Identification of Suitable Landfill Sites for Kumo Urban Area Gombe State, Nigeria

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Abstract

In this study, Sentinel 2A satellite imagery, SRTM, soil, geology, hydrology and topographic maps were used in driving thirteen criteria themes for the selection of suitable landfill sites that is environmentally friendly for Kumo urban area by the aid of remote sensing and Geographic Information System (GIS) techniques. To achieve this goal, pairwise comparison technique of Analytical Hierarchy Process (AHP) method was used for generation of criteria weights. Multi-Criteria Decision Analysis (MCDA) technique was employed for the production of landfill site suitability index map. The results obtained shows that, among the forty six identified sites only six satisfied a half Km^2 required benchmark. Site five was proposed for landfill development due to its proximity (3.311Km) to the waste generation center, closeness (0.5Km) to the main road and convenient morphology (with slope between 1 to 4°). The outcomes of this study showed that there is a sizeable suitable land for landfill development within the study area. Finally, it is recommended that the proposed landfill sites should be open further for geotechnical and hydrological investigations before its take-off.

Keywords: Solid Waste disposal, Landfill, MCDA, AHP, SRTM

INTRODUCTION

Environmental vulnerabilities of varying degree dangerously threaten human and animal lives as well as the existing landcover landuse in most urban centers in Nigeria (Oyeniyi, 2011). The scenario of waste generation in Nigeria has been of great concern because of the increasing volume of waste material and the scarcity of places to deposit it (Aderemi *et al.,* 2011). This was due to continuous population growth, urbanization, economic development as well as the intensity of man's activities, to a large extent influences waste generation (Cointreau, 1982; Doan, 1998; Elizabeth, 1998; Aderemi *et al.,* 2011; Emeka, 2011; Al-Anbari *et al.,* 2014; Olusina and Shyllon, 2014 and Evwierhoma *et al.,* 2014). This waste generation problem continues to increase in rural or urban areas, coupled with lack of infrastructure for adequate waste treatment and indiscriminate disposal of solid waste which makes the solid waste management system inefficient (Babalola and Busu, 2011; Emeka, 2011).

Lack of solid waste collection centers and disposal location such as landfilling are among the solid waste management problem in Kumo urban area, as a result, solid waste is disposed in gutters, streams, pits, undeveloped plots and farmlands. Uncontrolled dumping and improper waste handling causes a variety of problems, including contaminating water, attracting insects and rodents, and increasing flooding due to blocked drainage canals or gullies. These indiscriminate disposals of solid waste would lead to significant negative impact on public health and the existing land uses (USEPA, 2012). Evwierhoma *et al.,* (2014) carried out an assessment of groundwater quality around Soluos and Abule-Egba municipal solid waste landfills in Lagos, Nigeria. The study has shown that the groundwater sources within 0 - 800m radius of the landfills area is unreliable for drinking water supply purposes due to contamination by physio-chemicals and heavy metals.

Landfilling is recognised as an inevitable part of municipal solid waste management system (Tchobanoglous *et al.,* 1993). Solid waste management techniques such as source reduction, recycling and waste transformation methods are broadly used to manage solid waste, however in all of these methods there is always remaining matter even after the recovery process for disposal; this is what makes landfilling unavoidable. Landfill is a disposal site for nonhazardous solid wastes, designed to greatly reduce or eliminate the risks that solid waste disposal may pose to the public health and environmental quality. Appropriate selection of landfill site is important in order to minimize environmental damage as well as to prevent negative impact on the public health, thereby improving the overall sustainability associated with the life cycle of the landfill.

Moreover, as ideal selection of landfill site depends on several factors like, environmental, socio-economy and political factors (Erkut and Moran, 1991; Lober, 1995 and Siddiqui *et al*., 1996), the use of multi criteria method seems to be inevitable. Combining GIS and Multi-Criteria Method (MCD), and Analytical Hierarchy Process (AHP) is a powerful tool to solve the landfill site selection problem, because GIS provides efficient manipulation and presentation of data, MCDA supplies consistent ranking of the potential landfill areas based on a variety of criteria and AHP provides factors' weights of the landfill sites according to the importance of the criteria. Many researchers (Sener, 2004; Babalola and Busu, 2010; Ajide and Olubumi, 2013; Adeofun *et al.,* 2014; Olusina and Shyllon, 2014 and Ahmadi *et al.,* 2014) have conducted studies on landfill site selection in different parts of the country and the world in general, but no any similar research has been carried out for Kumo urban area. In addition, their models cannot be efficiently and effectively use in Kumo without any modifications due to the diversity of economic, environmental, political and social parameters as well as availability of data.

The Study Area

Kumo urban area is the Akko local government headquarters located at Gombe state of Nigeria. The study area located between latitudes 9° 59′ 03″ - 10° 07′ 28″ and longitudes 11° 07′ 13″ - 11° 18′ 19″. The size of the study area covers a total land mass of 314.85Km² (Figure 1). The study area experiences a two season climate, rainy and dry seasons. Over the period of three decades (1977-2008), the length of rainfall season lasted for 27-50 days and spread within six months from April to October with annual mean rainfall of 970.55mm (Yusuf and Yahaya, 2017). The mean maximum monthly temperature is 37ºC, Occurring in March – October while from December to February the temperature lowers to 21ºC. Relative humidity has the same pattern being 94% in August and dropped to less than 10% during harmatan December/January (Maina *et al.,* 2016). The population of Kumo urban is 35,712 in the 2006 census and is projected to reach about 56,978 in 2017.

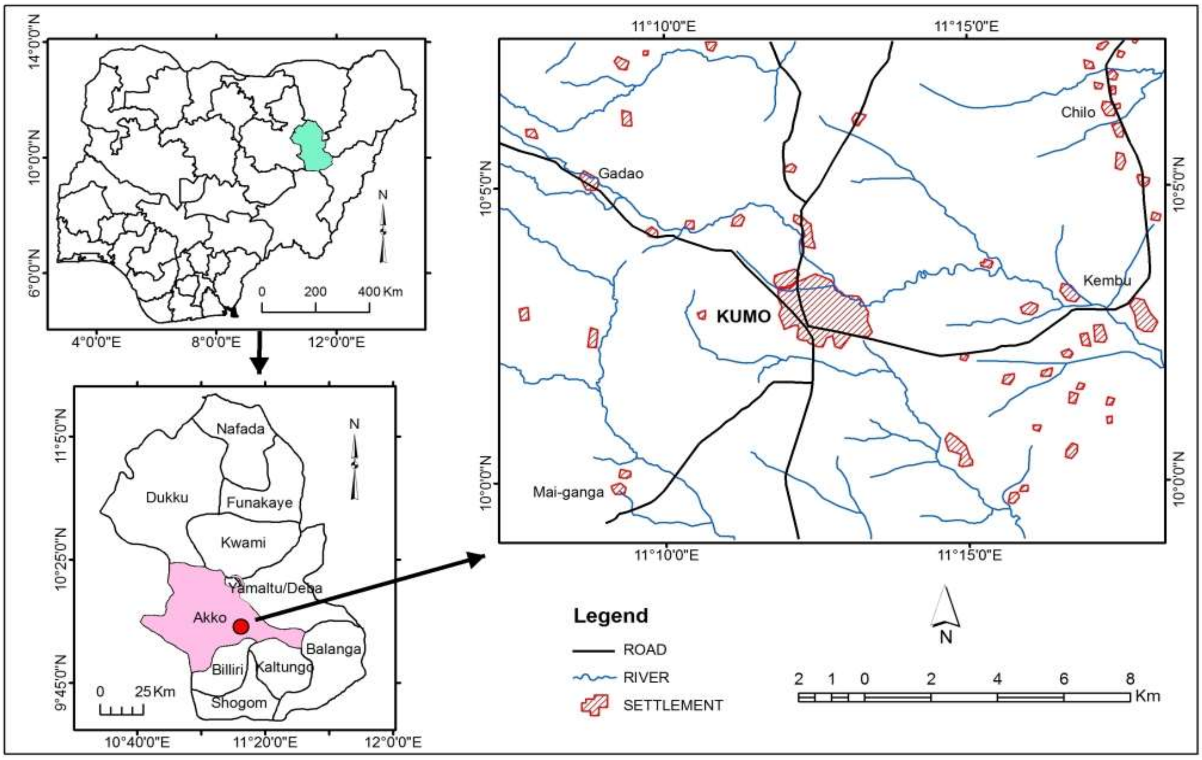

Figure 1: Location of Kumo town, the study area.

MATERIALS AND METHODS

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

Table 1: Data Specification

Data	Data type	Resolution/Scale	Date	Source
SENTINEL 2A	Raster	10m	09/09/2017	Earth
SRTM (Height)	Raster	90m	2000	GLCF
Soil map	Hardcopy	1:100000	1987	GSADP
Geology map	Hardcopy	1:500000	1987	GSADP
Hydrology map	Hardcopy	1:500000	1987	GSADP
Topographic	Hardcopy	1:100000	2010 Revised	OSGOS

The methodology starts with the identification of evaluation criteria needed for landfill site selection in Kumo urban area. The criteria employed in this study are based on factors used by Olusina and Shyllon (2014) and Ahmadi *et al.,* (2014), since there are no established regulations with regards to landfill site selection in Gombe state. Based on the availability of data thirteen criteria were identified for landfill site selection in Kumo. These criteria were grouped into constraints (distance from urban area, rural areas, rivers, main road, mining site and educational institution) and factor (soil type, geology, hydrology, landuse and landcover, slope, proximity to urban and road) criteria. The process of generating thematic layers of these criteria began by scanning and importing of the topographic map into ArcGIS 10.4.1 environment and georeferenced. Road network, rivers and settlements were digitized and edited from the georeferenced topographic map. Geology, soil and hydrology maps were also scanned, imported into ArcGIS 10.4.1 environment and georeferenced. Thematic layers of the study area showing spatial distribution of lithology, soil types and depth to ground water were also digitized from the georeferenced geology, soil and hydrology maps respectively. Slope map of the study area was generated from the SRTM data. Landuse map, educational institution and coal mining site were derived from SENTINEL 2A imagery using supervised classification (Maximum Likelihood) and digitization method.

The study used spatial multi-criteria analysis to identify the most suitable site for solid waste disposal. Firstly, buffer operation was employed for constraint criteria so as to delineate exclusively all unsuitable areas from consideration in the landfill site selection. Table 2 shows the buffer distances used for the varying constraint feature. A dissolve operation was performed to aggregate the attributes of the raster data set of the layers generated by the buffer operations. The output result gives an integrated constraint map showing the overall suitable and unsuitable areas for siting a landfill.

Table 2: Set Aside Distances of Constraint Criteria

Constraint Criteria	Buffer Distance (m)
Distance from urban settlement	2000
Distance from rural settlement	500
Distance from main road	500
Distance from river/stream	100
Distance from institutions	500
Distance from mining site	500

The seven factor maps considered for this study (soil type, geology, depth to groundwater, slope, landuse, distance from urban and main roads maps) were standardized using reclassified tool in order to use a common scale of measurement, such as 1 to 5, the higher the scale value, the more suitable a location is. As the criteria are not of equal importance, an AHP's pairwise comparison method was used in calculating criteria weights. Criteria weights had been computed by solving comparison matrix generated from comparison of two criteria at a time using Saaty words scale values of 1 – 9 (Table 3).

Table 3: Saaty Words Scale for Pairwise Comparison

Intensity of importance	Definition
1	Equal importance
2	Equal to moderately
3	Moderate importance
4	Moderate to strong
5	Strong importance
6	Strong to very strong
7	Very strong importance
8	Very to extremely strong
9	Extreme importance

Source: Saaty (1980)

A weighted sum overlay technique was employed to generate landfill suitability index. With the weighted sum overlay tool in ArcGIS 10.4.1, factors (standardized factor criteria layers) were combined each by their calculated weight followed by summing them together to yield a suitability index map. Using extraction operation all the identified constraint areas were masked and discarded from the evaluation. The remaining index map was classified into five suitability classis (very high, high, moderate, low and unsuitable class), and converted to vector data format and queried so as to identify suitable landfill sites that are greater than or equal to a half Km^2.

RESULTS AND DISCUSSION

Identification of Constraint Areas

Methodology requires constraints (unsuitable) areas to be mapped out first. The six constraint maps were combined and integrated to a single constraint map portraying unsuitable and suitable areas for siting landfill in Kumo urban area.

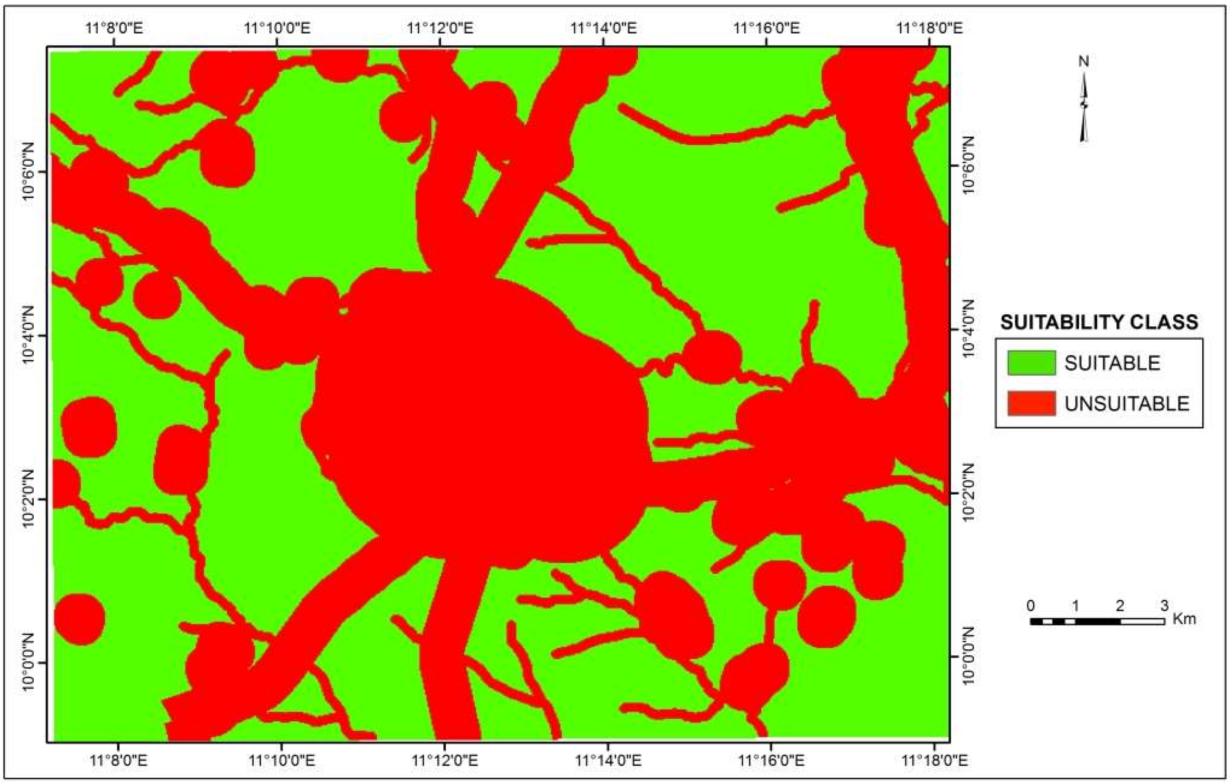

Figure 2: Integrated Constraint Map for Landfill Site Selection

Unsuitable locations for installation of landfills were determined in figure 2, which is the systematic overlay of all constraint criteria. Red areas were ascertained as unsuitable while green areas are suitable for installation of landfill. Table 4.1 shows the statistical representation of the two classes.

Table 3: Suitability According to Constraint Criteria

Rank	Suitability	Area (Km^2)	%
0	Unsuitable	146.599	46.37
1	Suitable	169.526	53.63

Table 3 shows the statistics of the combined constraint map. The results reveals that the constraint area amounted to 146.599Km^2, which corresponds to 46.37% (less than half) of the total study area. In other words, the remaining area (suitable lands) which will be evaluated further represents around 33.63% (169.529 Km^2) of the total area, which shows that there is a considerable space to be evaluated for landfill development. This finding is disagree 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 of percentages was due to the use of different buffer zones for delineating constraint areas.

Generation of Factor Criteria

Factor themes such as soil, geology, slope, depth to groundwater, landuse, and proximity to urban settlement, and roads were produced and reclassified to exhibit suitability of a specified feature. The suitability ranges from the unsuitable to the suitable class.

i) Soil Type

Soil with medium, relatively low, and very low permeability are considered fairly suitable and optimal to site a landfill. Specifically, the solid waste disposal site should be constructed on clay-rich soils (Sener, 2004). Figure 3 Table 4 shows statistics and spatial distribution of the identified four soil types covering the study area and these soil types were converted into five suitability zones.

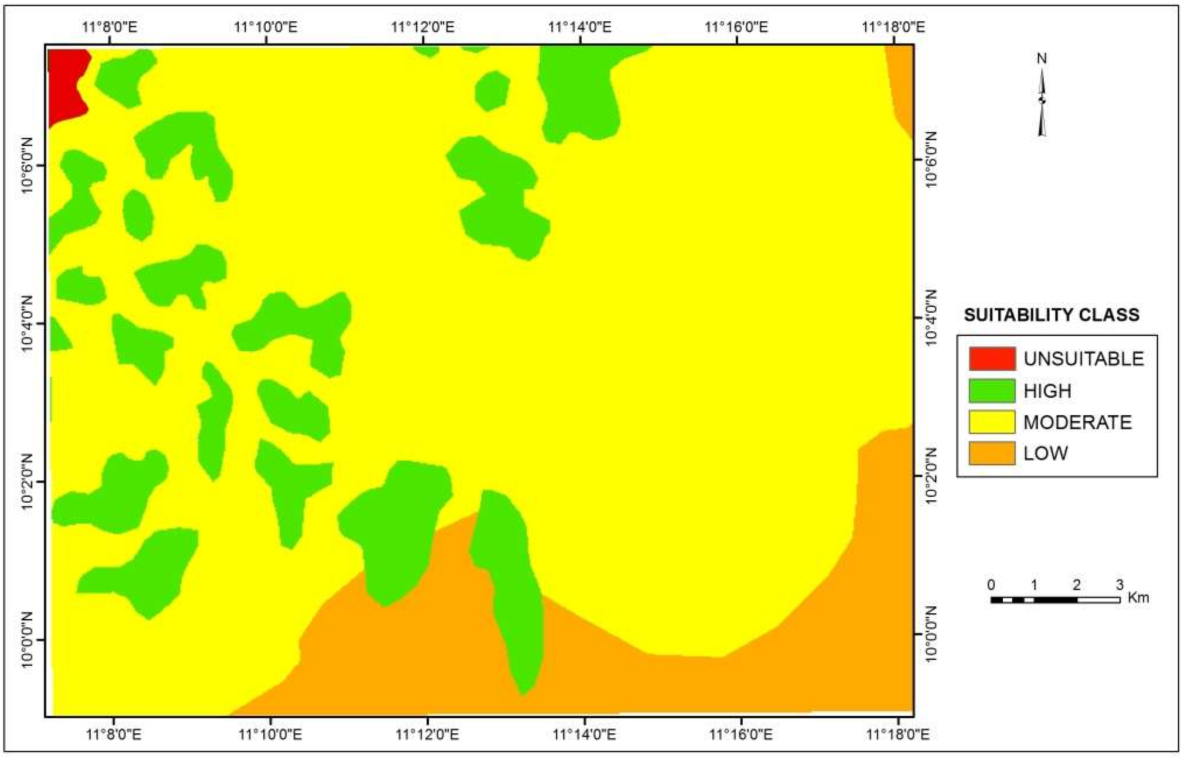

Figure 3: Classified (Standardized) Soil Map

Table 4: Soil Suitability Classes.

Soil type	Rank	Suitability	Area	%
Sandy loam	1	Unsuitable	1.459	0.46
Cracking	2	Low	43.333	13.71
Sandy clay	3	Moderate	228.292	72.21
Clay loam	4	High	43.060	13.62

ii) Geology

Sener (2004) and Yesilnacar and Cetin (2005) classification of lithology for landfill selection based on bedrock aquifer and permeability properties of the lithological classes is adopted in this study. Therefore, the lithological groups covering the study area were categorized into five suitability classes as shown in Figure 4 and Table 5.

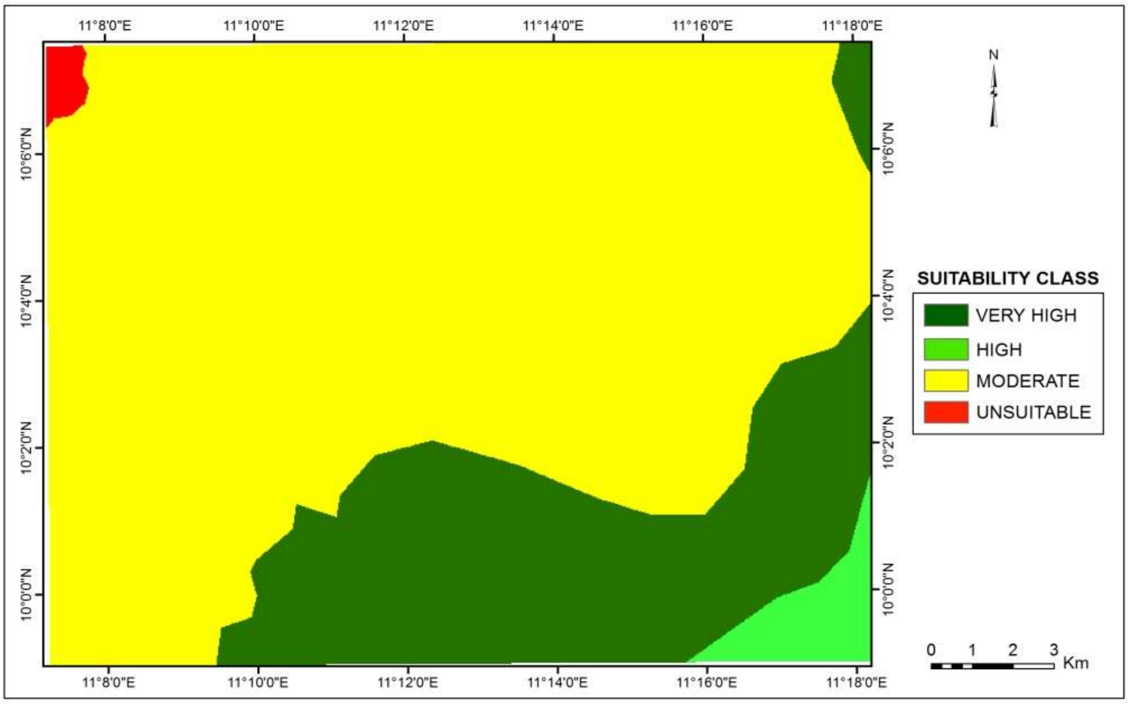

Figure 4: Suitability with respect to Geological Formations

Table 5: Suitability Classes Based on Geology

Formation	Lithology	Rank	Suitability	Area (Ha)	%
Pindiga formation	Marine shales with limestone	5	Very High	73.491	23.25
Yolde formation	Sandstone, shales and mudstone	4	High	8.528	2.70
Gombe formation	Estuarine and deltaic sandstones, shales, ironstones	3	Moderate	232.427	73.52
Keri Keri formation	Estuarine grit, sandstones, siltstones kaolinites	1	Unsuitable	1.675	0.53

iii) Depth to Groundwater

In order to limit potential contamination of groundwater; depths to groundwater table were sorted from the hydrological map of the study area. Based on the literature, suitability is found in areas where depth to ground water is greater than 10m (Babalola and Busu, 2011; Issa and Shehhi, 2012). This layer was reclassified according to the distance to groundwater table from the topographical surface (Figure 5 and Table 6).

Table 6: Landfill Site Suitability Based on Depth Groundwater Table.

Depth	Rank	Suitability	Area (Ha)	%
1 – 10	NA	NA	NA	NA
11 – 20	2	Low	8.528	2.70
21 – 30	3	Moderate	263.646	83.40
31 – 40	4	High	42.092	13.32
>40	5	Very high	1.855	0.58

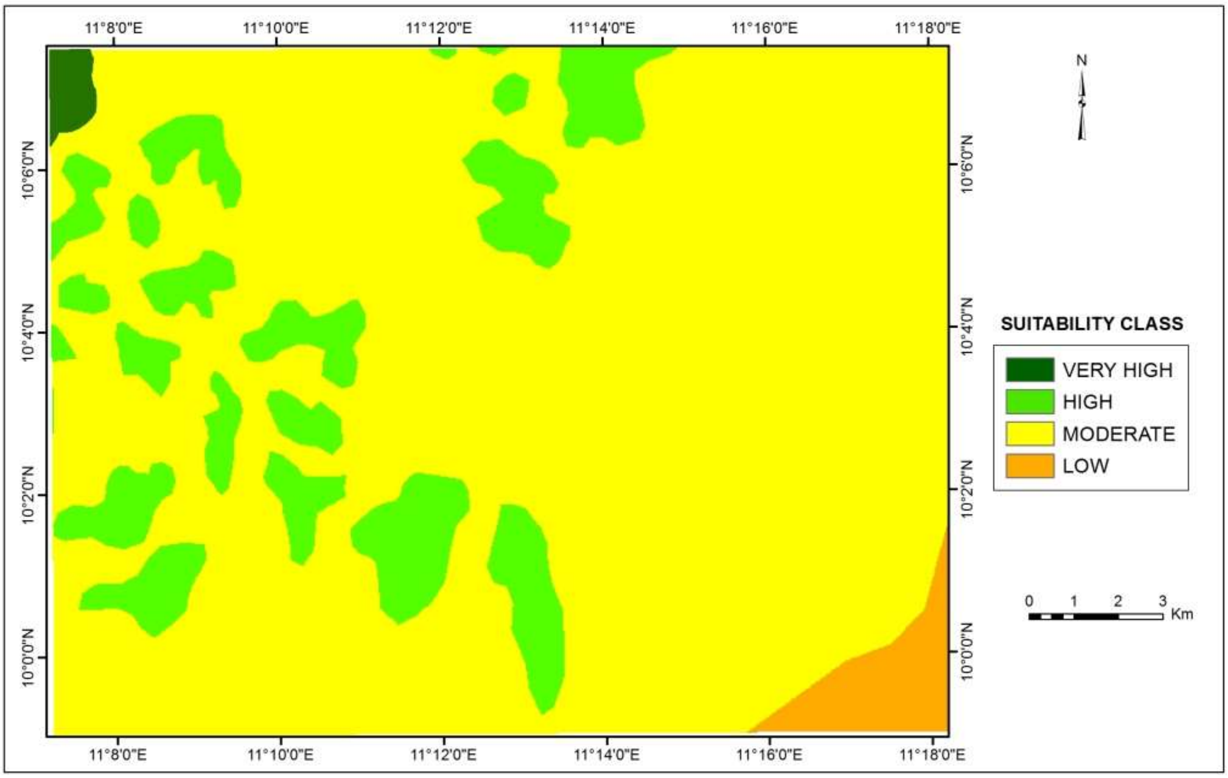

Figure 5: Suitability of Depth to Groundwater Table

iv) Landuse

In order to limit the long term impacts on the areas surround the landfill and risks to public health, landuse and landcover were regrouped into four suitability classes and their numerical representation is given in Figure 6 and Table 7.

Table 7: Land Use Types Suitability Rankings.

Class Name	Rank	Suitability	Area (Ha)	(%)
Bare surface	5	Very high	58.982	18.65
Farm land	3	Moderate	185.897	58.79
Shrub	2	Low	31.188	9.87
Built-up area and wood land	1	Unsuitable	40.136	12.69

v) Proximity to Urban Settlement

In general, landfill areas should be located at a significant distance away from settlement, also it should not be far from settlement due to cost of transportation (Nas *et al.,* 2010). Therefore, a buffer of 2000m was assigned around the urban area, then, the remaining area was equally divided into four suitability classes. Figure 7 and Table 8 shows spatial distribution and the numerical representation of each class.

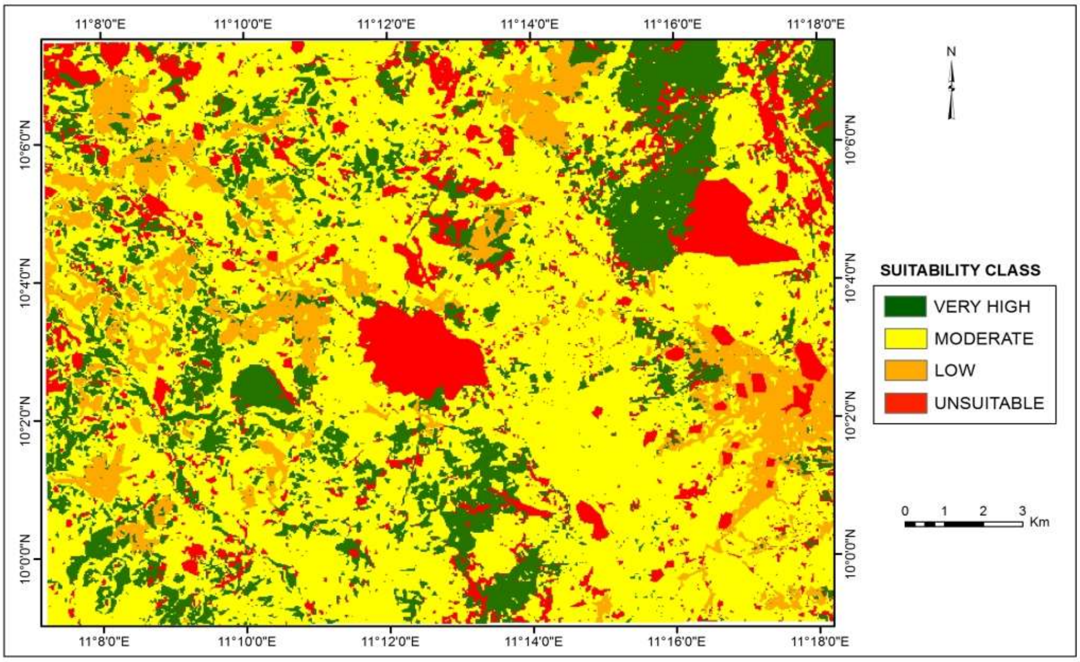

Figure 6: Reclassified Landuse and Landover suitability for Landfill Siting

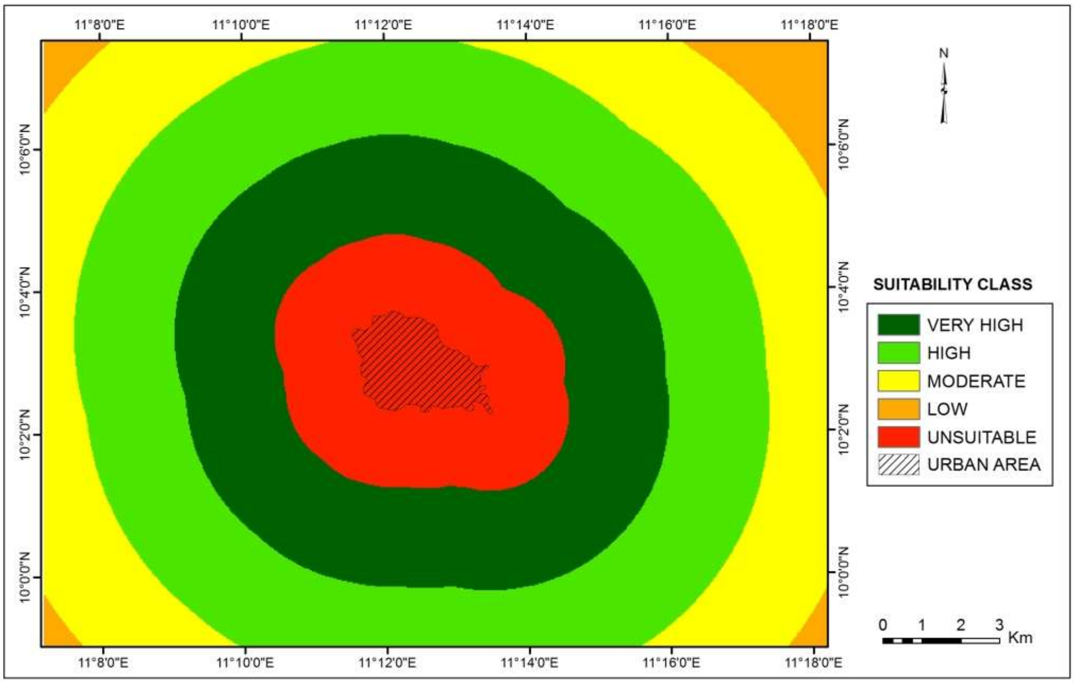

Figure 7: Proximity to Urban Settlement

Table 8: Suitability Classes of Distance from Urban Settlement

Distance to Urban (m)	Rank	Suitability	Area (Ha)	%
< 2000	0	Unsuitable	111.570	35.29
2000-4576	5	Very high	78.800	24.93
4576-7155	4	High	111.570	35.29
7155-9733	3	Moderate	75.412	23.86
9733-12310	2	Low	11.010	3.48

vi) Slope

The areas which have high altitude or higher slope values are not proper for siting a landfill (Kamariah, 1998). Moreover, low slope is required to minimize erosion and water runoff. Therefore, this study considers areas with greater than 16° as unsuitable for siting a landfill. While slope values between 1° and 15° were group at an interval of 3°. Suitability zones and rankings were assigned from lower to higher slope values respectively (Figure 8 and Table 9).

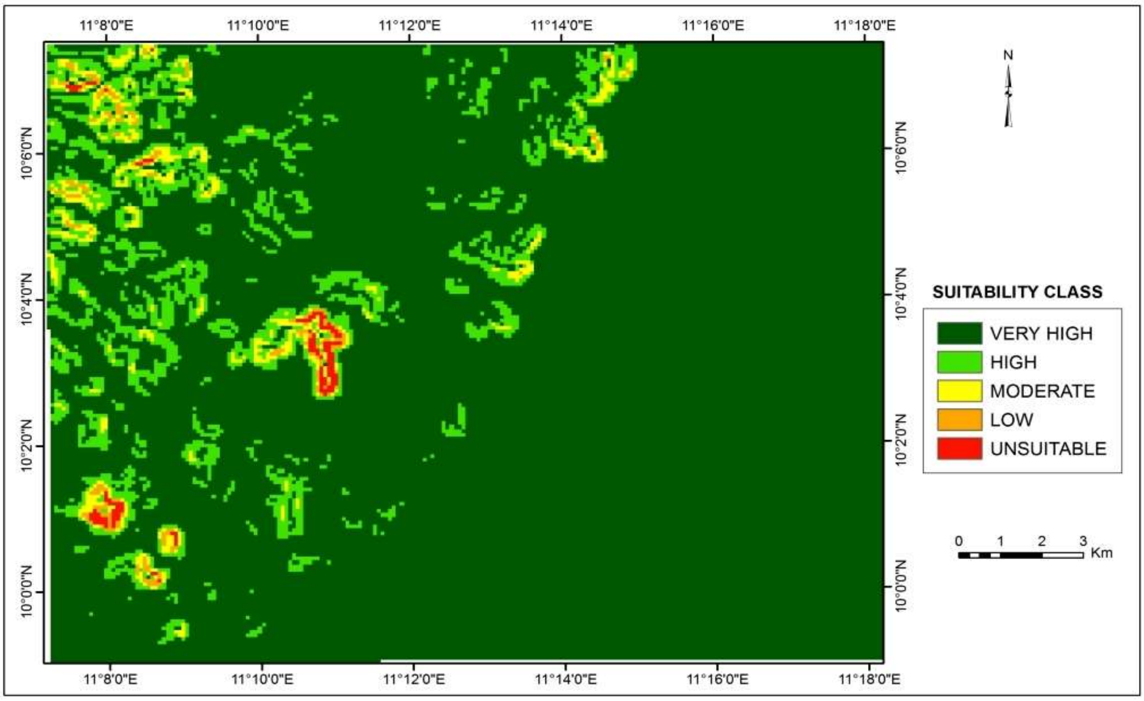

Figure 8: Reclassified Slope Map

Table 9: Slope Suitability Classes

Slope Value (°)	Rank	Suitability	Area (Ha)	%
1 - 4	5	Very high	281.046	88.91
4 – 8	4	High	26.162	8.28
8 - 12	3	Moderate	5.840134	1.85
12 - 16	2	Low	1.930648	0.61
>16	0	Unsuitable	1.132631	0.36

vii) Proximity to Main Road

This study considers 500m buffer for main roads as constraint areas for siting of landfills. Figure 9 shows that suitability is increasing outwards from the 500m buffer around the main road. The suitability classes Table 10 shows how proximity to main roads zoned equally at an interval of 1731m starting from the buffer end.

Table 10: Suitability Classes of Distance from Main Road.

Distance from main road (m)	Rank	Suitability	Area (Ha)	%
<500	1	Unsuitable	59.364	18.
500 – 2230	5	Very high	144.135	45.
2230 – 3962	4	High	83.221	26.
3962 – 5692	3	Moderate	24.464	7.7
5692 – 7423	2	Low	4.936	1.5

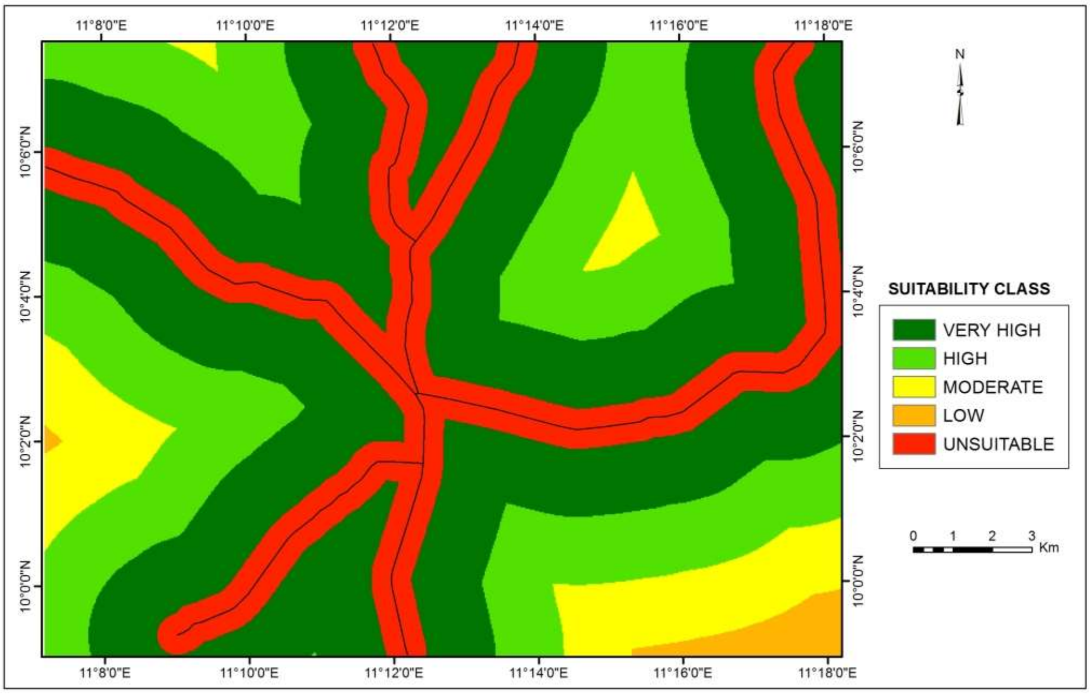

Figure 9: Landfill site suitability classes of proximity to roads.

Analytical Hierarchy Process (AHP)

Prior to the integration of the factor maps the most preferential factors for siting of waste management facility were considered because some factors are more influential than others. Therefore, this stimulated the need to compute the preferential weights for each factor. Pairwise comparison technique was used in the computation of factor weights (Figs. 10 and 11).

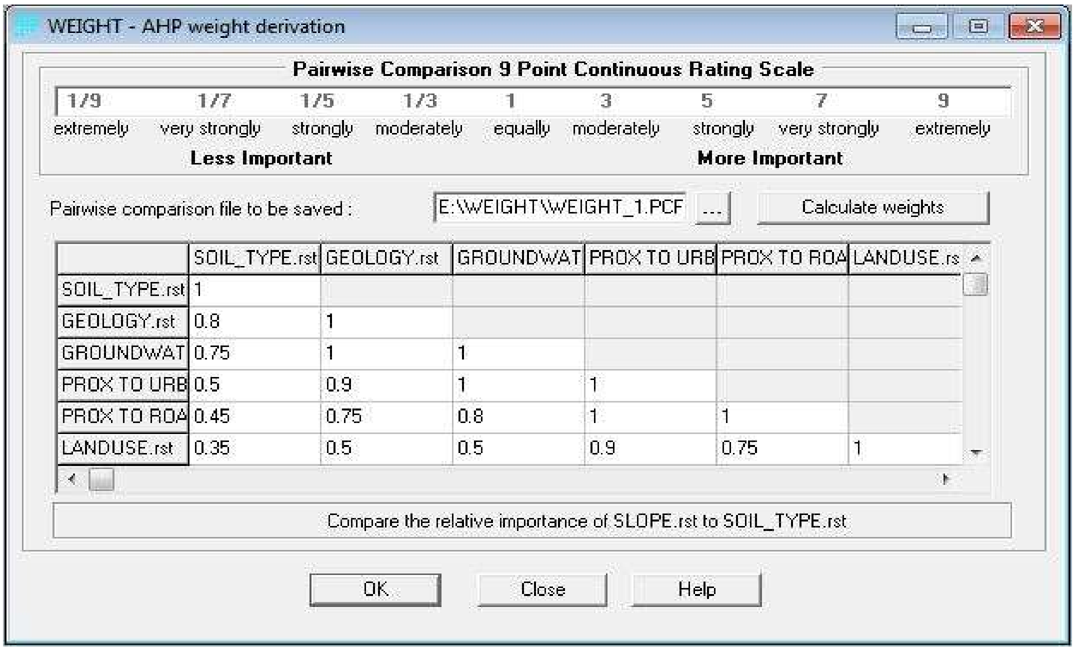

Figure 10: Pairwise Comparison Matrix

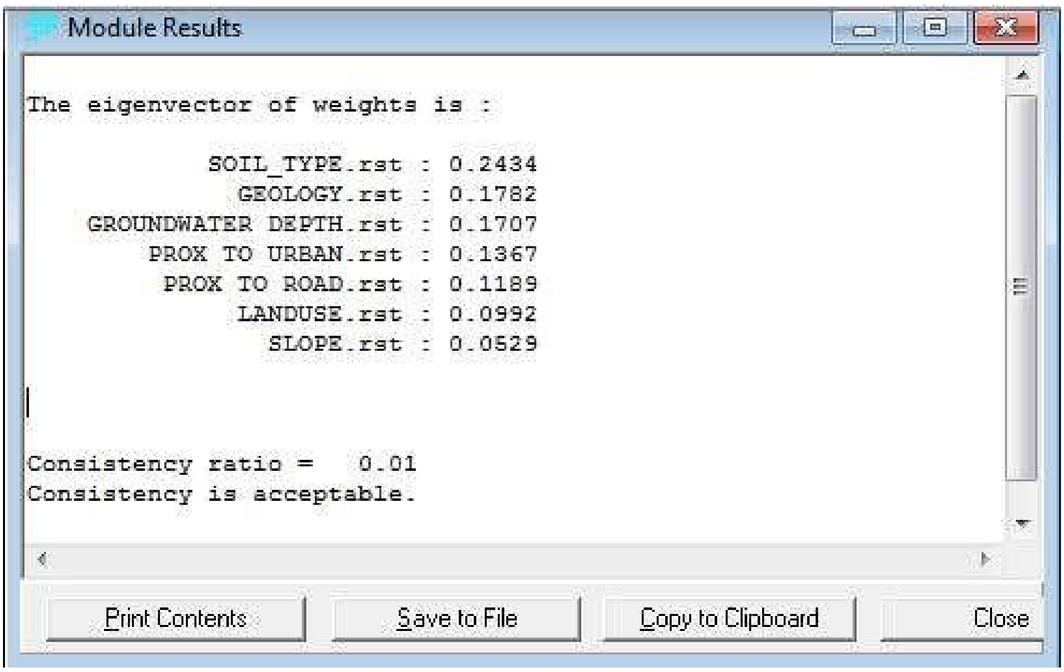

Figure 11: Relative Weights of Landfill Siting Factors

Fig 11 shows the relative criteria weights generated by AHP using pairwise comparison technique. This also reveals that the Consistency Ratio (CR) of the pairwise comparison evaluation is 0.01. According to Saaty (1980), for the result of pairwise matrix (evaluated weights) to be acceptable the value of CR should be less than or equal to 0.1 (10%). In this case, CR value was identified as 0.01 hence, the consistency is acceptable and thus, subjective evaluation about the generated factor's preferences is consistent.

Identification of Suitable Sites

Weighted sum overlay was used in generating suitability index map for landfill site selection. With this method, all the reclassified multidimensional geographical data were aggregated into one-dimensional values map through applying weight to each followed by a summation of results to yield a suitability map as shown in Figure 12.

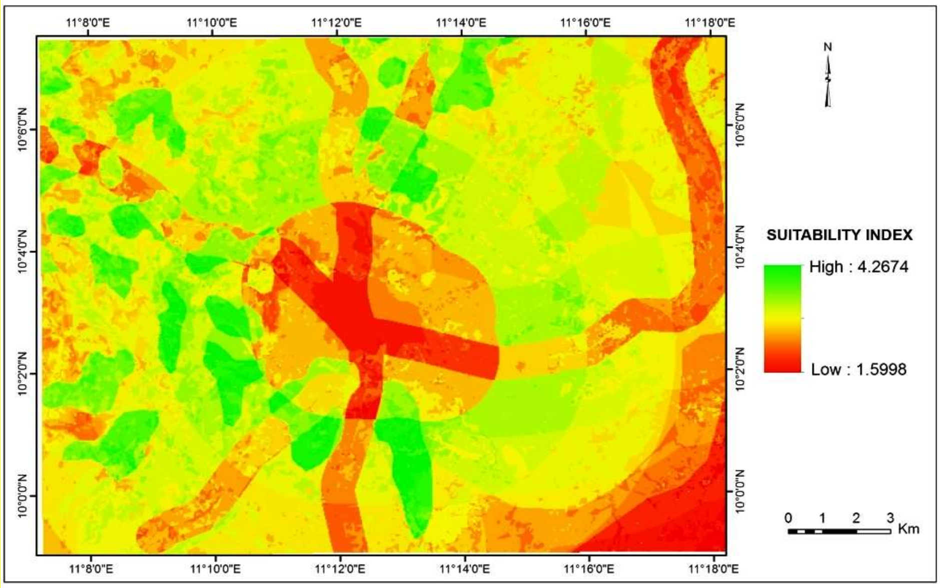

Figure 12: Landfill Site Suitability Index Map.

The result of the successive application of MCDA model on the factor maps was presented in figure 12. The model gives out suitability index with pixel values ranges from 1.5998 to 4.2674, areas with values towards lower index value are very low suitable while regions with values near maximum index value are identified as very high suitable areas for siting landfill. This result concurs well with Al-Anbari *et al.,* (2014) who used similar studies and found that the index values generated by weighted overlay analysis ranged from 0.436 to 4.161 which is analogous to values obtained in this research. The identified constraint areas were clipped from the index map as it's exclusively considered unsuitable. Figure 13 and Table 11 portrays how the remaining area of the index map was further classified to five landfill site suitability classes

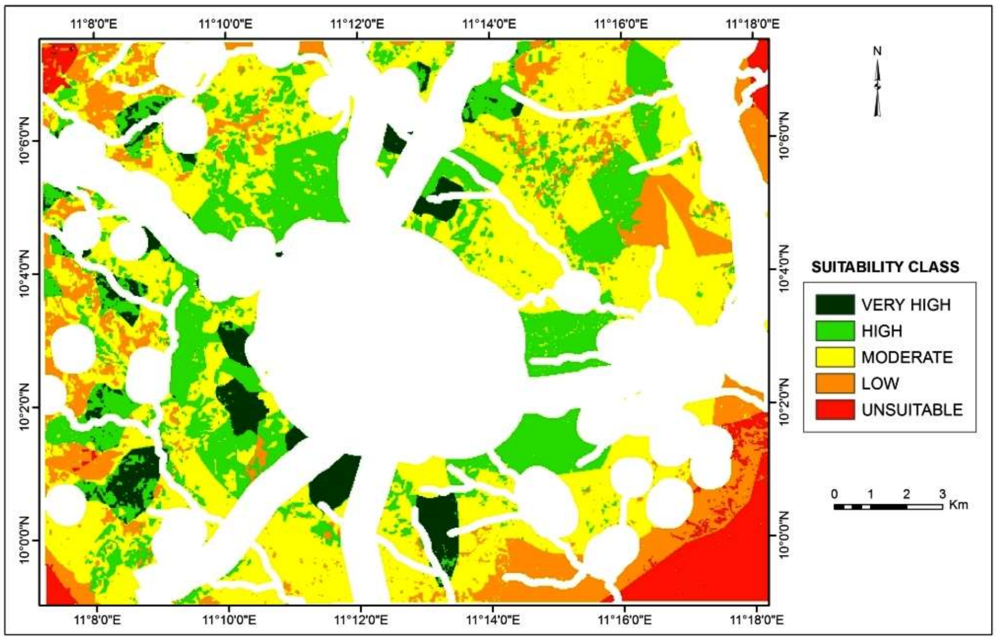

Figure 13: Classified Landfill Site Suitability

Table 11: Statistics of the Clipped Classified Landfill Site Suitability

Suitability Class	Area (Ha)	%
Very high	11.519	6.83
High	43.556	25.8
Moderate	77.626	46.0
Low	26.519	15.7
Unsuitable	9.434	5.59

Best Landfill Sites

The clipped classified landfill site suitability map was converted from raster data set to vector data format (feature class). A query was prepared to find available landfill sites that are greater than or equal to 0.5Km^2 from the very high suitable class. The sites that satisfied the query were six (Table 12) out of 46 that belong to very high suitable class. A half Km^2 bench mark was used because area of this size would accommodate large volume of municipal solid waste for longer period.

Table 12: Available Sites for landfill site with area >= 0.5Km^2.

Site	Dist. from Urban Center (Km)	Dist. from Road (Km)	Area (Km^2)	Slope (°)	Centroid Coordinate
1	4.458	0.500	0.796	1 – 4	743253mE,
2	3.842	1.710	0.599	1 – 6	737646mE,
3	4.589	1.551	1.307	1 – 8	737916mE,
4	7.225	2.608	1.397	1 – 7	734815mE,
5	3.311	0.500	1.324	1 – 4	740515mE,
6	4.203	1.225	1.541	1 – 1	743324mN,

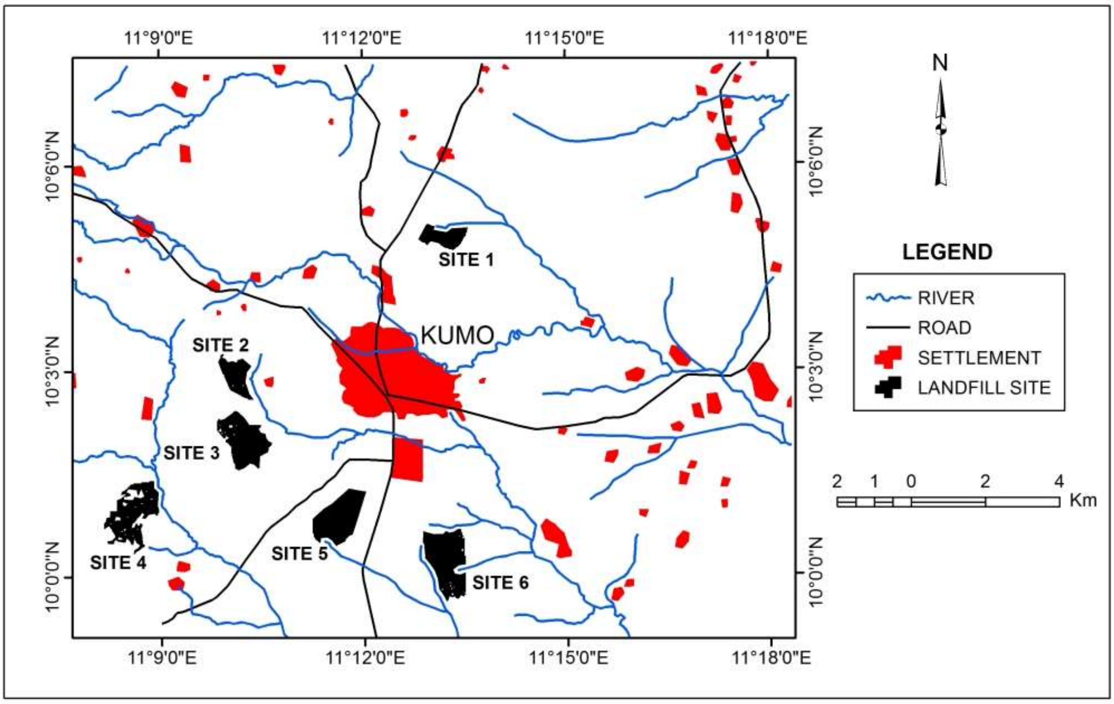

Figure 14: Location of the Suitable Landfill Site

Table 12 shows the attributes of the six sites that satisfied the query. It was found that these sites did not falls on any restricted area according to the parameters used in this analysis; therefore, these sites would have very less opposition from public (not in my back yard syndrome). Site five (see Figure 14) was suggested for landfill development because this site is the most closed to the urban center (waste generation center), which cover the distance of 3.311Km, this will minimize transportation cost. The other important economic reason is that this site is only 0.5Km from the main road; hence it will save cost of constructing access road. Additionally, it has convenient morphology, which falls between the slope range of 1and 4°. Hence, the excessive cost of landfill construction in a steep slope is avoided and also there will be easy control of runoff water in and around the site. Therefore, site five is proposed for landfill development for Kumo urban area.

CONCLUSION

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

In view of the findings of this research it is recommended that Government and researchers should integrate the efforts toward an integrated solid waste management in Kumo taking into consideration the results obtained in this study so as to curtail the environment and public from the impact of indiscriminate disposal of solid waste. Moreover, the selected landfill site(s) should be encompassed in the existing landuse, master and development plans of Kumo urban area. Also, it is noted that a more complete study on current and future land uses such as different grades of agricultural lands as well as population growth and waste generation rate is recommended for future studies. Finally, the proposed site subjected to further detail geotechnical and hydrogeological investigations prior to its development.

Acknowledgment

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