CONSTRAINT MAP FOR LANDFILL SITE SELECTION IN AKURE METROPOLIS, SOUTHWESTERN NIGERIA.

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ABSTRACT

An integration of remote sensing, soil type, geological, geoelectrical, hydrogeological and geotechnical data was carried out in a GIS environment with a view to developing a constraint map for the location of landfill (waste disposal) site(s) in Akure, Metropolis.. Geomorphological features identified from satellite images include residual hills, pediments, pediplain and etchplain . The slope (gradient) map displays surface gradients of 0 - 2.5° along river channels while areas with moderate and high relief have surface gradients of 2.5 - 6.35° and 6.35 - 29.53° respectively. Satellite-imagery-delineated lineaments predominantly trend NNW-SSE, ENE-WSW and NNE-SSW with subsidiary NW-SE and W-E trends that are typical of the Basement Complex region of Nigeria. The engineering geotechnical results show that charnockite-derived soils are very clayey and silty in nature (with % clay content > 18%) with low permeability, and are therefore more suitable for waste disposal (landfill) site than the sandy and gravely (with low % clay content < 7%) granite and migmatite gneiss-derived soils. VES-derived topsoil and weathered layer are characterized by relatively low layer resistivity values (< 100 ohm-m) over basic charnockitic rocks. The synthesis of the above results enables the classification of the Akure metropolis into three landfill suitability zones – unsuitable (28.6%); moderately suitable (40.4%), and suitable (13%) for waste disposal (landfill) sitting.

Keywords: GIS, Remote Sensing, Geoelectric, Geotechnical, Constrain Map, Landfill Site.

INTRODUCTION

One of the major problems in urban areas is the shortage of land for waste disposal. In as much as it is desirable to establish waste disposal (landfill) sites, it is essential that the site selection is based on sound geological, geophysical, hydrogeological and geotechnical considerations. Where such landfill is constructed on or within unsuitable materials, leachate may leak into the environment thereby impacting on the biophysical environment and the ecology of the surrounding area. Constraint map for landfill site selection can easily be used for the location of safe landfill site in urban areas, Akure Metropolis inclusive. Such constrain map can be developed using Geographic Information System (GIS). GIS is a set of software tools that is used to input, store, manipulate, analyse and display geographic information. It combines spatial data (maps, aerial, photographs, satellite images) with the other quantitative, qualitative and descriptive information databases (Choududhury and Das, 2012). Authors who have worked on the use of GIS, Remote Sensing, geological, geophysical, hydrogeological, and soil types for the selection of landfill site includes (Olayinka and Olayiwola 2001; Baban and Flnnagan 1998; Nishanth et al., 2010, Choududhury and Das, 2012; and Al-Hanball et al., 2011.

In this study, GIS was used to synthesize results obtained from geomorphology, slope, soil type, geological, geoelectric, hydrogeologic, geotechnical and classify the Akure Metropolis into different landfill suitability zones.

Site Description

The study area (Akure Metropolis) lies within Latitudes 7° 09' and 7° 19'N and Longitudes 5° 07' and 5° 17'E (Northings 790820 – 809277 mN and Eastings 733726 – 752139 mE, UTM Minna Zone 31) (Fig. 1). It covers an areal extent of about 340 km^2. The metropolis is located on a gently undulating terrain surrounded by isolated hills and inselbergs. Topographic elevations vary between 260 and 470 m above sea level (Owoyemi, 1996). The metropolis is drained by several streams and rivers. The major ones are Rivers Ala, Ogburugburu and Elegbin and their tributaries. The courses of most of the rivers are structurally controlled while others simply follow the paths of least resistance.

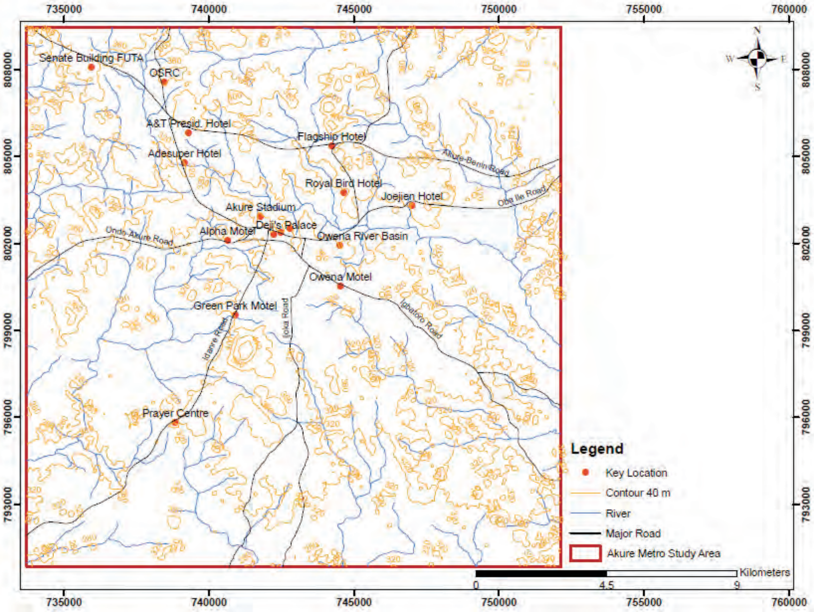

Fig. 1: Map of Akure Metropolis – The Study Area, Showing the Topographic Variations.

Geology and Hydrogeology

The geological mapping and other related studies of the area around the Akure Metropolis have been carried out by several workers amongst whom are Olarewaju, 1981; Anifowose, 1989; Owoyemi, 1996; Odeyemi *et al.,* 1999, Aluko, 2008 and Sobogun, 2008. The area around the Akure Metropolis is underlain by four of the six petrological units of the Basement Complex of Suthwestern Nigeria as identified by Rahaman (1988). These are the Migmatite-Gneiss-Quartzite Complex, Charnockitic and Dioritic rocks, Older Granites and Unmetamorphosed dolerite dykes (Fig. 2). The study area exhibits varieties of structures such as foliation, schistosity, folds, faults, joints and fractures. Generally, the structural trends in the study area are NNW-SSE and NNE-SSW. These structural trends fall within the principal basement complex fracture direction identified by Oluyide, 1988. The lineament map generated by Owoyemi, 1996, showed high density of lineament and lineament intersections in the eastern, southwestern and north central part of the metropolis underlain by granites and migmatite gneiss while the north central part underlain by charnockites has very low lineament density.

The groundwater, in a typical basement complex area like the Akure Metropolis, is contained in two major aquifer units, namely weathered and fractured basement aquifers (Ako and Olorunfemi, 1989; Aniya and Schoeneick, 1992; Olorunfemi and Fasuyi, 1993; Afolayan *et al.*, 2004 and Bayode *et al.,* 2006). The former is derived from chemical alteration processes while the latter is the product of tectonic activities. The unstable ferromagnesian minerals rich Basement Complex rocks tend to weather into clay, sometimes, micaceous impermeable poor water discharging rock formations while those rocks rich in quartz and other stable minerals will disintegrate into porous and permeable water bearing gravelly or sandy medium (Offodile, 2002). The weathered layer aquifer may occur singly or in combination with the fractured aquifer (Olorunfemi and Fasuyi, 1993). The direct exposure of the uppermost part of the vadose zone of the weathered layer aquifer system makes it vulnerable

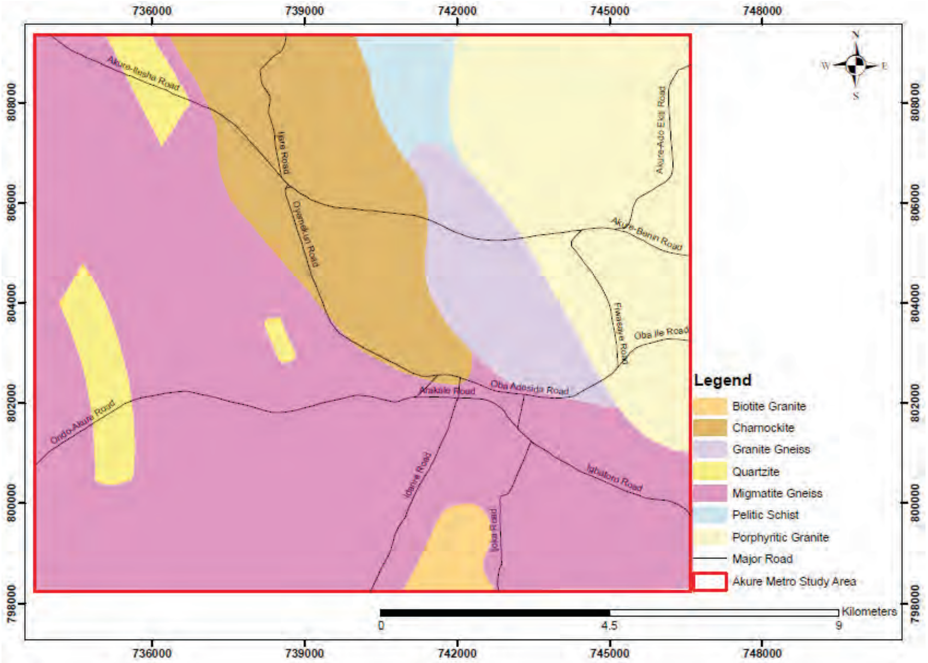

Fig. 2: Geological Map of Akure Metropolis (After Owoyemi, 1996)

to surface/near surface pollutants such as leachate from a waste dump and surface flooding.

METHODS OF STUDY

Many factors need to be incorporated into landfill site selection decision making process. GIS is an ideal tool for this type of preliminary studies due to its ability to analyse and manage large volume of data from a variety of sources. Chouduhury and Das (2012), proposed some principal criteria that can be used for spatial analysis which include: Lithology, geomorphology, slope, drainage, population and distance from major roads, streams and drainages. Thematic maps for this criterion were generated and weightages were allocated to them on the basis of key factors for the selection of suitable landfill site.

Remote Sensing

Geology, being an important factor in this study, deserves the utmost focus as a field component of terrain evaluation. The data used for the remote sensing interpretation include subset Topographic map, Aster DEM, Landsat EMT+ surface reflectance image of 2002 of the study area which were pre-processed for geometric correction, haze reduction and re-sampling. Optimum index factor and covariance analysis were carried out in order to determine the least correlated bands and these bands were subjected to convolution filters, texture analysis at 3X3 window size, histogram equalization, de-correlation stretch, principal component analysis (PCA) and the Aster DEM to topographic analysis such as sink fill and shielded relief to generate classified land cover, geomorphological, slope and lineament maps.

Residual Soil Types

The nature of residual soils (except for the topmost layer) in Akure is determined by the underlying geology. Smith and Montgomery (1962) recognized three major soil associations in the study area. These include Iwo, Ondo and Itagunmodi Associations (Fig. 3).

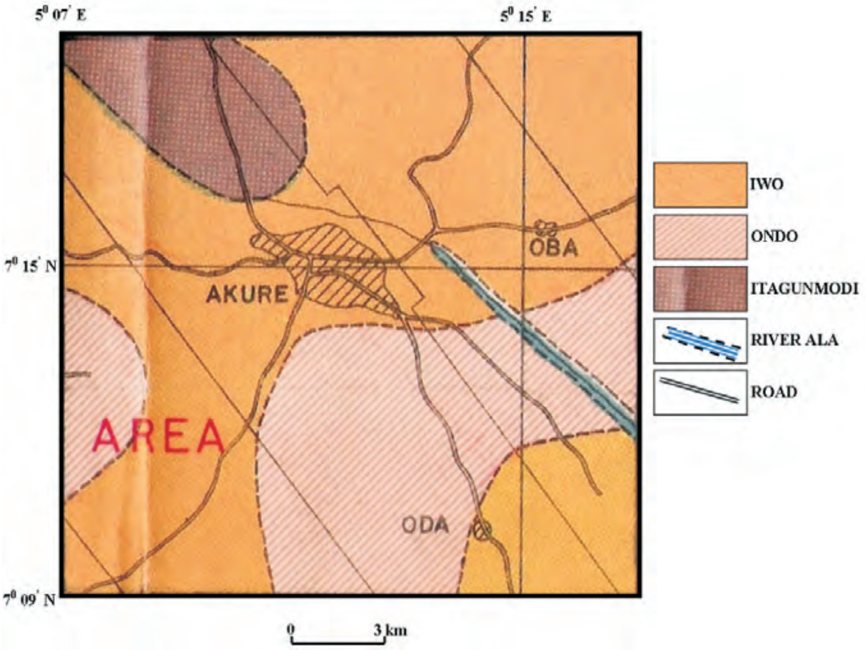

Fig. 3: Soil Map of the Area around Akure Metropolis (Extracted from Smith & Montgomery, 1962).

Engineering Geological Investigation

Engineering geotechnical test results were acquired for thirty two geo-referenced locations from the study area (Owoyemi, 1996). The samples were analyzed for liquid and plastic limits, plasticity index, linear shrinkage and percentage clay content.

Geophysical Investigation

The geophysical investigation involved the Vertical Electrical Soundings (VES) with the Schlumberger array. The half current electrode spacing (AB/2) was varied from 1 m to a maximum of 100 m. The choice of the VES stations was constrained by the geology, structure (lineament) map, terrain, accessibility and representativeness of the spread of the stations. Every VES station was appropriately geo-referenced. Secondary information on existing VES data were assessed, re-processed and incorporated. Four Hundred and two (402) VES data from 114 localities were sourced and collated. Additional one hundred and eleven (111) primary VES data were collected from Aule and Ilupeju areas of Akure Metropolis where the secondary data were not representative or non-existent. In all, five hundred and thirteen (513) VES data set from 116 localities were acquired. A GPS generated base map with sample locations are shown in (Fig. 4). The VES data were presented as depth sounding curves and interpreted quantitatively using the partial curve matching technique and computer assisted 1-D forward modeling with W-Geosoft software. The interpretation results (layer resistivities and thicknesses) were used for geoelectrical characterization.

RESULTS AND DISCUSSION

Geomorphology/Slope, Geology and Structures (Lineaments)

Sattelite-imagery-derived geomorphological map is presented in Figure 5. The map shows

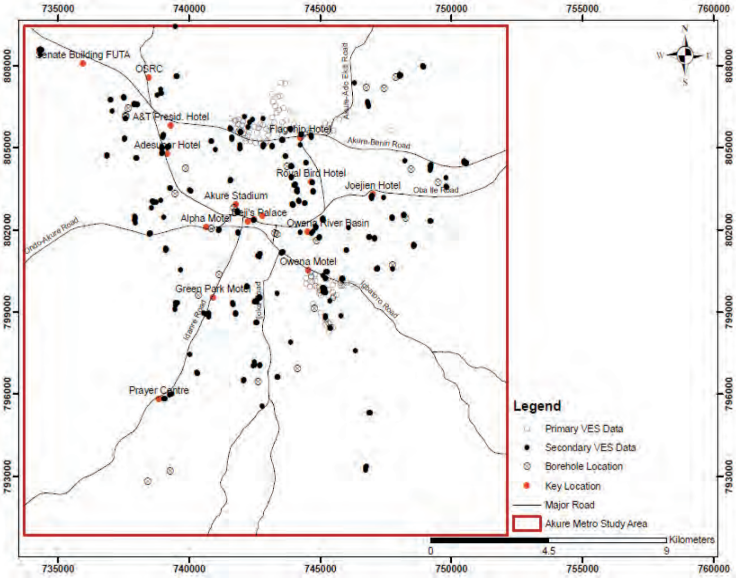

Fig. 4: Geophysical (VES) and Borehole Data Acquisition Map

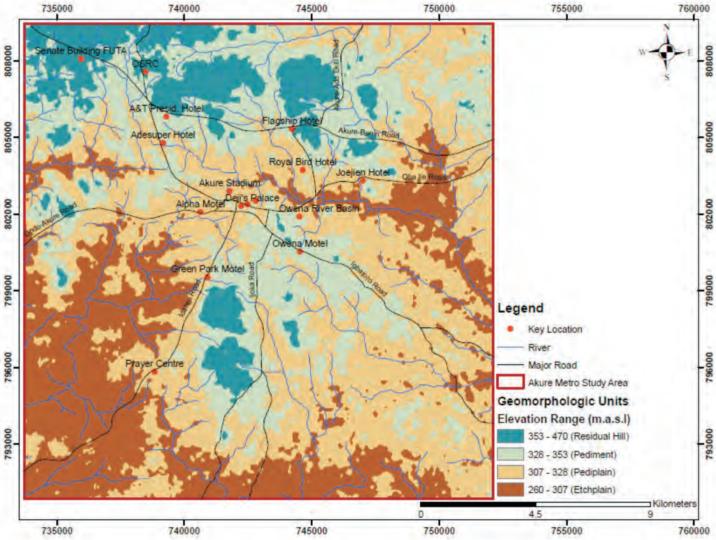

Fig. 5: Geomorphological Map of Akure Metropolis

geomorphological units which include residual hills with elevations of 353 – 470 m above sea level (a.s.l.) located at the northern, south central and western flank of the metropolis. The pediments are located at the foot of the residual hills with elevations in the range of 328 – 353 m a.s.l. Both relatively high elevation geomorphological units constitute the water shed for the numerous streams and rivers. The pediplain (307 – 328 m a.s.l) and etchplain (260 – 307 m a.s.l.) fall within and around the stream/river channels and are located at the western/southwestern, southern and eastern flank. The slope (gradient) map (Fig. 6) displays surface gradients that range from 0 - 29.5°. The river channels and the flood plains are characterized by very low gradients (0 - 2.5°) while areas with moderate and high relief have surface gradients of 2.5 - 6.35° and 6.35 - 29.53° respectively. Surface gradient influences run-off and precipitates erosion.

The satellite-imagery-delineated lineaments are shown in Figure 7. The geological structures show lineaments with predominantly NNW-SSE, ENE-WSW and NNE-SSW orientation and subsidiary NW-SE and W-E trending lineaments that are typical of the Basement Complex region of Nigeria (Oluyide, 1988; Owoyemi, 1996 and

Odeyemi et al., 1999).

Engineering Geotechnical Investigation

Table 1 displays the engineering geotechnical consistency results. The charnockite-derived soils are very clayey and silty in nature (with % clay content > 18%) and are therefore of low permeability than the sandy and gravely (with low % clay content < 7%) granite and migmatite gneiss-derived soils. The soils vary in plasticity index from non plastic to up to 32 while the linear shrinkage ranges from 0.72 to 17.2 with the clayey charnockite-derived soils having generally high linear shrinkage of > 13.

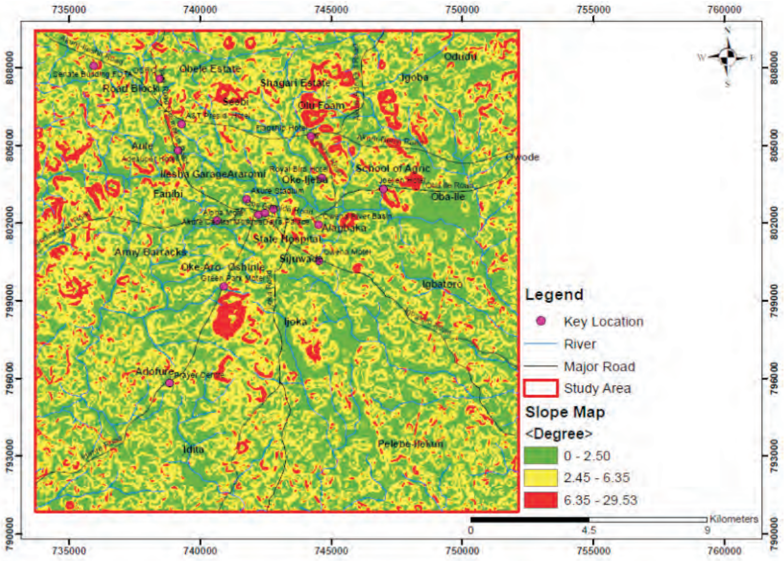

Fig. 6: Slope Map of Akure Metropolis

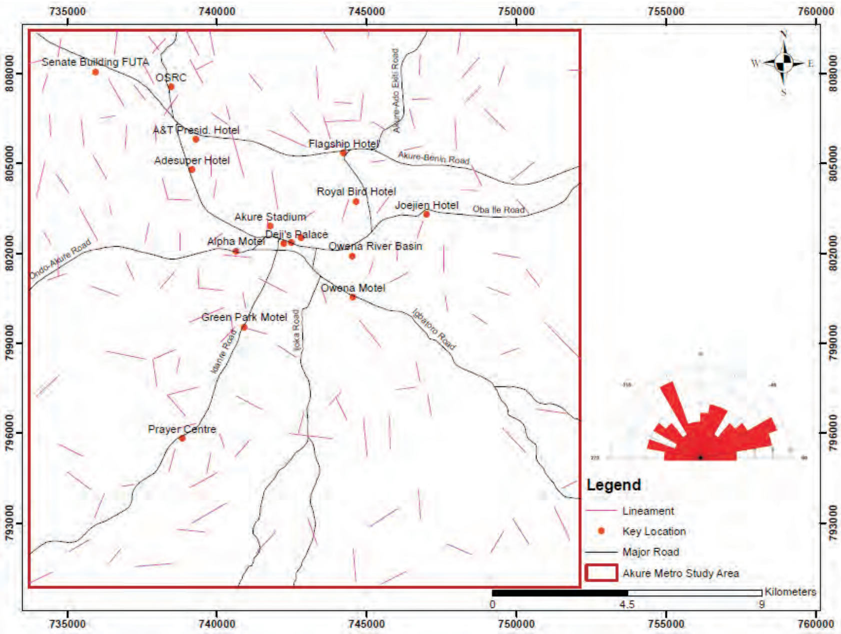

Fig. 7: Lineament Map of Akure Metropolis

Subsurface Geoelectric/Geologic Sequence

The Vertical Electrical Sounding (VES) interpretation results (layer resistivities and thicknesses) show that the VES type curves range from 2-layer to three-layer H; four-layer AA, HA, KH and QH; five-layer AKH, HAK, KHA, KQH and QHA and six-layer HKHA, HKQH, KHKH, KQHA and QHKH type (Fig. 8). The KH and H type curves predominate with frequencies of 26% and 24% respectively (Fig. 8) while the HA and HKH type follow with frequencies of 13% and 11% respectively. The four type curves account for 74% of the total. The geoelectric parameters obtained from the study area are presented in Table 2. The VES interpretation results delineate four main subsurface geologic units.

Table 1: Consistency Test Results.

S/N/Station No.	Geographic Co-ordinates Northings (m)	Eastings (m)	Plasticity Index/	% of Clay Fraction	Linear Shrinkage	Geology
1	804302.666	740076.282	8.11	23.7	13.62	CH
2	804400.871	738768.614	7.72	18.5	12.98	CH
3	804950.720	738090.918	20.41	6.2	11.11	MG
4	803480.841	739141.239	3.6	3.7	7.2	GR
5	803386.419	738672.197	6.81	4.2	8.94	GR
6	803276.903	738902.864	4.88	2.4	5.08	MG
7	802916.444	739346.467	32.03	3.4	3.33	MG
8	802992.392	739806.397	NP	2.4	0.50	MG
9	802652.491	739409.102	16.37	4.2	8.19	MG
10	801307.643	740900.798	2.57	2.3	5.12	MG
11	800849.841	741547.443	NP	1.4	17.2	GR
12	800604.618	741671.375	3.02	2.8	3.47	GR
13	800481.711	741671.967	2.88	1.4	4.39	QTZ
14	799958.323	741459.667	9.91	3.9	5.73	GR
15	799622.070	741823.410	0.39	3.1	4.33	GR
16	799040.063	742200.617	NP	2.3	3.18	QTZ
17	798913.318	742679.980	23.21	6.3	13.17	MG
18	799558.939	742750.517	15.84	5.3	10.37	MG
19	800058.884	743196.156	3.71	2.1	0.72	MG
20	800299.016	743290.128	5.33	2.3	4.08	MG
21	800705.104	743389.431	4.84	5.1	5.81	GR
22	799605.034	740835.317	2.86	2.1	2.96	GR
23	799456.929	740707.134	3.57	2.1	3.90	GG
24	799453.407	739970.626	14.01	2.4	10.71	GG
25	799859.231	740017.789	26.25	2.3	10.53	GG
26	799934.221	740278.280	13.1	2.1	2.38	GG
27	799955.229	740815.225	5.22	0.7	4.14	MG
28	801459.353	743048.205	4.16	3.2	5.18	MG
29	804047.743	742010.718	NP	0.8	-	MG
30	804280.167	739229.471	7.34	21.6	14.03	CH
31	804362.259	743500.535	22.07	6.7	2.78	GR
32	804113.485	742894.160	19.66	8.2	8.63	GR

NP: Non Plastic;CH: Charnockite; MG: Migmatite; GR: Granite; GG: Granite Gneiss
(Source: Owoyemi, 1996)

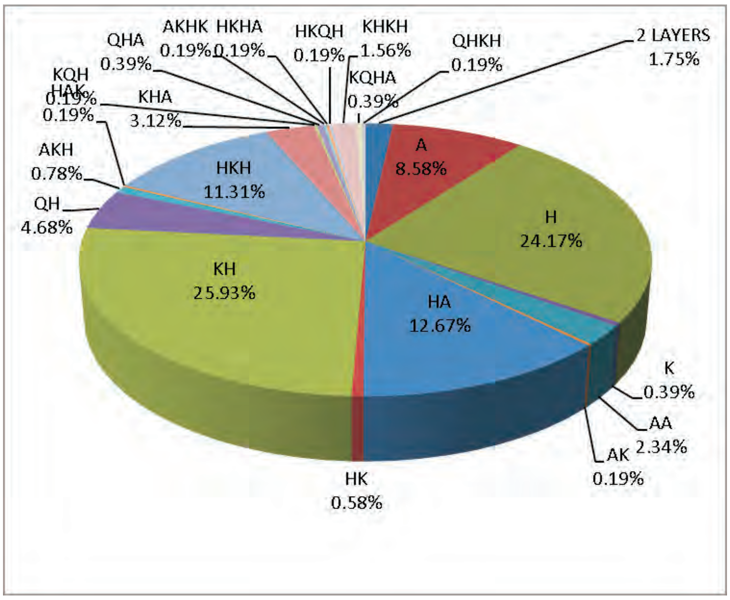

Fig. 8: Pie Chart of VES Type Curve Distribution.

Table 2: Summary of Geoelectric Characterization of the VES Interpretation Results from the Study Area.

Layering	Resistivity Range (ohm - m)	Thickness (m)	Lithologic Description
Topsoil	13 – 7133	0.3 – 5.2	Clay and Sandy Clay, Clayey sand, Sand and Laterite
	Low < 300		Clay and Sandy Clay
	High/Very high > 300		Clayey sand, Sand and Laterite
Weathered layer	6 – 727	0.3 – 106	Clayey, Sandy/Clayey sand
	Low < 100		Clayey
	High > 100		Sandy/Clayey sand
Partly weathered/Basement Bedrock	17 - 985	0.2 – 108	Partly Weathered/Fractured Basement
Basement Bedrock	Generally > 1000	–	Fresh Bedrock

*Depth to Bedrock varies from 0.3 to 108 m

These include the topsoil, weathered basement, partly weathered/fractured basement and the fresh basement bedrock. Table 2 shows that the wide variation in layer resistivity of the topsoil depicts variations in composition (Fig. 3), degree of fluid saturation (or moisture content) and degree of compaction. Also, the weathered layer varies in resistivity and composition depending on the parent rock – typically clayey with low layer resistivity values (< 100 ohm-m) over basic charnockite and sandy/clayey sand (> 100 ohm-m) on fine-coarse grained granitic/gneissic rocks. Two major aquifer units were delineated in the study area. These include the weathered basement and the partly weathered/fractured basement. The two aquifer units occur in five combinations as observed by (Olorunfemi and Fasuyi, 1993; and Bayode *et al.,* 2006). The weathered layer however remains the main aquifer unit.

Constraint Map for Landfill (Waste Disposal) Location

A prospective landfill (or waste disposal) site must meet some selection criteria (Olorunfemi and Ojo, 2001; Robalo and Vendes, 2003 and Choududhury and Das, 2012). These are that: site must be located away from any residential area, it must be located outside protective water supply reservoir or area prone to flooding, site must not be tectonically active (i.e. must be located outside area of known seismicity), drainage system in the area must be such that minimizes seepage water entering the landfill site, the overburden at the site must be thick (8-10 m in Europe) uniform and of low permeability (clayey material) and the landfill floor must be made up of impermeable (clayey) material. Moreover, site must be free from seepage paths such as joints, faults and fractures, vertical or near vertical lithological boundaries or contacts and cavities/sinkholes. It implies from the above that a suitable site for landfill must be characterized by low lineament (fracture/joint) density, significant overburden thickness of > 10 m, clayey overburden and sub-base material with characteristically low resistivity (< 100 ohm-m) and low relief that would not precipitate run-off. However, the nature of the overburden (soil) is determined by the geology.

In this study, thematic maps of soil, geology, distance from drainage, and distance from lineament density, geomorphology and distance from road were synthesis in a GIS environment and used to generate the constraint map for landfill site. The Multi-criteria Evaluation MCE parameters used are contained in Table 3. Figure 9 shows the constraint map for Akure Metropolis. The map classifies the metropolis into three zones – unsuitable (28.6%); moderately suitable (40.4%), and suitable (13%). The suitable sites are scattered and discontinuous all over the metropolis but significantly continuous within the charnockite-derived clayey soils in the northwest.

CONCLUSION

A multi-disciplinary approach involving remote sensing, soil type, geological, geophysical, hydrogeological and engineering geotechnical methods was used to develop a constraint map for landfill (waste disposal) location in Akure Metropolis. Geomorphological map generated from satellite images identifies residual hills, pediments, pediplain and etchplain with elevation of 353 – 470 m, 328 – 353 m, 307 – 328 m and 260 – 307 m respectively above sea level (a.s.l.). The slope (gradient) map displays very low surface gradients (0 - 2.5°) along river channels and the flood plains while areas with moderate and high relief have surface gradients of 2.5 - 6.35° and 6.35 - 29.53° respectively.

The satellite-imagery-delineated lineaments show predominantly NNW-SSE, ENE-WSW and NNE-SSW orientations and subsidiary NW-SE and W-E trends that are typical of the Basement Complex region of Nigeria. The engineering geotechnical investigation shows that charnockite-derived soils exhibited very clayey and silty nature (with % clay content > 18%) and are therefore of lower permeability than the sandy and gravely (with low % clay content < 7%) granite and migmatite gneiss-derived soils. The VES delineate four main subsurface geologic units. These include the topsoil, weathered basement, partly weathered/fractured basement and the fresh basement bedrock. The weathered layer

Table 3 Multi-criteria Evaluation (MCE) Parameters for the Generation of Groundwater Potential Map

S/N	Thematic Map (Layer)	Attribute	Suitability Score	Weightage (%)
1	Soil	Iwo	2	30
		Ondo	5	
		Itagunmodi	8	
2	Lineament Density (km/sq. km)	0-0.16	1	30
		0.16-0.43	2	
		0.43-0.70	5	
		0.70-1.06	7	
		1.06-1.96	8	
3	Distance from Drainage (km)	0-0.4	1	15
		0.4-0.8	2	
		0.8-1.2	3	
		1.2-1.6	5	
		1.6-2.0	6	
		2.0-2.4	7	
		2.4-2.8	8	
4	Geomorphology	Residual Hill	3	10
		Pediment	5	
		Pediplain	7	
		Etchplain	1	
5	Geology (Lithology)	Charnockite	8	10
		Biotite Granite	5	
		Migmatite Gneiss	4	
		Porphyritic Granite	2	
6	Distance from Road	0-1000	1	5
		1000-2000	3	
		2000-3000	5	
		3000-4000	6	
		4000-5000	7	

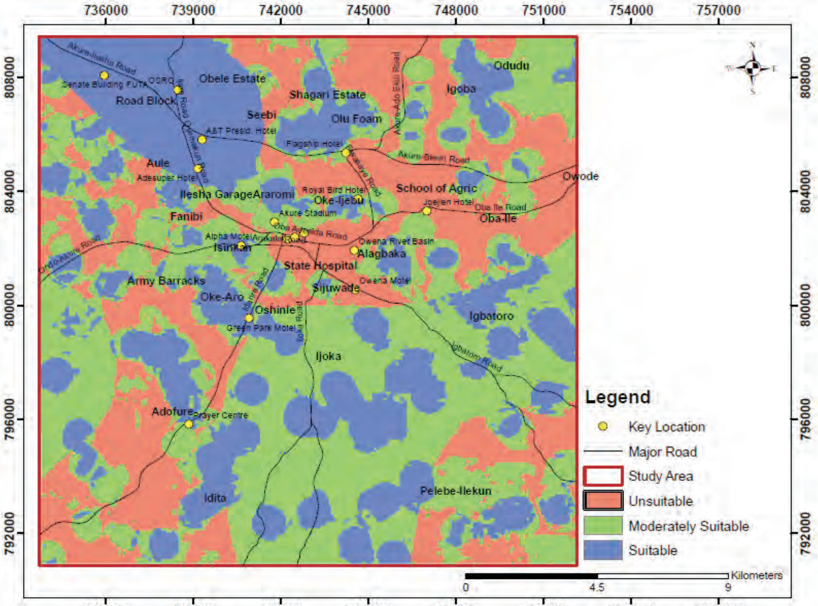

Fig. 9: Constraint Map for Landfill Site Location in Akure Metropolis

varies in resistivity and composition depending on the parent rock – typically clayey with relatively low layer resistivity values (< 100 ohm-m) over basic charnockite and sandy/clayey sand (> 100 ohm-m) on fine-coarse grained granitic/gneissic rocks. The estimated thicknesses to the bedrock range from 0.3 m and 106 m. Thematic maps of geomorphology, slope, lineaments, engineering geotechnical and geophysical characteristics were synthesized in a GIS environment to generate a constraint map which classifies the Akure Metropolis into three landflll suitability zones - unsuitable (28.6%); moderately suitable (40.4%), and suitable (13%). The suitable sites are scattered and discontinuous all over the metropolis but significantly continuous within the charnockite-derived clayey soils in the northwestern part of the study area.

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