Sanitary Landfill Sitting Using Geo-Spatial and Geoscience Investigations in Parts of Southwestern Kwara State, Nigeria

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Abstract: - **Africa population growth rate is the highest among the regions of the world, especially in the urban areas. This also brings about increase in waste generation, notably is also the corresponding increase in waste disposal sites. Hence, the urgent need to develop means of safe waste disposal. Engineered sanitary landfill are designed to be environmentally friendly on a long term. However, several salient considerations, starting from proper sitting must be taken to ensure that it means its purpose. This study is aimed at determination of appropriate landfill sites employing a multi criteria analysis. The study area falls within 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. Prescribed sites for appropriate landfill areas for Jimba, Ijagbo and Omu Aran were investigated using geophysics, geotechnical and Geographic Information System (GIS) techniques as tools to aid the decision-making processes. The geoelectric sections displayed four lithological successions (top soil, latheritic clay, clayey soil and weathered to fresh basement). In the same light, Aeromagnetic survey lineament data indicate no major fault in the area. The particle size distribution curve showed presence of sandy CLAY (SC/CL) and gravelly SAND (GP/SP) soil in the area. The soils liquid limit ranges between 28% to 44%, while plasticity index ranged between 11% to 36%. The clay activity values range between 0.28 to 0.72, implying low hydraulic conductivity and non swelling. The Permeability coefficient test also ranged between $3.2x10^{-7}$cm/s to $8.5x10^{-7}$ cms-^{1}, within the 10^{-8} to 10^{-6} range required for natural leachate attenuation without potential of lateral migration of leachate. However, other geotechnical results such as compaction, CBR, firing and consolidation results met engineering characteristics of soil material. All sites investigated met environmental impact criteria for sanitary landfill except one site. An integration of IKONOS, geology, geophysics and geotechnical data were modelled with designed Environmental geo-spatial model builder in ArcGIS 10.3 environment using Analytic Hierarch Process (AHP)**

Keywords: **Sanitary Landfill, WLC, MCDA, Satellite Imagery, Southwestern Nigeria**

I. INTRODUCTION

The development of environmentally friendly means of waste disposal as been identified as one of the key targets in attaining the sustainable development goals of the century[1]. In many parts of rural Africa, landfills are common in solid waste disposal. However, many of such landfill are indiscriminate and poorly sited and tend to constitute a threat to the underground water bodies and the immediate environment [2]. It is imperative to note that an engineered landfill is designed to prevent downward percolation of leachate into the underground water system. Hence, the selection of an appropriate landfill site with natural liners that can impede leachate percolation is thereby crucial. The discipline of Environmental Geology and GIS modelling provides a ready platform to identify suitable sites vis a vis environmental criterion [3]. Primal in sitting an engineered sanitary landfill is the systematic evaluation of prevailing natural geological conditions that support safe waste disposal in the proposed location. This must align with international best practice and recommended requirements of existing relevant local authority vis environmental, social, health and economic considerations [4]. Geographic information system, Analytical Hierarch Process, environmental geology procedures were used for sanitary landfill sites selection. Development of the environmental geo-spatial model was driven by the need to identify sites with suitable geological materials to reduce potential risks of groundwater contamination by landfill leachate and to establish a scientific approach to landfill site selection in order to promote public confidence and overall transparency of the site selection process using innovative and modern approach [5]–[8].

II. STUDY AREA DESCRIPTION

The study locations are Jimba, Oke Oyi, Ijagbo and Omu Aran South western Nigeria (figure 1), these are all located within the crystalline basement complex of Nigeria as shown in Figure 2. The area is underlain by the following rock types Migmatite, Granite Gneiss, Biotite and Biotite Hornblende Gneiss, Quartzite[9], [10] 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 area. The study area has typical tropical climate, alternate rain and dry seasons [11], [12]. The average annual rainfall range of 1270mm to 1254mm are dsitrubtuted mainly from April all through to October. The month of March is notably the warmest month with temperature reaching an estimated 32°C while August experience the coldest temperature of 23°C. The population within the study area is rapidly increasing according to the 2016 estimates, the 3,192,893 Population in parts of Kwara state Forecasts [13]

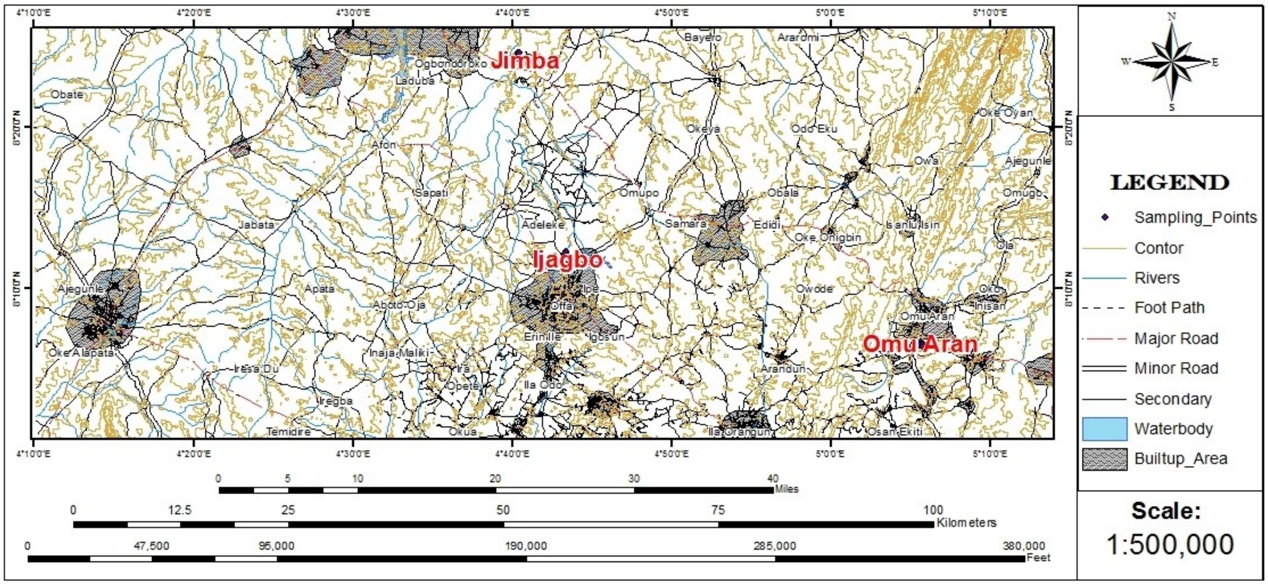


Figure 1: Topographical Map of the study area

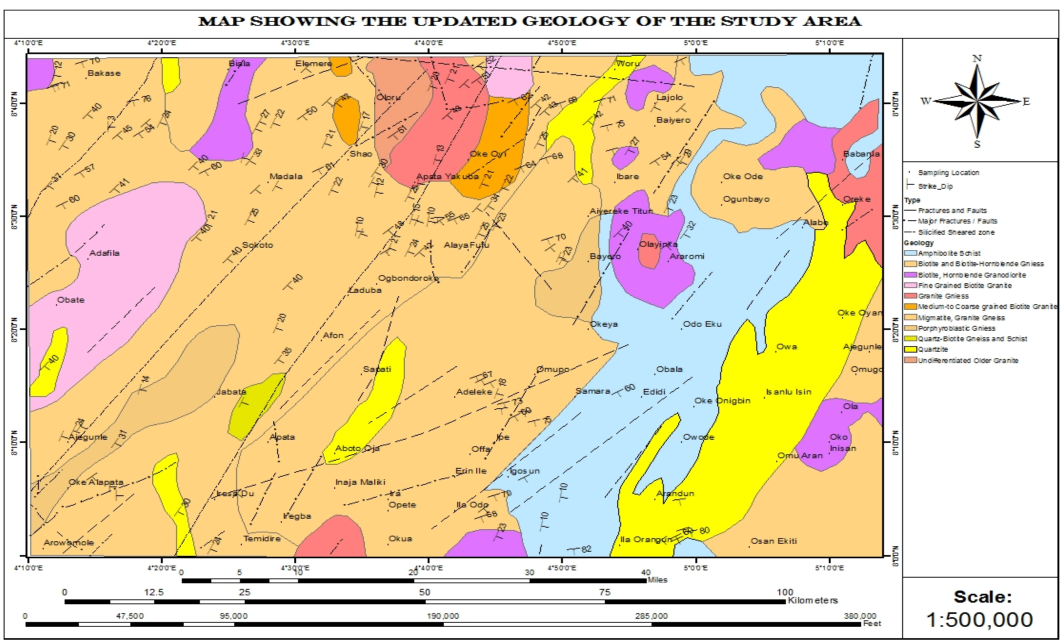


Figure 2: Geological Map of Study Area.

III. METHODS OF STUDY

Reconnaissance survey of prescribed landfill sites by relevant local authorities were done to access present state of such locations. This was followed by an environmental impact assessment, Geological field work, geophysical survey and geotechnical soil sample collection for laboratory material testing and analysis. Geological sub-surface characteristics and bedrock topography were evaluated with the use of electrical resistivity and aeromagnetic technique. Vertical electrical soundings (VES) were done employing Schlumberger array [9]. Fifteen VES points (VES01-05) were selected for investigation, a campus Omega resistivity equipment was used to measure lithological apparent resistivity (pa) responses. Maximum electrode spacing was limited to 100m due to observed proximity of bedrock to the surface. The software used for data analysis is called

ZONDIP, is a simple inversion and forward modelling program for 1-D models that consists of vertical and horizontal layers. Besides normal resistivity surveys, the software was used to model IP as well as pseudo section, winreisit software was used alongside to correlate ZONDIP interpretation and curve.

Aeromagnetic survey lineament data of the area was used to delineate fractures and faults. The data and materials used for this research are IKONOS Imagery, Toposheets – RO1C07 to R18C13 (scale - 1:50,000), LANDSAT ETM+ (2017, 28.5m resolution, path and row wrs2 190, 53). Also the ASTER imagery of (30m resolution) which covers the study locations were employed to generate Digital elevation Maps. The geological data of the areas was collected during geological field work, satellite imagery and from Nigeria Geological Surveys agency (NGSA).

Soil data were collected during site investigation and used together with Soil map to extract the soil types in the area. The digitized topographic map (1:50,000) were employed to displayed the river bodies in the study area. IKONOS imagery of the study area was used to extract the built-up area, landuse, rivers, road network and also to verify water bodies within the study area. The surface water body, depth to water body, soils, slope, roads and settlement; six set criteria patterned after Alavi et. al., (2013) was developed for landfill selection [14]. This Environmental Suitability Model (ESM) six classes where then ranked on a scale of one to ten (1-10) with ten being the highest and vice versa. The results were then incorporated into expert GIS software using the workflow described in Figure 3. Each mapped criterion was represented as GIS layers in the geo-database. Slope analysis, reclassification, weighted overlay, Euclidean distance analysis and rasterization were performed as shown in figure 3.

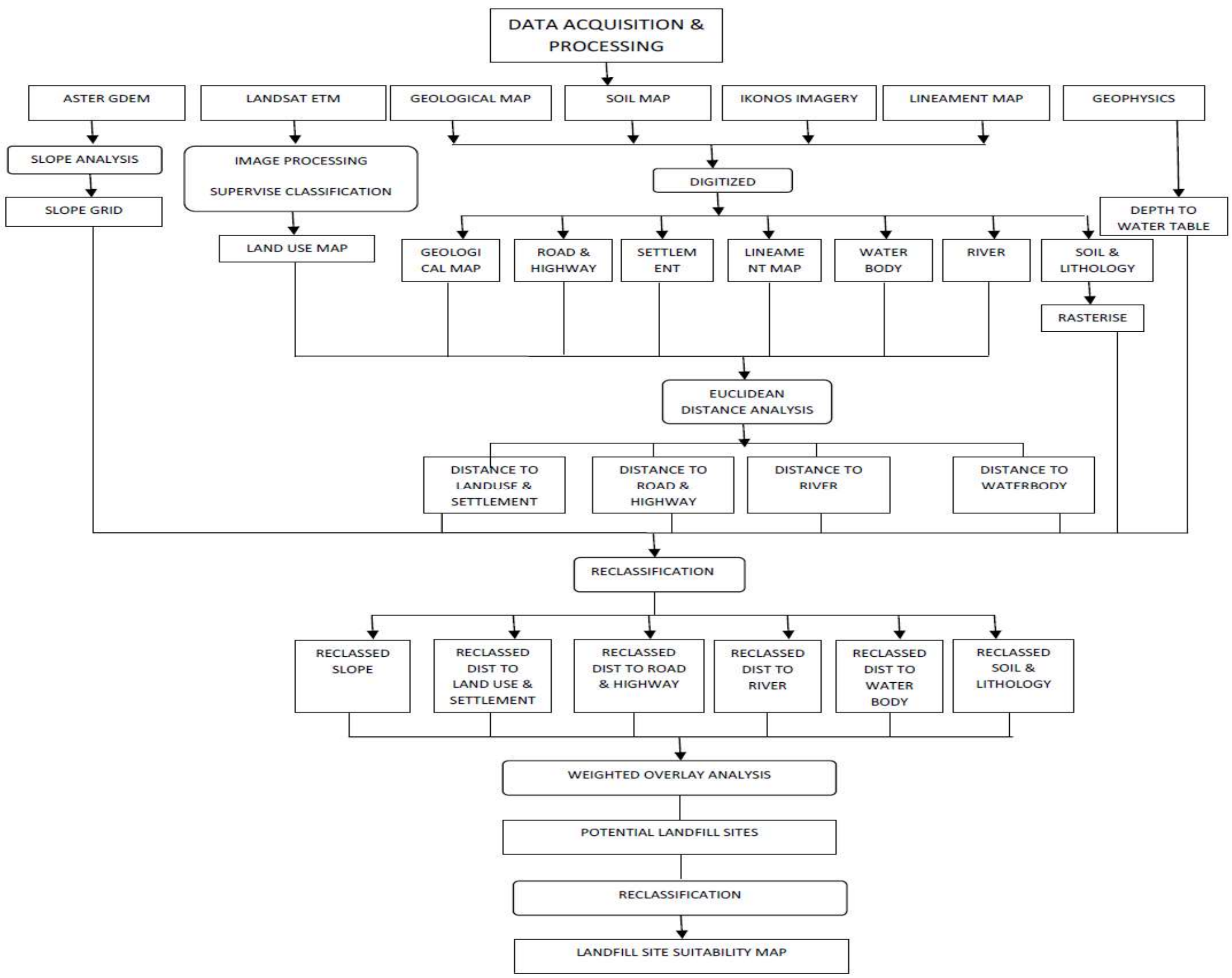


Figure 3: The Work flow diagram.

The Analytical Hierarchy Process (AHP) employed also helps to aggregate the relational representation among the selected criteria (table 1) in view of site selection. AHP provides a platform for consistency checking, prioritise ranking of alternative terms in view of overall importance. Weightage of each criterion are estimated on a scale of 1 -10 with zero value assigned for restricted parameters based on significance and suitability. Hence, the sum of percentage influence adds up to 100%0 (43+4+3+20+10 = 100).

Table 1: AHP Ranking and weighting for each criterion used for Geo-Spatial Modelling

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

However, pairwise comparisons for factors and sub-factors were checked for reliability after which EISM (Environmental Impact Suitability Model) for sanitary landfill in parts of south western Nigeria was built using a WLC method.

$S = \Sigma_{i=1}^{n} w_i x_i.$

Where

S = ESM final score,

W_i = sub-factor weight, and

X_i = standardized class rating of factor i.

IV. RESULT AND DISCUSSION

4.1 Geophysical Investigation

The summary of VES interpretations are displayed in table 2 and on Figure 4 to 6. It shows the recorded apparent resistivity and the corresponding thickness of each soil layer. VES signature recorded were typical of basement terrain, that is H and A-type curves. The subsurface generally consisted of three to four layers; Topsoil/laterite, clay, weathered basement, moderate to fresh basement with resistivity reading of 201Ωm to 824Ωm, 49Ωm to 1150Ωm, 105Ωm to 690Ωm and 109Ωm to 580Ωm respectively. However, it can be inferred from geophysical VES curves that some sites and locations have poor aquifer characteristic, while some, which compose partially Weathered basement with confined and unconfined fractures between 25m to 50m depth are considered as potential aquifer zones. All sites investigated met lithological depth and hydrogeological requirement for sanitary landfill according to Gallas et al, (2008) depth to water table should be ≥1.8m from the base of Mineral seal). Corresponding lithology Correlation of the sites are shown on Figure 7 to figure 9.

Table 2: Lithology Interpretation of VES Points

VES NO	LAYERS	RESISTIVITY (Ωm) RANGE	DEPTH RANGE (M)	LITHOLOGIC DEDUCTION
Site 5	1	153	0.6-2	Lateritic Soil
	2	38	2-10	**Clay**
	3	130	10-50	*Highly Weathered Biotite Hornblende Gneiss*
Site 6	1	247-750	2-4	Laterite mix with Top soil
	2	230-590	4-18	Lateritic Soil
	3	174-490	2-42	Highlly Weathered Quartzite
	4	340-580	16-42	Partially Weathered Quartzite
Site 7	1	490-720	2-4	Top soil
	2	120-220	4-12	Lateritic Soil
	3	49-72	9-40	Clay
	4	109-1480	10-20	*Highly Weathered Biotite Hornblende Gneiss*

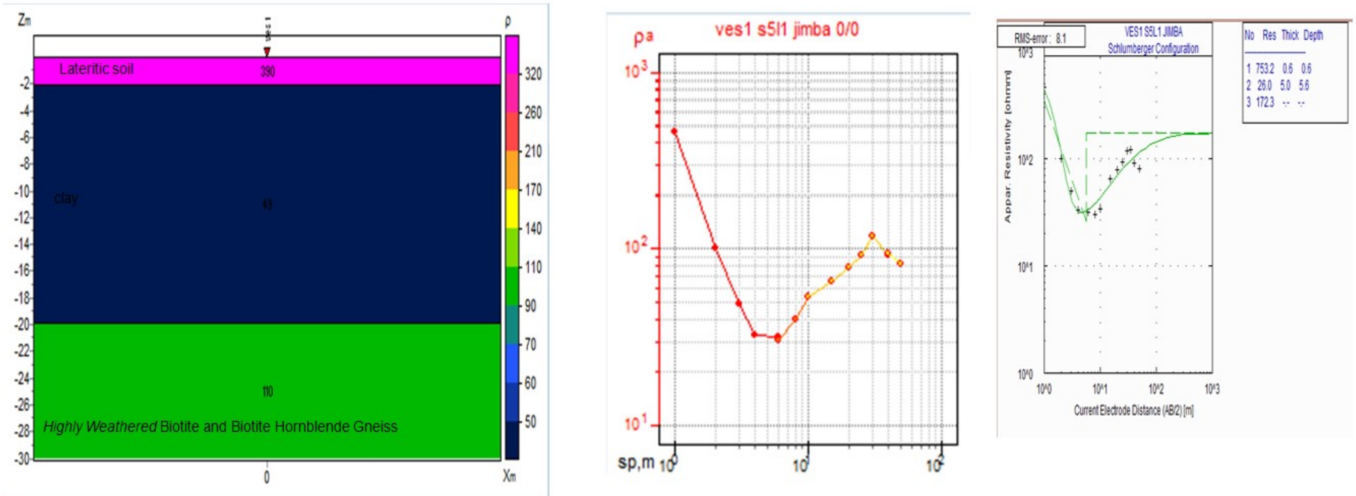


Figure 4: Typical Pseudo Section and VES Curve for S5L1 Jimba

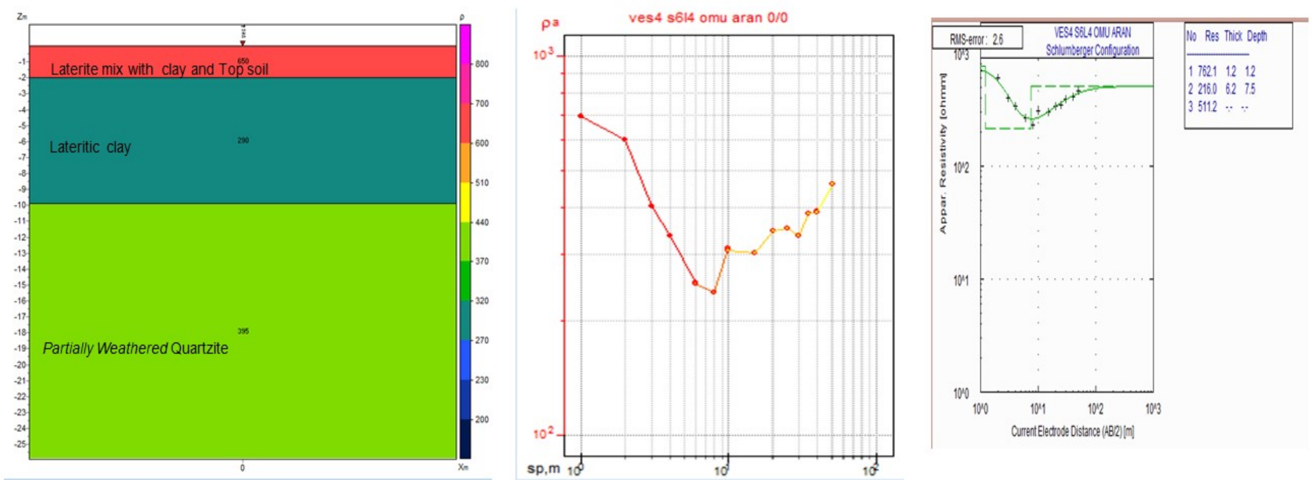


Figure 5: Typical Pseudo Section and VES Curve for S6L4 Omu Aran

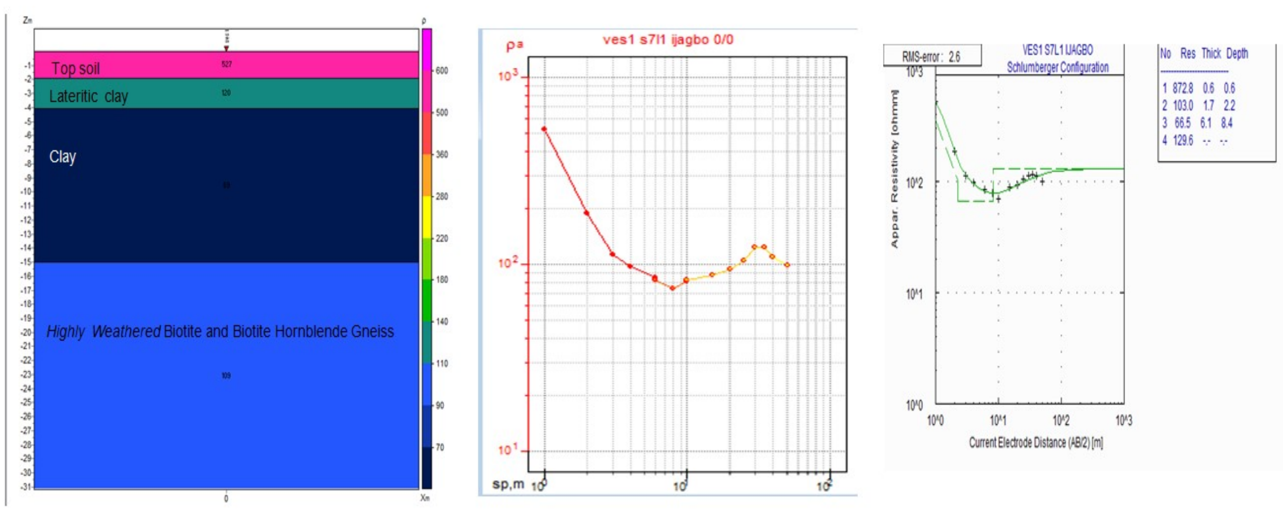


Figure 6: Typical Pseudo Section and VES Curve for S7L1 Ijagbo

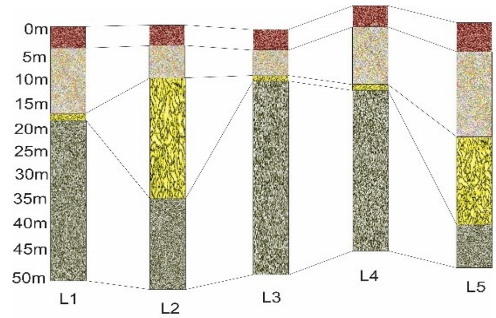


Figure 7: Lithological Section for VES 02 to VES 05 Jimba

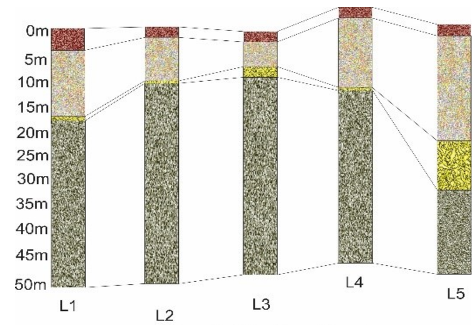


Figure 8: Lithological Section for VES 02 to VES 05 Omu Aran

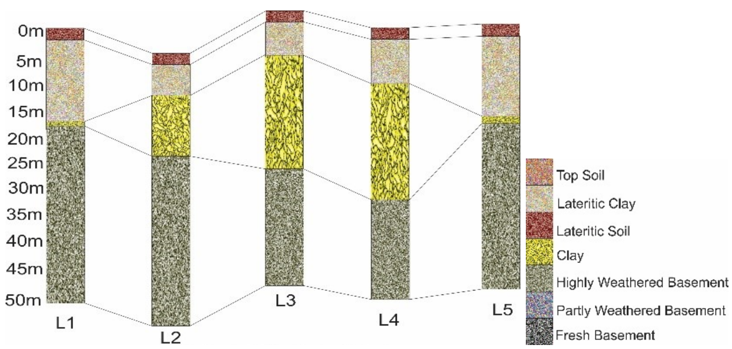


Figure 9: Lithological Section for VES 02 to VES 05 Ijagbo

The Model Map Showing Interpolated Resistivity of the Topmost, intermediate and bottom layers in the Study Area are shown in figure 10 to figure 12.

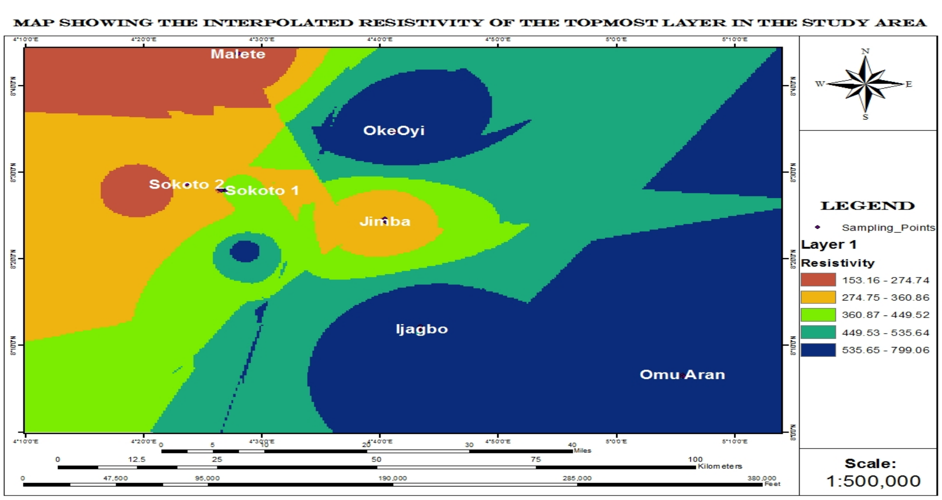


Figure 10: Model Map Showing Interpolated Resistivity of the Topmost Layer in the Study Area

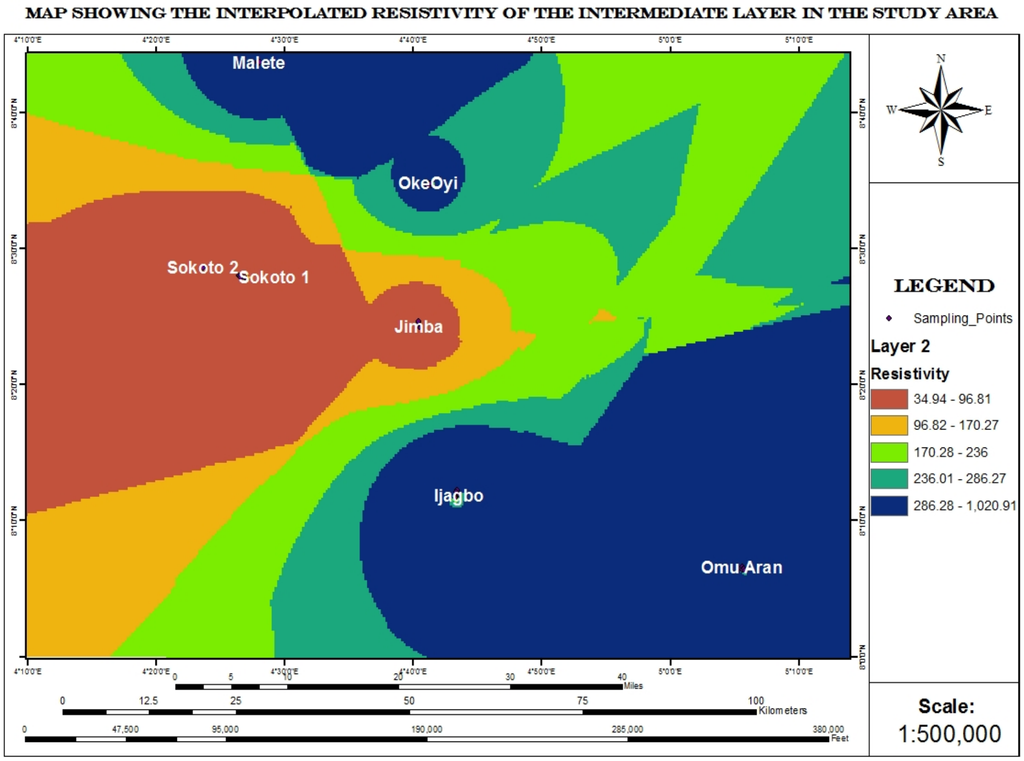


Figure 11: Model Map Showing Interpolated Resistivity of the Intermediate Layer in the Study Area

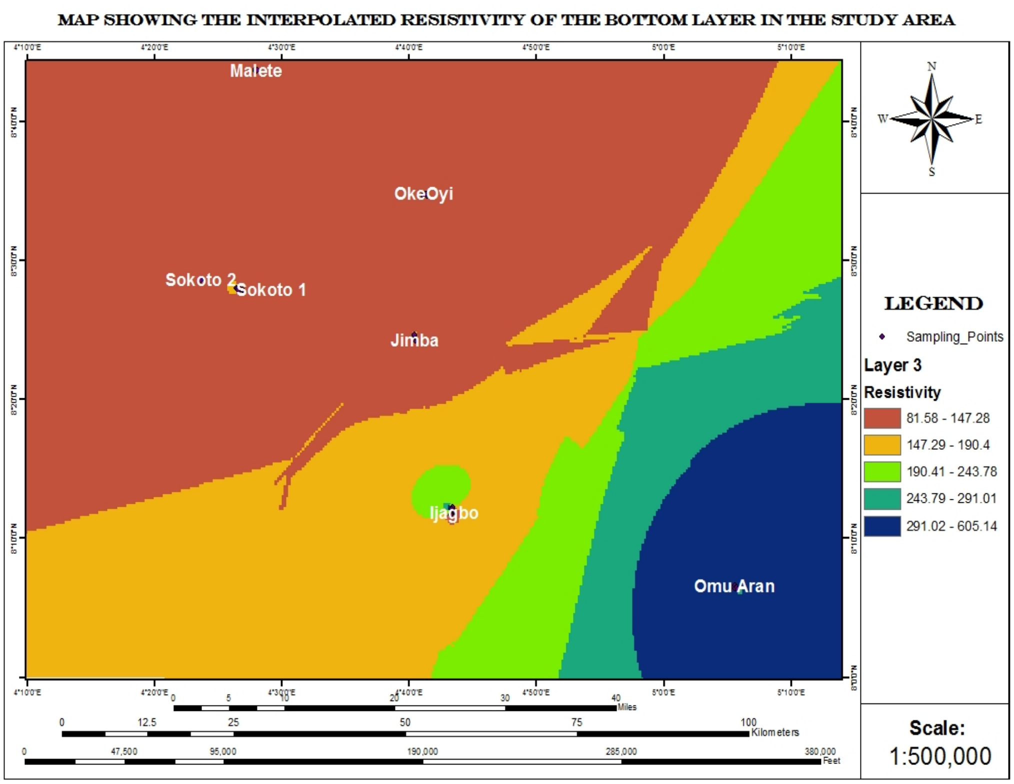


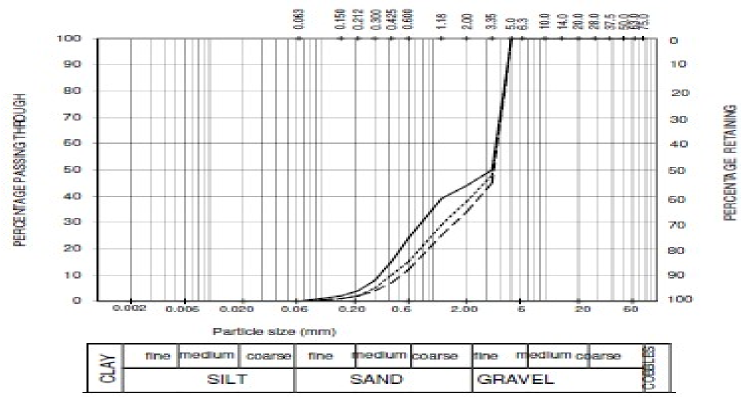
Figure 12: Model Map Showing Interpolated Resistivity of the Bottom Layer in the Study Area

4.2 Geotechnical Analyses

Fifteen (15) exploratory test pits within the study area were dug, five (5) for each site to depth of 3 meters, fifteen soil samples were collected from each of the sites at varying depths, (0- 3)m vertically – down the test pit which were separated by minimum of 300m from each other, within the unit that represents the lateritic zone. 45 samples were collected and analysed, all analyses were carried out according to British Standard International, 1377(1990) [15].

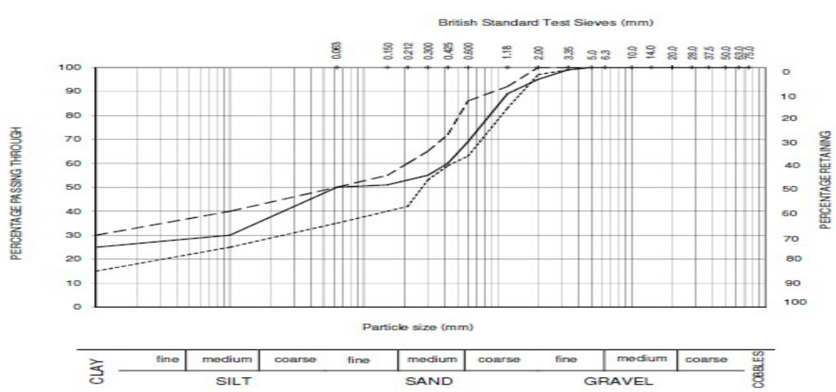
4.2.1 Grain Distribution

Figure 13 and 14 display the particle size distribution curves, using the British classification scheme (BS 1377: Part2: 1990, clause 9.2, 9.3 and 9.5); the samples here are described appropriately. However Based on PSD classification test result as shown in figure 22 for Sample S5L1 to S5L5 Jimba Oja, the soil material are described as gravelly SAND (GP/SP) the dominant soil material here is over 60% well graded gravelly SAND which are good for sanitary landfill drainage material but very poor for mineral seal, while S6L1 to S6L5 Omu Aran and S7L1 to S7L5 Ijagbo: Based on PSD classification test result as shown in figure 23 for Sample S7L1A, S7L1B, S7L1C Ijagbo, which are similar to other sample here, the soil material are described as sandy CLAY (SC/CL) the dominant soil material here is over 70% sandy CLAY (SC/CL) which are good for sanitary landfill drainage and mineral seal materials according to Declan and Paul, (2003) who suggested 10% clay content as requirement for soil to qualify for use in sanitary landfill as mineral seal [16].



CURVE	SAMPLE	DEPTH [m]	SAMPLE DESCRIPTION
———	S1L1A	1.00	gravelly SAND (GP/SP)
— — —	S1L1B	2.00	gravelly SAND (GP/SP)
....	S1L1C	3.00	gravelly SAND (GP/SP)

Figure 13: Particle Size Distribution Curve for Sample S1L1A, S1L1B, S1L1C



CURVE	SAMPLE	SAMPLE DESCRIPTION
———	S7(L1A)	sandy CLAY (SC/CL)
— — —	S7(L1B)	sandy CLAY (SC/CL)
....	S7(L1C)	sandy CLAY (SC/CL)

Figure 14: Particle Size Distribution Curve for Sample S7L1A, S7L1B, S7L1C

4.2.3 Atterberg Liquid Limit

Figure 15 display the Atterberg limit test results. The method of obtaining the results is (BS 1377: Part2: 1990, clause 9.2, 9.3 and 9.5), plasticity index for most samples is above 20%, representing medium to high plasticity compressibility of the soils as shown in table 2 [17]. Clayey soils with liquid limit (≥35%) and plasticity index of >15% are good for consideration as mineral seal. S6 Omu Aran and S7 Ijagbo clay meet the requirement for consideration as mineral seal material and site locations. A kaolinitic soil has an activity of 0.3 – 0.8, while illitic soil has an activity of approximately 0.9 and soils with montmorillonite have activities of >1.5 (these are expansive and are often not workable on the field) [18]–[20]. The soil samples have activity value varying between 0.28 and 0.80 representing soils of kaolintic/illitic clay mineral which typify the wet tropical area of Nigeria [21], [22]. It therefore indicates that the soils are non-expansive, non – active and workable on the field.

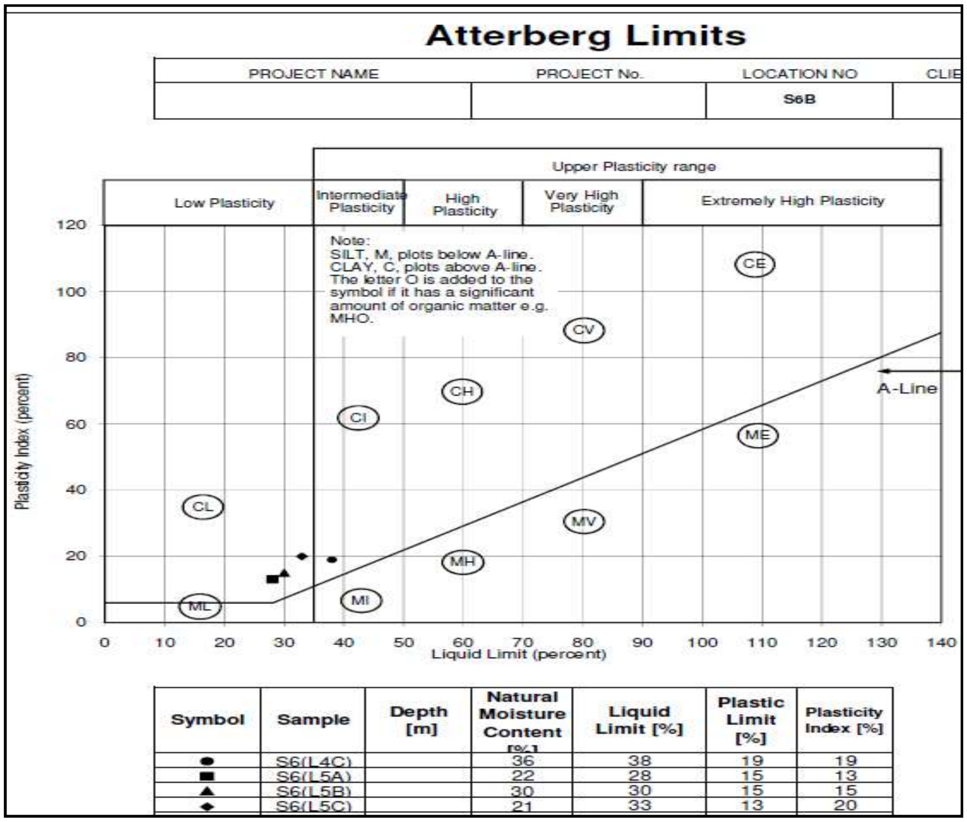


Figure 15: Atterberg Limits Curve for S6L4C, S6L5A and S6L5B and S6L5C

4.2.4 Analysis Results of Permeability Test

The values of the coefficient of permeability were obtained using the Darcy‘s law of liquid flow. The soil samples have coefficient of permeability (*k*) values show in table 3. Falling and constant head permeability test were conducted on samples show in table 3. Permaebility test shows the flow of water through a porous media (soil), testing the soil stability when subjected to percolation forces. Therefore, falling head permeability test conducted on samples show in table 3 falls under clay with poor drainage, which show that the material can serve as natural clay mineral seal for sanitary landfill. Sample S5L1C, S6L1C and S8L1C were stabilized under falling head permeability with 10% cement and the materials show improvement in stability as shown in table 3. However, according to Allen, 2000 natural geological materials considered for attenuation of leachate in landfill should possess an optimum coefficient permeability range of 10^{-6}cm/s to 10^{-8}cm/s which area investigated fall within range.

Table 3: Results of the Coefficient Permeability

S/No	Sample Symbol	Falling Head Permeability k(mm/sec)	Falling Head Stabilization With 10% cement Permeability k(mm/sec)
1	S5L1C	7.4×10^{-7}	
2	S6L1C	6.7×10^{-7}	3.2×10^{-7}
3	S6L2C	6.2×10^{-7}	
4	S6L3C	5.7×10^{-7}	2.9×10^{-7}
5	S7L1C	8.5×10^{-7}	
6	S7L2C	8.8×10^{-7}	

4.3 Model showing Landfills Site based on their Suitability Level

Model showing the suitability of landfill sites using geo-spatial model builder in expert GIS software were created. In prescribing suitable landfill sites within the study area, obtained IKONOS image, geophysical data, geotechnical data environmental data and soil analysis were all incorporated into the GIS data base. AHP and WLC (in which criteria such as distance from settlement, roads, highway, land use, water body, river, water table, elevation, slope were used after geo referencing, reclassifying, weighting of selection criteria) were used in determining the final suitability model map. The map was delineated as "most suitable", "moderately suitable" and "not suitable areas" for landfill sitting (Figure 16). Figure 17 to 19 shows the various categories on an IKONOS satellite imagery backdrop.To ensure suitability for landfill siting while satisfying environmental requirements.

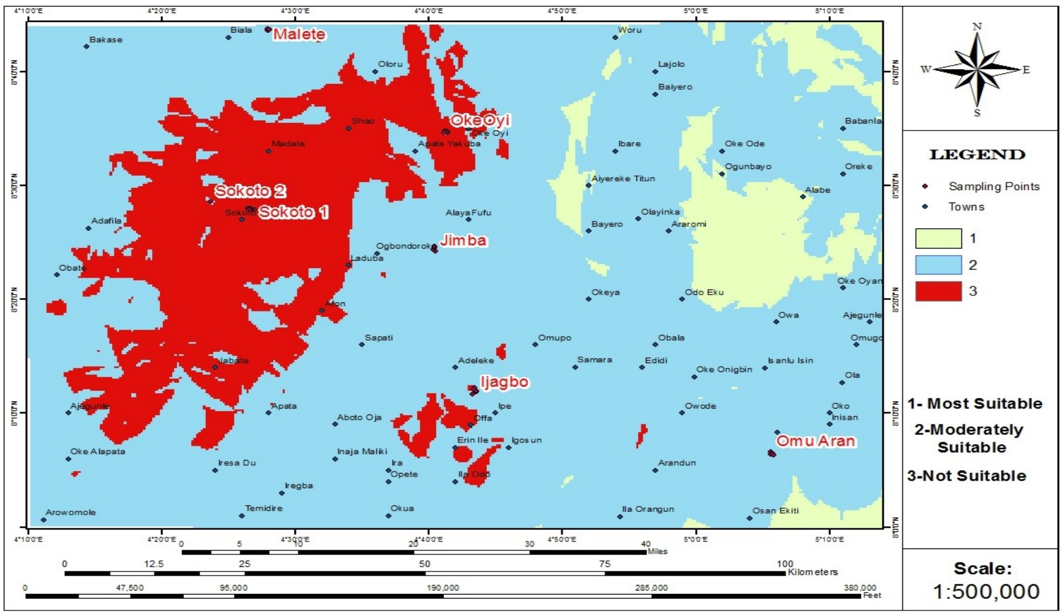


Figure 16: Model Map showing Landfills Site based on their Suitability Level

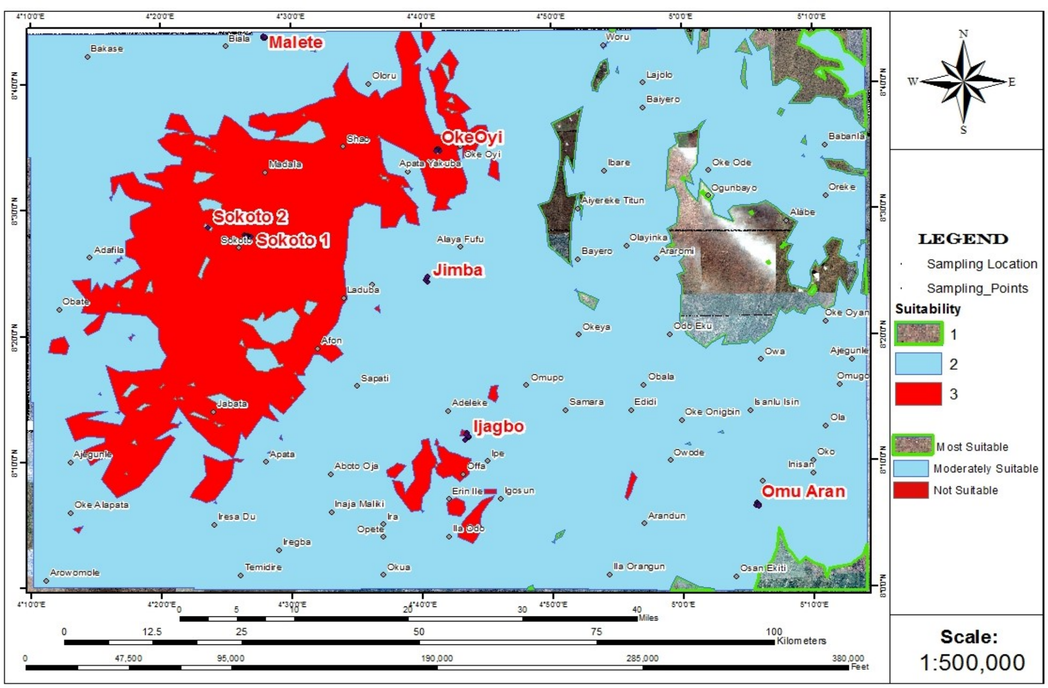


Figure 17: Model Map Showing Most Suitable Sites for Landfills Dropped on IKONOS Image

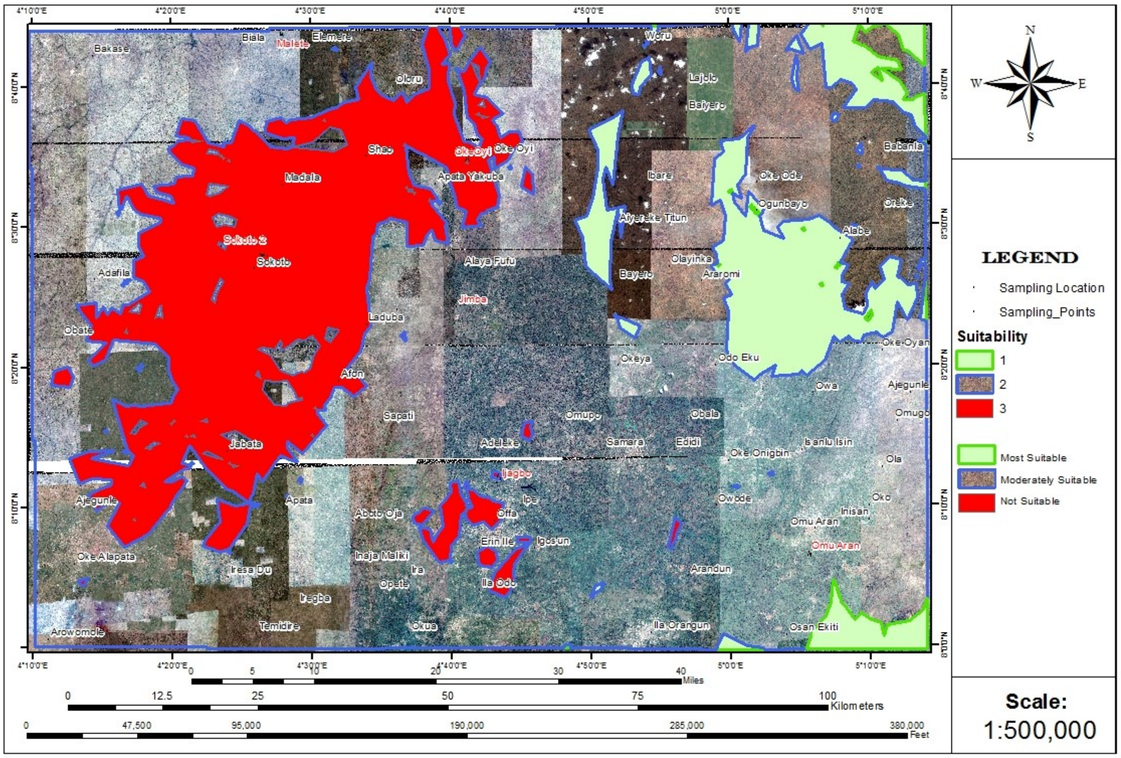


Figure 18: Model Map Showing Moderately Suitable Sites for Landfills Dropped on IKONOS Image

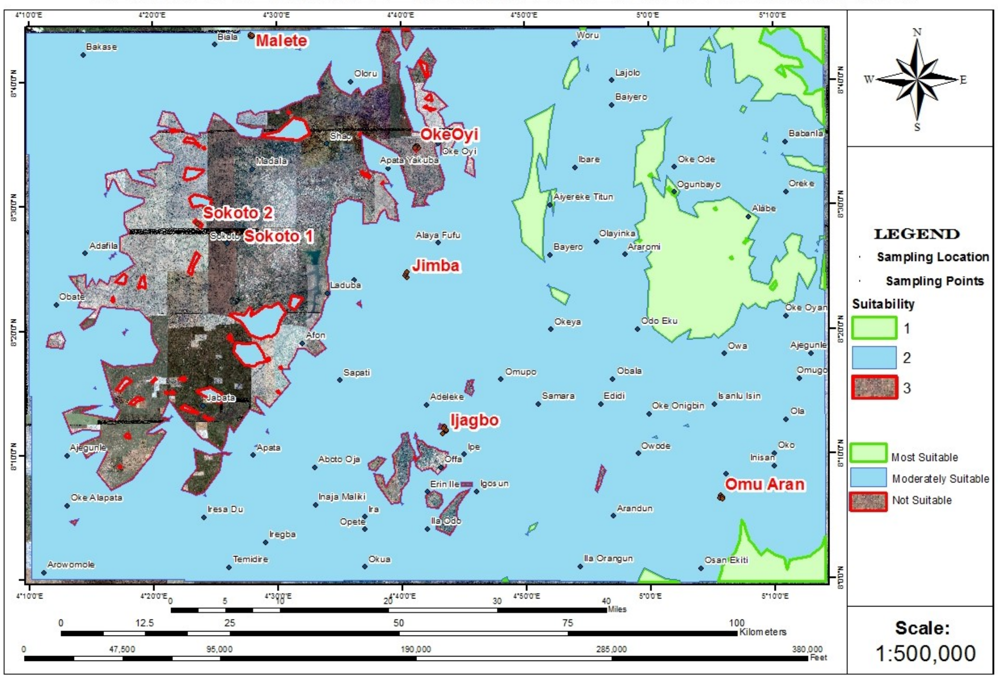


Figure 19: Model Map Showing Not Suitable Sites for Landfills Dropped on IKONOS Image

V. CONCLUSIONS

This study aimed at prescribing suitable sites for sitting sanitary landfill within parts of Kwara state, southwestern Nigeria using using geophysical, geotechnical techniques and environmental suitability models. Three locations sites were selected, namely S5 Jimba, S6 Omuaran, and S7 Ijagba all the sites met geological requirement for sanitary landfill location and geological procedure showed that soil samples are derived from migmatite gneiss, Migmatite, Granite Gneiss, Biotite Hornblende Gneiss, Quartzite.

Geophysical investigation revealed presence of thick overburden with predominant clay in most sites except Jimba. Geo-electric sounding and Aeromagnetic data indicate no major fault in the areas with poor hydrogeological characteristics. Geotechnical site investigation and laboratory material testing indicated that some sites and materials are suitable for sanitary landfill site while some are not. Classification, strength, specialize test showed that the soils were dominated by sandy CLAY (SC/CL) and gravelly SAND (GP/SP), medium to high plasticity, soils of low hydraulic conductivity with no potential lateral migration of leachate and adequate bearing capacity which could support moderately steep slopes. S6 and S7 met all these requirements with natural mineral seal, while S5 partially met geotechnical requirement but will need transported sealing material and soil improvement procedures such as artificial liner or geomembranes.

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