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Sanitary Landfill Sites Selection Using Multi-Criteria Decision Analysis And GIS-Modelling In Parts Of Kwara Sate, Nigeria.

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Abstract
The rapid growth in urban populations in developing nations such as Nigeria in recent decades and the subsequ ent accelerated urbanization trend have highlighted the need to establish environmentally suitability models.
The study area falls within lines of latitude 8°44'6"N and 7°59'40"N and Longitudes 4°09'40"E and 5°14'8"E all within the basement complex of Nigeria. This work aims at finding suitable landfill sites with less environmental effects.
Potential landfill sites for Sokoto1, Sokoto2, Malete, Jimba, Oke Oyi, Ijagbo and Omu Aran have been explored using Environmental Geology and Geographic Information System (GIS) approaches as strategies to help decision-making processes.
One of the primary methods of urban solid wastes management is sanitary landfill.
Improved sitting decisions have gained significant interest in ensuring minimal damage to the different environ mental subcomponents as well as raising the dangers associated with the residents living in its vicinity, thus imp roving the overall sustainable development associated with a landfill's life cycle. This paper uses modern appro ach to sitting a new landfill.
Geology, geophysics and geotechnical data were modelled in ArcGIS 10.3 environment using multiple criteria decision analysis (MCDA) in which criteria such as distance from settlement, roads, highway, land use, water body, river, water table, elevation, slope were used after classification, reclassifying, weighting of criteria, data overlaid and finally suitability model map was generated to identify most suitable, moderately suitable and not suitable areas.

Keywords: *Sanitary, Landfill, AHP, WLC, MCDA, criteria, Geology, Model, Southwestern, Nigeria*

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I. Introduction

Sanitary Landfills are the most commonly used solid waste disposal infrastructure; they are used to minimize the amount of water that infiltrates into solid waste landfills, remove solid waste from the environment and regulate the movement of gases.

The location and management of solid waste sites is one of the significant environmental issues confronting developing nations, Nigeria inclusive. Therefore, the locations of landfill sites require development of Environmental Geology and GIS model to identify suitable sites and other environmental criteria.

The substantial amount of municipal solid waste produced exceeds the environmental capacity to decompose and recycle this waste through natural activities (Jovanovic et al., 2015). The lack of proper municipal solid waste management is a serious environmental issue (Nascimento et al., 2015). Low environmental impact includes efficient urban solid waste management. An integral aspect of this phase is the proper disposal of waste, as municipal solid waste facilities are permanent facilities that present environmental and population risks because they have to be controlled over long periods of time (Leao et al., 2004).

Municipal solid waste disposal methods in underdeveloped countries include dumping sites and landfills as some of the most prominent. Open dumps are unmanaged locations where waste is disposed off directly on the ground without any control which causes several impacts. In comparison, sanitary landfills use methods and techniques to help manage environmental effects, and are widely used worldwide, especially in developed countries (Weng et al., 2015).

Landfill sites are considered a serious hazard to groundwater supplies, whether through waste products that come into contact with under flowing groundwater or by precipitation (Taylor and Allen 2006). Land filled waste disposal site frequently releases interstitial water and by-products that pollute the water moving through the deposit, as well as liquids that contain several distinct organic and inorganic compounds at the lower part of the deposit and flow into the soil, affecting its chemical and physical properties. (Al-Yaqout & Hamoda, 2003).

Many waste management aspects have the possibility to pollute the environment including waste collection, storage, treatment, handling and disposal. Uncontrolled groundwater also has the tendency to pollute the environment, as it is hard to control the leachate migration that occurs at landfill sites, and may end up polluting groundwater and causing wider issues.

The arrival of extremely advanced computerised GIS software, hardware, digitized map data and satellites and other remote detectors that help define forms of infrastructure and land use has impressively increased GIS' potential to help develop a more systematic framework to landfill site selection. Preferably, such technique should combine computer controlled GIS and the methodologies of geotechnical site investigation (Allen et al. 1997).

The integration of GIS and AHP is a vital tool for solving the problem of landfill site selection since GIS offers efficient data handling and presentation, AHP gives a comprehensive ranking of possible landfill areas based on a variety of criteria (Sener et al., 2006).

The development of the geospatial environment model was driven by the need to classify sites with suitable geological materials in order to reduce possible risks of water pollution by landfill leachate and to build a systematic approach to landfill site selection with a view to promoting public trust and integrity of the site selection process using innovative procedures.

II. Study Area Description

The locations of the region under study are Sokoto1, Sokoto2, Malete, Jimba, Oke Oyi, Ijagbo and Omu Aran Southwest Nigeria as shown in Figure 1.

The study region climate usually switches with the dry one and rainy season with an annual average rainfall of between 1270 mm and 1524 mm between April and October and a monthly temperature of around 32 ° C in March and around 25 ° C in October (Meteoblue, 2018).

The population of the region is rapidly increasing according to the 2016 estimates, the 3,192,893 Nigeria Population Forecasts (National Population Commission and National Bureau of Statistics, *2016*) among these, 81.17 percent were inhabitants among urban areas. Approximately 1500 tons of waste is generated daily in this area, but the major issue here is the inaccessibility of the disposal sites. Thus, this part of Nigeria is a major issue of waste management.

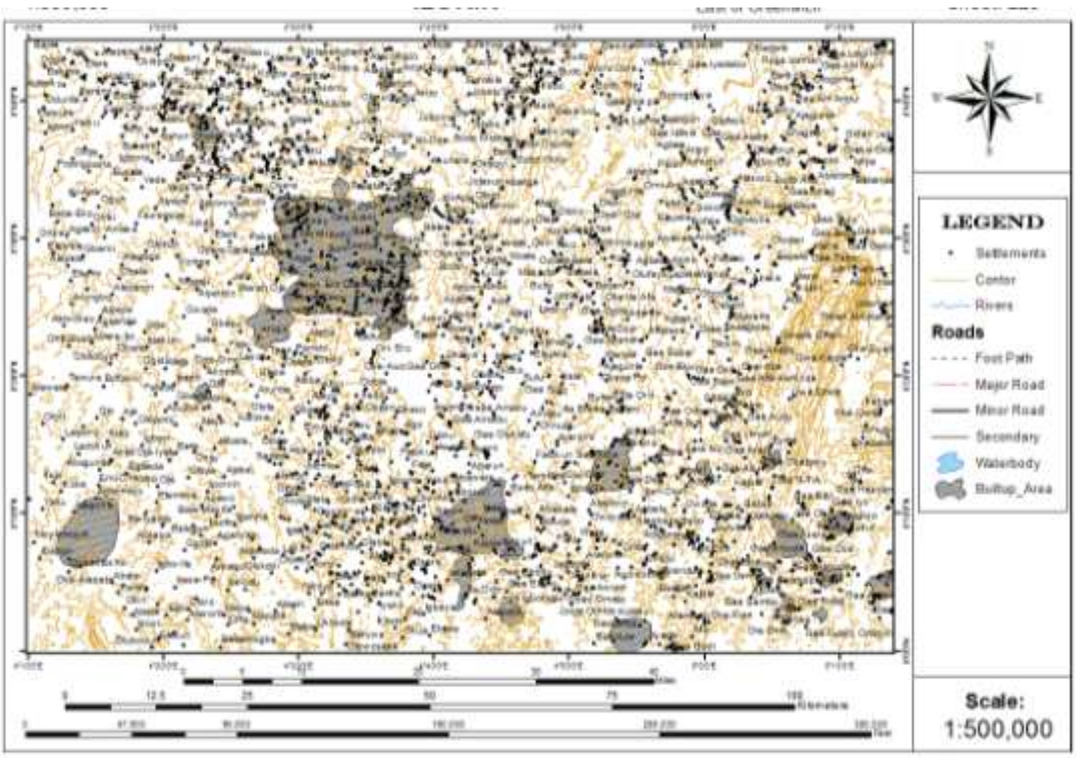

Figure 1: Topographical Map of the study area

III. Geology Of The Area

The area of study falls within Nigeria's basement complex as shown in figure 2. The information obtained from the geological mapping shows that three types of rock, namely Granite Gneiss, Biotite Gneiss and Migmatite, underlie the region. The detailed geology can be divided into two, which are surface and subsurface geology. The surface geology ranges from clay, lateritic soil and the crustal top layer. This differs from place to place but in most places, the lateritic soil obscure most of the underlying geology of the region.

The geological map of the area was compiled from field mapping data, literature reports, maps obtained from Nigeria Geological Survey Agency and IKONOS imagery. The prepared geology map was scanned, processed, and digitized. A database was developed, and added to the map, including lithology, icon and interpretation. There are different lithologies in the sampling sites, and a database is prepared in the GIS environment which includes icon, lithology and interpretation. The lithologies were grouped and graded for a landfill site according to their adequacy as shown in Table 1. The lithology vector map is then transformed to a raster map for analysis to be completed. The diagram for the raster appears in Figure 2.

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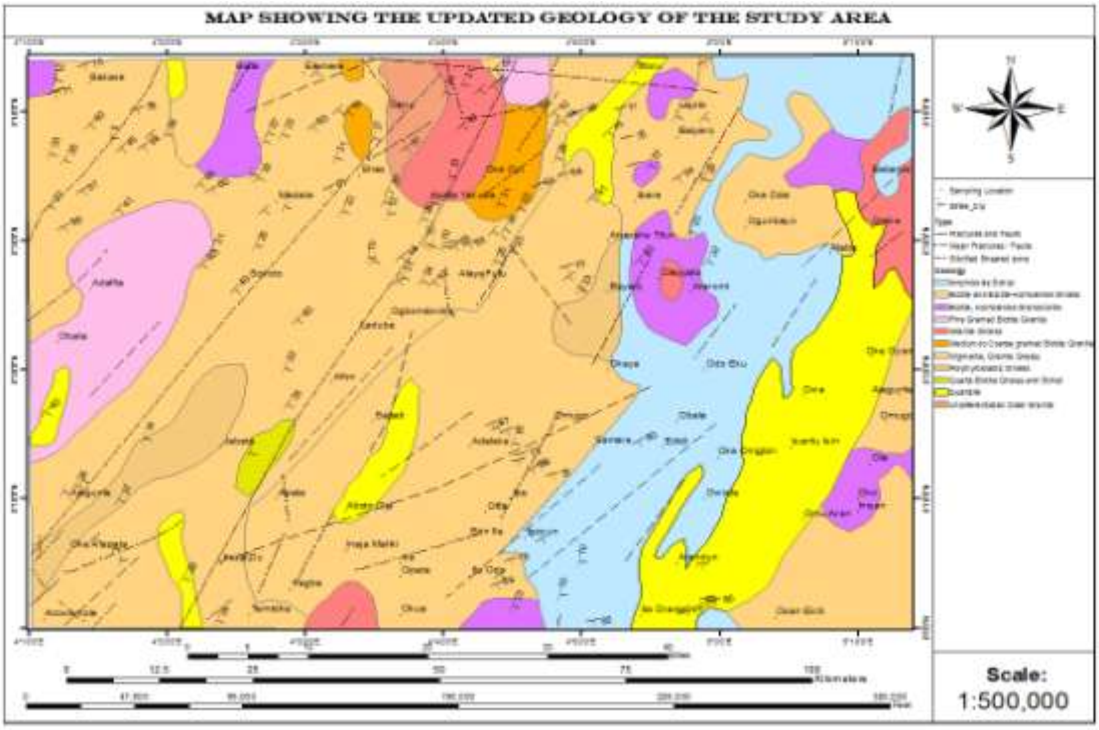

Figure 2: Geological Map of Study Area. Modified from IKONOS Imagery 2018, Field mapping, Geological map of Kwara State, NGSA, 2017

The dominant rock type are Migmatite Granite Gneiss, Porphyroblastic Gneiss and Biotite Granite with coarse to medium grained texture as shown in figure 2. According to EPA., 2006. Granite rock highly suitable, Migmatite-Gneiss complex fairly suitable and Quartzite has lowest degree of suitability for Landfill. All sites mapped met Geological requirement for sanitary landfill as shown in table 1

Table 1: Rock Suitability Level

SITE	LOCATION	ROCK	SUITABILITY LEVEL
S1&2	SOKOTO		
	1	Migmatite Granite Gneiss	Highly Suitable
S3	MALETE		
	1	Migmatite Granite Gneiss	Highly Suitable
S4	OKE OYI		
	1	Biotite Granite	Highly Suitable
	2	Granite Gneiss	Highly Suitable
	3	Porphyroblastic Gneiss	Moderately suitable
S5	JIMBA		
	1	Granite Gneiss	Highly Suitable
	2	Biotite and Honrnblend	Moderately suitable

		Gneiss	
S6	OMU ARAN		
	1	Migmatite Granite Gneiss	Highly Suitable
	2	Granite Gneiss	Highly Suitable
	3	Quartzite	Least suitable
S7	IJAGBO	Biotite Gneiss	
		Biotite and Biotite Hornblende Gneiss	Moderately suitable

IV. Materials And Methods

The first activity was to identify the maps and site data to be evaluated as shown in Figure 3 which comprises the topographic map, spatial data, hydrological map, geological map, remote sensed image. The topographic map helps to show if the terrain is undulated or flat, and to identify the locations and roads that lead each site. The geological map helps to understand the types of rock present in the region and the way they were formed. IKONOS satellite was used to acquire satellite imagery for entire area; this helps to identify outcrops, built-up area, water body, geomorphology, slope, road network and environmental features, spatial data used for sanitary landfill modelling are shown in table 2. The satellite image was analyzed and interpreted along with the geological map of the region using ERDAS IMAGINE 2014 & ArcGIS 10.3 However, the interpretation of satellite imagery only applies to those features which develop recognizable environmental parameters, geomorphic and geological feature; the soil map was used to derive the types of soil in the study region. The main goal of the selection process for landfill sites is to ensure that the disposal facility is situated at the best possible location with very little effect on the environment or the community. A comprehensive assessment process is needed for a sanitary landfill site to identify the best disposal location available that meets the standards of environmental laws and best minimizes economic, environmental and health. The Data Acquisition and Processing used for this modelling is shown in figure 3.

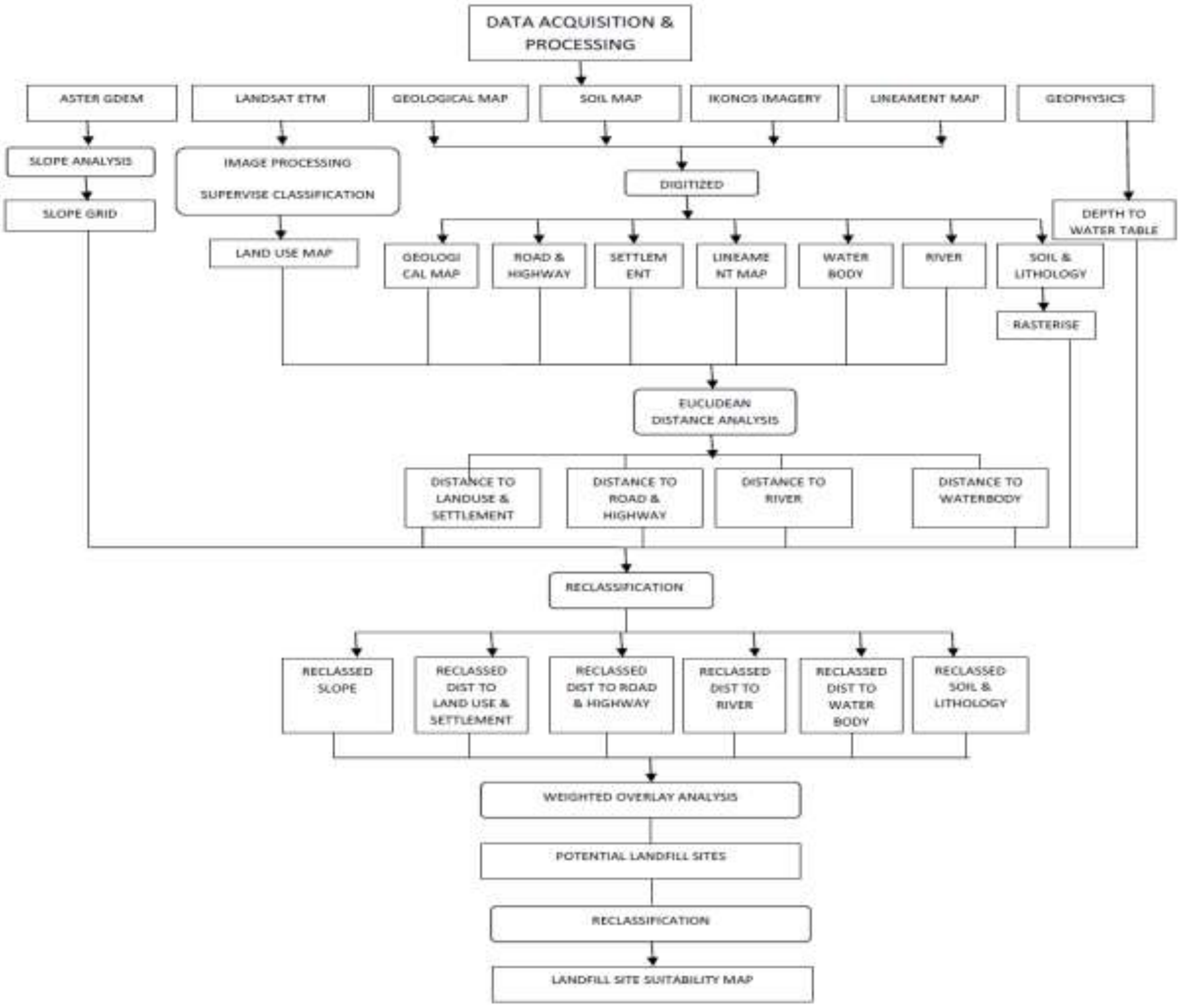

Figure 3: Data Acquisition and Processing

4.1 Data Acquisition for GIS Database

The materials used for this work are IKONOS Imagery, Toposheets – RO1C07 to R18C13 (scale - 1:50,000), LANDSAT IMAGERY+ (2017, 28.5m resolution, path and row wrs2 190, 53) as shown in table 2. The ASTER imagery of high resolution covering the study region was also used in the research to generate elevation and slope of the study area. Geological data of the areas was collected during geological field work, satellite imagery and from Nigeria Geological Surveys agency from which the local geology of the study areas was derived and updated.

Soil data was collected during site investigation and used together with Soil map to derive the soil types in the region. Topographic map at a scale of 1:50,000 were used to derive the river system of the study region. IKONOS data of the study region was used to derive the built-up area, roads and also to confirm water systems within the study region.

Table 2: The Adopted Data and their Properties

S/n	Data	Source	Year	Resolution	Relevance
1	Ikonos Imagery	Sat Imaging	2017	90m	2D Base Map
2	LANDSAT ETM	USGS	2016/2017	28.5m	Land use cover
3	ASTER DEM	Sat Imaging	2017	30.0m	3D Image (Terrain Analysis)
4	Geological map	NGSA	2017	Nil	Base Map
5	Aeromagnetic map	NGSA	2017	Nil	Inclination, Lineation fault
6	Topographical map	OSGF	2017	Nil	Base Maps
7	Drainage map	OSGF	2017	Nil	Drainage
8	Soil map	Field work	2017/2018	Nil	Soil distribution
9	GPS coordinates	Field	2017/2018	3m	Location Cordinates

4.2 Data Selection for environmental decision factors

The spatial database used in the Environmental Suitability Model for waste disposal utilized in part of south-western Nigeria was generated using a wide range of sources including geologic, soil, geophysics, environmental field data, geomorphologic and hydrologic data of different scales (Table 3). However, using ERDAS IMAGINE 2014 & ArcGIS 10.3 Model Builder as a starting point for the Analytical Hierarch Process and MCDA: multiple criteria decision analysis, all data layers were processed, modified, evaluated and visualized. Model Builder is an ArcGIS integral part that encrypts complex GIS operation segments into a simple graphic model from which several GIS operations are perform. Also WGS 1984 UTM zone 31N was used to geo-referenced the data layers.

Table 3: Field and Spatial data used for sanitary landfill Modelling

S/N	Factors	Sub-factors	Sources	Information Used to create layers	Format	Scale or Resolution	Date
1	Geology	Distance to Faults Rock Exposure Porosity	Aeromagnetic Survey Ikonos Imagery/Field Mapping Geophysical Survey	Structures Geological/ Geotechnical Lithology	Digital Digital Digital	1:500,000	2017
2	Geotechnical/Soil	Type of Soil	Field work and Geotechnical Lab test	Type of Soil	Digital	1:500,000	2017
3	Geomorphology	Slope	ASTER Image	Elevation	Digital	1:500,000	2017
4	Water-Surface	Distance to Rivers	Hydrology Report: Ikonos Image	River, stream and Dams	Digital	1:500,000	2017
5	Water-Underground/Geophysics	Distance to Wells Aquifer Flow Aquifer Vulnerability	Hydrology Report Field Geophysical survey	Aquifer Flow Classes Aquifer Vulnerability Classes	Digital Digital Digital	1:500,000	2018
6	Road	road	IKONOS	Road Network	Image	1:500,000	2017
7	Build-up Area	Build-up area	IKONOS	Settlement, land use and water body	Image	1:500,000	2017

4.3 Definition of Classes, Rating and Ranking

Each of the eighteen sub - categories used in the ESM; Environmental Suitability Model for sanitary landfill was subdivided into groups. Every class has been graded on a scale from one to ten, with one representing the lowest suitability level and ten representing the highest suitability level for environmental effects.

The rating interval between one and ten was chosen based on previous scales used by Hughes et al., 2005; as well as based on reviewed literature. In addition, the importance for each class may differ depending on the region of interest and particular area features (Al-Hanbali, et al., 2011). In this analysis the classes were allocated taking into account the related conditions in the research area and the reviewed literature (Table 4).

Table 4: Environmental Criteria for Buffer Zones rating interval

S/NO	CRITERIA (with respect to distance)	RECOMMENDATIONS (With References)
1	LAKE	≥ 60m (Nathanson, 2000) ≥ 300m (Keller, 1976; Bagchi, 1994; USEPA, 2005
2	SLOPE	≤ 15° EPA., 2006, Flat area (Bagchi,1994; Gentle slope 10° -20° (Hughes *et al.*, 2005)
3	FLOWING STREAM	>90m (Bagchi, 1994); ≥150 (World Bank, 2004)
4	HIGHWAY	≥150m(Howard and Remson, 1978) ≥167m(WRSC, 1993); ≥500m(Zuquette *etal*,1994)
5	WATER SUPPLY WELL	≥635m(Bhardway and Singh, 1997); ≥500(World Bank, 2004) ≥800m(Bell,1999)
6	AIRPORT	≥330m(WRSC, 1993) ≥3048m(Bagchi,1994)
7	FLOODING FREQUENCY	50years(Gallas *et al*,2008) 100years (WRSC, 1993; Bagchi, 1994)
8	NEAREST SETTLEMENT	>500m(Bagchi 1994) >250m(World Bank, 2004) 1000m (Allen 2000)
9	DEPTH TO WATER TABLE (From the base of Mineral seal)	≥1.8m (Gallas *et al*, 2008), >0.6m(Howard and Ramson, 1978) 1.57(WRSC, 1993); ≥3.0(Frempong, 1999) >6.0m(Zuquette *et al*,2001) >1.5m(Nathanson, 2000; World Bank, 2004)
10	DEPTH TO BASEMENT ROCK	≥1.2m(Gallas *et al* ,2008) 3.3m (WRSC, 1993) >5m(Zuguette *et al*,1994)
11	PROXIMITY TO FAULT	≥33m(WRSC, 1993); 60m (Nathanson, 2000)
12	PROXIMITY TO SINKHOLE	≥250m (WRSC, 1993)
13	PROXIMITY TO SOCIAL AMENITIES (POLES,GAS, WATER PIPES etc)	167m(WRSC, 1993; World Bank, 2004)
14	ACCESSIBILITY	30minutes drive or 10km from source (World Bank,2004)

4.4 Data standardization to a common scale of measurements

It is important to standardize the data into a specific measurement scale in order to overlay the spatial information to determine the suitability of the environmental impacts. In the ArcGIS 10.3 environment, the eighteen sub-factors were translated into raster grid format consisting of 50 m x 50 m cells using weighted overlay tools. The Weighted Overlay process employs one of the most widely used methods for spatial analysis to solve multiple criteria problems, such as site selection using suitability models for suitability analysis, standardizing all data to a specific scale ranging from a scale of 1 to 10, where a score of 1 is the least appropriate and a score of 10 is the most appropriate, as shown in Table 5

Table 5: Rating classes for sub-factors in the Modelling

Factors	Sub-factors	Class	Rating	% of Influence
Geology	Distance to faults	<500 m	1	No
		500 – 1000 m	2	Applicable
		1000 – 1500 m	3	
		1500 – 2000 m	4	
		2000- 2500 m	5	
		2500– 3000 m	6	
		3000– 3500 m	7	
		3500– 4000 m	8	

		4000– 4500 m	9	
		>4500 m	10	
	Porosity of Rock	Highly weathered rock	1	
		Moderately weathered rockFresh rock	5 10	
Geotechnical/Soil	Type of Soil	No soil	1	20
		Peat	2	
		Gravel	3	
		Gravely sand	4	
		Sand	5	
		Loamy sand	6	
		Sandy clay	7	
		Silty clay	8	
		Clay	10	
Water Resources - Surface	Rivers and Stream	<500 m	1	22
		500 – 1000 m	2	
		1000 – 1500 m	3	
		1500 – 2000 m	4	
		2000- 2500 m	5	
		2500– 3000 m	6	
		3000– 3500 m	7	
		3500– 4000 m	8	
		4000– 4500 m	9	
		>4500 m	10	
Water Resources - Underground/ Geophysical survey	Water Body: Lake, Dam and other man made water	<500 m	1	21
		500 – 1000 m	2	
		1000 – 1500 m	3	
		1500 – 2000 m	4	
		2000- 2500 m	5	
		2500– 3000 m	6	
		3000– 3500 m	7	
		3500– 4000 m	8	
		4000– 4500 m	9	
		>4500 m	10	
	Depth to rock	1m	1	20
		2m	2	
		3m	3	
		4m	4	
		5m	5	
		6m	6	
		7m	7	
		8m	8	
		9m	9	
		10m	10	
	Aquifer Vulnerability	High	2	
		Medium	6	
		Low	10	
Land use	Road/High way	<300m	4	3
		>300m	10	
	Built up Area	<300m	1	10
		500m	2	
		700m	3	
		900m	4	
		1000m	5	
		1200m	6	
		1400m	7	
		1600m	8	
		1800m	9	
		>2000m	10	
Slope	Elevation	<2°	10	4
		4°	9	
		6°	8	
		8°	7	
		10°	6	
		12°	5	
		14°	4	
		16°	3	
		18°	2	
		>20°	1	

4.5 Criteria weight assignment using AHP

A collection of six landfill site selection criteria was established through review of literature when considering economic, social and environmental factors; each of the six sub - criteria included in the ESM: Environment Suitability Model was divided into classes for sanitary landfills. Every class has been scored on a scale from one to ten, with one representing the lowest suitability level and ten representing the highest suitability level for environmental effects.

Weighting is a process for expressing the relative significance using raster data. Giving equal consideration to all the parameters whatever their relative value is usually unsatisfactory. Yet because these are common standards, fair prioritization of them is difficult. Consequently, the Analytical Hierarchy Process (AHP) was used as a site selection method in this study; AHP offers more reliable and good relational representation of different parameters. This mathematical process provided information on relative value and the integration of knowledge (including accuracy checking) and prioritized all alternatives in terms of their overall choice.

The weights of a particular criterion are built up by ranking them on a scale of 1 to 10 and assigned value of zero for restrained cells which could not take part for final selection on the basis of their significance and suitability. Each input raster is weighted according to its significant. The weight is a relative percentage, and the sum of the percent influence weights must equal 100 (20+20+4+10+3+22+21= 100) as shown in Table 6

The development of a Pairwise comparison matrix and the derivation of weights in this study were carried out as shown in table 7. First, the AHP technique was applied to the factors in the parameters, and afterwards the global weighting for each sub-factor was derived by multiplying those two outcomes.

Table 6: AHP Ranking and weighting for each criteria used for Geo-Spatial Modelling

S/N	Layer/ Sub layers	Ranking	Weight (%)
1	Surface water body		
	≤200m	1	43
	>200m	10	
2	Slop		
	≤10	10	4
	≤20	5	
3	Roads		
	≤300m	5	3
	>300m	10	
4	Depth to water table		
	≤5	1	20
	>5	10	
5	Settlements		10
	Water body/River land	1	
	Built up area	2	
	Park	3	
	Cultivated land	4	
	Open/Barren land	10	
6	Soil		
			20
	River Bed/ Restricted Area	0	
		1	
	Urban Area (No Soil)		
		2	
	Loamy Sand		
		3	
	Silt Loam		
		4	
	Silty Clay Loam		
		5	
	Loams/ Clay Loam		
	clay	10	

Table 7: Pairwise comparison matrix, ranking, and weights for factors in the ESM for Sanitary Landfill

Factors (CR2.1%)	1	2	3	4	5	6	Rank	Weight (%)
Road &Highway	1						5	5.6
Geotechnical/Soil	3	1					2	17.9
Built-up area	2	1/2	1				4	10.4
Surface Water	4	2	2	1			1	26.0
Underground Water/Geophysics	4	2	2	1	1		1	26.0
Slope	3	1/2	2	1/2	1/2	1	3	14.1

4.6 Weight linear combination method

The Environmental Impact Suitability Model for sanitary landfill in part of south-west Nigeria was developed using a Weight Linear Combination method with (Equation) after evaluating the accuracy of the pairwise comparisons for factors and sub-factors.

$S = \sum_{i=1}^{n} wi\ xi$

In this equation, S is the final score of the ESM, Wi is the weight of the sub factor and Xi is the factor I standardized class ranking. Since the amount of weight for factor I is a production of Wi and Xi for each sub-factor, the Wi is restricted to one, while Xi ranges from zero to ten, and the final cumulative value is provided on that scale.

For each raster cell, therefore, the final score of the EISM was obtained as a sum of the ranking products allocated for each class. The findings were divided into three environmental suitability groups for sanitary landfill: Not suitable (S1) Moderately suitable (S2) and most suitable (S3) as shown in table 8.

Table 8 - ESM categories for Sanitary Landfill

Categories	Value
Not Suitability (S1)	0-4
Moderately Suitability (S2)	4-7
Most Suitability (S3)	7-10

V. Results And Discussion

Given that the selection process for landfill sites relies on a number of rules, regulations and considerations, vast quantities of spatial data should be analyzed and processed. GIS is widely used to address this challenge in choosing suitable landfill sites (Allen et al., 2002)

(Siddiqui et al., 1996) authored a methodology for finding best landfill sites by combining GIS and Analytical Hierarchy Process (AHP), this process is called Geospatial-AHP.

Based on the multiple criteria evaluation and the Analytical Hierarchy Method for locating sanitary landfills, the Analytical Hierarchy Process (AHP) is incorporated into a raster-based geographic information system using model builders in the ArchGIS setting. Models are typified as sets of spatial processes, as shown in Figure 4, such as buffer, slope, euclidean distance, rasterization, classification, and reclassification and overlay. Reclassification of soil from 1 (the least appropriate) to 10 (the most appropriate), this rating is based on defined environmental standards. The performance model results are shown in Figures 5 through 21.

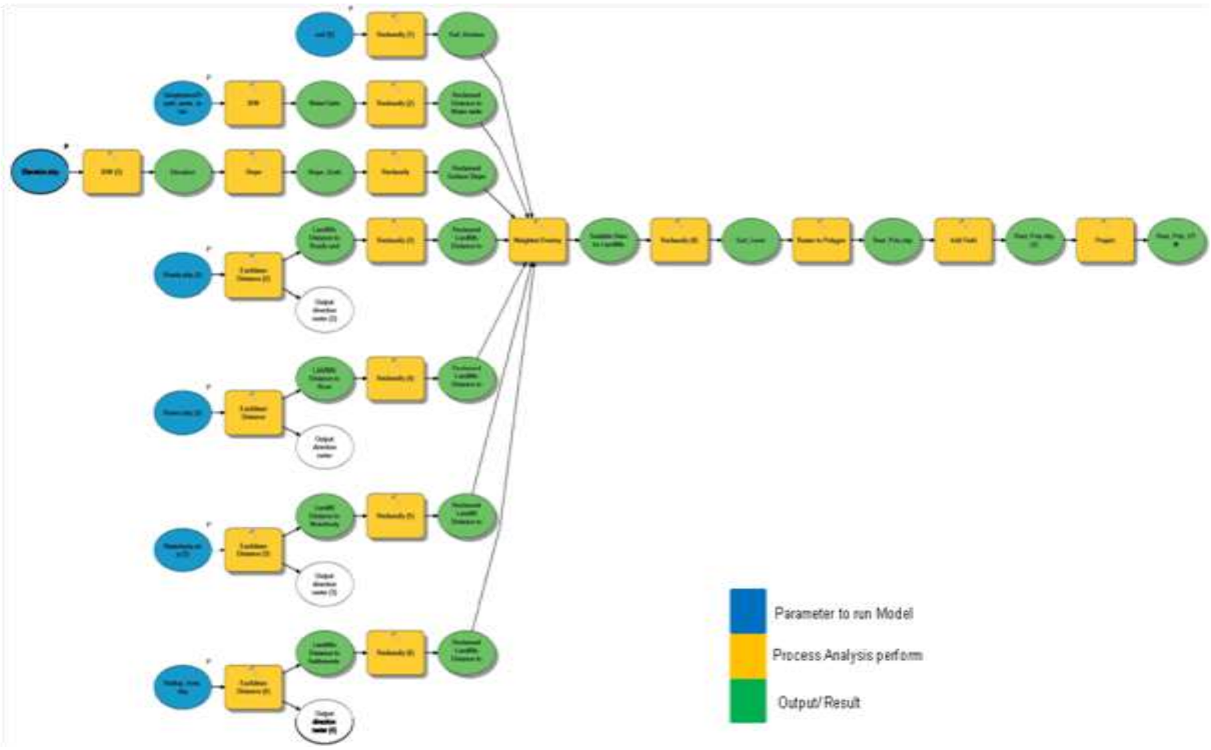

Figure 4: GIS Geo-Spatial Modelling flow Chart

5.1. Soil Map

There were four types of soils in the study area: Gravel, Sand, Silt and Clay from site investigation carried out and existent soil data of the area, figure 5 show distribution of different soil types in the area. The map of the exploratory soil of the region (scale of 1:500,000) was scanned in polygon form to prepare the layer for the "types of soil."

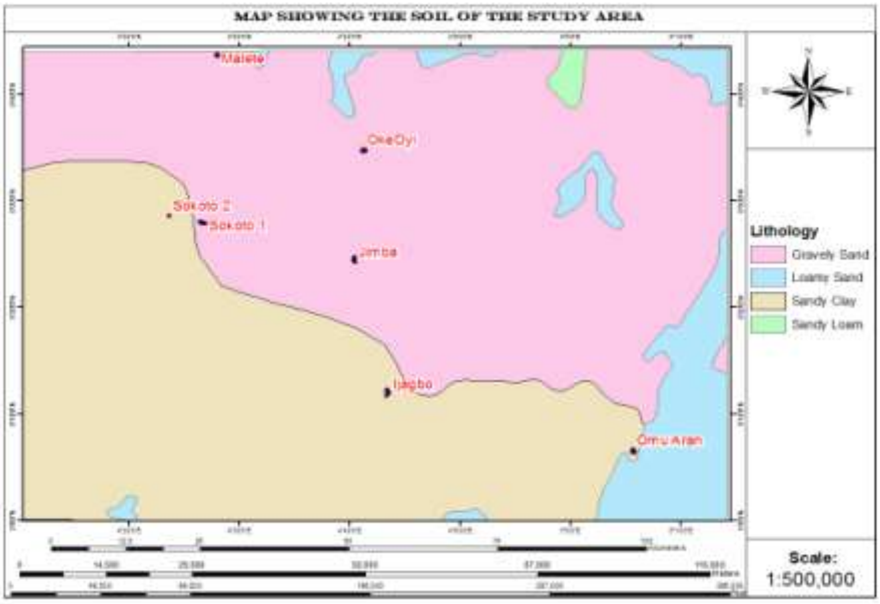

Figure 5: Model showing the Soil Map

5.2 Model shows the Soil Reclassification based on their Suitability Level

The soil was reclassified as shown in figure 6 based on the environmental criteria for buffer zone rating interval of 1-10 for checking the suitability level based on the class interval (No soil-1, Peat-2, Gravel-3, Sand-4, Silt-6 and clay-10). The model shows locations that are not suitable, moderately suitable and most suitable.

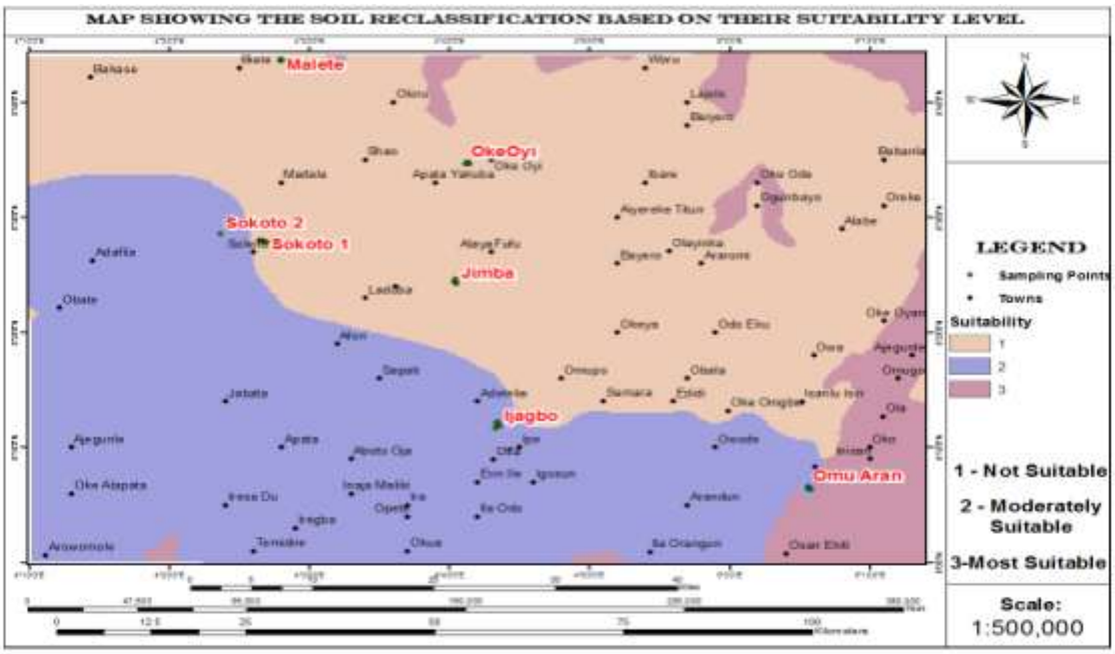

Figure 6: Model shows Soil Reclassified based on their Suitability Level

5.3 Model showing the Watertable IDW Interpolation

The model map in figure 7 was produced from geophysical data of the study area and IKONOS imagery, the model map shows depth to water table of any location within the boundary of the area.

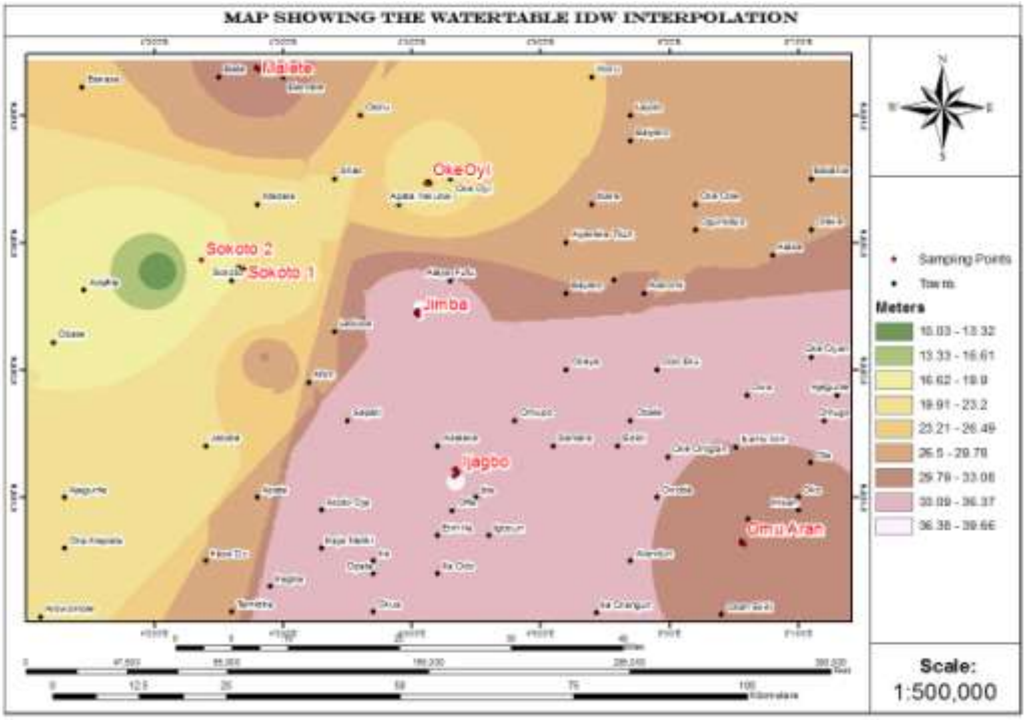

Figure 7: Model Map shows the Watertable IDW Interpolation

5.4 Model showing the watertable Reclassification based on their Suitability Level

The depth to watertable was reclassified as shown in figure 8 based on environmental criteria for buffer zone rating interval of 1-10 to check for the suitability level base on the class interval (1m, 2m, 3m, 4m, 5m, 6m, 7m, 8m, 9m and 10m) depth to water should be>6.0m according to Zuquette *et al*, 2005. The model shows locations that are not suitable, moderately suitable and most suitable.

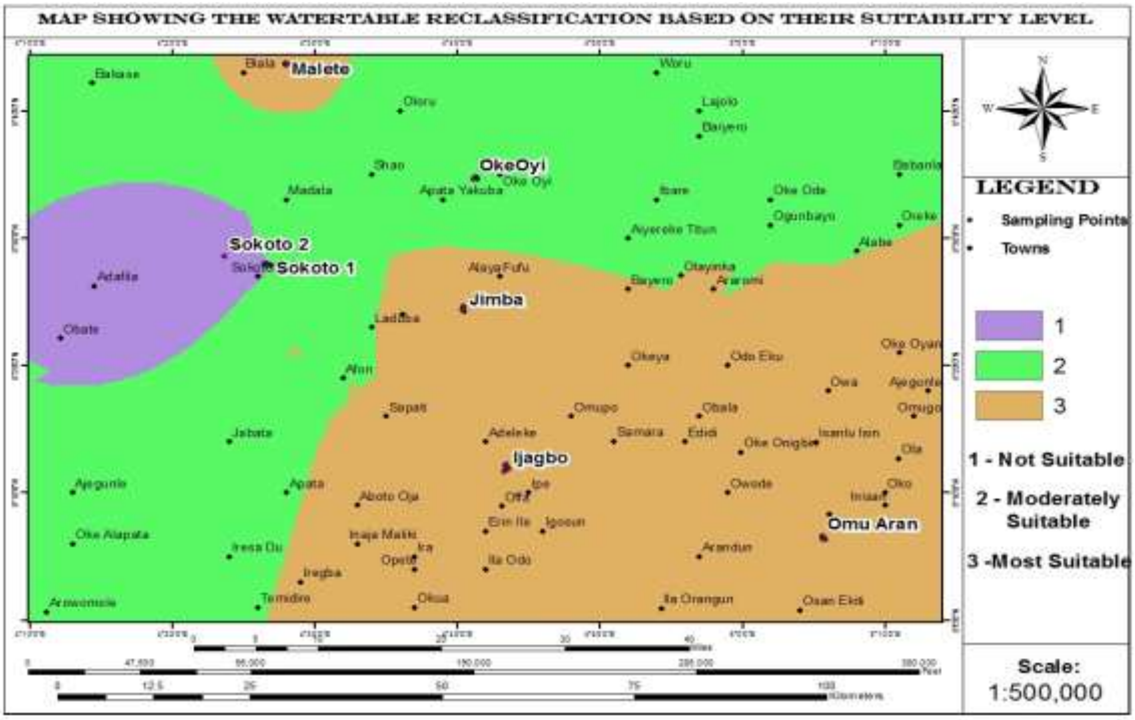

Figure 8: Model Map shows watertable Reclassified based on their Suitability Level

5.5 Model showing Landfills distance to Water-body

The model map in figure 9 was produced from IKONOS imagery data; the model map shows distance to water body of any location within the boundary of the study area.

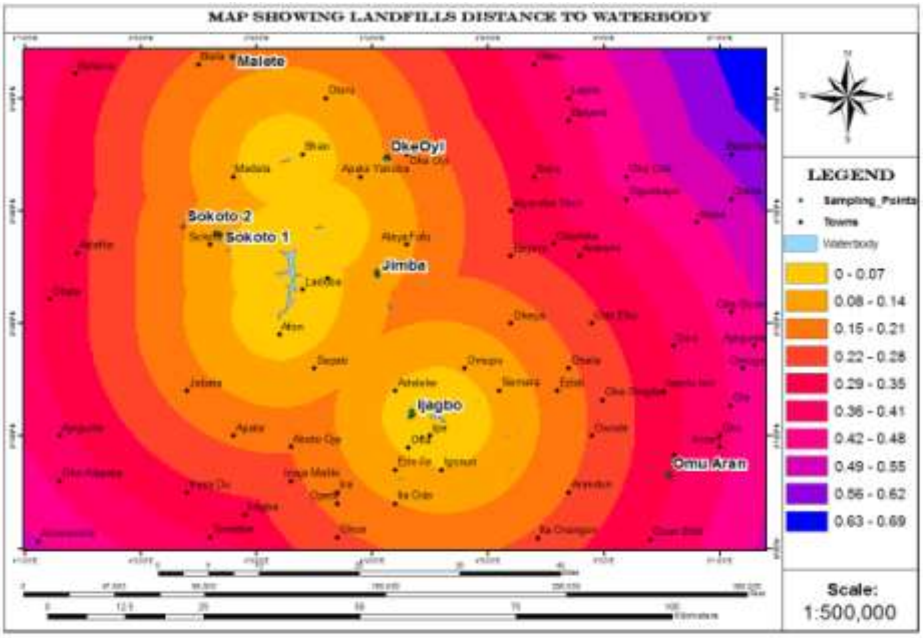

Figure 9: Model Map shows Landfills Euclidean distance to Waterbody

5.6 Model showing Reclassified Landfills distance to Waterbody

The distance to waterbody was reclassified as shown in figure 10 based on environmental criteria for buffer zone rating interval of 1-10 to check for the suitability level base on the class interval (500 – 1000m, 1000 – 1500m, 1500 – 2000m, 2000- 2500m, 2500– 3000m, 3000– 3500m, 3500– 4000m, 4000– 4500m, >4500m), distance to water body should be ≥ 300m according to Keller, 1976; Bagchi, 1994; USEPA, 2005. The model shows locations that are not suitable, moderately suitable and most suitable within the study area.

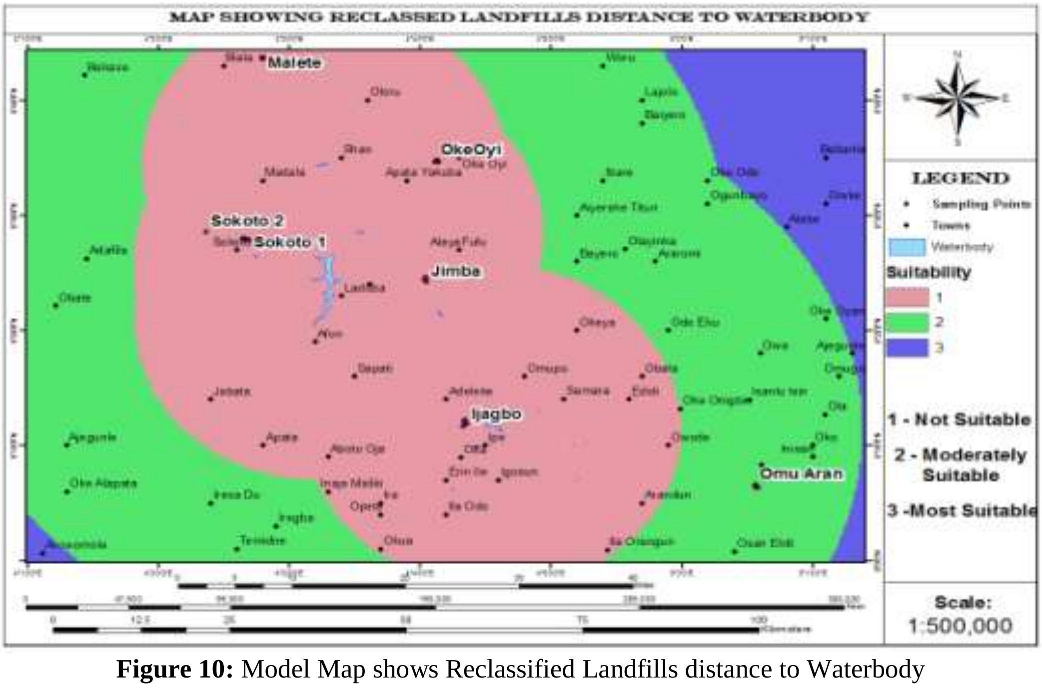

Figure 10: Model Map shows Reclassified Landfills distance to Waterbody

5.7 Map showing Elevation Generated using ASTER 3D

The map in figure 11 was generated from ASTER with resolution of 30m using field data; the map shows elevation of any location within the boundary of the study area.

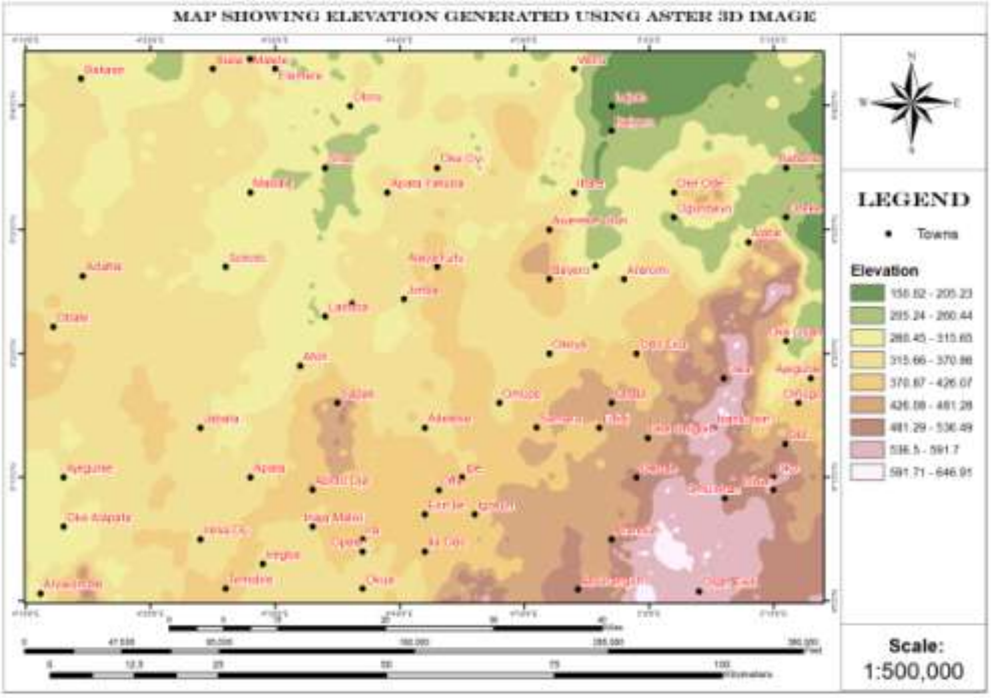

Figure 11: Map shows Elevation Generated using ASTER 3D

5.8 3D Model showing Elevation Generated using ASTER 3D

The map in figure 12 was generated from ASTER; the map shows elevation of any location within the boundary of the study area in 3D.

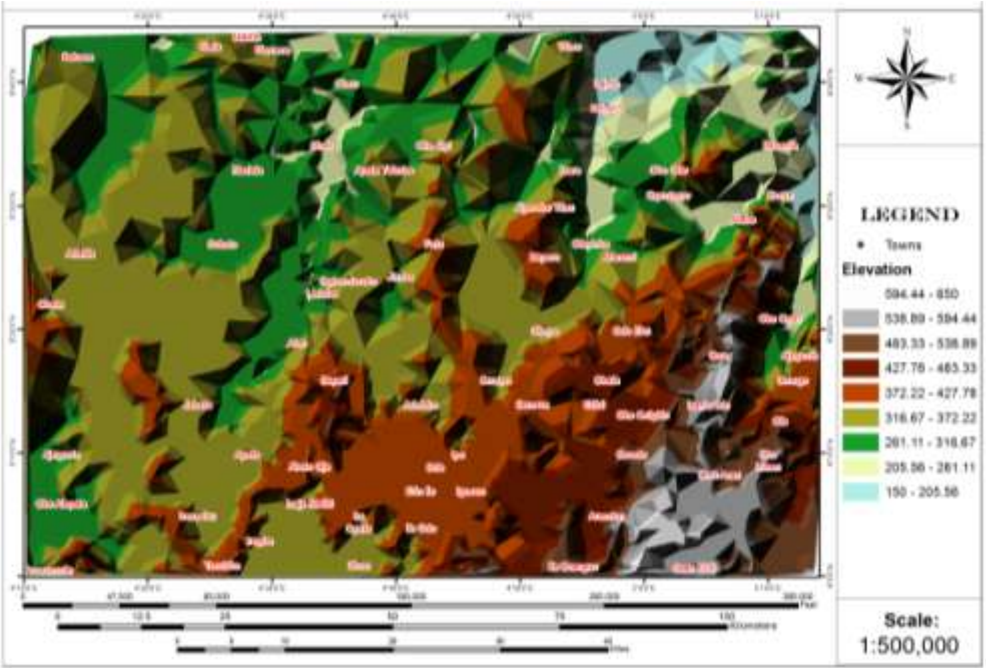

Figure 12: 3D Model shows Elevation Generated using ASTER 3D

5.9 Model Map showing Slope Grids Generated using ASTER 3D Image

The slope layer shown in figure 13 was extracted in GIS environment from the ASTER 3D layer. Nine distinct groups are defined, taking into account slope percentage. The higher the slope's value scales, the lower the land's suitability for landfill decreases. Digital Elevation Model (DEM) was used to produce slope map. In the study area the distribution of slope values varies from 0 to 80 °.

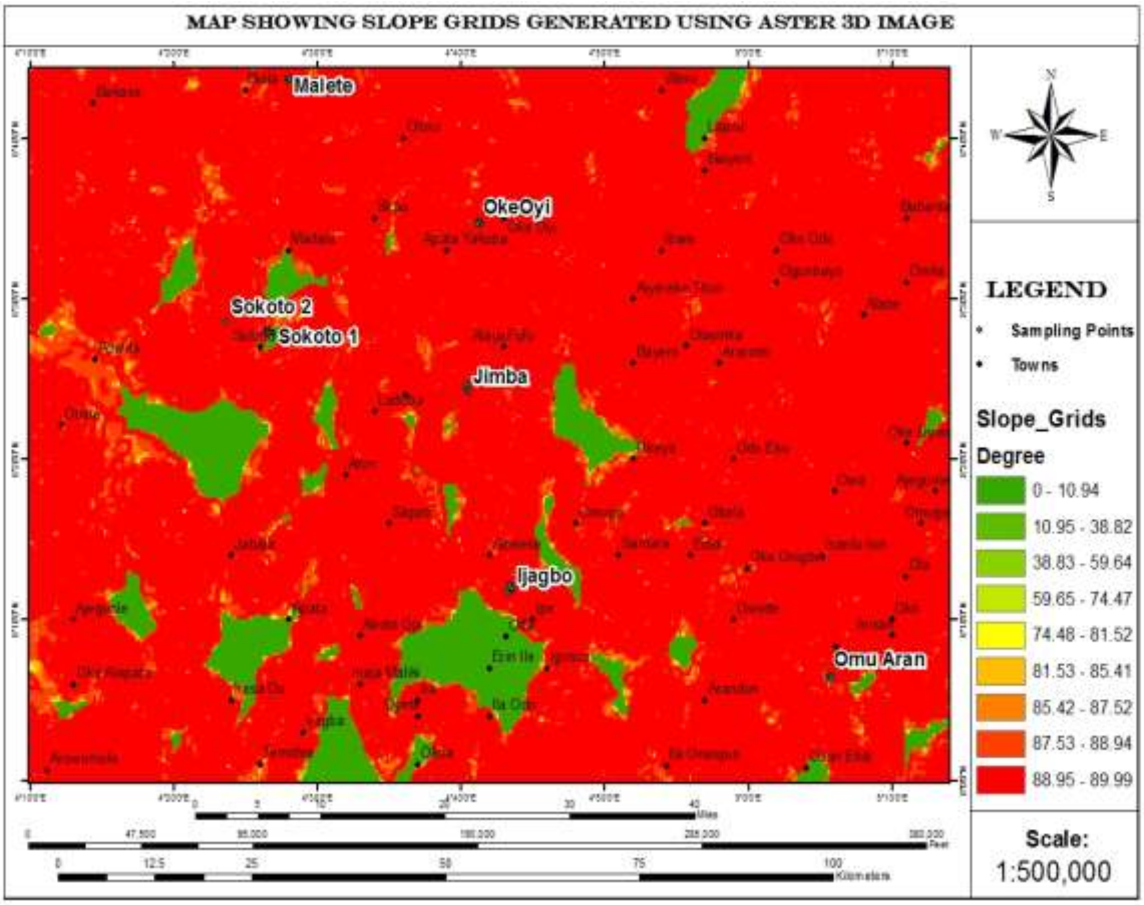

Figure 13: Model Map shows Slope Grids Generated using ASTER 3D

5.10 Model showing Slope Reclassification based on their Suitability Level

The slope was reclassified as shown in figure 14 based on the environmental criteria for buffer zone rating interval of 1-10 for checking the suitability level based on the class interval (<2°, 4°, 6°, 8°, 10°, 12°, 14°, 16°, 18°, 20°)

There are several recommendations in literature on slope. As described by Allen (2000) and Oweis et al. (1990) and applied in this work, for a landfill location areas with slopes greater than 15 ° should be avoided, too steep a slope would make it difficult to construct and maintain and too flat a slope would impair the drainage of the runoff. High slopes can favour leaching drainage to flat areas and ground water, and cause pollution. Areas with a slope over 20 percent are not appropriate for landfill location (Leao et al., 2004).

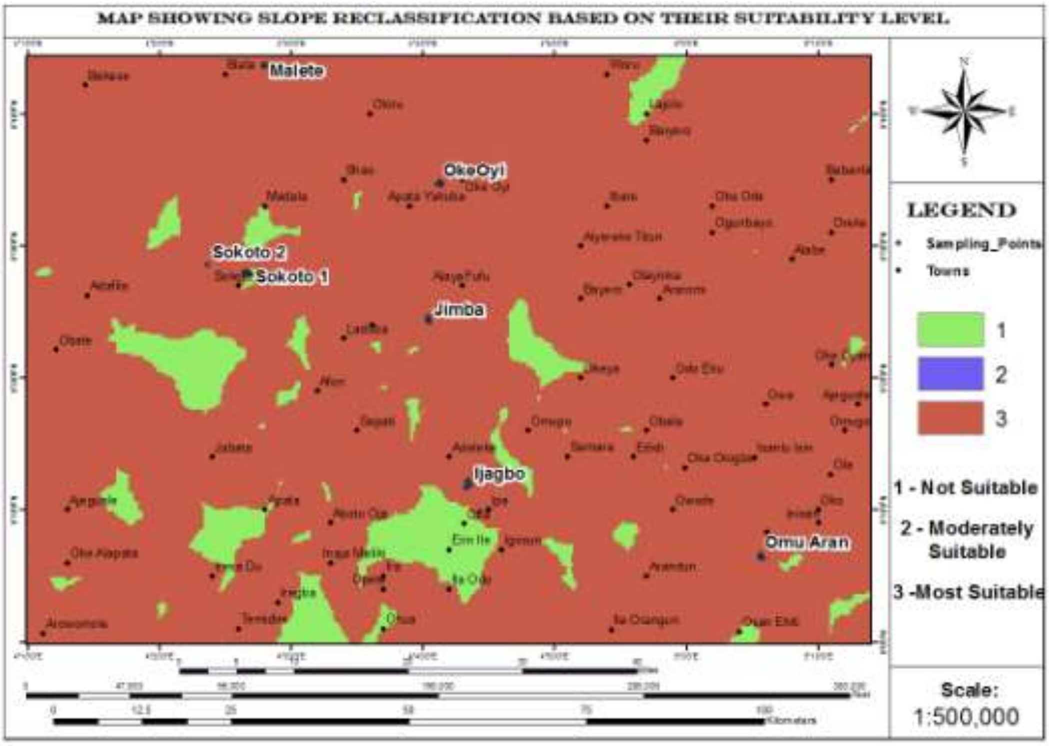

Figure 14: Model shows Slope Reclassified based on their Suitability Level

5.11 Model showing Landfills distance to Road and Highway

The roads were digitized from the IKONOS image as shown in figure 15 and divided into two sections. First section comprises of major roads and the other smaller roads; this was done in order to apply unique buffer zone distances according to the significant of the roads.

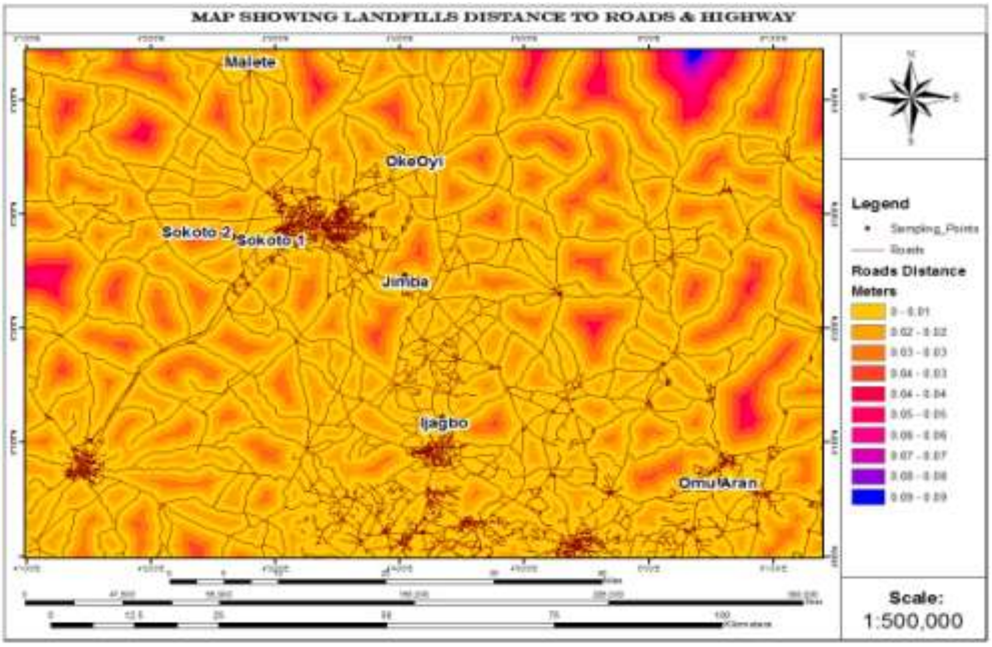

Figure15: Model shows Landfills Euclidean distance to Roads

5.12 Model showing Reclassified Landfills distance to Roads and Highway

Landfills distance to road was reclassified as shown in figure 16 based on the environmental criteria for buffer zone rating interval of 1-10 for checking the suitability level.

However according Allen (2000), the distance from major roads and highways should be obviated at more than 1 km. According to Allen (2000) the distance from major access roads should be less than 3 km.

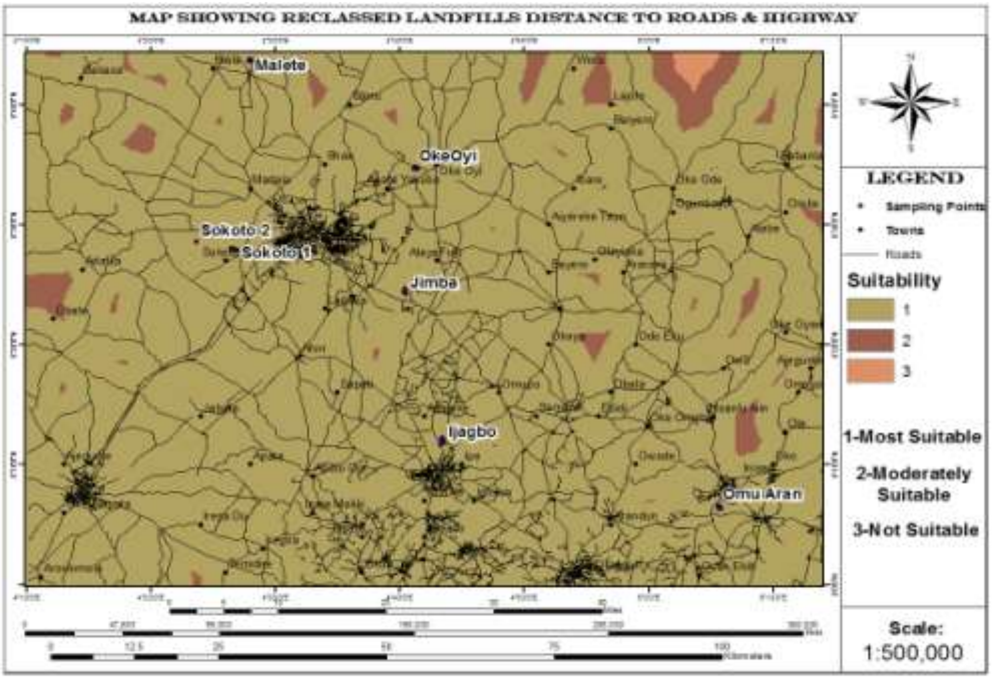

Figure 16: Model Map shows Reclassified Landfills distance to Roads

5.13 Model showing Landfills distance to Rivers

The model map in figure 17 was produced from IKONOS imagery, the model map shows landfills distance to river of any location within the boundary of the study area.

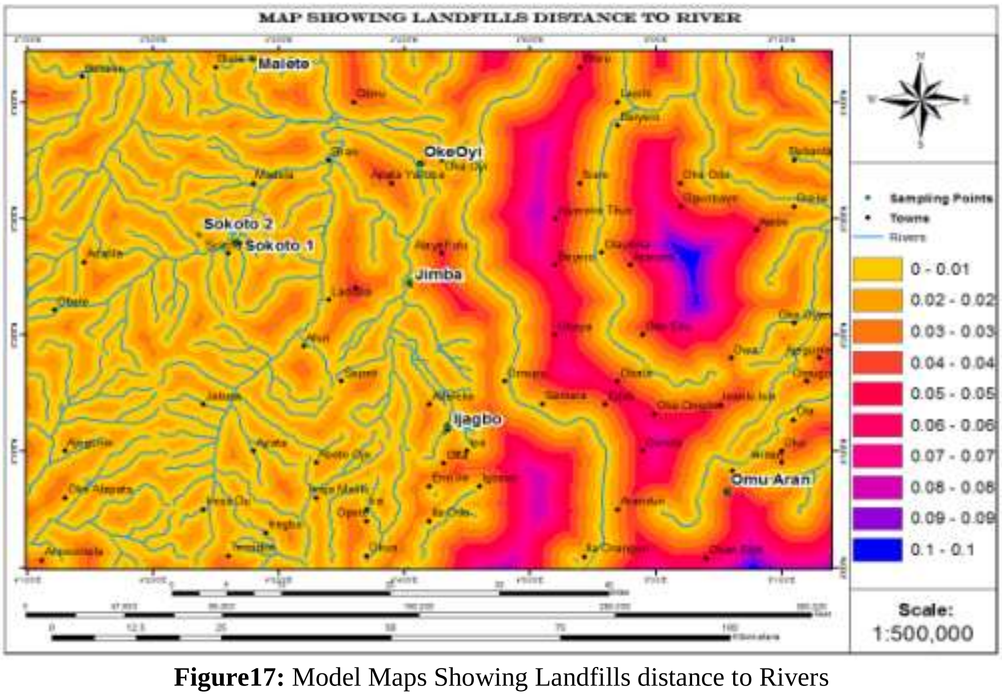

Figure17: Model Maps Showing Landfills distance to Rivers

5.14 Model showing Reclassified Landfills distance to Rivers

Landfills distance to river were reclassified as shown in figure 18 based on environmental criteria for buffer zone rating interval of 1-10 to check for the suitability level. This criterion has a significant impact with land adequacy to be used as landfill, there will be more preferences to be chosen for the farther lands from water bodies and river banks. A buffer zone higher than 1000 m is an appropriate distance from a river boundary to a landfill site for pollution protection (Yildirim, 2012). The model shows locations that are not suitable, moderately suitable and most suitable within the study area.

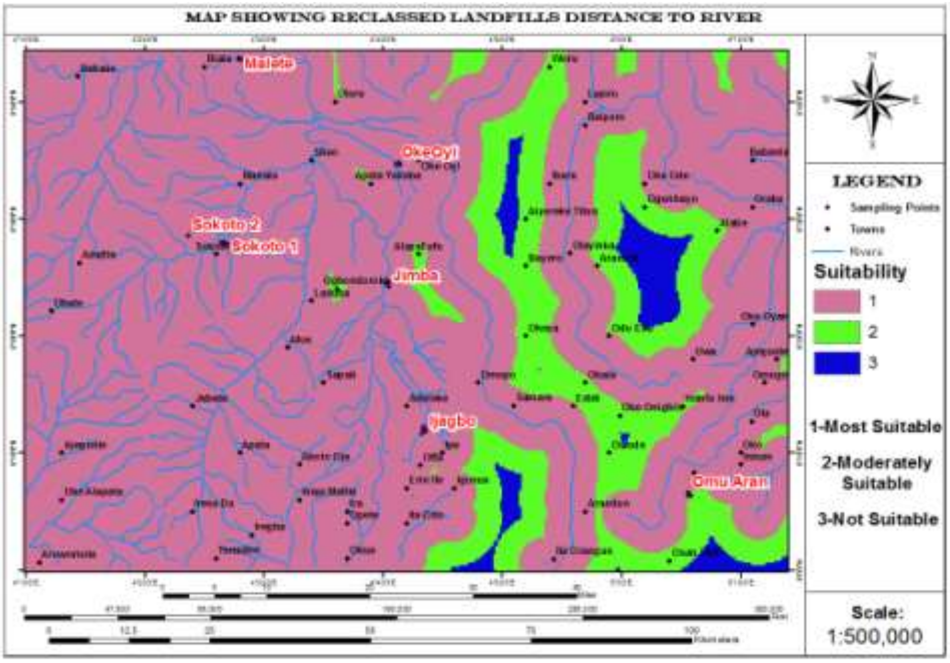

Figure 18: Model Map shows Reclassified Landfills distance to Rivers

5.15 Model showing Landfills distance to Settlement and Land use

The model map in figure 19 was produced or digitized from IKONOS imagery, the model map shows landfills distance to settlement of any location within the boundary of the study area. In addition, future household and business growth in landfill site allocation was mooted. Separate zones are therefore ranked with increasing priority directly related to distance from built up areas as shown in figure 19

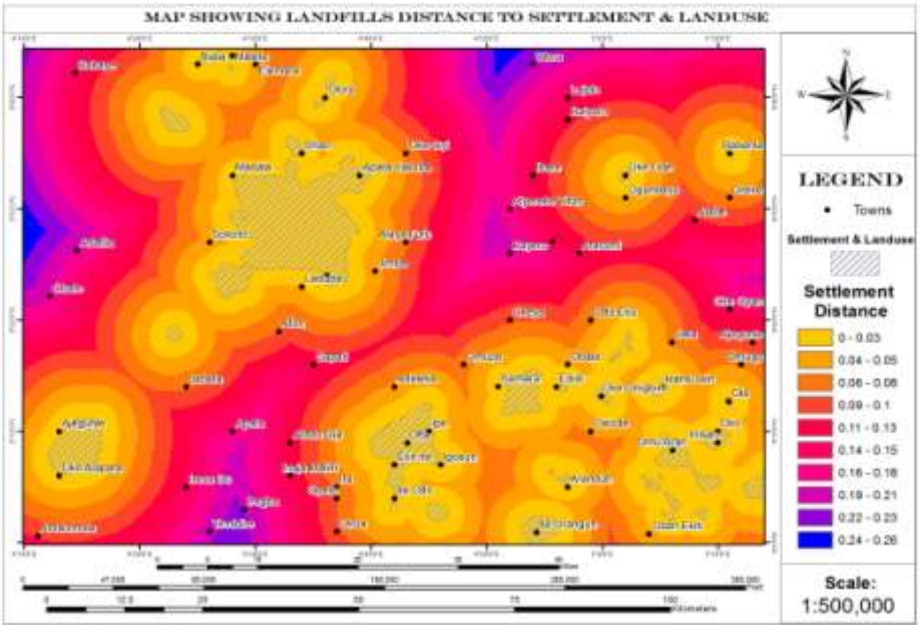

Figure 19: Model Map shows Landfills Euclidean distance to Settlement and Land use

5.16 Model showing Reclassified Landfills distance to Settlement and Landuse

Landfills distance to settlement was reclassified as shown in figure 20 based on environmental criteria for buffer zone rating interval of 1-10 to check for the suitability level. However, safe distances from the residential areas are defined by literature review. According to Allen (2000), the distance from metropolitan areas should be at least 5 km and from secluded houses 500m to site a landfill site. Because of social-economic considerations the landfill site should be sited within 10 km of a large city (Serwan, et al, 1998).

Taking into account all the recommended safe distances in the literature, average distances for the areas are set as 5 km for urban centres and 1 km for towns.

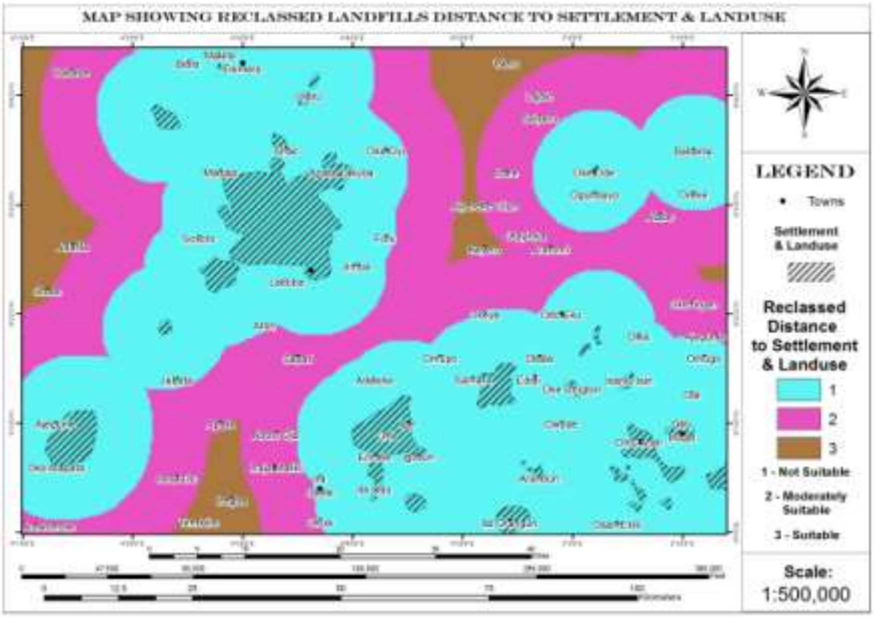

Figure 20: Model Map showing Reclassified Landfills distance to Settlement and Landuse

5.17 Weighted Overlay using Analytic Hierarch Process (AHP)

For solving multi -criteria issues such as site location and suitability models, the Weighted Overlay procedure applies one of the most frequently used methods for overlay analytics. Each of the general overlay analytics measures is followed in a weighted overlay evaluation. As with all overlays analyzes, the sanitary landfill problem was described in weighted overlay analysis, the model was split into sub-models, and the input layers were established.

Because the input criteria layers is in distinct numeric systems with different ranges, to integrate them in a single analysis, each cell for each criterion was reclassified into a common predilection scale such as 1 to 10, with 10 being the most preferable. An assigned preference on the common scale indicates the phenomenon's preference for the criterion. The predilection values are on a proportional scale. That is a predilection of 10 is twice as favoured as a predilection of 5.

The preference values were assigned proportional to each other within the layer but have the same interpretation between the layers. Each of the criteria in the weighted overlay evaluation may not be equal in importance. The criteria were more relevant on weight than the other criteria.

The final stage in the process of overlay analysis is to verify the model to ensure that what the model suggests is actually present at a location. The model was validated; sites were chosen as shown in figure 21.

4.18 Model showing Landfills Site based on their Suitability Level

The final suitability map for locating suitable sites for solid waste disposal sites are shown in figure 21; six raster layers were ranked for site suitability on a scale of 1 to 10. The weighted overlay outcomes were reclassified further to a scale of 1 to 3, the final result shows that an area of 1711.75sqkm is not suitable, 7214.63sqkm is moderately suitable and 1711.75sqkm is best suitable.
The summary of suitability level of the total study areas is shown in Table 7.

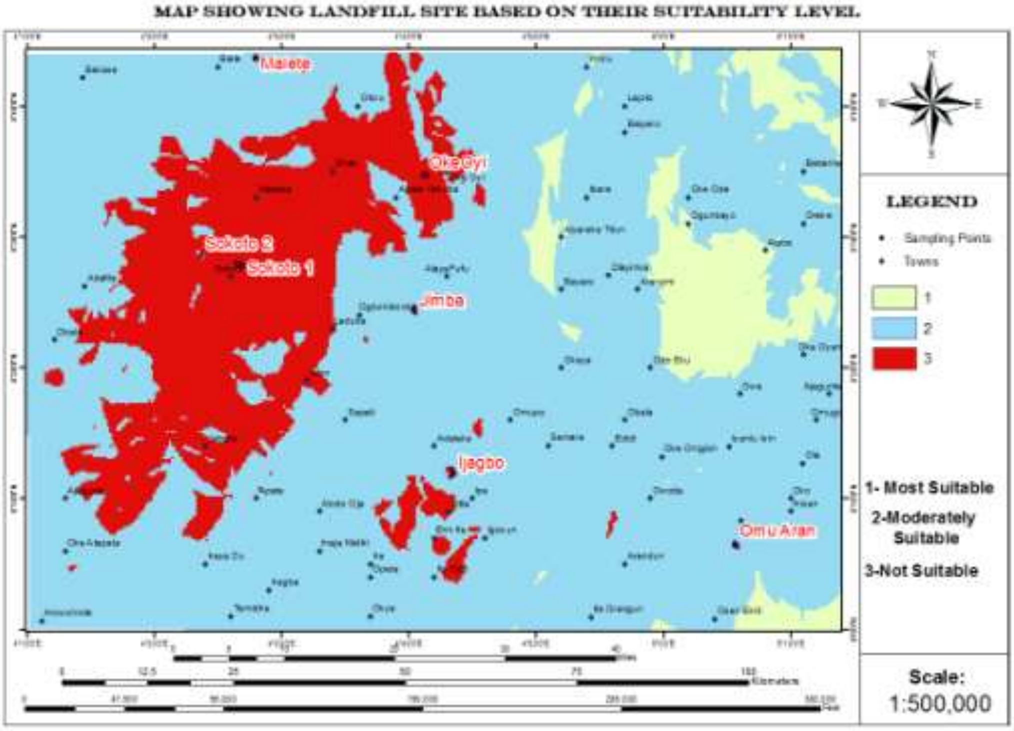

Figure 21: Model Map shows Landfills Site based on their Suitability Level

Table 9: Suitability Level Summary

S/N	Site Name	Site No	Area Cover	Suitability Level
1	Sokoto1	S1		Not Suitable
2	Sokoto2	S2		Moderately suitable
3	Malete	S3		Moderately suitable
4	Oke Oyi	S 4		Not suitable
5	Jimba	S 5		Moderately suitable
6	Ijagbo	S 6		Not suitable
7	Omu Aran	S 7		Moderately Suitable
8	Outside Research Scope	S 8		Suitable
9	Outside Research Scope	S9		Suitable
10	Outside Research Scope	S10		Suitable
11	Outside Research Scope	S11		Suitable
12	Outside Research Scope	S11		Suitable

VI. Conclusions

An Integration of remote sensing, geology and other environmental data was modelled with Environmental geospatial software in the ArcGIS 10.3 environment using Analytic Hierarch Process (AHP) and Weighted Linear Combination (WLC) using parameters such as distance from settlement, roads , highways, land-use, water source, river, water level, elevation , slope after geo-referencing, reclassification, weighting of criteria, data overlaid and finally suitability model map built to locate most suitable, moderately suitable and not suitable area. However, after completing the analysis process, in the category of “most suitable” on the final map in the study area, some sites were identified as most suitable landfill amongst several sites outside the scope of this research, four candidate sites were identified for moderately suitable landfill (Sokoto2, Malete, Jimba and Omuaran) amongst several sites within the scope of this research while three sites are not suitable (sokoto1, Ijagbo and Oke oyi). These sites were verified on the IKONOS satellite images (2017) to validate that these locations are suitable for landfill and satisfy the minimum requirements of the landfill sites.

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