Application of GIS models in site selection of waste disposal in an urban area

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Abstract

Site selection using multi-criteria decision is one of the most important abilities for GIS application, which can be helpful for finding the best site based on some favorite factors and constraints. Siting and finding the appropriate place is one of the most important parts of the landfill waste management system for a city. Koya city, with a population of 59,725, is one of the largest cities in the Erbil Province in Kurdistan Regional Government. Due to the recent population increase, the changes in the consumption habits of people and the use of packaging materials have all in recent decades increased the waste volume produced in the city. Despite this problem, there is not still an appropriate way for solid waste disposal in this city. One of the most important factors, which should be considered in the new waste disposal process, is the location of the disposal center. The suitability of selected site for the disposal center affects the amount of generated energy and the cost of disposal generation. Suitable sites should be determined based on technical, economical and socio-environmental issues. Therefore, multiple criteria should be considered in this process. GIS along with appropriate models and a spatial analysis method can be used to define the suitability of different locations for the construction of disposal centers. This research focused on determining suitable locations for the construction of suitable disposal centers. Our case study is Koya city in the Kurdistan Regional Government. At first, important parameters in a hazardous material disposal center siting for the studied area were identified. Then, the maps of the studied area were prepared and integrated. Boolean, index overlay was used for the integrating of maps. Then the Boolean process was run for

finding a proper site as the best location. Finally, Boolean processes have found an area.

1 Introduction

An increasing level of municipal solid waste is, nowadays, a serious problem in urban areas of the world. A high population growth rate and increasing per capita income have resulted in the generation of enormous municipal solid waste (MSW), posing a serious threat to environmental quality and human health. This is particularly relevant in the case of developing countries where large quantities of MSW are dumped haphazardly, thereby putting pressure on scarce land and water resources. At the same time, this adversely affects the health of human beings, mostly that of poor persons who have greater exposure to it (Chakrabarti [3]).

According to Schubeler *et al.* [10], MSW is defined as refuse from households, non-hazardous solid waste from industrial, commercial and institutional establishments (including hospitals), market waste, yard waste and street sweepings.

It has been estimated that approximately 80% of the MSW generated throughout the world is land filled (Richards [9]), although the figure for Kurdistan Regional Government may be as high as 85%. Although the composition of land filled MSW varies considerably among countries of different socio-economic backgrounds, it usually includes organic material (such as paper and paperboard, wood, textiles, food residues and garden waste), as well as inorganic material (such as builders' rubble, metal, glass and plastics). Organic material consisting of cellulose, carbohydrates and proteins is readily decomposed by microbes into carbon dioxide (CO₂) and methane (CH₄), and contributes some between 6 and 18% to global methane production (Bingermer and Crutzen [1]).

Municipal solid waste generation is among the most significant sources that threaten the global environmental health. Accordingly, it is essential that integrated systems of waste management be considered within the path towards achieving sustainable development. The components of municipal solid waste (MSW) management include reducing the waste, reusing, recycling, energy recovery, incineration and land filling (Abdoli [8]). Even if a combination of the mentioned or other management techniques is utilized and if policies of waste reduction and reuse are applied, the existence of a sanitary landfill is necessary to a MSW management system (Tchobanoglous *et al.* [5]). As sanitary landfilling is an inevitable part of MSW (municipal solid waste) management system (Tchobanoglous *et al.* [5]), appropriate site selection of landfills may play a key role in reducing the environment contamination.

Regarding the problems related to making decisions on (e.g., siting landfill with multi criteria) it can be said that decision making is not simple in this case, and the speed and precision are greatly reduced due to the lack of standards (Moeinaddini *et al.* [7]).

Landfill has become more difficult to implement, residents opposition and environmental contamination. Land is among invaluable and finite resources that must be used shrewdly. Suitable sites should be determined based on technical, economical and socio-environmental issues and meet multiple criteria. The use of a multi criteria evaluation (MCE) method seems inevitable. Taking benefit of Geographic Information System (GIS) as a tool in combination with geographical information technology (GIT) equips the spatial decision support systems (SDSS) in appropriate site selection of sanitary landfills.

In Kurdistan Regional Government, the waste demand has grown rapidly over the past years.

Therefore, in this paper, the required conditions for the establishment of disposal centers are comprehensively studied for Koya city in Kurdistan Regional Government in north east of Iraq. Then, important parameters in disposal center are identified. Later the factor maps of studied area was prepared and integrated. There are several map combination processes; these are Boolean logic combination, algebraic combination, and index overlay combination and so on. In this project, Boolean, index overlay was used for integrating of maps. Finally, the suitable locations for the construction of disposal center are selected.

2 Materials and methods

2.1 Study area

The study area covers Koya city. As of July 2013; this city includes 6 municipalities. (Koya city located in south, east of Erbil governorate (Fig. 1).) This county has common borders with Dukan on the east, Erbil city on west and Ranya city on north and Kirkuk city on south. The city is located between the two lofty mountains of Bawaji and Haibat-Sultan. The study area approximately located between ($44^{\circ}34' - 44^{\circ}17'$) eastern longitudes and ($36^{\circ}18' - 35^{\circ}47'$) northern latitudes. The highest point of the study area is situated at an elevation of 1300 m and the lowest point 300 m above sea level. The rainfall average of 702 mm (weather station of Koya) in this county has been registered. The main land cover types of the mentioned area are pastures, fallow lands, agriculture, water and residential areas. Economic growth in recent years has led to a remarkable increase in population and consequently in solid waste generation. The population of Koya city is approximately 60,000 (Koya municipality). Accordingly, appropriate site selection for regional solid waste land filling is a major need within the path towards sustainable development.

It is estimated that solid waste production of the city is approximately 60 ton/day. In this place, about 60 tons of waste is collected daily (Koya municipality). 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 (Koya – Sulaimaniyah) or the arterial roads within 2 km from the site, the pungent odor of the waste can be smelt. Because it is relatively a short distance from the residents' area, it causes problems and

Figure 1: Location map of the study area.

complaints for the residents. Therefore, the existing solid waste landfill site is not appropriate. To protect and support ecosystem, in terms of ecology, important selecting a suitable site is of importance and cooperation and collaboration of other relevant bodies and organizations is necessary. In this regard, a study to investigate the suitability of landfill to be site within 5–10 kilometers of Koya city has been carried out and is reported in this paper.

3 Required land for rubbish burying

3.1 Analysis method

Landfill site selection requires effective criteria assessment according to the governmental legislations to reduce social, economic, environment and health costs (Siddiqui *et al.* [11]). In the present study, by taking into account these criteria the overlaying method of information layers were used to achieve suitable landfill site selection. The first step in the methodology consists of development of a digital GIS database in which spatial information is formed. Because of different scales upon which criteria are measured, it is necessary that factors be standardized before combination. Considered criteria classify the areas in to two classes: unsuitable (value 0) or suitable (1). The major and minor sub criteria used in the present study are shown in Table 1. All the maps are geographic data layers stored in the GIS raster-based with the 30m × 30m grid cells.

Table 1: Major and minor criteria used in landfill site selection process (data layers used in this study).

Major criteria	Minor criteria
Geomorphologic	Slope
Hydrologic	Distance from rivers
	Depth of underground water table
	Distance from springs and wells
Humanistic	Distance from residential areas (Distance from city, Koya city and distance from village)
Land use	Distance from roads
	Distance from farmlands
	Distance from Ttopco

3.2 Uses of GIS in waste management

One of the most important applications of GIS is the display and analysis of data to support the process of environmental decision-making. A decision can be

defined as a choice between alternatives, where the alternatives may be different actions, locations, objects, and the like. For example, one might need to choose which is the best location for a hazardous waste facility or perhaps identify which areas will be best suited for a new development. The role of GIS in solid waste management is very large as many aspects of its planning and operations are highly dependent on spatial data. In general, GIS plays a key role in maintaining account data to facilitate collection operations. In this manner, aspects such as customer service; analyzing optimal locations for transfer stations; planning routes for vehicles transporting waste from residential, commercial and industrial customers to transfer stations and from transfer stations to landfills; locating new landfills and monitoring the landfill, are important. GIS is a tool that not only reduces time and cost of site selection, but also provides a digital data bank for future monitoring programme of the site (Tomlison [12]). GIS can also play an important role in the long term environmental monitoring of closed landfill sites.

4 Discussion

A landfill must be situated and designed to meet the necessary conditions for preventing pollution of the soil, groundwater or surface water and ensuring efficient collection of leachate. Also, a landfill site should be kept as far as possible away from population density, for reducing pollution impact to public health. On the other hand, the landfill site should be placed as close as possible to existing roads for saving road development, transportation, and collection costs. Eight suitability criteria, were used in this study. A map was created for each suitability criterion and a final composite map was finally produced by Boolean Logic Overlay Model. The criteria analysis for landfill site selection is described in the following sections.

Slope: Land morphology is a fundamental factor in landfill establishment. Land morphology is evaluated by slope gradation that is defined in percent or degrees. Steep slopes are not suitable for landfill establishment where the construction costs of excavation increases in higher slopes. Also, the suitable slope of land surface is important in preventing the leachate flowing. The slope layer map was obtained from the study area DEM map on the basis of pixel size in percentage. The lands with the slope of more than 15 percent with 0 values were considered unsuitable. The lands with the slope of Less than 15 percent with 1 value were considered suitable.

Surface water: This criterion is important from the point view of both environmental and economic concerns because in addition to causing pollution problems, it may require an efficient drainage system with high expenses. Areas located within distances less than 500 m from permanent and seasonal rivers are excluded due to the possible interaction between the landfill and the rivers and according to the Boolean logic were given 0 values.

Proximity to wells: A landfill must not be located near any surface streams, lakes, rivers, wells, or wetlands. Proximity to wells was an important criterion to accessing the landfill site. Landfills create noxious gases and leachate that make them unsuitable to be in proximity to water wells. Then due to its negative effects the areas, 400m distance from well are omitted from the potential areas and according to the Boolean logic were given 0 values.

Residential areas: Landfill site should be located away and far from populated centers of the city. Otherwise, it causes aesthetic, bad odors and land value of the surrounding area. Due to its negative effects the areas of 3 kilometers distance around the Rural areas and 1500m distance around the Urban areas, also 5 kilometers distance around Koya city are omitted from the potential areas and according to the Boolean logic were given 0 value.

Road network: Building roads for landfill access especially in long distances requires huge preliminary expenses. So the selected site should be close to the highways and main roads. For the connection road map, to prevent the interference of solid waste transferring vehicles with the main traffic, the lowest pixel value (0 value) allocated to 500 m distance from existed roads. In addition, by increasing distance from roads, the suitability decreases to 0 and the distances of more than 500 m were considered unsuitable due to the more transportation expenses.

Land use: This criterion concerns with natural features that may be exposed by the threats imposed because of landfill adjacency. Parameters like water, agricultural potential, pastures, fallow lands and built up areas have been taken in to consideration. This criterion is not based on specific directions and may alter according to the study area. From the standpoint of economy, it is better to choose bare lands which can be used after landfill site completion or can be sold.

Topco: There is a petroleum field in the study area in the southwest area. The landfill site shall be the lowest pixel value (0 value) allocated to 3 kilometers distance from existed petroleum field (Taq Taq Operating Company Ltd (TTOPCO)).

5 The direct impact of the study on Koya city

The present study shows the combination of GIS, Boolean Logic Overlay Model and multi criteria evaluation techniques in identifying solid waste landfill site suitability and selection. The site suitability was provided by considering 8 criteria. The gained results from expert opinions shows that among physical sub criteria, surface water, groundwater, slope and among socio economic sub criteria, residential areas, land use, and access roads are important in order respectively. The extension of some suitable areas is more than required landfill site, so it is possible to arrange the related equipment's of bio compost and recycling beside it to manage solid waste better in addition to reducing transition expenses.

Applying of GIS and multi criteria decision analysis is desired in site selection problems. GIS is flexible in considering criteria and it is possible to develop this method by taking into account other effective criteria. A GIS is a good tool to help aid in the finding of suitable sites for landfill siting purposes. The use of GIS for evaluation of future waste disposal sites has shown to save time when there is a need for fast evaluation. In addition, the possibility of GIS usage in Boolean Logic and having cell information permits that the characteristics of the study area be investigated precisely at small regions of cell size.

Multi criteria decision analysis is also providing necessary conditions to consider different criteria within the site selection evaluation problem and therefore helps decision makers towards correct option selection. GIS combination with decision analysis as decision supporting system can assist decision makers in each site selection problem as an effective tool. On the other, for taking final decision, field investigation of the proposed landfill sites should be proposed in addition to the other expenses and political aspects is considered. The proposed method can help managers in the disposal and solid waste management activities.

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