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LANDFILL SITE SUITABILITY SELECTION FOR GOMBE METROPOLIS, NIGERIA

Jibril, A, B[1] Taiye, O. A.[2] Ibrahim, M. M[3] and Auwal, S. A.[4]

[1]Geoinformatics Department, National Centre for Remote Sensing Jos, Nigeria.

[2]Department of Geography, Nigerian Defence Academy, Kaduna, Nigeria

[3]Department of Surveying and Geoinformatics Abubakar Tafawa Balewa University Bauchi, Nigeria.

[4]Department of Building Technology Jigawa State polytechnic Dutse, Nigeria

*Correspondence Author**:** **hamzasaji100@yahoo.com**

ABSTRACT

This study is aimed at identifying suitable sites for developing a municipal solid waste (MSW) landfill that is environmentally and socio-economically friendly for Gombe metropolis. In this study, suitable landfill sites were selected using Geographic Information Systems (GIS), Remote Sensing, Multi-Criteria Decision Analysis (MCDA), and Analytical Hierarchy Process (AHP) techniques. For optimal site selection, seventeen different criteria were identified and their themes derived from landsat-8 of 2015, SRTM of 2000, topographic, geology, hydrology, and soil maps, and point coordinates from fieldwork. Each criterion was weighted using the pairwise comparison method, and the MCDA reveals that only four out of the twenty-seven sites that belong to the very high suitable class are greater than the 10ha required. A site (Site 3) was further selected as the most suitable and cost-effective landfill site in the study area due to its size (193.85 ha), proximity to Gombe (6.7 km from the waste generation center), accessibility (0.7 km from the main road), and convenient morphology (with a slope of less than 6°). The results showed that there is considerable land for landfill development within the study area. Finally, it is recommended that the selected landfill sites be incorporated into the existing master and regional development plans for Gombe metropolis and its surroundings.

Key words: *Landfill, Suitability, Pairwise, Distance, Proximity and Buffer,*

1.0 INTRODUCTION

The waste generation scenario in Nigeria has been of great concern because of the increasing volume of waste material and the paucity of places to deposit it (Aderemi, et al., 2011). MSW has also been recognized as one of the major problems confronting governments and city planners in the world (Rahman, et al., 2002). Among the different categories of waste being generated, solid waste posed a problem beyond the scope of various solid waste management systems in Nigeria (Emeka, 2011). Rapid increases in population and industrialization in Nigeria have resulted in a dramatic increase in the generation of municipal solid waste (Sulaiman & Maigari, 2016).

Solid waste collection and disposal is still among the main environmental problems in Gombe metropolis, as waste collection locations are not enough and are completely absent in some areas. As a result, waste is either disposed of in pits, farmlands, undeveloped plots, drainages, and streams, or in uncontrolled dumps without any further management, and it may likely have a significant negative impact on public health and the existing land uses. According to studies conducted by Adamu et al., (2010) and Aderemi et al., (2011) in Kano and Lagos, respectively, on groundwater quality assessments, the underground water near some selected dump sites was unsuitable for domestic purposes due to the contamination by leachate.

Though different tools and techniques are being developed for the selection of waste disposal sites, landfills are the most common method used in many countries. These landfills are always located far away from human settlements to avoid the nuisance associated with them. Source reduction, recycling, and waste transformation methods are widely used to manage solid waste. However, in all of these methods, there is always residual matter to dispose of. The necessity of getting rid of these waste yields in an economically and environmentally friendly way is called landfilling (Sener, 2004). A landfill is a disposal site for non-hazardous solid wastes. Landfills are designed to greatly reduce or eliminate the risks that solid waste disposal may pose to the public's health through environmental quality. It is usually placed in areas where land features act as natural buffers between the landfill and the environment. For sustainable urban development, environmental protection, and human health concerns, it is imperative not only to set up an effective system for waste collection but also to select a suitable site for waste deposition.

Many studies such as (Ghoutum et al., 2020; Basak, 2004; Babalola & Busu, 2010; Emeka, 2011; Wang et al., 2009; Aderemi et al., 2011; Ajide & Olubumi, 2013; Adeofun et al., 2014; Olusina & Shyllon, 2014; Ahmadi et al., 2014; Al-Anbari et al., 2014; Mahini et al., 2006; Hatzichristos & Giaoutzi, 2006; Siddiqui et al., 1996; Al-jarrah & Abu-Qdais, 2006; Tirusew et al, 2013; Kanchanabhan et al., 2016; Katpatal et al., 2011; Pandey , 2012; Koushik, 2014; Sunil et al., 2012; Yesilnacar et al. 2012; Shukla, 2016; Jibrin et al., 2017 and Baiocchi et al., 2014) have conducted studies on landfill site selection using RS and GIS in different parts of the country and the world in general, but no any similar research has been carried out for Gombe metropolis. In addition, their models cannot be efficiently and effectively used in Gombe without any modifications due to the diversity of economic, environmental, political, and social parameters as well as the availability of data.

Therefore, this study identified suitable areas for landfill development in Gombe metropolis by adapting the model used by Olusina and Shyllon (2014) and using GIS methods incorporating MCDA and AHP tools in selecting landfill sites. Some parameters used in their research were modified due to the diversity of economic, environmental, and socio-cultural factors in the study area. For commuters not to see and smell odor from landfills, the distance of 100m used by Olusina and Shyllon (2014) as a set-aside distance from main roads is too close to the roads. Therefore, this distance needs to be increased to a safer distance so as to preserve aesthetic values and avoid bad odor. A 500-metre buffer around built-up areas was considered a constraint for sitting a landfill, but this distance is considered insufficient not only for aesthetics, odor, noise, and health concerns but for a rapidly developing area such as Gombe because in less than ten years development may reach or pass the said distance. Therefore, this may raise the issue of "Not in My Back Yard" (NIMBY) syndrome and affect property values around the area. Surface water (sea, lagoons, and ponds) and airport criteria used in their research are not considered in this research because they do not exist within the study area. However, criteria such as depth to ground water, land use, and distance from cultural places (churches, Eid prayer grounds, and grave yards that are not within the residential area), which are important environmental and socio-economic factors that are not considered by their studies, are added.

2.0 MATERIALS AND METHOD

2.1 Study Area

Gombe metropolis is located in the north-eastern part of Nigeria. The study area is located between latitudes 10°08’43" to 10°25’13" north of the Equator and longitudes 11001'19" to 11018'55" east of the Greenwich meridian. It covers a total land mass of 994.33 km2 (Figure 1). Gombe metropolitan area experiences a two-season climate: dry seasons (November–March) and rainy seasons (April–October), with an average rainfall of 800mm (Waziri and Rabiu, 2014). The minimum and maximum average daily temperatures of the study area are 17.32 ^{c}o. in January and 36 ^{o}C in April, respectively, with an annual average temperature of 27.62^{o}C. The population of Gombe metropolis was 312,467 in the 2006 census and is projected to reach about 573,000 in 2023.

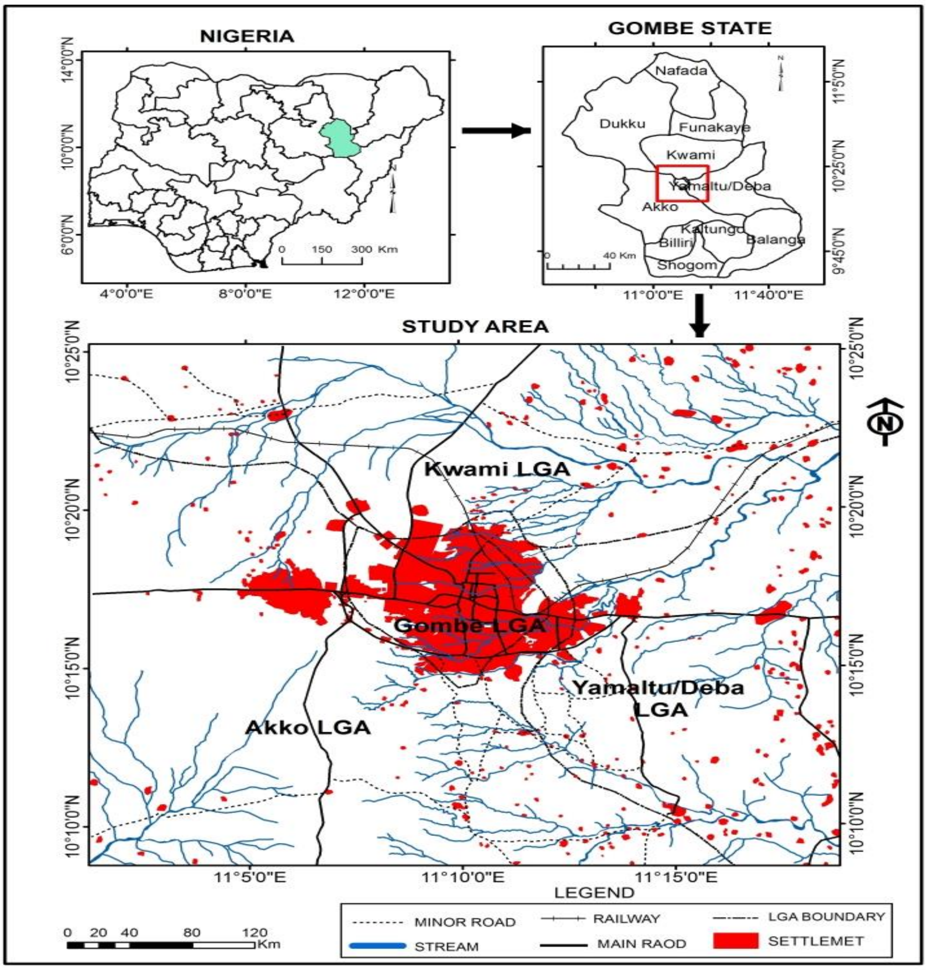


Figure 1: Study area

2.2 Materials

The types of data used in this study include satellite images, existing maps, and positional coordinate data. The specifications of the required data are summarized in Table 1.

Table 1: Data Specification

Data	Data type	Reso	PR/Sheet	Date	Source
LandSat-8 OLI	Raster	30m	P186r053	03/11/2015	Earth
SRTM (Height)	Raster	90m	P186r053	2000	GLCF
Soil map	Hard copy map	1:10	152	1962	GSADP
Geology map	Hard copy map	1:50	10	1987	GSADP
Hydrology map	Hard copy map	1:50	9	1987	GSADP
Topographic	Hard copy map	1:10	152	2010 Revised version	OSGOS
Power line	Vector (X, Y)	1m	NA	December, 2015	Field
Cultural area	Vector (X, Y)	1m	NA	December, 2015	Field
Ground truth	Vector (X, Y)	1m	NA	December, 2015	Field

NA = Not Applicable

2.3 Methods

Landfilling involves an extensive evaluation process in order to identify the optimal disposal location. This location must satisfy basic government regulations and also take into consideration how to minimize important factors like health, economic, environmental, and social costs. The criteria considered were based on recognized guidelines retrieved from studies like Olusina and Shyllon (2014) and Ahmadi et al. (2014) since there are no established regulations with regards to landfill site selection in Gombe. Based on the availability of data, seventeen criteria were identified for landfill site selection in Gombe and are given as follows:

- Distance from urban settlement: to avoid adversely affecting land value and future development; and to protect the general public from possible environmental hazards released from landfill sites.
- Distance from rural settlements: As above, different distances are considered due to different population densities and rates of development.
- Distance from major roads: for aesthetic reasons and to protect commuters from seeing and perceiving odors.
- Distance from minor roads: to avoid the cost of constructing connecting roads and to protect commuters from seeing and smelling odors
- Distance from drainages: to protect surface water from contamination
- Distance from railroad: to protect commuters from seeing and smelling odors
- Distance from power lines: to avoid disrupting the infrastructure
- Distance from cultural areas: to respect people's beliefs
- Depth to groundwater: To prevent contamination of groundwater.
- Landuse and landcover: to limit the impacts on the areas surrounding the landfill and risks to public health.
- Ecological value of the flora: to avoid degrading natural, environmentally sensitive areas.
- Slope: to avoid the cost of landfill construction and difficulty in accessibility.
- Geology: Avoid fractured crystalline bed rocks that allow rapid transportation of fluids, which will contaminate groundwater.
- Soil types: Avoid porous soil so as to protect leachate from contaminating groundwater.

- Proximity to urban settlements: to cut transportation costs
- Proximity to major roads: to avoid the cost of connecting roads
- Proximity to minor roads: to avoid the cost of constructing connecting roads

As a result of the large volumes of spatial data required from a variety of sources, GIS was adopted for decision-making. The process began by scanning and importing the topographic, geology, hydrology, and soil maps into the ArcGIS 10.4.1 environment and georeferencing them, from which different layers such as road and railway, settlement, rivers, soil type, lithologies, and depth to the groundwater table were derived. Coordinates of power lines and cultural areas were typed in Excel, exported to ArcGIS, and plotted as line and polygon features, respectively. The created digital thematic layers served as input data for GIS and MCDA, from which a suitability map for waste disposal in the study area was produced.

The study used spatial multi-criteria analysis techniques to identify the most suitable site for solid waste disposal. First, the criteria were divided into two categories: constraint and factor variables, in order to apply different treatment to each category. Furthermore, constraints were delineated as unsuitable areas using buffer operations for landfills ranging from 30 to 2000 m, depending on the significance of the constraints. A dissolve operation was performed to aggregate the overlapping attributes of the constraint criteria. On the other hand, factors were illustrated using the suitability of a specified feature on a graduated scale such as 0 to 5, where the higher the scale value, the more suitable a location is.

Factors considered in this work were not of equal importance; some had more preferences than others. All factors were weighted, assigning each a percentage of influence; the higher the percentage, the more influence a particular criterion has in relation to other criteria under consideration. The pairwise comparison method was used in calculating criteria weights. Criteria weights had been computed by solving a comparison matrix generated from the comparison of two criteria at a time using Saaty's (1980; 1996; and 2005) words scale values of 1–9 as well as Cheng & Heng's (2005).

A weighted sum overlay was employed to accomplish this step. With the weighted sum overlay tool in ArcGIS 10.4.1, factors (standardized criteria layers) were combined by their given weight, followed by summing them together to yield a suitability index map using an equation 1:

$$S = \Sigma (w_i x_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Source: Malczewski, (1997).

Where, S is suitability, w_i is weight of factor $_i$ and x_i = criterion score of factor$_i$.

The masked suitability index map was then served as an input raster in the reclassified tool and segmented into different ranges of suitability classes, from low to high suitability classes. The reclassified suitability map was converted from raster to vector format, and from this, the most optimally suitable site was selected.

3.0 Results and Discussion

3.1 Constraint Areas

Methodology requires constraints (unsuitable) areas to be mapped out first. The nine constraint maps were combined using the dissolved operation, which maps the overlapping of all the unsuitable areas. The result (Figure 2) is the map of the integrated unsuitable areas for the siting of waste management facilities such as landfills in Gombe metropolis.

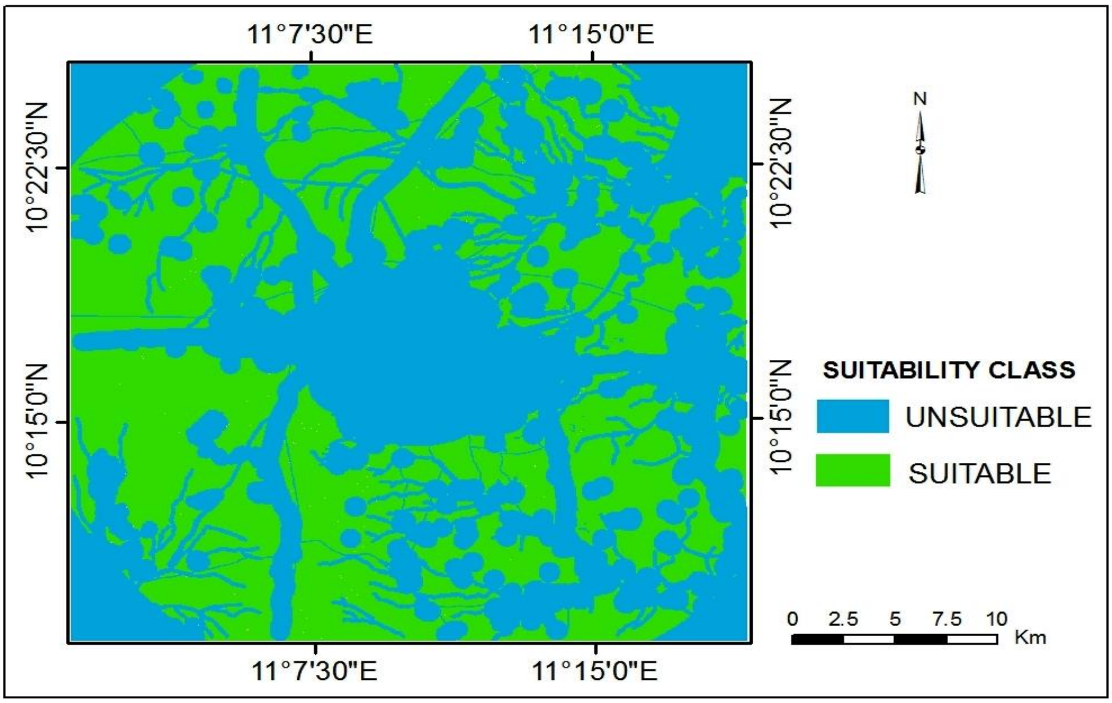


Figure 2: Integrated Constraint Map of the Study Area.

Source: Fieldwork, (2016).

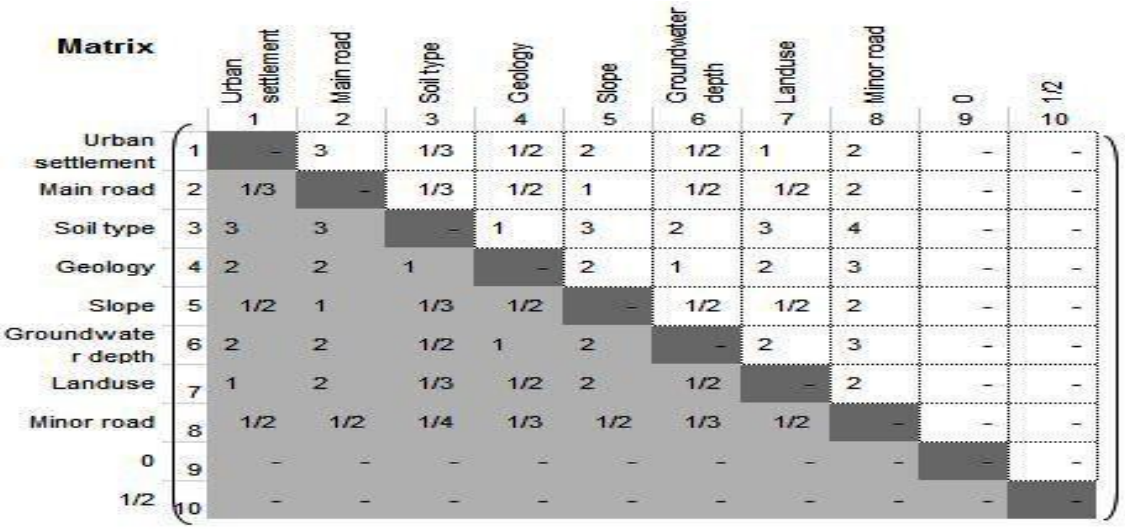
Unsuitable locations for the installation of landfills were determined in Figure 2, which is the systematic overlay of all constraint criteria. Blue areas were ascertained as unsuitable, while green areas are suitable for landfill installation. The results of the loose scenario gave a total unsuitable area of 58203.63 ha, which corresponds to 56.31% (more than half) of the total study area. In other words, the remaining area (suitable lands) that will be examined further represents around 43.69% (45157.36 ha) of the total area, which shows that there is a reasonable amount of space to be evaluated for landfill installation. This finding differs from the result of Baiocchi et al. (2014), where 80.2% of the area under consideration is unsuitable and only 19.8% is suitable. The variation in percentages was due to the use of different buffer zones for delineating constraint areas.

3.2 Factor Criteria

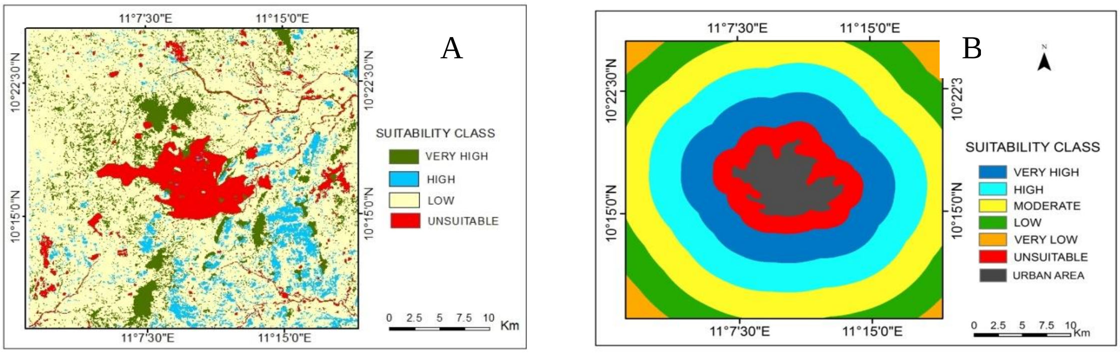
Since the unsuitable areas were identified, the rest of the territory was evaluated for landfill suitability. Several factor maps, such as soil, geology, slope, depth to groundwater, land use, distance from urban settlement, and main and minor roads, were produced as shown in Fig. 3 to demonstrate the suitability of a specified feature that ranges from the unsuitable locations to the suitable locations. The eight factors considered for the siting of MSW disposal facilities were evaluated, standardized, and ranked on a common scale of measurement in order to compare them as shown in figure Fig.3.

Prior to the integration of the factor (suitability) maps, the most preferential factors for the siting of waste management facilities were considered because factors are not of equal importance; some factors are more influential than others. Therefore, this aroused the need to compute the preferential weights for each factor. The pairwise comparison technique was used in the computation of the weights of the eight factors. The pairwise comparison matrix and the eigenvector values, together with the consistency ratio, were computed using the Goepel, K. D., BPMSG AHP version of MS Excel 2013. Table 2 gives the comparison matrix and the generated factor weights.

Table 2: Pairwise Comparison Matrix for determination of Preferential Weights



Matrix		Urban settlement 1	Main road 2	Soil type 3	Geology 4	Slope 5	Groundwater depth 6	Landuse 7	Minor road 8	0 9	1/2 10
Urban settlement	1	–	3	1/3	1/2	2	1/2	1	2	–	–
Main road	2	1/3	–	1/3	1/2	1	1/2	1/2	2	–	–
Soil type	3	3	3	–	1	3	2	3	4	–	–
Geology	4	2	2	1	–	2	1	2	3	–	–
Slope	5	1/2	1	1/3	1/2	–	1/2	1/2	2	–	–
Groundwater depth	6	2	2	1/2	1	2	–	2	3	–	–
Landuse	7	1	2	1/3	1/2	2	1/2	–	2	–	–
Minor road	8	1/2	1/2	1/4	1/3	1/2	1/3	1/2	–	–	–
0	9	–	–	–	–	–	–	–	–	–	–
1/2	10	–	–	–	–	–	–	–	–	–	–



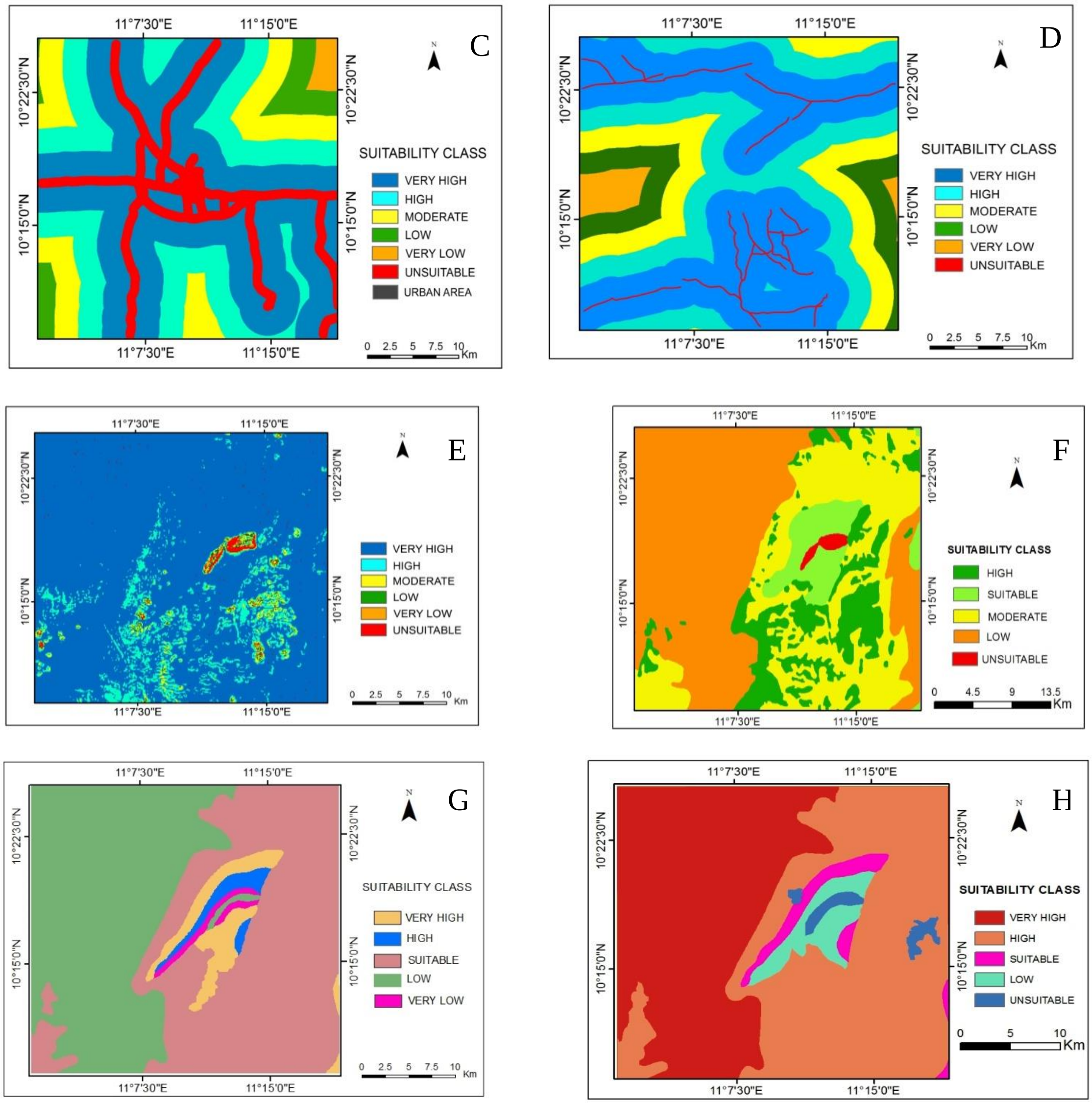
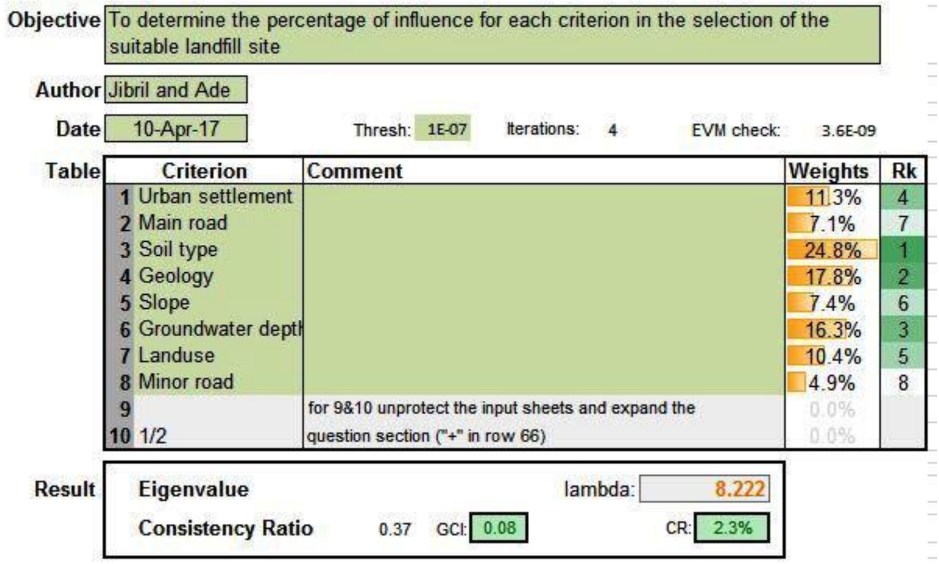


Figure 3 (A)Land use, (B) Proximity to urban settlement, (C) Proximity to Major roads, (D) Proximity to Minor roads, (E) Slope, (F) Soil type, (G) Geology and (H) Underground water.



Objective To determine the percentage of influence for each criterion in the selection of the suitable landfill site

Author Jibril and Ade

Date 10-Apr-17

Thresh: 1E-07 Iterations: 4 EVM check: 3.6E-09

Table

	Criterion	Comment	Weights	Rk
1	Urban settlement		11.3%	4
2	Main road		7.1%	7
3	Soil type		24.8%	1
4	Geology		17.8%	2
5	Slope		7.4%	6
6	Groundwater dept		16.3%	3
7	Landuse		10.4%	5
8	Minor road		4.9%	8
9		for 9&10 unprotect the input sheets and expand the	0.0%	
10	1/2	question section ("+" in row 66)	0.0%	

Result

Eigenvalue lambda: 8.222

Consistency Ratio 0.37 GCI: 0.08 CR: 2.3%

Figure 4: Eigenvector (weights) and Consistency Ratio

Figure 4 shows the criteria weights generated by AHP using the pairwise comparison technique. The consistency ratio (CR) is determined to be 2.3%; this shows that the subjective evaluation of the generated factor's weights is consistent because the value is less than 10% (Saaty, 1980).

The Gombe State Environmental Protection Agency suggested that more importance should be given to environmental factors so as to go in line with its mandate for sanitation, environmental, and ecological control in the state. Therefore, more preference was given to environmental criteria such as soil types (24.1%), geology (17.43%), and depth to groundwater (15.9%). On the other hand, socio-economic factors such as distance from urban areas, land use, slope, and distance from main roads have weights of 11.18%, 10.32%, 8.97%, and 7.21%, respectively, which are considered fairly less important than the environmental criteria. Similarly, distance from rural roads, assigned a weight of 4.88%, is considered to have the least preference. This finding agreed with the results of similar studies carried out in Abadan, Iran, and Damaturu, Nigeria, by Ahmadi et al. (2014) and Babalola and Busu (2011), respectively, which gave more priority to environmental factors than socio-economic factors.

3.3 Identification of Suitable Sites

A weighted sum overlay was employed to accomplish this step. With a weighted sum overlay, factors (standardized criteria layers) were combined by applying weight to each, followed by a summation of results to yield a suitability map in Figure 5.

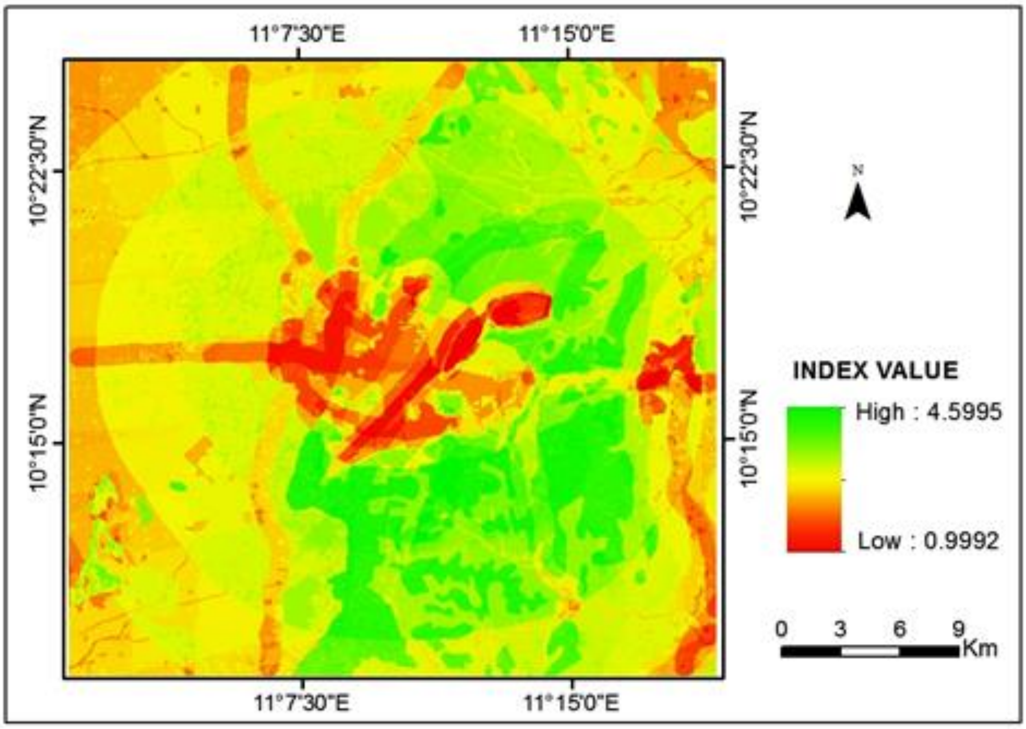


Figure 5: Landfill Site Suitability Index Map

The model gives out a suitability index with pixel values ranging from 0.9992 to 4.5995; areas with values closer to the lower index value are considered very low-suitable areas, while regions with values closer to the maximum index value are recognized as very high-suitable areas for sitting landfills. This result is confirmed by Al-Anbari et al. (2014), who found that the index values generated by weighted overlay analysis range from 0.436 to 4.161, which is analogous to the values obtained in this research. The landfill site suitability index map was further classified into seven suitability classes (Figure 6). Before then, the determined constraint areas were discarded from the index map.

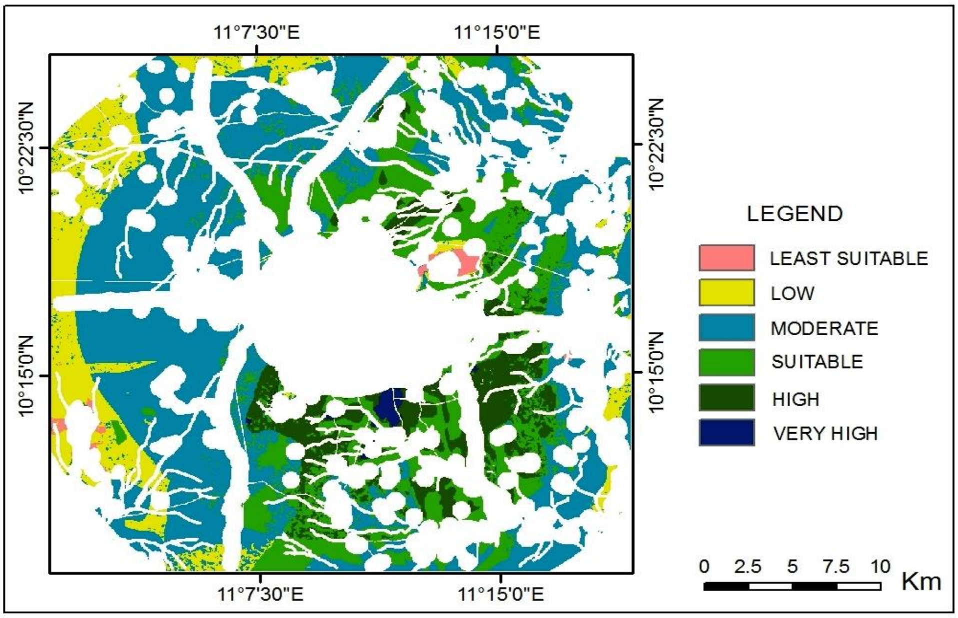
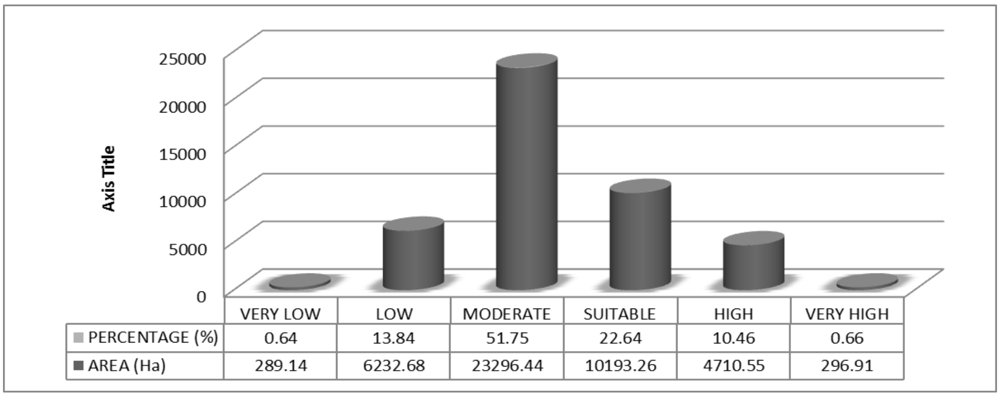


Figure 6: Unmasked Classified Landfill Suitability

Figure 6 exhibits the result of the masking operation, where all constraint areas are excluded from consideration in the siting of suitable landfill locations. Figure 7 reveals the histogram representing the remaining areas for landfill evaluation.



	VERY LOW	LOW	MODERATE	SUITABLE	HIGH	VERY HIGH
PERCENTAGE (%)	0.64	13.84	51.75	22.64	10.46	0.66
AREA (Ha)	289.14	6232.68	23296.44	10193.26	4710.55	296.91

Figure 7: Histogram of Landfill Suitability Classes.

Figure 7 revealed that the areas that belong to the very low suitable class cover 289.14 ha, which is equivalent to 0.64%; the low suitable class covers 6232.68 ha (38.2%); the moderately suitable class covers 23296.44 ha (51.75%); the suitable class covers 10193.23 ha (22.64%); the highly suitable class takes 4710.55 ha (10.46%); and the very highly suitable class approximately covers 295.91 ha (0.66%) of the unmasked region. The result shows that there is enough space for landfill installation in the study area. However, this result disagrees with the findings of Sener (2004) due to the different geographical, environmental, economic, and socio-cultural settings of the two study areas.

3.4 Optimal Landfill Sites

In order to ascertain the suitable landfill site(s), a query was prepared to find available landfill sites that are greater than or equal to 10 ha in the very high suitable class. The sites that satisfied the query were 4 out of 27 that belong to a very high-suitability class (Table 3). A 10-hectare bench mark was used because an area of this size would accommodate a large volume of municipal solid waste for a longer period of time. Prior to query analysis, the masked suitability map (Figure 5) was converted from raster to vector data format so that the data could be queried.

Table 4: Available areas for landfill site with area ≥10Ha

Site	Location	Perimeter (Km)	Area (Ha)	Centroid Coordinate
1	Along Gona Road	2.224	26.065	740726.341mE, 1132663.514mN
2	Along Gona Road	1.951	19.856	740713.104mE, 1132068.231mN
3	Along Gona Road	8.926	193.852	739993.298nE, 1131814.599mN
4	Along Yola Road	1.435	10.208	732164.667mE, 1132980.388mN

Table 4 shows the attributes of the four sites that satisfied the query of area ≥ 10H. The selected sites and the suitability map were superimposed on the revised 2010 topographic map to relate them to the existing ground features (Figure 8).

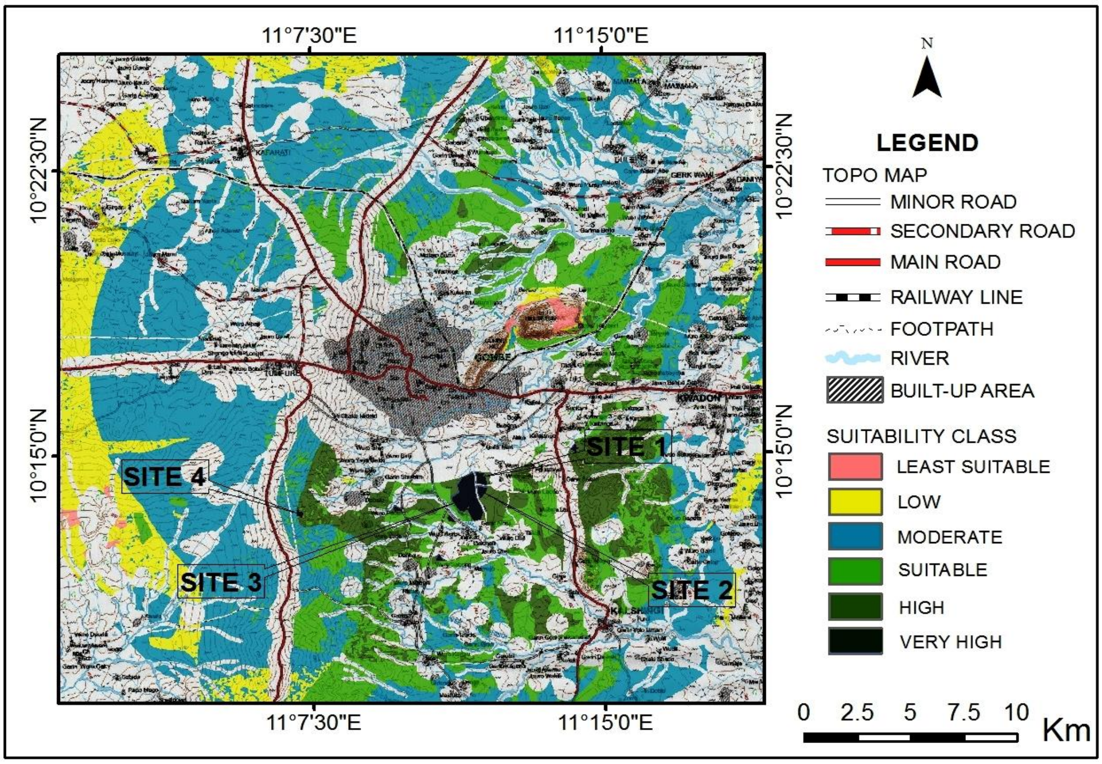


Figure 8: Landfill Site Location for Gombe Metropolis

Figure 8 shows the distributions of landfill suitability classes and the four selected sites in relation to the existing ground features within the study area. It was found that the sites did not fall within any restricted area according to the parameters used in this analysis; therefore, these sites would have very little opposition from the public. The selected sites 1, 2, 3, and 4 have approximately 26.07, 19.86, 193.85, and 10.21 ha, respectively, and all of them met the 10ha size requirement. Therefore, these four candidate sites seem to have an appropriate size for the disposal of MSW for a longer period of time. All the selected sites are located south of Gombe metropolis and within a distance of 6.7 to 14.1 km from the waste generation center by road and 0.7 to 2.1 km from the roads.

Furthermore, site three was suggested for development because this site has the largest size (193.85 ha). The other important economic reason is that this site is only 6.7 km from the metropolitan center (waste generation center) and 0.7 km from the main road; hence, it will save on transportation costs and the cost of constructing an access road. Additionally, it has a convenient morphology (with a slope of less than 6°); hence, the excessive cost of landfill construction on a steep slope is avoided, and there will also be easy control of runoff water. Therefore, site three is determined for further detail in geotechnical and hydrogeological investigations, which are out of the scope of this research. Sener (2004) corroborates this finding, where the author determined four sites that are suitable for sitting landfills. Although he didn't give the area coverage of these sites, he didn't state on what basis they were selected. Additionally, he described Site 2 as the most suitable area among the selected sites. However, the selected site has some flaws as the site is inside a valley and the base of the valley is used as agricultural land, which will likely be opposed by farmers.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

This study shows that the integration of GIS, MCDA, and AHP is an effective and efficient landfill site selection process in Gombe metropolis and environs. Using tools for locating landfill sites is an economical and practical way, as it shows the capability of producing useful, high-quality maps for landfill site selection in a short period of time. Also, the research shows that the model used for landfill site selection in other areas can be modified to fit any given location.

4.2 Recommendations

In light of the findings of this research, it is recommended that the selected landfill site(s) be incorporated into the existing land use, master, and development plans of Gombe metropolis. It is obvious that the selected criteria list is not final for the study area. This list may be increased according to the availability of data. Additional criteria, such as land ownership and land prices, different grades of agricultural lands, population growth, and waste generation rate, are recommended for future studies.

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