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Full Length Research Paper

Urban solid waste management based on geoinformatics technology

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The solid waste materials in cities are the natural outcome of human activities. Provision of such system appears to be a major problem due to the complication and the wide nature of waste production. Due to the different parameters involved, deciding upon a suitable location is also very complicated, costly and time consuming. Different criteria are working in determination of an appropriate place for disposal; each of them is of high importance and may cause specific restrictions as to the selection of the location. The ultimate aim of these criteria is the selection of a site that is likely to have at least possible detrimental environmental effect on the nearby area. The pollution of underground water and soil of surrounding area can be considered as some of these bad effects. However, geospatial system can serve as an efficient way of employing and managing various data that can be utilized in locating more appropriate places for the disposal of solid waste. The methodology being implemented utilized geospatial technology for management and visualization of spatial data while fuzzy logic sets is used in searching the best location for landfill.

Key words: Geospatial technology, sanitary landfill, fuzzy logic sets.

INTRODUCTION

Increasing population, the rapid economic growth and the rise in community living standards accelerate municipal solid waste (MSW) generation in developing cities. Municipal solid waste management (MSWM) is one of the critical environmental challenges of rapid urban development facing the developing countries including Iran. Solid waste arising from human domestic, social and industrial activities are increasing in quantity and variety as a result of growing population, rising standards of living and development of technology (Suess, 1985; UNEP, 1991; Dickerson, 1999). A decade ago, Beede and Bloom (1994) estimated the global MSW generation rate at 1.3 billion tons per day; translated to an average of two-thirds of a kilogram per capita per day or ten times per capita body weight per year. According to a United Nations Development Programme survey of 151 mayors of cities from around the world, the second most serious problem that city dwellers face (after unemployment) is insufficient solid waste disposal (UNDP, 1997). Many countries and institutions currently pay great attention to landfill site selection. When current waste disposal sites are filled, the search for a new waste site can be a time consuming process. Pokhrel and Viraraghavan (2005) in their studies have reported an evaluation of solid waste management concerning the sitting of landfills in Nepal and in another research which have been done by Al-Jarrah and Abu-Qdais (2006); they also focused on the problem of sitting a new landfill using an intelligent system based on fuzzy inference.

Previous studies have reported several techniques for landfill sitting, which can be found in the literature (Halvadakis, 1993; Bonham-Carter, 1994; Ehler et al., 1995; Balis et al., 1998; Dorhofer and Siebert, 1998; Yagoub and Buyong, 1998; Herzog, 1999; Lukasheh et al., 2001). Surveys such as that conducted by Charnpratheep et al. (1997), Kao et al. (1997) and Sener et al. (2006) have shown that Geographic information

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system (GIS) is a digital database management system designed to manage large volumes of spatially distributed data from a variety of sources. They are ideal for advanced site-selection studies because they efficiently store, retrieve, analyze, and display information according to user-defined specifications. GIS has been extensively used to facilitate and lower the cost of the landfill site-selection process.

Several studies have revealed that other sitting techniques combine multiple criteria analysis with GIS (Minor and Jacobs, 1994; Kao and Lin, 1996; Lin and Kao, 1998; Allen et al., 2002; Kontos and Halvadakis, 2002). They also stated that these techniques are used to evaluate the sitting suitability for the entire study region based on a suitability index. Erkut and Moran(1991) have developed analytical hierarchy process (AHP) is a decision-making technique which can be used to analyze and support decisions which have multiple and even competing objectives. To do this, a complex problem is divided into a number of simpler problems in the form of a decision hierarchy. Accordingly once the hierarchy had been established, a pair wise comparison matrix of each element within each level is constructed and participants can also weigh each element against each other within each level, which is related to the levels above and below it and mathematically tie the entire scheme together and also numerous studies have attempted to explain that the landfill sitting problems using GIS and multi-criteria analysis or intelligent system approaches in Greece, Turkey, and Jordan (Vatalis and Manoliadis, 2002; Kontos et al., 2005; Al-Jarrah and Abu-Qdais, 2005; Sener et al., 2006).

Case study and statement of problem

Mashhad is located at 36.20º latitude and 59.35º east longitude, in the valley of the Kashaf River near Turkmenistan, between the two mountain ranges of Binalood and Hezar-masjed. Around city exist the mountains, having cool winters, pleasant springs, mild summers, and beautiful autumns. It is divided into 4 districts, 14 villages and 660 hamlets and is considered as one of the biggest cities in Khorasan Razavi.

Mashhad is a provincial center (Khorasan Razavi) and second metropolis in Iran in terms of its population, industrial and agricultural productions (Table 1) . And also one of the largest religious city in the world and according to Mashhad statistic center, more than 20 million tourists and pilgrims visits this city annually (Table 2). The rapid development of Mashhad city is highly accelerating in comparison with that of population density in surface unit. A variety features like geographical, geological, topographical, climatically and meteorological, geomorphologic, hydrological and hydro geological qualification as well as population distribution and density, fauna, vegetative and flora, distribution and density, distribution of rural settlements and high tourism potentials, have given "Mashhad" the unique attribution elements to be the center of focus.

Mashhad because of certain parameters such as geographic location, high population density, weather condition, low level of underground water, lack of useless land and the other hand due to inappropriate current solid waste disposal, seems to be inevitably in need of planning for a new standard site for landfill.

The current waste dumping site is placed 5 km south-east of Mashhad. In this place, about 13630 tons of waste is collected daily. Due to lack of fencing, lack of soil cover and access of wild animals, the spread of parasitic and infectious diseases is inevitable. On the other hand, by passing the main road or the arterial roads within 3 km from the site, the pungent odor of the waste can be smelt. Because it is relatively a short distance from a cemetery center, park, it causes problems and complaints for the residents. To Protect and support this spectacular ecosystem, in terms of ecology, is unique and important selecting a suitable site is of importance and cooperation and collaboration of other relevant bodies and organizations is necessary.

METHODOLOGY

The main strength of GIS (Geographical Information Systems) is the common analysis of compound spatial and attributive data (Geo spatial). Related issues to the implementation of GIS include interpreting the minimum requirements for waste disposal by landfill so as to identify spatial data required for the GIS analysis (Figure1). A database of the data identified for the project is assembled. This is achieved by sourcing the datasets required from various national data custodians, in tandem with the landfill requirements. Data used to conduct the analysis was obtained from various sources, including the Chief Directorate of Surveys and Mapping. In The main steps are: Entering; saving and categorizing and data managing; processing and data analyzing and at last data combining and interpretation for making decisions and outputs. The study has been organized in four stages as follow.

In the first step, the city of Mashhad was studied with regard to its spatial-physical characteristics in the context of its master plan. Also the socio-economic features of the city were carefully investigated (Table 3). In the second stage, the basic maps were used to update the recent different urban land use changes. This stage was followed by regular field observation to complete some possible shortcomings. In the third stage, the main works have been done in laboratories. This works include analysis and interpretation to provide the different layers by extensive application of Arc GIS, Arc/view and Edrisi-3 for geometric correction and digitization. In the process of the finding the optimum site, the conceptual model and effective criteria for waste disposal were defined and introduced. In this study, 15 input map layers including man and animal habitats, surface water (rivers and lakes), ground water (aquifer type, hydraulic conductivity and depth to water), airport, land use (agricultural land, forest land, and special land), slope, altitude, price of land, waste production centers and road. Ground water maps and data were obtained from Khorasan organization of water. In addition, its scale is 1:250,000. The land use map was obtained from the National Fundamental Geographic Organization in Iran. Its scale is 1:100,000. The other maps were obtained from the National Fundamental Geographic Organization Iran too and their scale is 1:250,000 (Table 4). The preparations of these layers were done in the form of topology, correction and editing, geometric

Table 1. Population and growth rate in Mashhad (1976-2009) (1000 persons).

Years	1976	1986	1991	1996	2001	2006	2009
Population	670	1450	1750	1900	2150	2500	2900
Increase	-	119	20	7	14	13	12

Table 2. Population of tourism, pilgrim in Mashhad (1976-2009) (1000 person).

Years	1976	1986	1991	1996	2001	2006	2009
Population	6800	9100	12000	13500	15500	17500	19500

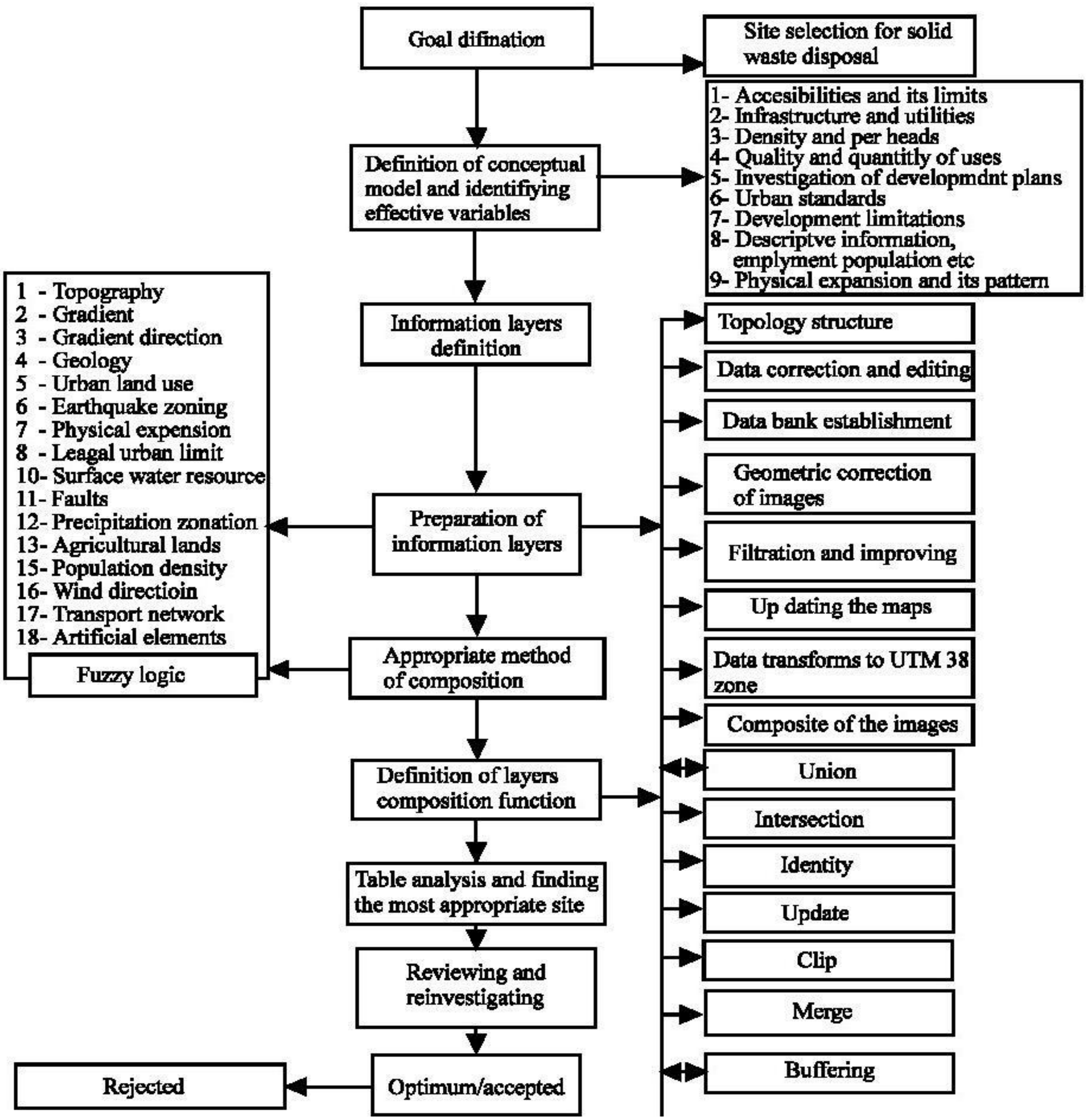

Figure 1. Structure of Methodology Pak.j.Biol.Sci.,10(22):4000-4007, 2007).

Table 3. Criterion limits for standardization (Boolean).

Map layer	Accepted limit for site selection	Value
Slope	Less than 30%	1
Distance from forest	More than 300 m	1
Distance from Mashhad City	Over 7.5 km	1
Distance from swamp, wetland,	Over 350 m	1
Distance from surface water	Over 1000 m	1
Distance from access roads	Less than 500 m	1
Distance from residential areas	Over 500 m	1
Distance from farm lands	Over 250 m	1
Distance from wells, rivers	Over 300 m	1
Distance from landslides	Over 200 m	1

This table is filled according to expert questionnaires and all cases have been filled their value was one, in Boolean model items are correct or wrong, if they are correct their value will be one and if they are wrong their value will be zero.

Table 4. Threshold and fuzzy function type for standardization of the fuzzy and criterion maps used in fuzzy logic.

Map layer	Fuzzy function	Fuzzy function type	Threshold	
			c or a	d or b
Slope %	Sigmodial	Decreasing	3	40
Distance from forest (m)	Sigmodial	Increasing	0	350
Distance from Mashhad City (km)	J-shape	Decreasing	3	40
Distance from swamp, wetland, …	Sigmodial	Increasing	200	500
Distance from surface water	Sigmodial	Increasing	150	1000
Distance from access roads	J-shape	Decreasing	100	1000
Distance from residential areas	Sigmodial	Increasing	250	1000
Distance from farm land	Sigmodial	Increasing	0	250
Distance from wells	Sigmodial	Increasing	200	600
Distance from landslides	Sigmodial	Increasing	100	300

correction of images and maps. After defining the appropriate method of incorporating, the recognition of the integrated functions of the layers were done in the frame of union, intersection, clipping, buffering, merge, updating and then after the table analysis of integrated information banks the appropriate site was identified and investigated.(Different criteria are used to obtain GIS data sets of the buffer zone).

All the descriptive and spatial data were incorporated using the Boolean method; the suitability map is created and secondly using fuzzy logic (WLC and OWA) the suitability map are created. In this study at first, the fuzzy logic is used for a limited part of study area, certainly the appropriate membership function and operator should be selected to have an accurate result of the training data. The higher the score is, the more suitable the area is for landfill sitting.

RESULTS AND DISCUSSION

By reviewing results derived from different methods, it can be seenin the method based on boolean operation, by considering its absolute limitations, the selected regions are lesser than those of selected based on fuzzy logic but in terms of confidence in obtained results, the best method is applied to Boolean operation; results are less reliable. So by using the resulting layers of standardized maps and the application of the end operator, it is easy to overlay the layers and find a suitable place for solid waste dumping by referring to the analysis menu and selecting the map query command. By selecting the overlay function, the suitable places for landfill will be selected from these layers.Then the final result is a suitable place for dumping should be converted to shape format for final analysis. By using the “convert poly line to polygon” option, the desired polygons are made.Then point to the “Update Area and Length” command so that the area of each polygon is measured and those with an area of more than 74 ha will be highlighted and the results shown in a description (Table 5). A query menu is used for

Table 5. Criteria of ordered weights that are used in site selection.

Site selection criteria			
Group priority	**Importance (%)**	**Investigated items**	**Importance (%)**
Public hygienic	39.7	Distance from surface water	23.0
		Distance from wells	5.0
		Distance from swamp or wetlands	11.7
Environmental issues	22.5	Distance from landslide zone	6.0
		Distance from forests	11.0
		Distance from farm land	5.5
Public issues	20.5	Distance from residential areas	11.5
		Distance from Mashhad City	9.0
Economical issues	17.3	Distance from roads	7.3
		Slope	10.0

extracting the regions of more than 74 ha and then the suitable places will be shown. By using IDRISI and the WLC method and by considering the vast abilities of this software, multi-attribute decision making (MADM) analysis was used. In this step, by referring to multi-criteria evaluation (MCE) then choosing WLC, the limitation and criterion maps are overlaid with their respective weights. The result is a map with a scale of 0 to 255.The regions with the 0 value are the worst regions. The grey scale is arranged between 0 to 255.

To make precise decisions and investigating the values of the study regions by using the Reclass Menu, the values are classified into 4 regions. The first one is the best choice with a value of 235 to 255, the second 210 to 235, the third 153 to 210 and the fourth 0 to 153. For measuring the area of every region, we use the Area menu then select those with more than 74 ha. These lands are more suitable for landfill use.

The increasing generation of municipal solid waste in the Mashhad (second city in Iran) is one of the greatest challenges faced by governmental authorities. The development of our model is motivated by the desire to mitigate the impact of landfill sites on the environment, public health and economy. We have integrated GIS and OWA, WLC models in the assignment of site suitability for landfills. Our study provided scientific evidence for the Khorasan. By considering the current situation in Sarri city, hygienic dumping is the best way for urban solid waste dumping in short term, because the topography and physiology of the city to some extent is difficult (Figure 2)

The Boolean method in restricted areas is not suitable as fewer areas would be selected in the wake of the considered criteria. By applying more tolerances to the criteria, more maneuverability over the decisions is achieved. By considering the factors for site selection via Boolean operation only, three candidate areas were chosen for a landfill in Mashhad city.

CONCLUSIONS AND SIGNIFICANT RESULTS OF THE METHODS USED

It can be seen that in the method based on the Boolean operation and by considering its absolute limitations, the selected regions are fewer than those selected based on fuzzy logic. However, in terms of confidence in the results obtained, the best method is applied to the Boolean operation although the results are less reliable. By considering the wide range of classes available in the 255 class methods, including fuzzy methods such as WLC and OWA, that are used, more trustworthy decisions can be taken and the derived decisions are used by decision makers in order to reduce costs (including economic and environmental costs) so the appropriate changes can be applied.

The OWA algorithm, by using ordered weights, gives an opportunity to decision makers to implement factors on the basis of their importance and gives priority to influence site selection issues. Using OWA gives better separation ability from the available strata. The interesting point in this issue is reducing the average map value derived from cells of OWA compared to WLC. In other words OWA cells with a higher-value, rate more and cells with less value, rate lower. Important issues in the two later methods are the correct selection of weights and the optimum usage of several information layers to give us appropriate results.

Overall, the obvious outcome from fuzzy results with regard to the rate of risk that the decision maker considers in comparison with the Boolean method is that more places are selected. This can be done by ordering

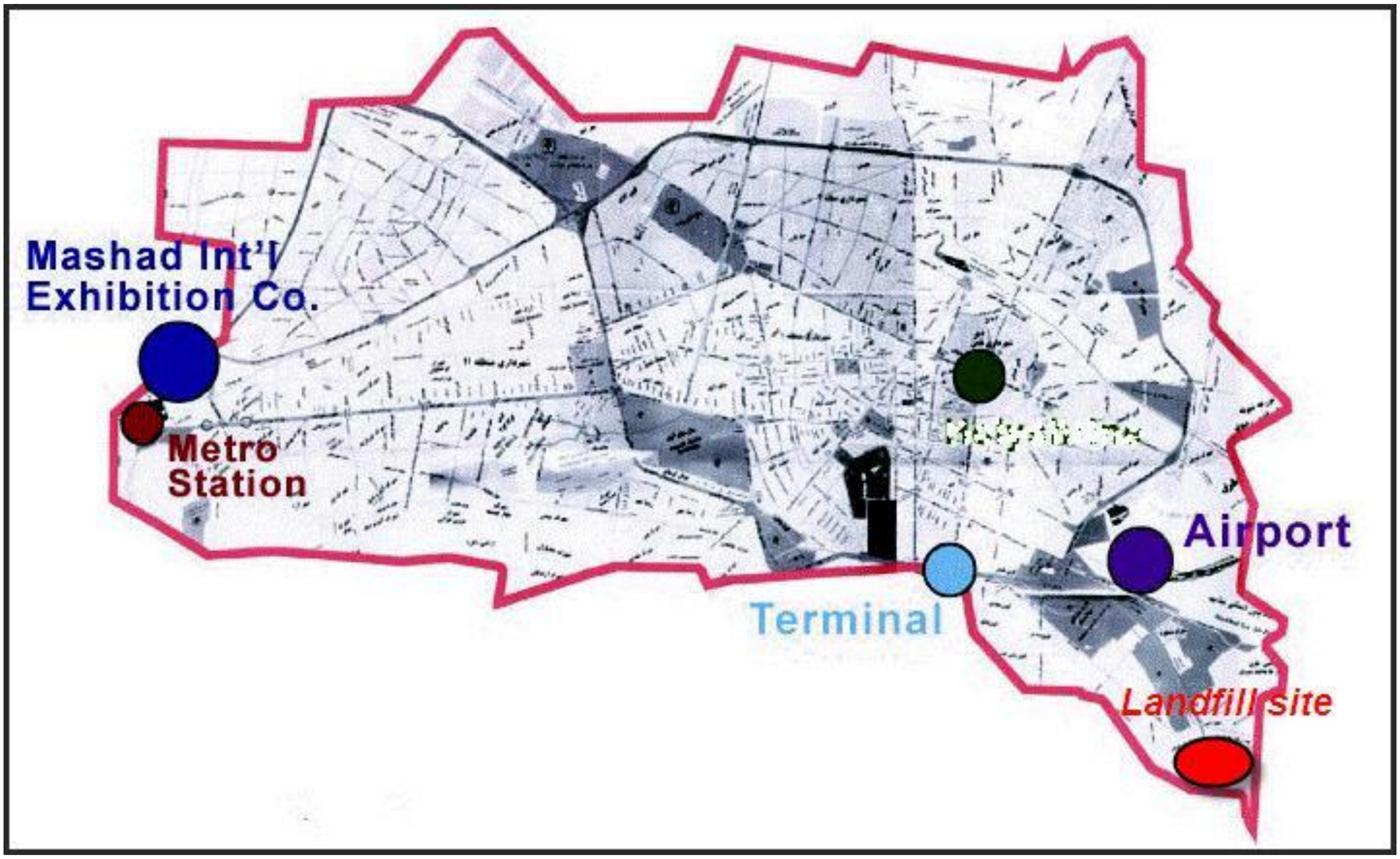

Figure 2. The resulted map for site selection with WLC method.

different layers on the basis of their priority and with regard to economical and environmental effects. By reaching the final decision gradually, fewer areas are selected and the result is areas that have more appropriate conditions for the intended purpose. It is expected that the method can be used as a guide to the implementation of sanitary landfills in appropriate areas, with a view to decrease the operating and environmental costs, especially in Mashhad.

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