Integrating GIS and MCDM to Deal with Landfill Site Selection

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Abstract-- The evaluation of a hazardous waste disposal site is a complicated process because it requires data from diverse social and environmental fields. These data often involve processing of a significant amount of spatial information which can be used by GIS as an important tool for land use suitability analysis. In this study, the most suitable candidate sites for locating landfill in Mansoura city, Egypt. As a case study area are determined by using an integration of the Geographical Information System (GIS) and Multi Criteria Decision Making (MCDM) method. For this purpose, eight input map layers are prepared and two different MCDM methods which are Weighted Linear Combination (WLC) and Analytical Hierarchy Process (AHP) are implemented to GIS. The first stage of the procedure is initial screening process to eliminate unsuitable land where only 2.93% of the total study area is suitable for landfill sitting. These suitable areas are further examined by deploying the AHP method in order to obtain relative importance weights followed by the application of WLC method for a calculation of suitability index. The resulting land suitability is reported on a grading scale of 1-5, which is the least to the most suitable areas respectively. Research findings show that only five areas are identified as the most suitable location for landfill with the grading values greater than 2.67.

Index Term-- Decision-Making, Site Selection, analysis, landfill site selection, multi-criteria evaluation, GIS, MCDM, AHP.

I. INTRODUCTION

One of the serious challenges faced by human beings in urban areas nowadays is the solid waste management (SWM). Obviously, the way to limit the impact on our planet’s ecosystem is by reducing the amount of solid waste generation. Waste management (WM) must be achieved by intensive recycling program and composting. If these programs are not sufficient, solid waste must be incinerated and only as a last resort, should landfills be utilized with energy recovery mainly methane (CH4) and carbon dioxide (CO2) gases in order to prevent atmosphere contamination (Messineo and Panno, (2008))[1].

Extensive studies have been reported in this area and are still underway. In 2005, Alhumoud[2] presented recycling of solid waste should be integrated with other SWM options to abate degradation in urban environment; this can be accomplished through promotion of economical and environmentally friendly WM practices. Troschinetz and Mihelcic (2008) [3] analyzed the recycling of municipal solid waste (MSW) in developing countries. Twenty-three case studies provided MSW generation and recovery rates and composition for compilation and assessment. According to EPA (2003) [11] about 56% of MSW goes to Landfill sites, 30% is recovered, recycled or composted and 15% is incinerated and in European Union EU around 45% is disposed by co-disposal methods (Haines, 1988). Saeed et al., (2008) [4] reported the generation of solid waste is directly proportional to population, industrialization, urbanization and the changing lifestyle, food, habits and living standard of the people. The rapid and constant growth in urban population leads to a dramatic increase in urban solid waste generation, with a severe socio-economic and environmental impact. The site selection of sanitary landfill is perhaps the most difficult and controversial issue of the planning process (Syed and Walter, (1994) [5].

For many years, rubbish has simply been dumped on ground open areas. Failing in a proper way of siting landfill in developing countries, leads to some negative effects such as fires due to landfill gases, rodents, insects, and birds due to organic food, bad odours and leachate that causes groundwater pollution. In this case, the landfill is indentified as unsanitary which poses the issue of public health hazard.

Benítez et al., (2008) [6] established mathematical models that correlate the generation of per capita residential solid waste (RSW) to the following variables: education, income per household, and number of residents. This work was based on data from a study on generation, quantification and composition of residential waste in a Mexican city. A study from Greece by Karadimas and Loumos (2008) [7] examined an innovative model for estimation of MSW generation and collection. In their model spatial geodatabase that is part of integrated GIS was applied for SWM. A landfill diagnosis method ‘EVIAVE’ integrated with GIS spatial data for landfill site in Spain has been assessed by Montserrat et al., (2008) [17]. They concluded that landfill siting should take into account a wide range of territorial and legal factors in order to reduce negative impacts on the environment. Yagoub and Buyong (1999) [8] reported that the use of GIS in SWM not only save time and cost of design and spatial analysis of site selection, but also provides a digital data bank for future monitoring of the sanitary landfill site.
Sitting of a new landfill using a multi-criteria decision analysis (MCDA) and overlay analysis using GIS proposes a system that considered several factors in the sitting process, such as geology, water supply resources, land use, sensitive sites, air quality and groundwater quality. This system could help government bodies set guidelines and regulations, and evaluate prevailing strategies for handling and disposal of waste.

Saaty (1980) [9] proposed for first time, the AHP that used a four step down approach to solve a multi criteria decision making problem. The decision problem was broken down into a hierarchy (Tree) of interrelated decision elements. Input data was then collected by pair wise comparisons of decision elements. The “eigenvalue” method was used to estimate the relative weights of decision elements. Then it was aggregated to arrive at a set of ratings for the decision alternatives. Chang et al., (2008) [10] reported that siting landfill is a difficult, complex, tedious and protracted process that requires analysis of multi criteria through programming model.

In this paper, the GIS multiple criteria evaluation (MCE) for new landfill site in Mansoura city has being described. The spatial decision in accordance with MCE for new sanitary landfill problem was solved through the assessments of AHP. The pair-wise comparison model was utilized to determine the relative weights of the decision criteria which is then integrated with the GIS Boolean and FUZZY logic model to produce feasible sites for landfill siting in the study area.

II. DESCRIPTION OF THE SITE

Dakahlia province is located to the north east of the Delta in Egypt. Its capital is the city of Mansoura, with a population of the province about 5 million people, making it one of the largest populated governorates of Egypt. Bounded to the East the Eastern province and the West Western Province, and north of the Mediterranean and north-eastern Damietta province, and north-western Kafr el-Sheikh province to the south Qaliubiya between latitudes 30.5 °, 31.5 °, N, and longitudes 30 °, 32 ° east longitude. The total area of the Dakahlia province is 3459 km². The total population in the Dakahlia province in 1/1/2008 is (4,985,178 people) by 7% of the total population of the Republic (VI) and the rate of population growth by 1.9%.

![Fig. 1.(a) Delta Wady El Nile](image)
III. The Methodology

The presented method starts with the identification of evaluation criteria or parameters needed for landfill siting. All these parameters have been identified based on the local guidelines such as Town and Country Planning Department (TCPD) guideline for waste disposal siting and also guideline from the Department of Environment (DOE). Besides, the related information about landfill siting has also been reviewed from the international practices like Environmental Protection Agency (EPA) [11] from the United States plus review from related literatures. All the data pertaining to these parameters were taken from the relevant agencies, however not all parameters are included in this study due to the lack of data availability.

In this study seven (7) parameters have been identified for landfill site selection namely surface water, residential area, railway, archeology or historical site, sensitive area, road accessibility and urban area.

There are two stages of analysis as shown in above diagram 1 where, firstly it starts with an elimination process of unsuitable parcels of land for siting a landfill. Suitable parcels of land resulted from the first stage undergo a second stage of analysis where there are two types of Multi Criteria Decision Making (MCDM) methods have been employed a namely analytical hierarchy process (AHP) and weighted linear combination (WLC). Table I above explains list of the constraint criteria. At the first stage, these criteria are used to identify unsuitable parcel of land for landfill according to the local regulation. By considering these criteria, it was found that only 2.93% of the total area than can be considered as suitable land. These few areas can be suggested as a suitable list of land to the Local Authority but, this is not a final result as further step needs to be applied in order to narrow down these suitable areas.
The analysis of digital elevation model (DEM), soil type and slope are neglected. The study area has a flat topography (horizontal slope) and the contour surfaces are very less. Also has a clay soil which is one of the best sites for landfill siting because clay can prevent leachate problems. Leachate migration from the landfill could be a potential source of surface and groundwater contaminations. This stage is applied to rank the potential areas based on attributes recorded on GIS data maps. These criteria are not easily quantifiable or measurable using related units and thus, a suitable approach is needed to make these criteria commensurable. Therefore, a grading scale value of 1 to 4 is applied to these criteria to indicate its suitability for landfill siting which is ranging from least to the most suitable, respectively.

**Table I**

<table>
<thead>
<tr>
<th>No.</th>
<th>Criteria</th>
<th>Buffer Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Surface water</td>
<td>300m</td>
</tr>
<tr>
<td>2</td>
<td>Historical places</td>
<td>3000m</td>
</tr>
<tr>
<td>3</td>
<td>Urban areas</td>
<td>1000m</td>
</tr>
<tr>
<td>4</td>
<td>Railway</td>
<td>1500m</td>
</tr>
<tr>
<td>5</td>
<td>Roads network</td>
<td>1000m</td>
</tr>
<tr>
<td>6</td>
<td>Military areas</td>
<td>2000m</td>
</tr>
<tr>
<td>7</td>
<td>Airport</td>
<td>3030m</td>
</tr>
</tbody>
</table>
Figure 2. (a & c), Shows the region has a good roads and railway network system and access to the landfill anywhere in this area is possible. Figure 2.(b&d), Shows the buffered distance for roads and railway where no landfill site is suitable to be constructed in. According to international guidelines for landfill siting the criterion map has indicated that the suitable distance from road network is within 1000 m buffer [12-16]. This is very important for the environmental requirement and property protection. Besides, it helps to reduce the pollution already caused by traffic on the road.

Figure 3.(a), Shows shawa airport that Landfill must be within 3030 m (10,000 ft) away from any airport-railway, thus birds are attracted to landfill sites where different types of food are available [18-19]. Figure 3.(b), Shows shawa airport with buffer 3030 m that indicate the restricted area around the air port.
Surface water (rivers) is very important because of its ecological balance to all the human being activities and as a nature resource. Rivers can be endangered by the landfill because of leachate issue which is dangerous it can bring a great pollution to the river. Figure 4.(a), shows the river network. Based on World Bank guidelines to encounter the leachate problem, a buffer distance of 300 m from the river is considered for landfill location as shown in Figure 6.(b). According to Samuel Weiss 1974 leachate may leave the landfill down at the ground surface as a spring or percolated through the soil and rock that surround the waste.

Figure 5.(a), Shows urban areas in the study area where landfills should not be placed too close to high-density urban areas in order to mitigate conflicts relating to the Not in My Back Yard syndrome (NIMBY). This guard against health problems, noise complaints, odour complaints, decreased property values and mischief due to scavenging animals. Development of landfills shall be prohibited within 3000 meters from village or rural settlements. According to EPA (2003) [11], a landfill site should be located in an area which is at least 500 meters from an urban residential or commercial area. Figure 5.(b), Shows urban areas with buffer zone 1000m that represent restricted area in green color. The geology properties of the study area are not considered as factor or constraints. There are limitations of geological data for this area, therefore the depth to the bedrock and groundwater is not taken into consideration that requires more expert interpretation and fieldwork to collect the data, which is beyond the scope of this study.
The next step is the integration of the analytical hierarchy process (AHP) and weighted linear combination (WLC) on this part. The AHP method which is developed by Saaty, T. L. (1980) [9] is based on the calculation of using the eigenvector methods. This method of a pairwise comparison matrix is graded by a decision maker and stored in pair wise comparison modules.

A matrix is constructed where each criterion is compared with the other criteria relative to its importance, based on a scale of 1 to 9 which means its level of importance varies from equal importance to the extreme importance, respectively. Then, a weight estimate is calculated and used to derive a consistency ratio (CR) of the pairwise comparisons. If CR > 0.10, then some pairwise values need to be reconsidered and the process is repeated until the desired value of CR < 0.10 is reached. A detailed explanation about the AHP method can be found in Saaty, T. L. (1980) [9]. Finally, WLC method is applied to compute the suitability index value of the potential areas based on the equation as follows (equation 1):

\[
Si = \sum_{j=1}^{n} w_j * x_{ij}
\]

Where \( \text{Si} \) is the suitability index for area i, \( w_j \) is the relative importance weight of criterion j, \( x_{ij} \) is the grading value of area i under criterion j and \( n \) is the total number of criteria. The suitability index is calculated using the grading value of factor criteria with their corresponding relative importance weight taken directly from the last column in the Table II.

The level of suitability for each cell on these potential areas is finally calculated by applying the above formula. Suitability index value is the final value obtained where it varies from lowest to the most suitable site according to the grading scale of 1 to 5. Figure 7 below displays the final grading value obtain which is called suitability index. An increasing of the suitability index indicates the more suitable that site to be a landfill. Sites with suitability index from 39.012 to 43.215 are less suitable to become a landfill site. Sites with index from 75.797 to 93.949 are considered the most suitable ones however it covers only on the small part. Therefore, the second ranking of suitability index which is from 63.219 to 75.797 can be considered as the most suitable sites available at the study area.
IV. CONCLUSION
The presented approach is easy to understand, it can illustrate which areas are better or less suitable for landfill site selection, and it can be used to select landfill sites in the shortest possible time and least costs. The criteria used in this study are not fixed factors since they can vary from area to area and these criteria can be changed accordingly in the analysis process. The level of uncertainty of the results depends on the accuracy of the data, the weights a user assigns to parameters, and the functions or process used in the spatial model. Apart from that, the presented methodology can explain clearly and directly the analysis and results in an easily understandable format. As a result, when the approach and results of the suitability map could be clearly understood, it can assist in getting full support especially from the public.

REFERENCES