

A GIS-AHP Based Approach for Siting Municipal Landfill in Ilorin

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Abstract

Selecting the most appropriate landfill site has been a major challenge to municipal solid waste managers because it involves the consideration of several environmental factors. This study employed the combination of Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) to select the most suitable location for a landfill in Ilorin, Nigeria. GIS was used to digitize all the spatial features related to landfill selection while excluding unsuitable areas. A total of eleven potential landfill sites were identified from GIS analysis and an AHP model was developed to rank these sites. The AHP model rated Candidate site 10 as the most preferable landfill site after trade-offs between key environmental factors such as slope, area and proximity to major road, pipeline, airport, railway line, built-up areas and water bodies. This illustrated approach makes it very easy for environmental planners to spatially buffer unsuitable locations for landfills, identify criteria priorities, and select the most suitable site under each criterion.

Keywords: Solid waste, landfill, Geographic Information System, Analytic Hierarchy Process, environmental factors

1.0 Introduction

As world population and prosperity continues to grow, huge amounts of solid waste are generated and the efficient disposal of the generated solid wastes continues to be a major concern to municipal authorities. Landfilling is the most widely used method of solid waste disposal throughout the world because it is simple, cheap and cost effective (Aderemi, 2011). The use of landfills as the last disposal option usually progresses from primitive open-dumping, controlled dumping, controlled landfilling, to the sophisticated sanitary landfilling (Hoornweg and Bhada-Tata, 2012). Nowadays landfills serve several functions such as avenue for material separation, processing, and energy and material recovery rather than waste disposal alone. However, landfills have been associated with significant socio-economic and environmental problems thereby necessitating proficient approaches to select site, design, operate, and manage closed landfills.

Site location for a municipal solid waste landfill is perhaps the most fundamental and difficult task to be accomplished in the development of a landfill (Ball, 2005; Davis and Cornwell, 2009). It has been recognised that several factors such as haul distance to disposal site, location restrictions, available land area, site access, soil conditions and topography, climatological conditions, surface water hydrology, geologic, hydrologic and local environmental conditions are to be taken into consideration before siting landfills (Tchobanoglous et al., 1993). Therefore, relevant information about an area and neighbouring environment are necessary in order to select a suitable landfill site. At times trade-offs between competing social, economic and environmental factors are required to justify the selection of a particular site among several alternative sites.

Geographic Information System (GIS) is a computer-based tool for capturing, storing, manipulating and displaying geographically referenced data, and generating spatially referenced results (Lo and Yeung, 2007). Geographic Information System (GIS) is a powerful set of computer based tools used to collate, store massive data, manage, analyze and communicate spatially referenced results (Bunch et al., 2012). GIS is a valuable tool for processing large amounts of demographic information related to evaluation of potential landfill sites (Mihelcic and Zimmerman, 2010). In specific location analysis, GIS has the capability to handle and stimulate the necessary economic, environmental, social, technical and political constraints governing

such analysis (Nas et al., 2010). However, the use of GIS for planning processes has limitation of scope for the incorporation of judgments, values and arguments, and Multi-Criteria Decision Analysis (MCDA) is often required to evaluate multiple criteria problems (Kabite et al., 2012).

Several MCDA tools exist in literature, and the methods and ideas of multiple criteria decision making have been integrated in new areas such as data envelopment analysis, negotiation science, e-Commerce, spatial modeling, finance and engineering (Wallenius, 2008). The Analytic Hierarchy Process (AHP) is a vital MCDA tool that utilizes hierarchical structure and pairwise comparisons in the formalization of a complex problem (Saaty, 1980). In order to make comparisons, a scale of numbers which shows how many times more important or dominant an element is over another with respect to the criterion to which they are paired (Saaty, 2008). The consistency check offered by AHP allows for improvement in decision making and makes it a unique tool.

Therefore, the integration of GIS and AHP can be a veritable tool for landfill site selection problem. The GIS provides efficient way of manipulating and presenting data while AHP supplies consistent ranking of potential landfill areas based on a variety of criteria (Khan and Samadder, 2014). This study illustrates the application of GIS and AHP to select the most suitable site for the location of a landfill in Ilorin, Nigeria.

2.0 Materials and Methods

2.1 Study Area: This study was conducted in Ilorin, Kwara state. Ilorin is located on Latitude $4^{\circ}30'N$ and Longitude $4^{\circ}35'E$ in the north central part of Nigeria. The city is composed of three Local Government Areas; Ilorin East, Ilorin South, and Ilorin West and has a combined population of 777,667 in 2006 (NPC, 2007). The Kwara State Management Company (KWMC), a public private partnership was introduced in 2003 to manage municipal solid wastes in Ilorin metropolis. The problem of municipal solid waste management is quite enormous because large amounts of solid waste are generated on a daily basis. In order to solve this problem and difficulty in accessing waste generation points, large storage metal containers of 7.54 m^3 capacity (Roll-on Roll-off bins) are placed at strategic locations along some major roads within Ilorin metropolis (Aremu et al., 2012). When the containers are full, they are hauled to the disposal site using medium sized trucks and the contents are emptied, after which the empty container is returned.

2.2 Method: The approach adopted in this study is shown in Figure 1. Data collection involves obtaining relevant analog maps and Digital Elevation Model (DEM) of Ilorin. The features considered for the selection of suitable landfill site in Ilorin include major roads, airport location, slope, pipeline, railway line, built-up areas and water bodies. The maps were geo-referenced into earth coordinates and features of relevance to the study were subsequently digitized. Buffer analysis (negative mapping) was performed on the digitized features so as to generate maps of unsuitable sites for landfill development. These maps were then combined to generate a map overlay thereby excluding all areas unsuitable for landfill siting leaving only potential landfill sites.

An AHP model was developed from the map overlay which identified potential landfill sites from GIS analysis. The AHP model analysis involves level formation (hierarchy), assignment of weights, pairwise comparison, consistency test, and weight estimation. The developed AHP model with its hierarchical structure is presented in Figure 2.

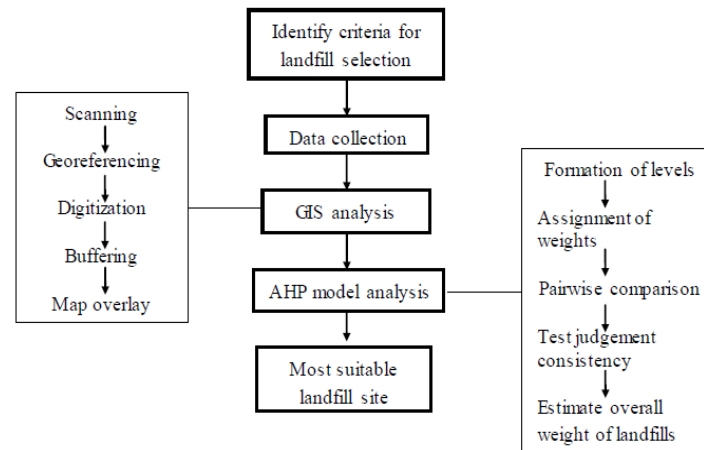


Figure 1: Flowchart showing methodology adopted in the study

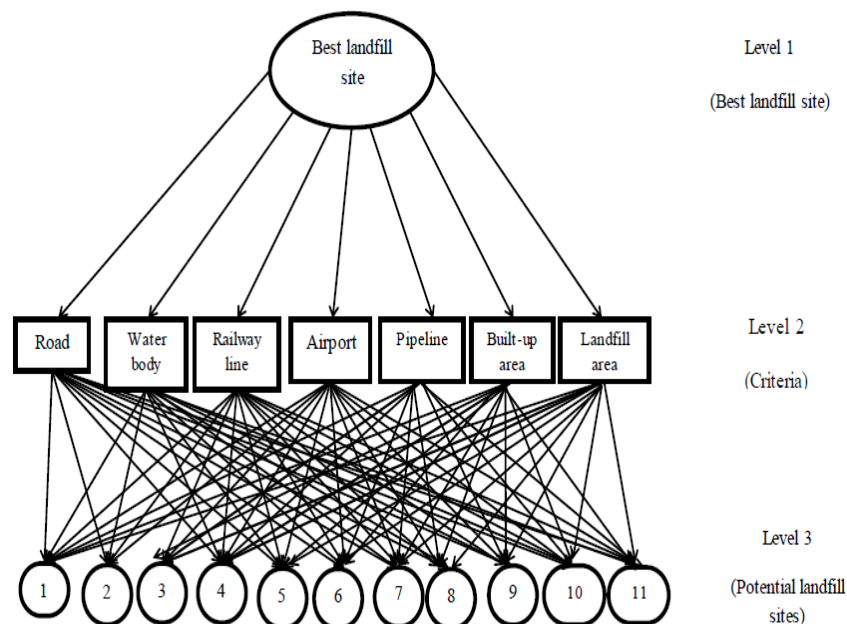


Figure 2: Hierarchy in the developed AHP model for selection of landfill site

The topmost level (Level 1) of the hierarchical structure of the AHP model represents the main goal which is the selection of the best landfill site. Level 2 represents the criteria considered in the selection process. The last level (Level 3) represents various alternatives (potential landfill sites) generated from GIS analysis. The potential landfill sites were prioritized based on characteristic features of the sites obtained from GIS analysis. The procedure of Saaty (1980) was used to solve the AHP problem. Table 1 presents weights assigned to characteristic features in the evaluated potential landfill sites. A favourable condition is given more numeric value than an unfavourable condition.

Table 1: Assigned weights to characteristic features of potential landfill site

Landfill-area (km ²)	Weight	Proximity to water body (m)	Weight
1.0 – 2.0	3	500 – 510	3
2.1 – 3.0	5	511 – 530	5
– 4.0	7	531 – 600	7
>4.0	9	>600	9
Proximity to major road (m)		Proximity to airport (m)	
200 – 215	9	1000-5000	3

216 – 250	7	5001 – 9000	5
251 – 510	5	9001 – 13000	7
511 – 1000	3	>13000	9
>1000	2	Proximity to pipeline (m)	
Proximity to built-up area (m)		800 – 2000	3
200 – 250	3	2001 – 3500	5
206 – 211	5	3501 – 5000	7
212 – 217	7	>5000	9
218 – 220	8		
>221	9		

The Consistency Ratio (CR) was determined by evaluating the maximum Eigen value, Consistency Index (CI) and Random Consistency Index (RI). A program was written in Microsoft Excel and incorporated into MATLAB application to determine the Eigen value for different scenarios to be evaluated. The comparison matrix for a given n -rows and n -columns is denoted by the matrix relation (Sivaraos et al., 2014):

$$A = a_{ij} = \begin{bmatrix} a_{11} & a_{12} & a_{1n} \\ a_{21} & a_{22} & a_{2n} \\ a_{n1} & a_{n2} & a_{nn} \end{bmatrix} \quad (1)$$

where, a_{ij} = the value obtained from the fundamental scale of comparison;
 i, j = the row and column positions respectively; and
 n is the number of rows and columns in the matrix.

The maximum Eigen value is evaluated from the average column vector

$$\begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \lambda_n \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{1n} \\ a_{21} & a_{22} & a_{2n} \\ a_{n1} & a_{n2} & a_{nn} \end{bmatrix} \begin{bmatrix} PV_1 \\ PV_2 \\ PV_n \end{bmatrix} \quad (2)$$

Where, λ_n = Eigen value, and PV_n = Priority vector

The priority vector (PV) for the comparison matrix formed is evaluated from equation (3) while the maximum Eigen value (λ_{max}) is computed using equation (4).

$$PV = \frac{\frac{a_{n1}}{\sum a_{i1}} + \frac{a_{n2}}{\sum a_{i2}} + \dots + \frac{a_{nn}}{\sum a_{in}}}{n} \quad (3)$$

$$\lambda_{max} = \frac{\lambda_1 + \lambda_2 + \dots + \lambda_n}{n} \quad (4)$$

The consistency ratio (CR) which evaluates the consistency in judgment is given by the relation

$$CR = \frac{CI}{RI} \quad (5)$$

where, CI = Consistency index; RI = Random consistency index

The consistency index (CI) and the random consistency index (RI) can be evaluated using the following equations

$$CI = \frac{(\lambda_{max} - n)}{n - 1} \quad (6)$$

Where, λ_{max} = Maximum Eigen value
 n = number of rows or columns in the comparison matrix

$$RI = 1.98 \left[1 - \frac{n-1}{\frac{n}{2}(n-1)} \right] \quad (7)$$

1.98 is the average value of the ratio of each value computed for $n = 3$ to $n = 15$. The judgment is considered to be consistent if the Consistency Ratio (CR) is less than 0.1, else the judgment has to be re-evaluated to ensure proper decision making. However all the priority vectors must always add up to unity.

4.0 Results and Discussion

The map obtained by superimposing the map of each unsuitable site is shown in Figure 3. The potential landfill sites extracted from the map of unsuitable landfill sites (Figure 3) is presented in Figure 4. It consists of eleven potential landfill sites. The characteristic features of these sites are presented in Table 2.

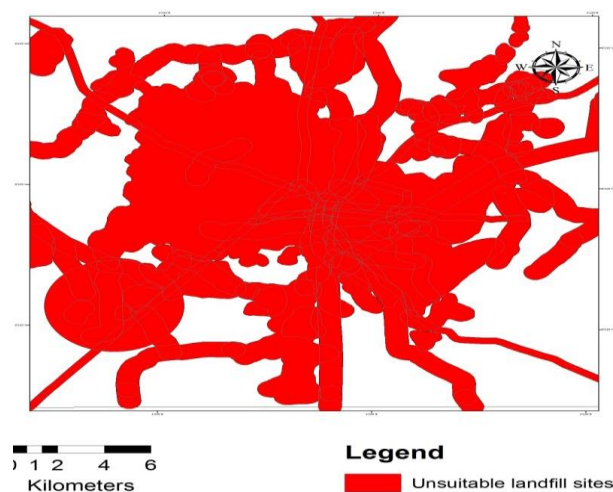


Figure 3 Superimposed map of unsuitable landfill sites

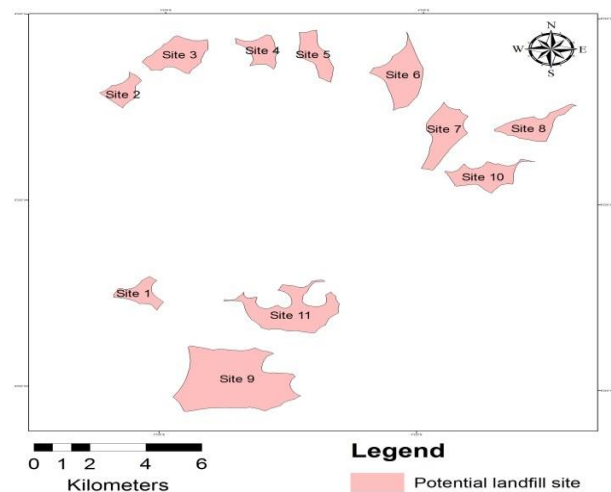


Figure 4 Potential landfill sites within the study area

Table 2: Characteristic features of potential landfill sites

Potential landfill site	Landfill-area (km ²)	Proximity to:					
		Major road (m)	Water body (m)	Railway line (m)	Pipeline (m)	Airport (m)	Built-up area (m)
1	1.2502	1424.67	561.16	7414.49	7665.54	3050.31	211.04
2	1.1638	216.09	562.69	9963.67	17433.09	12557.77	204.27
3	2.658	2340.75	594.04	8439.86	17652.30	14543.96	205.27
4	1.3335	2471.09	570.64	5537.86	15094.00	16060.32	222.74
5	1.6268	213.46	842.04	3613.49	13202.64	15992.64	218.72
6	3.3224	1979.12	516.81	509.03	9699.34	16116.15	213.27
7	2.8501	216.60	509.11	513.41	7970.03	14785.47	235.51
8	1.9681	207.92	511.66	3161.17	3944.67	18369.62	218.67
9	10.1437	1628.12	502.54	5174.26	2650.34	2990.11	210.96
10	2.3095	501.55	501.55	1513.52	1676.02	15188.92	221.71
11	4.5392	524.41	524.41	997.84	883.50	5542.51	208.00

The combined weight of the potential landfill sites using the characteristic features of each potential landfill site presented in Table 2 and making comparison with Table 1 to score

individual potential landfill site is presented in Table 3. A weight of 9 indicates that the potential landfill site is extremely important with respect to the criterion feature under consideration while a weight of 2 indicates that the potential landfill site is less important with respect to the criterion feature under consideration.

Table 3: Weight of each potential landfill site based on characteristic features

Potential landfill site	Landfill-area (km ²)	Proximity to:					
		Major road	Water body	Railway line	Pipeline	Airport	Built-up area
1	3	2	7	2	9	3	3
2	3	7	7	2	9	7	3
3	5	2	7	2	9	9	5
4	3	2	7	2	9	9	3
5	3	9	9	3	9	9	3
6	7	2	5	9	9	9	7
7	5	7	3	9	9	9	5
8	3	9	5	3	5	9	3
9	9	2	3	2	5	3	9
10	5	5	3	7	3	9	5
11	9	3	5	9	3	5	9

The criteria considered for siting municipal landfill were prioritized based on key information obtained from waste managers and environmental planners within the study area. The vector priorities evaluated from initial assessment gave a maximum Eigen value of 8.558 while the Consistency Index (CI), Random Consistency Index (RI) and Consistency Ratio (CR) are 0.2597, 1.4143 and 0.8136 respectively.

Since the Consistency Ratio (CR) is greater than 0.1, the initial judgment was subsequently re-evaluated by pairing the vector priorities obtained from the initial assessment. The comparison and normalized matrices that were re-evaluated for the criteria considered are presented in Tables 4 and 5 respectively. Thus, road is considered the most important landfill criterion within the study area because it has the highest value in the AHP model. On the other hand, proximity to railway line is considered as the least important landfill criterion because it has the smallest value of priority vector.

Table 4: Paired comparison matrix for each criterion

Landfill criterion	* Priority vector	Road	Water body	Railway line	Airport	Pipeline	Land use	Landfill Area
Road	0.3687	1.0000	1.5144	20.1177	4.7700	6.8511	2.3342	4.5848
Water body	0.2435	0.6603	1.0000	13.2841	3.1497	4.5239	1.5413	3.0274
Railway line	0.0183	0.0497	0.0753	1.0000	0.2371	0.3406	0.1160	0.2279
Airport	0.0773	0.2096	0.3175	4.2176	1.0000	1.4363	0.4894	0.9612
Pipeline	0.0538	0.1460	0.2210	2.9364	0.6962	1.0000	0.3407	0.6692
Land use	0.1580	0.4284	0.6488	0.0144	2.0435	2.9351	1.0000	1.9641
Landfill-Area	0.0804	0.2181	0.3303	4.3879	1.0404	1.4943	0.5091	1.0000

* Priority vector obtained from initial assessment was used to obtain paired comparison matrix for criteria

Table 5: Normalised matrix for landfill criteria

Landfill criteria	Road	Water body	Railway line	Airport	Pipeline	Land use	Landfill-Area	Priority Vector
Road	0.3687	0.3687	0.4377	0.3687	0.3687	0.3687	0.3687	0.3786
Water body	0.2435	0.2435	0.2890	0.2435	0.2435	0.2435	0.2435	0.2500
Railway line	0.0183	0.0183	0.0218	0.0183	0.0183	0.0183	0.0183	0.0188

Airport	0.0773	0.0773	0.0918	0.0773	0.0773	0.0773	0.0773	0.0794
Pipeline	0.0538	0.0538	0.0639	0.0538	0.0538	0.0538	0.0538	0.0553
Land use	0.1580	0.1580	0.0003	0.1580	0.1580	0.1580	0.1580	0.1354
Landfill-Area	0.0804	0.0804	0.0955	0.0804	0.0804	0.0804	0.0804	0.0826

The potential landfill sites were prioritized under each criterion using the combined weight for individual potential landfill site (presented in Table 3). The vector priority obtained for each criterion was considered while prioritizing the potential landfill sites. Similarly, the initial judgment made to evaluate the vector priorities under each criterion gave a consistency ratio greater than 0.1 for all considerations. They were subsequently re-evaluated by pairing the vector priorities obtained from the initial assessment to obtain better judgment under each criterion.

The overall rank obtained by summing up the priority vector under each criterion is presented in Table 6. The highest value in the rank indicates the most preferable potential landfill site while smallest value indicates the least preferable landfill site. Therefore candidate site 10 is the most preferred followed by candidate sites 5, 7, 1, 8, 6, 11, 2, 4, 3 and 9 in descending order of priority.

Table 6: Overall rank of candidate sites under various criteria

Candidate site	Landfill area (0.0826)	Proximity to:						Overall rank
		Road (0.3687)	Water body (0.25)	Railway line (0.0188)	Pipeline (0.0553)	Airport (0.0794)	Built-up area (0.1354)	
1	0.0099	0.0173	0.0413	0.002	0.0086	0.0045	0.0207	0.1043
2	0.0041	0.0367	0.0243	0.0083	0.0051	0.0058	0.0041	0.0884
3	0.0064	0.0109	0.0243	0.0083	0.0051	0.0063	0.0041	0.0654
4	0.0038	0.0109	0.0243	0.0083	0.0051	0.0063	0.0123	0.071
5	0.0038	0.0592	0.0312	0.0125	0.0051	0.0063	0.0109	0.129
6	0.009	0.0109	0.0174	0.0374	0.0051	0.0063	0.0096	0.0957
7	0.0064	0.0383	0.0104	0.0374	0.0051	0.0063	0.0123	0.1162
8	0.0038	0.0482	0.0174	0.0125	0.0028	0.0063	0.0109	0.1019
9	0.0115	0.0109	0.0104	0.0083	0.0028	0.0024	0.0068	0.0531
10	0.0123	0.1088	0.0316	0.0532	0.0092	0.0245	0.0368	0.2764
11	0.0115	0.0164	0.0174	0.0374	0.0013	0.0041	0.0068	0.0949

5.0 Conclusions

This study successfully applied the combination of Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) to select most suitable landfill location in Ilorin, Nigeria. GIS was used to identify potential landfill sites within the study area while the AHP was used to prioritize the potential landfill sites. The criteria used to select the most suitable landfill site are landfill area, and proximity to major road, pipeline, airport, railway line, built-up areas and water bodies. The AHP model rated Candidate site 10 located on Latitude 4036'13.533" and Longitude 8030'42.968" along Jebba road as the most preferred site to locate a landfill in Ilorin. It has an approximate area of 2.3095 km², 501.55 m from the nearest water body and major road, 1513.52 m from railway line, 1676.02 m from pipeline, 15857.83 m from the airport and 221.71 m from built-up area. The application of GIS-AHP framework in this study has helped to solve time consuming challenge often associated with selection of landfill site. This framework makes it very easy for environmental planners to spatially buffer unsuitable locations for landfills, identify criteria priorities, and select the most suitable site under each criterion.

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