). According to Turkish Solid Waste Control Regulations (TSWCR, 1991), landfills cannot be located within 1000 m of settlement areas. Most European countries have the rule that those who generate waste must bear the cost of its management and disposal. According to Canada Solid Waste Management Rules, RA 9003 provides that segregation and collection of solid waste shall be conducted at the small community

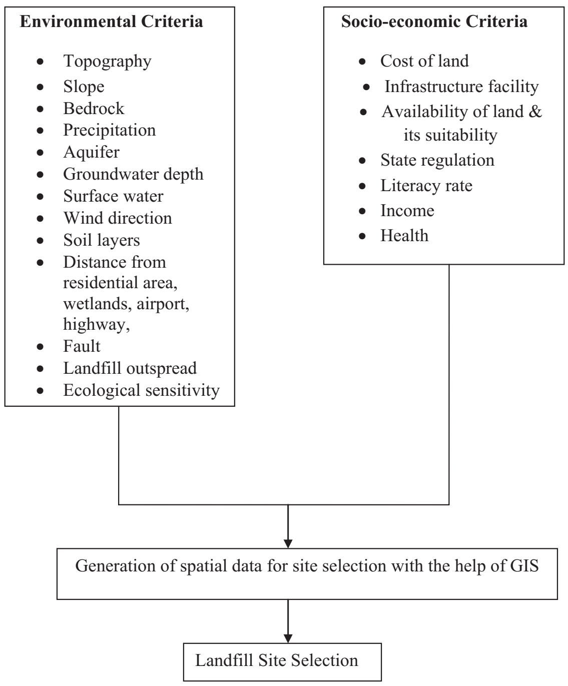

Figure 2. Landfill site selection process.

level, specifically for biodegradable and reusable waste. The said law also provides for the establishment of a materials recovery facility (MRF) in every barangay or cluster of barangays (Philippines-Canada Local Government Support Program, 2003). The site selection procedure, however, should make maximum use of the available information and ensure that the outcome of the process is acceptable by most stakeholders and thus landfill siting generally requires processing of a variety of spatial data. The utilization of artificial intelligence technology, such as expert systems, will help in solid waste planning and management, particularly in the landfill siting process (Thomas et al., 1990). A similar study has also been done by Lukasheh et al. (2001) where they discussed the integration of an expert system, GIS and decision support system and its efficiency in solving the landfill design. GIS has the ability to combine spatial data (maps, aerial photographs and satellite images) with a quantitative, qualitative and descriptive information database that can support a wide range of spatial queries (Hanbali et al., 2011). GIS, however, converts georeferenced data into computerized maps, while GIS map analysis tools make it possible to efficiently manipulate maps with a computer. Figure 2 describes the sequential steps for locating landfill sites considering environmental and socio-economic criteria using GIS. The Spatial Decision Support Tool for landfill site selection is a model that converts input data into an output map using a specific function such as a buffer or overlay (Gao et al., 2004). Spatial modelling is the process of manipulating and analysing spatial data to generate useful information for solving complex problems (Haggett and Chorley, 1967). GIS has been used successfully in various aspects of SWM, including suitable landfill site selection, and optimization of solid waste collection and transportation. Kao and Lin (1996) proposed a siting model that was explored for use with raster-based GIS. Kao et al. (1997) applied a multimedia network interface to evaluate the environmental, social and economic engineering feasibility issues for the suitability of a candidate landfill site. Jensen and Christenensen (1986) identified potential sites for the storage of industrial wastes and then they demonstrated how the required in situ and remotely sensed data can be placed in a GIS to model. The model developed by Leao et al. (2004) consists of a loose-coupled system that integrates GIS and Cellular Automata (CA) in order to give it spatial and dynamic capabilities to provide significant insights into the design of SWM activities. Vaillancort and Waaub (2002) carried out environmental site evaluation of waste management facilities embedded into the EUGENE model. The model objective function is to minimize the total system cost and Global Impact Index. Zamorano et al. (2009) concluded that GIS is a useful tool for the optimal siting of landfills as it has the potential to assist planners, decision makers and other agents involved in the process of selecting suitable sites for municipal landfills since it increases the knowledge about the physical terrain, thus facilitating the analysis and implementation of action plans. The use of GIS can facilitate zone exclusion based on a set of screening criteria and effective graphical representation (Sener et al., 2006). The following section presents the techniques of evaluating municipal landfill sites with GIS-aided methodologies.

Mixed integer programming model

A Mixed Integer Programming Model (MIPM) was developed to obtain a landfill site with optimal compactness of the site, which refers to the ratio of the perimeter to the site area. GIS, although capable of processing spatial information effectively, cannot implement an optimization model successfully. In the past, when a siting area is large, GIS could only offer limited assistance. This limitation was improved by developing a mixed integer spatial optimization model based on vector data to assist decision makers in finding a suitable site for solid waste disposal (Kao and Lin, 1996). Benabdallah and Wright (1992) used a raster-based linear mixed integer model to solve a multiple site land use planning problem. It can be said that for a mixed integer linear programming model, an increase in the number of integer variables rapidly increases the computational time required to solve the model. However, an increase in the number of non-integer variables does not have such a significant effect (Kao and Lin, 1996). When integrated with GIS, the model is capable of processing digital spatial data efficiently to facilitate landfill siting analysis. The MIPM is helpful in location allocation models when incorporated with the environmental factors (air pollution, leachate impacts, noise control, traffic congestion and material recycling) within a long-term planning framework during the siting of a landfill (Chang and Wang, 1996). To deal with the siting problem in planning of a regional SWM scheme, a new analytical model "Fuzzy interval multi-objective mixed integer programming" was proposed by Chang et al. (1997). The model specifically showed how the internal messages related to the input parameter values and the fuzzy goals pertaining to the decision maker's aspiration levels are communicated into the multi-objective optimization processes. It is effective in generating a set of more flexible optimal solutions for real-world SWM problems. The model approach contributed significant improvement in both the theory of multi-objective programming and the application for long-term planning of a SWM system (Chang et al., 1997).

Multi-criteria decision analysis

Multi-Criteria Decision Analysis (MCDA) made the handling of the large complex information easier. A Multi-Criteria Decision Making (MCDM) problem is characterized by the ratings of each alternative with respect to each criterion and the weights given to each criterion. Commonly used MCDM software tools include Analytic Hierarchy Process (AHP), ELECTRE and PROMETHEE (Achillas et al., 2013). MCDM provides a support for the identification of components of a decision making problem, organizing the elements into a hierarchical structure, understanding the relationships between components of the problem and stimulating communication among participants (Malczewski, 2006). In order to reach the goal several criteria need to be evaluated and MCDA can be termed as Multi-criteria Evaluation (MCE) in that case. The basic aim of MCE analysis using GIS techniques is to investigate a number of possible choices in the light of multiple criteria and conflicting objectives (Voogd, 1983). It is a system that offers a rich collection of techniques and procedures to reveal decision maker's preferences and to incorporate them into GIS-based decision making. GIS-based MCDA is a collection of different techniques for analysing geographic events where the results of the analysis depend on the spatial arrangement of the events (Cowen, 1988). It is a part of the tool "Multi-dimensional decision and evaluation technique" that helps in analysing the complex tradeoffs between alternative choices (e.g. sites, plans) with different environmental and socio-economic impacts (Carver, 1991). MCE provides the means of performing complex tradeoffs on multiple and often conflicting objectives while taking multiple criteria and the expert knowledge of the decision maker into account. GIS and MCE-based systems have the potential to provide a more realistic and unbiased approach for decision making in landfill siting. A complete integration of a GIS would allow one to perform successive routines and to analyse territory on a global scale (Vaillancourt and Waaub, 2002). The MCE technique has the ability to simultaneously evaluate a number of possible choices in the siting process, while taking into account various relevant criteria, as well as frequently conflicting objectives (Vasiljević et al., 2012). In site selection problems, the GIS performs deterministic overlay and buffer operations while MCDM methods evaluate alternatives based on the decision maker's subjective values (e.g. risk and confidence) and priorities (Eldrandaly et al., 2003). A GIS-based MCDA is a procedure that converts and combines geographical data and decision maker's preferences in order to obtain useful information for decision making (Boroushaki and Malczewski, 2010; Eastman et al., 1995; Malczwerski, 1999). Due to this complementary aspect, multi-criteria analyses integrated into GIS can provide proper manipulation and data presentation with consistent ranking based on a variety of factors that could influence the analyses (Vasiljević et al., 2012). The MCDA method divides the decision-making problems into smaller parts that helps to easily understand and analyse the problem and the GIS provides efficient manipulation and presentation of the data. Demesouka et al. (2014) have provided a useful review regarding the Multi-Criteria Spatial Decision Support System (MC-SDSS) and its implementation in various other case studies. The MC-SDSS has emerged as an integration of the GIS and MCDA methods.

The MCE method served the inventories to classify, analyse and conveniently arrange the available information about possible choices in regional planning (Voogd, 1983). Vasiloglou (2004) has used Multi-Criteria Analysis (MCA) to locate new landfill sites for a pilot study area in Greece, but the exact mechanisms by which the general public could input into the decision-making process were not specified. The solid waste disposal site selection requires many factors that should be integrated into one system to analyse (Hanbali et al., 2011). They reported a study on the MCE method using GIS that was implemented for landfill site selection in Mafraq city in Jordan. Several such studies (Allesch and Brunner, 2014; Kontos et al., 2005; Sharifi et al., 2009; Sumathi et al., 2008) on the application of MCE with GIS for landfill siting have been reported. The coupling of these two management tools offers great possibilities, but without data and expertise, these possibilities are still limited (Jankowski, 1995).

MCDA, when coupled with GIS, helps in choosing a suitable landfill by selecting the simple additive weighing method and analytical hierarchy method, based on the weighted average to analyse the data using GIS. The suitability of a site is decided as per the score through the comparative study. Major difficulties are faced when too many criteria are taken as they lead to a higher number of criteria yielding a large number of pair-wise comparisons (Sener et al., 2006).

Another study in Regina city, Canada, was done by integrating MCDA and Inexact Mixed Integer Linear Programming (IMILP) methods to select an optimal landfill site as well as the waste flow allocation pattern to minimize the total system cost (Cheng et al., 2003). In the multi-objective programming model, only quantitative parameters are evaluated, whereas the subjective considerations such as risk of groundwater pollution as well as the other environmental and socio-economic factors are ignored.

Aggregation methods. Aggregation methods normalize criteria scores to enable comparison of performance on a common scale.

Weighted linear combination. Weighted Linear Combination (WLC) is one of the widely used MCE techniques that are used to evaluate the suitability of a site. It is a concept that combines maps by applying a standardized score to each class of a certain parameter and a factor weight to the parameters (Yalcin, 2008). In the procedure for MCE using a WLC, it is necessary that the weights sum to one (Mahini and Gholamalifard, 2006). WLC is based on the concept of a weighted average in which continuous criteria are standardized to a common numeric range, and then combined by means of a weighted average. The relative weights are assigned to each attribute in the map layer by the decision maker. One of the advantages of the WLC method is its ability to give different relative weights to each of the factors by aggregation (Drobne and Lisec, 2009). WLC is used wherein individual classes of each parameter are rated and factor weights are assigned in order to produce a map layer by means of weighted average values (Ayalew et al., 2004). Hanbali et al. (2011) used different thematic layer integration using GIS, WLC and remote sensing techniques to achieve suitable landfill sites for a study in Jordan. The remote sensing technique helps to update the real-time information. A GIS-based MCE technique, using WLC analysis, examines a number of possible choices for a siting problem, taking into consideration multiple criteria and conflicting objectives. It combines multiple raster inputs, representing multiple factors, of different weights or relative importance (Hanbali et al., 2011). The WLC procedure allows full tradeoff among all factors and offers much more flexibility than the Boolean approaches.

Ordered weighted average. Another option for MCE is an Ordered Weighted Average (OWA; Eastman and Jiang, 1996). OWA is a relatively new MCE combination method that is analogous to WLC but considers two sets of weights. The first set of weights controls the relative contribution of a specific criterion while the second set of weights controls the order of aggregation of the weighted criteria (Malczewski, 1999, 2006). This method offers a complete spectrum of decision strategies along the primary dimensions of degree of tradeoff involved and degree of risk in the solution. OWA is extensively used due to the ability of these operators to provide the decision maker with a better insight into decision making under ignorance. The process by which the alternatives are ordered by integrating data (criteria) using decision preferences (weights) is termed as the decision rule (Chankong and Haimes, 1983). A variety of rules from simple additive weighting to Ideal Point Methods (IPMs) can be found in the literature (Bender and Simonovic, 2000; Despic and Simonovic, 2000; Keeney, 1980; Keeney and Raiffa, 1976). The order weights allow one to control the degree of tradeoff among criteria, thus providing control of the degree of optimism (attitude to risk) allowed in the planning process (Malczewski, 1999). Currently, applications of OWA range from geologic data analysis (Araújo and Macedo, 2002) to web-enabled spatial analysis (Rinner and Malczewski, 2002).

Unlike WLC and OWA, the IPM is a non-additive method that uses the original criteria scores. It identifies a point in criteria outcome space by specifying the preferred value of each criterion (Malczewski, 2004; Nyerges and Jankowski, 2010). The IPM represents a hypothetical alternative that comprises the most desirable outcomes for the evaluation criteria. The nadir represents a hypothetical alternative that comprises the least desirable outcomes for evaluation criteria. The alternative that is closest to the ideal point, and at the same time farthest from its nadir, is the best alternative under this decision rule (Nyerges and Jankowski, 2010). This ideal point may not be close to a feasible alternative, but there are a number of methods for selecting one, such as the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS; Chen et al., 2001; Liu et al., 2006). The Non-dominated set and reasonable goals method are also examples of non-additive methods. The non-dominated set identifies the set of alternatives that score at least as high as every other alternative on at least one criterion, also called the efficient set or Pareto set (Lotov et al., 2004; Malczewski, 1999). The reasonable goals method is an advanced version of the non-dominated set that helps to visually select from the alternatives using a series of two-dimensional graphs of criteria outcome space (Jankowski et al., 1999).

Weighting methods. Ranking, rating and the analytical hierarchy process (AHP) are used to derive relative criteria weights before applying an aggregation method (Malczewski, 1999; Nyerges and Jankowski, 2010). Ranking is the simplest of all weighting techniques. In this method criteria are arranged in an order of importance that reflects decision maker's preference. In rating a predefined scale is chosen to estimate criterion weights. Commonly, a scale of 0–100 is used in concert with a point allocation approach. These two methods were basically not used in multi-criteria-based landfill site selection due to a lack of theoretical foundation and a lack of managing criteria range (Nyerges and Jankowski, 2010). The AHP is the most popular weighting method with a strong theoretical background.

Analytical hierarchical process. The AHP is a decision-making technique that analyses and supports decisions having multiple and even competing objectives. Siddiqui et al. (1996) introduced the GIS and AHP procedure to aid in the site selection process. GIS is used to manipulate and present spatial data, while the AHP is used to rank potential landfill areas based on a wide variety of criteria. This technique provides a means of decomposing the problem into a hierarchy of sub-problems that can be more easily comprehended and subjectively evaluated. The subjective evaluations are converted into numerical values that are ranked on a numerical scale (Bhushan and Rai, 2004). It is implemented by dividing a complex problem into a number of simpler problems in the form of a decision hierarchy (Erkut and Moran, 1991). After that a pair-wise comparison matrix of each element is constructed. A pair-wise comparison matrix of each element within each level is done and later that can be weighed against each other within each level. The AHP is often used to compare relative suitability of a small number of alternatives concerning the overall process. For example, Wang et al. (2009) developed a hierarchy model for solving the solid waste landfill site selection problem using the AHP and they were the first to consider the economical constraints along with the environmental factors in Beijing, China. The combination of GIS and AHP enables the analysis of a number of required qualitative and quantitative factors for landfill site selection. When the complexity of factors influencing the landfill siting process is combined with the need to involve different stakeholders in the decision-making process, often there is a need to integrate multi-criteria techniques with GIS (Vasiljević et al., 2012). The AHP consist a special case of WLC in GIS-based raster-driven suitability analyses, since the AHP is used as criterion weights elicitation approach. In fact, in its typical form the AHP is performed only in vector-driven analyses where a small number of alternatives exist. The integration of the AHP into GIS combines decision support methodology with powerful visualization and mapping capabilities, which in turn should considerably facilitate the creation of land use suitability maps (Marinoni, 2004).

Landfill site selection is usually divided into two main steps: (i) the identification of potential sites through preliminary screening, and (ii) the evaluation of their suitability based on environmental impact assessment, economic feasibility, engineering design and cost effectiveness (Charnpratheep et al., 1997). The AHP is useful in estimating the weight coefficients for each criterion, which helps in structuring of multi-criteria in a decision hierarchy tree (Kontos et al., 2003). The AHP helps in group decision making, where group members can use their experience and knowledge to break down a problem into a hierarchy and solve it using the AHP steps. The AHP is considered as the most appropriate method because it allows dividing the problem, and focuses on one smaller decision set at a time. After that experts evaluate pairs of the chosen sub-criteria, followed by criteria and finally the factor groups regarding the element in the upper level of the hierarchy (Vasiljević et al., 2012). A similar methodology has also been created to evaluate the suitability of potential landfill sites in Northern Cyprus and the sites were chosen based on the suitability map results (Kara and Doratli, 2012).

Fuzzy multi-criteria decision making

Fuzzy Multi-Criteria Decision Making (FMCDM) methods have been used in environmental planning and decision-making processes in order to clarify the planning process, to avoid various distortions and to manage all the information, criteria, uncertainties and importance of the criteria. A combination of GIS and fuzzy multiple decision-making criteria for the landfill siting problem is used by Chang et al. (2008). A Spatial Decision Support System (SDSS) for waste management is done using thematic maps in GIS in conjunction with environmental, biophysical, ecological and socio-economic variables that further led to support the second-stage analysis where FMCDM is used as a tool in site selection. This approach follows two sequential steps (in the first step it uses MCDM using GIS for geospatial analysis and in the second step FMCDM is used to find the most suitable landfill site) rather than the conventional methods that use a single-step process with a fully integrated scheme. In this technique GIS solves the purpose of the initial screening process to eliminate the unsuitable land and FMCDM helps in identifying the most suitable site using the information provided by the regional experts with reference to five chosen criteria (transportation issues, environmental and ecological impact, public nuisance, economical impact and historical markers). The second-stage analysis for landfill site selection requires a careful evaluation of the advantages and disadvantages of different candidate sites with respect to compliance with preset criteria, because landfill siting is a complicated process that leads to multiple impacts on the area. Here, the technique of the pair-wise comparison matrix is used to establish the factors. In response to the vague (fuzzy) conditions, domain experts in the second stage got involved. The process of the expert opinions and combining them with the power of fuzzy and MCDA yielded a very clear structure that is very much dependent on the screening values of data sets. This is one of the most powerful tools in solving controversial political debates on landfill siting. FMCDM sometimes utilizes fuzzy additive weighting as a weighting method that adopts WLC using non-crisp criteria and weight values derived from fuzzy-linguistic quantifiers such as “high”, “medium” and “low” (Gemitzi et al., 2007; Malczewski, 1999; Zadeh, 1965). The disadvantage of this method is the selection of the most appropriate site that is dependent on the domain expert’s judgements and may be sensitive to changes in the decision weights associated with the criteria.

Fuzzy Logic (FL) was introduced by Zadeh (1965) to describe and to deal with such uncertainties. The selection criteria are weighted to represent the importance and contribution of each factor. This technique is beneficial in the process of initial screening to select a suitable landfill site. An intelligent system based on a fuzzy inference helps in representing the severity of the considerable factors, including topography, geology, natural resources, socio-cultural aspects, economy and safety, used for the analysis of the landfill site suitability. Hence this system is effective in terms of its ranking capabilities (Jarrah and Qdais, 2006). FL provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy or missing input information. The FL model is empirically based, relying on an operator’s experience rather than their technical understanding of the system (Fazlollahtabar et al., 2010). A number of methods have been developed to handle fuzzy comparison matrices. Among all the approaches, the extent analysis method has been employed in quite a number of applications due to its computational simplicity. In FMCDM, suitability is considered a fuzzy concept expressed as fuzzy set membership (Burrough et al., 1992, Hall et al., 1992). In criteria standardization fuzzy membership is highly appealing, because it provides a very strong logic for the process of criteria standardization. It can be considered as one of the recasting values in a statement of set membership and the degree of membership in the final decision set (Eastman et al., 1993). Compared with linear scaling, standardization using the fuzzy set membership function represents a specific relation between the criterion and decision set. The use of Fuzzy Multiple Criteria Analysis (FMCA) in SWM has the advantage of rendering subjective and implicit decision making more object oriented and analytical, with its ability to accommodate both quantitative and qualitative data (Ekmekçioğlu et al., 2010). A fuzzy set provides a mechanism to express the degree of membership rather than accepting or denying the membership. The broad use and popularity of fuzzy sets are associated with their ability to tolerate imprecise and qualitative data (e.g. small, medium or large), whereas the AHP helps to rank potential landfill sites based on a wide variety of criteria (Siddiqui et al., 1996). It assigns each element in the universe of discourse a value representing its grade of membership in the fuzzy set. This system is found reliable by planners and decision makers in the process of initial screening to select a suitable landfill site due to its flexibility and, hence, can be adapted for new information on the landfill site that may be incorporated into the knowledge base. This will allow for interaction of the user with the computer to help in better understanding the landfill siting process and can be easily used for the initial selection process of a landfill site (Jarrah and Qdais, 2006). Gupta et al. (2003) utilized FL, which took into account the uncertainty during the process of the environmental impact assessment of landfill siting and considered the frequency of impact occurrence. Charnpratheep et al. (1997) explored the prospect of combining fuzzy set theory with GIS for the preliminary screening of landfill sites in Thailand. The proximity of geographic objects, slope and elevation were the criteria used for the investigation. Table 1 summarizes the GIS-aided tools, their basic features, and their potential uses, including landfill site selection.

GIS-based MCE software

An important factor in the accessibility of research and methods is the availability of software and tools that implement them. Some readily available software and tools are ESRI's ArcGIS, IDRISI, CommonGIS, etc. The ArcGIS suite of products (http://www.esri.com) provides the building blocks needed to implement WLC, including weighted overlay, weighted sum and map algebra. There are numerous free and proprietary ArcScript implementing other GIS-based MCE techniques (http://arcscripts.esri.com). IDRISI and CommonGIS provide full integration of MCE (Nyerges and Jankowski, 2010). IDRISI (http://www.clarklabs.org) is a proprietary GIS package that includes decision-support modules based on WLC, AHP and OWA, among others, plus a wizard to assist in selection of appropriate decision techniques (Eastman, 2009). CommonGIS (http://www.commongis.com/tutorial/Appendix_1.html) also provides a number of multi-criteria decision capabilities including Ideal Point, WLC, OWA and Pareto sets. A list of a few open source desktop GIS software is given in Table 2.

Route optimization

The route optimization for collection of solid waste is the major component of MSWM to reduce the cost. A substantial amount of the total expenditure (85%) is spent on waste collection alone without any proper storage/collection system and sanitary landfill (Ghose et al., 2006). The implementation of an effective waste management program is a three-phase process (Simonetto and Borenstein, 2007) consisting of the following elements: (i) awareness campaigns so that the people drop the wastes into the right containers; (ii) elaboration of a collection plan; and (iii) waste treatment.

Various studies have been done to check the suitability of landfill locations and garbage transfer stations, and to compare the existing facilities and scientifically optimized locations of garbage bins and landfill sites. For example, a vector optimization model is formulated where the objectives are to minimize the cost, the quantity that is landfilled and the adverse environmental impacts. The main idea is to solve the insufficient landfill area problem and then plan the transfer stations and landfills as large as needed by examining the quantities that were shipped through and to the facilities (Eiselt, 2007).

There are many three-dimensional (3D) modelling applications, such as the *ArcGIS 3D Analyst* extension, that facilitates in creating a 3D road network and calculates segment-wise fuel consumption along the entire road network, and the *ArcGIS Network Analyst* extension, which performs the optimization of MSW collection for minimum fuel consumption.

Network attributes, such as the time to travel a given road length, the fuel consumption for a given road length, the nature of vehicle-specific restrictions for certain streets, the speed limit and the locations of one-way streets, control local traversability. Network analysis often involves the minimization of a cost (the impedance) during the calculation of a path (the optimal route; Tavares et al., 2009). The parameters considered for route optimization are population density, waste generation and composition, road networks, road length, collection vehicle speed, travel time, traffic direction, vehicle access, characteristics of waste containers and vehicles, which are depicted in Figure 3. A significant reduction in the number of containers, collection route length and time involved in waste collection, and related operational costs, such as personnel costs, fuel consumption and vehicle maintenance, may be achieved by using GIS technology (Zamorano et al., 2009). As a consequence, the cost of the collection service with the new optimized route is reduced (Ghose et al., 2006; Johansson, 2006; Li et al., 2008; Racero and Pérez, 2006).

Public acceptance

In the whole process of landfill site selection for MSW dumping, getting public acceptance of those selected sites is the most difficult job, especially in developing nations where population density is very high, literacy rate is poor and there is limited availability of land that has other priority use. It is reported that decision transparency and information accessibility are the key factors for public acceptance of proposed landfill sites (Joos et al., 1999). The integration of GIS and MCE techniques, which include public participation in the decision-making process, has the potential to help build consensus and reduce disputes and conflicts in the final siting decision (Higgs, 2006). Public perception and understanding vary from person to person and across regions depending on their educational, social and cultural background. The proposed landfill sites should always be socially accepted as well as environment friendly and economically sound (Garrod and Willis, 1998). The acceptance study of the proposed landfill site can be done by survey through a suitable questionnaire as per the background of the people. For better communication with people, it is essential to understand people's concerns and concepts of SWM facilities, which is an essential part of better SWM practice. It has been seen that locating a facility in the nearby areas is a predominant acceptance problem (Joos et al., 1999). To increase people's acceptance

Table 1. Salient features of different Geographical Information System (GIS)-aided methods and their uses in solid waste management.

SL No.	Tools coupled with GIS	Salient features	Uses	References
1	GIS and Mixed Integer Programming Model (MIPM)	• Capable of processing digital spatial data efficiently. • Can implement an optimization model. • Reduce system costs. • Applied for economic optimization.	• Mixed integer programming for multi-vehicle path planning. • An industrial application using mixed integer programming technique: A multi-period utility system model.	• Schouwenaars et al., 2001 • Hui and Natori, 1996
2	GIS and multi-Criteria Decision Analysis (MCDA)	• Provides a collection of techniques and procedures for structuring decision problems. • Can transform and combines geographic data and value judgements to obtain information for decision making. • Provides a rich collection of techniques & procedures for structuring decision problems, and designing, evaluating & prioritizing alternative decisions	• Integration of GIS-based suitability analysis and multi-criteria evaluation in a spatial decision support system for route selection • An integrated multi-criteria decision analysis and inexact mixed integer linear programming approach for solid waste management	• Jankowski and Richard, 1994 • Cheng et al., 2003
3	GIS and Multi-Criteria Evaluation (MCE)	• Provide the user with the means to evaluate various alternatives on the basis of multiple and conflicting criteria and objectives. • Analyse the complex tradeoffs between choice alternatives (e.g. sites, plans) with different environmental and socio-economic impacts. • MCE techniques are used to identify "best" compromise solution on the basis of this site-specific information and associated weights. • Contributes highly in the development of effective spatial decision support system.	• Application based on the search for suitable sites for the disposal of radioactive waste in the UK using the Arc/info GIS is included. • MCE-RISK: Integrating multi-criteria evaluation and GIS for risk decision making in natural hazards	• Carver, 1991 • Chen et al., 2001
4	GIS and Weighted Linear Combination (WLC)	• This technique is a decision rule for devising composite maps using GIS. • Offers much more flexibility than the Boolean approaches in the decision-making process. • The WLC approach results in continuous suitability image that makes selecting specific sites for landfill, or any other allocation, problematic. Also	• Siting MSW landfill using weighted linear combination and Analytical Hierarchy Process (AHP) methodology in GIS environment (case study: Karaj) • Landslide susceptibility mapping using GIS-based weighted linear combination, the case in Tsugawa area of Agano River, Niigata Prefecture, Japan.	• Moeinaddini et al., 2010 • Ayalew et al., 2004

Table 1. (Continued)

SL No.	Tools coupled with GIS	Salient features	Uses	References
5	GIS and Analytical Hierarchy Process (AHP)	• Offers an objective assignment process as it helps in identifying each criteria and give weightage. • Allow the decision maker to perform decision analysis functions such as ranking the alternatives to select the best option. • Each pair of factors in a particular factor group is examined at a time, in terms of their relative importance. • Provides a proven, effective means to deal with complex decision making. It can assist with identifying and weighing of selection criteria, analysing the collected data and expediting the decision-making process. • Uses both empirical data as well as subjective judgement of the decision maker. • Spatial-AHP takes into account regulatory restrictions, area attributes, and site assessment criteria provided by users.	• Combining AHP with GIS for landfill site selection: A case study in the lake Beysehir catchment area (Konya, Turkey). • Solid waste disposal site selection with GIS and AHP methodology - case study in Senirkent Uluborlu (Isparta) Basin, Turkey.	• Şener et al., 2006 • Şener et al., 2011
6.	GIS and Fuzzy Multiple Decision Making Criteria (FMDMC)	• Presents fuzzy multi-attribute and multi-objective decision-making methodologies. • It permits the assessment of the membership of elements in a set. • It has capability of representing vague qualitative data and presenting all possible results with different degrees of membership. • In situations where fuzzy sets are a suitable way of representing uncertainty, the decisions taken must be inherently fuzzy.	• A fuzzy knowledge-based decision support system for groundwater pollution risk evaluation • Multi-criteria decision-making methods based on intuitionistic fuzzy sets	• Urichhiho et al., 2004 • Liu and Wang, 2009

Table 2. List of open source desktop Geographical Information System (GIS) software and their hyperlinks.

SL No.	GIS software	Features	Hyperlinks
1.	GRASS GIS	Originally developed by the US Army Corps of Engineers: a complete GIS	http://en.wikipedia.org/wiki/GRASS_GIS
2.	gvSIG	Written in Java. Runs on Linux, Unix, Mac OS X and Windows	http://en.wikipedia.org/wiki/GvSIG
3.	ILWIS (Integrated Land and Water Information System)	Integrates image, vector and thematic data	http://en.wikipedia.org/wiki/ILWIS
4.	JUMP GIS	The desktop GISs OpenJUMP, SkyJUMP, deeJUMP and Kosmo all emerged from JUMP	http://en.wikipedia.org/wiki/JUMP_GIS
5.	MapWindowGIS	Free desktop application and programming component	http://en.wikipedia.org/wiki/MapWindow_GIS
6.	QGIS (previously known as Quantum GIS)	Runs on Linux, Unix, Mac OS X and Windows	http://en.wikipedia.org/wiki/QGIS
7.	SAGA GIS (System for Automated Geo scientific Analysis)	Hybrid GIS software. Has a unique Application Programming Interface (API) and a fast-growing set of geoscientific methods, bundled in exchangeable Module Libraries	http://en.wikipedia.org/wiki/SAGA_GIS
8.	uDig	API and source code (Java) available	http://en.wikipedia.org/wiki/UDig
9.	Capaware	A C++ 3D GIS Framework with multiple plug-in architecture for geographic graphical analysis and visualization	http://en.wikipedia.org/wiki/Capaware
10.	TerraView	Handles vector and raster data stored in a relational or geo-relational database, i.e. a frontend for TerraLib.	http://en.wikipedia.org/wiki/TerraView http://en.wikipedia.org/wiki/TerraLib

(Source: Steiniger and Bocher, 2009).

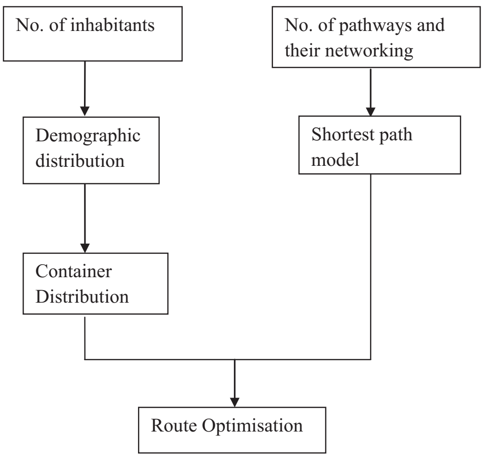

Figure 3. Elements of solid waste collection route optimization.

level of an SWM facility, discussion with neighbours or public involvement in the planning stage has become popular in recent years. This is studied from a questionnaire where the main focus is on people's concern towards the SWM and their attitude towards it. The major criteria are the pollution, health effect, reliability, damage to nature and cost. It has been noticed that people with a clear attitude towards a SWM facility are those who are less bothered about pollution and nuisance and also concerns are high among the residents of the parts of the cities that receive a higher quantity of waste. Usually the people who make visits to landfill sites have a positive attitude towards the SWM facilities (Rahardyan et al., 2004). The major influences on acceptance by people are attributed to knowledge level, awareness of benefits, confidence and trust (Hoban, 1997). Appropriate information disclosure is an important factor for acceptability and for avoiding disproportionate facility siting (Tchobanoglous et al., 1993). Another major problem related to public acceptance of waste policies is directly linked to the concept of social compatibility, raising the issues such as costs, illegal dumps and locating disposal facilities (Joos et al., 1999). Social compatibility can be evaluated on criteria such as discrimination, education, training, impact on inhabited areas, income distribution, information communication, participation, transparency and risks for the population. Ishizaka and Tanaka (2003) discussed the risk communication approach for the waste treatment and the disposal system. Risk communication can be defined as "an interactive process of exchange of information and opinion among individuals, groups, and institutions" (National Research Council, 1989). Residents are worried about the factors such as the possibility of environmental pollution due to the solid waste treatment and its disposal, movement of transportation vehicles, fall of asset values, impact on the ecosystem and deterioration of the landscape, but interestingly they do not always having any hatred towards waste. Sometimes strong distrust among residents is mainly due to incomplete disclosure of information by the municipality. The most important aspect of public acceptance of landfill is the distance of the landfill from their residence. It was

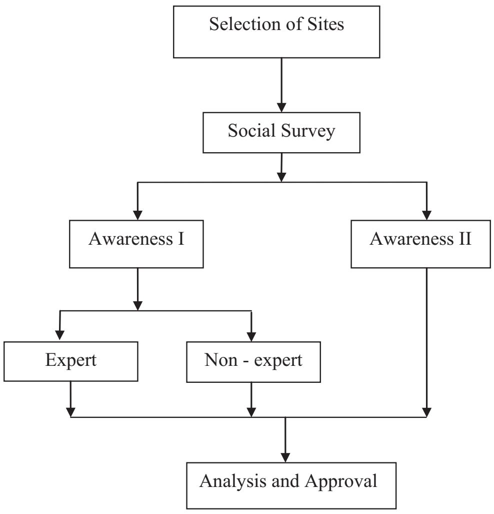

Figure 4. Components of proposed landfill site acceptance study.

observed that even though the distances of landfill sites were maintained by laws, people accept them more readily when the landfill distance is far from their houses. Sites that are far from sight are well accepted and residents do not like the garbage trucks to pass by their residence (Mutlutürk and Karagüzel, 2007). Figure 4 describes the generalized sequential procedure that may be followed to study the public acceptance of proposed landfill sites.

Conclusions

In most nations, solid waste disposal is one of the major and rising potential problems due to exponential growth of the urban population. Many efforts to reduce and recover the wastes have been made, but still land disposal of solid wastes is the most popular one. Selection of landfill sites in suitable areas can be best done by using GIS coupled with other tools. The tools coupled with GIS that are discussed in this paper to find the best landfill site are the MIPM, MCDA, MCE, WLC, AHP and FMCDM. The FMCDM tool coupled with GIS differed from other tools of landfill site selection. In the FMCDM process, a two-step sequential approach was applied where GIS helped in screening out suitable landfill sites and the final analysis was done by applying the FMCDM tool. The WLC procedure allows full tradeoff among all factors and offers much more flexibility than the Boolean approaches and the relative importance weights of factors can be estimated using the AHP. Integration of GIS and AHP provides an effective multi-indices evaluation tool using the spatial analysis techniques for evaluation of the most suitable landfill site. The AHP is used mostly to rank potential landfill areas based on a wide variety of criteria and can work on only pair-wise criteria, whereas MCDM can work on many criteria at a time. Most of the time classical MCDM methods cannot handle problems with exceptionally imprecise information; the representation and interpretation of "uncertainty" and human-related subjective preference is needed. In such situations fuzzy set theory is a more natural approach when uncertainty in the selection of criteria and their preference is required. The degree of suitability of a site is expressed as a weighted sum of all factors. The fuzzy set has a good ranking potential when several factors are considered for site selection. It also has the capability of representing vague qualitative data and presenting all possible results with different degrees of membership.

Collection of solid wastes consumes the majority of the resources of SWM. It is discussed how GIS can help in optimizing the route for collection of solid wastes from transfer stations to disposal sites to reduce the overall cost of SWM. Analysis of the network involving constrains such as the travelled distance, speed of the vehicles and their efficiency, number of collection bins and their location contribute a substantial reduction in the fuel consumption and hence it is cost effective. A GIS-based model for SWM improves the efficiency of waste management systems and thereby reduces the cost of waste collection and transfer to disposal sites.

Once the best environmentally sound landfill site is located, the next challenge is to get the public acceptance of the proposed site. A detailed analysis of a public acceptance study of proposed landfill sites is also described in this paper. It can be concluded that the highest concerns among the public are the pollution and health effect, reliability, facility management, damage to nature and cost. The acceptance level depends upon their knowledge, experience of visiting the SWM facility and the amount of information that is disclosed to them.

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The author declares that there is no conflict of interest.

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