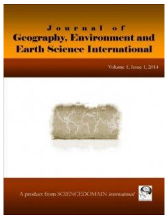

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Subsoil Competence Characterization of the Akure Metropolis, Southwest Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Authors JSO and MOO designed the study, wrote the protocol, authors MOO and OJA analysis the data, wrote the first and final draft of the manuscript. Authors SB and GOO managed the literature searches, author FOA handled the GIS aspects. All authors read and approved the final manuscript.

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ABSTRACT

Five hundred and thirteen Vertical Electrical Sounding data sets were acquired within the Akure9. Metropolis, processed and interpreted quantitatively. Akure Metropolis lies within Latitudes 07°10. 09' and 07° 19'N and Longitudes 05° 07' and 05° 17'E and covers an areal extent of about 340 km^2. The soil map of the study area was extracted from existing soil map and subsequently digitized. Geologic lineaments were delineated from satellite imageries acquired for the study area. The VES interpretation results delineate four subsurface layers which include the topsoil, weathered Basement, partly weathered/fractured basement and the fresh basement. The layer resistivity values for the topsoil used in this study range from 13 – 7133 ohm-m with layer thicknesses of between 0.3 and 5.2 m. Three major soil associations were identified. These include Iwo, Ondo and

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Itagunmodi Associations. The satellite-imagery-delineated lineaments show predominantly NNW-SSE, ENE-WSW and NNE-SSW orientations with subsidiary NW-19. SE and W-E trends. The topsoil resistivity, lineament density and soil thematic maps were integrated in a GIS environment to generate the subsoil competence map which classifies the Akure Metropolis into low competence (3.5%), moderately competent (26.6%) and highly competent (69.9%) zones. The study concluded that most parts (96.5%) of the metropolis are underlain by moderately to highly competent subsoil.

Keywords: Topsoil resistivity; soil, lineament density; subsoil competence; Akure Metropolis.

1. INTRODUCTION

Akure, the Ondo State capital, continues to witness rapid development in physical infrastructures such as housing, estate, road and bridge construction and other civil engineering works. However, engineering design and construction of foundation, especially of high rise buildings, dams, highway routes and bridges require a sound knowledge of the subsurface. Information are often needed on the configuration of the subsurface layers, the nature/competence of the subsoil, the bedrock topography and its structural disposition to enable structures to be designed and located to suit the variable character of the bedrock [1]. Where construction works have been carried out without taking cognizance of the site's geological, geomorphological and groundwater conditions, failure of foundation and structures have often occur [2-6]. The development of a subsoil competence map for the Akure Metropolis can therefore be very useful for short and long term planning.

The characterization of sites earmarked to host developmental projects is carried out as a matter of routine in developed countries and in keeping with relevant legislation [7]. This is done either to establish the suitability of the characteristics of such sites to host planned structures or to determine the likely impact such structures may have on the environment when eventually implemented [8]. The competence (or strength) of the subsoil is influenced by factors such as mineralogy, the character of the particles contact, rock texture, agents of weathering and the degree of compaction and cementation [9].

Subsoil strength investigation traditionally involves soil boring (auger or cone penetration), and soil sample testing for geotechnical properties such as grain size distribution, plasticity characteristics (index properties), bearing capacities and consolidation/ compressibility characteristic determination [10]. The plasticity index can be used as an index of subsoil competence evaluation as shown in Table 1.

However, engineering geophysics offers a wide spectrum of methods that can be used in site testing. The electrical resistivity method is the most frequently used in site investigation because the electrical resistivity of earth materials is determined by the amount and concentration of saturating fluid, degree of fracturing, rock texture, degree of grain cementation, degree of compaction and the extent of weathering [11,8] that significantly determine the competence of such earth materials. Clays, characterized by low resistivity values (< 100 ohm-m), are regarded as incompetent materials as they tend to flow under stress [5]. Whereas high resistivity laterites, compacted earth materials and crystalline rocks are regarded as competent, as they withstand stress. It has therefore been possible to relate resistivity with subsoil competence as shown in the Table 2. Electrical resistivity is also correlated with geotechnical index properties [12]. Soils with higher liquid limit or plasticity index have lower electrical resistivity [13] and hence lower competence. Other factors that can be used in the assessment of soil/subsoil competence is the nature of the soil which derives from the geology and lineament density.

Table 1. Engineering classification using plasticity index [10]

Plasticity index range	Index classification	Casagrande plasticity classification
< 10	Low	Low plasticity/low compressibility. High competence.
10 – 20	Medium	Medium plasticity/medium compressibility. Moderate competence
> 20	High	High plasticity/high compressibility. Low competence

Table 2. Rating of subsoil competence using Resistivity values [8]

App. resistivity range (ohm-m)	Lithology	Competence rating
< 100	Clay	Incompetent
100 – 350	Sandy clay	Moderately competent
350 – 750	Clayey sand	Competent
> 750	Sand/Laterite/Crystalline Rock	Highly competent

This study therefore intends to integrate topsoil resistivity, lineament density and soil in the GIS environment to generate subsoil competence map for Akure Metropolis. The generated map will be validated using existing geotechnical data.

2. DESCRIPTION OF THE PROJECT ENVIRONMENT

2.1 Geographic Location, Physiography and Drainage

The study area (Akure Metropolis) lies within Latitudes 07° 09' and 07° 19'N and Longitudes 05°07' and 05° 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 [14]. The metropolis is drained by several streams and rivers.

2.2 Geology and Structures

The geological mapping and other related studies of the area around the Akure Metropolis have been carried out by several workers amongst whom are [15-17,14,18-20]. The area around the Akure Metropolis is underlain by four of the six petrological units of the Basement Complex of Southwestern Nigeria identified by [21] and also described by [16,19,21]. These are the Migmatite-Gneiss Quartzite Complex, Charnockitic and Dioritic rocks, Older Granites and Unmetamorphosed dolerite dykes (Fig. 2). The basement rocks exhibit 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.

Numerous small and long fractures, joints and fissure zones which generally trend north south are common. These structural trends fall within the principal basement complex fracture direction identified by [22]. Lineaments extracted from aerial photographs, satellite imageries and Side Looking Airborne Radar (RADAR) imageries over Akure area showed that the lineaments predominantly trend in the ENE-WSW direction [14,18].

2.3 Soils

The nature of residual soils (excluding the very thin topmost layer) in Akure is determined by the underlying geology. There are three major soil associations in the study area (Fig. 3). These include Iwo, Ondo and Itagunmodi Associations [23]. The Iwo soil type is located on coarse grained granite and gneiss underlain area. The soil is composed of coarse textured, grayish brown to brown sandy to fairly clayey soils. The soil type occupies the central, northeastern/northwestern and southwestern part of the survey area. The sandy nature of this soil makes it competent for civil engineering foundation. The Ondo Association overlies the medium grained granite and gneiss underlain areas. The soil comprise fine to medium textured, orange brown to brownish red fairly clayey soils overlying orange, brown to red mottled clay. This soil type is located in the eastern/southeastern and western part of the study area. It is next in competence to the Iwo Association. The Itagunmodi Association is located on amphibolite and related basic rocks. The soil is composed of fine textured, brownish red or chocolate brown, very clayey soil. It is the least competent of all the soils because of its clayey nature.

3. METHODOLOGY

Soil samples were collected from thirty two (32) geo-referenced locations (Fig. 4) from the study area [14]. The samples were analysed for liquid and plastic limits, plasticity index, linear shrinkage and percentage clay content. Geophysical investigation involving the electrical resistivity method and the Vertical Electrical Sounding (VES) technique adopting a Schlumberger array was carried out. 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, terrain, accessibility and representativeness of the spread of the stations.

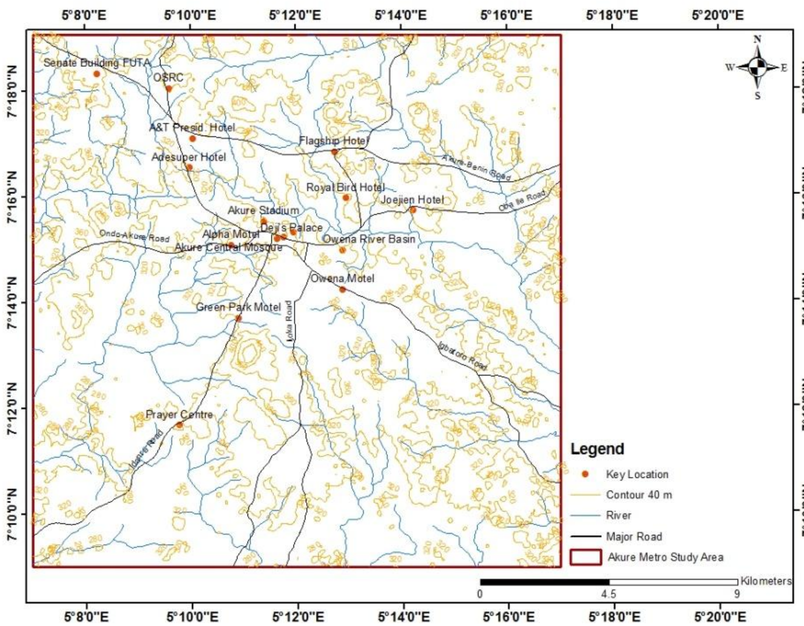


Fig. 1. Map of Akure metropolis – The study area, showing the topographic variations

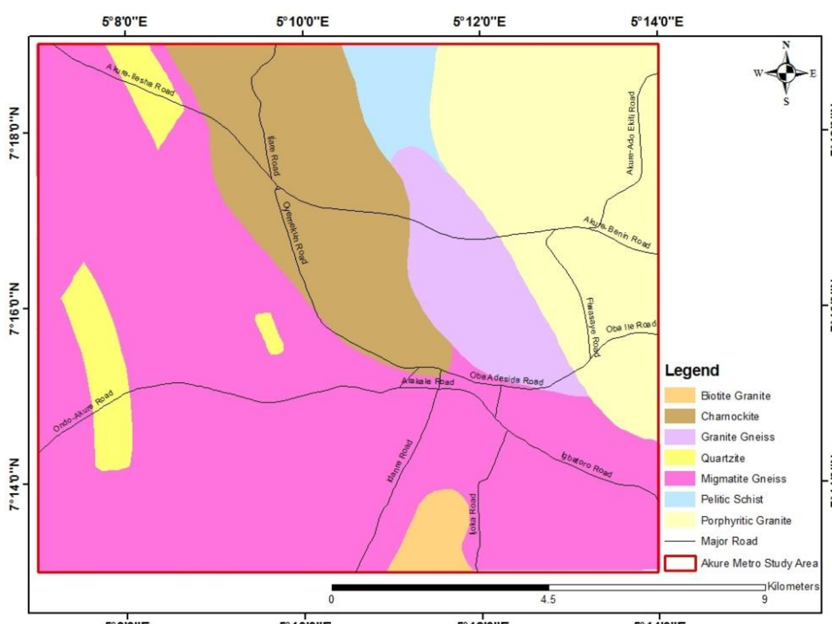


Fig. 2. Geological map of Akure metropolis [14]

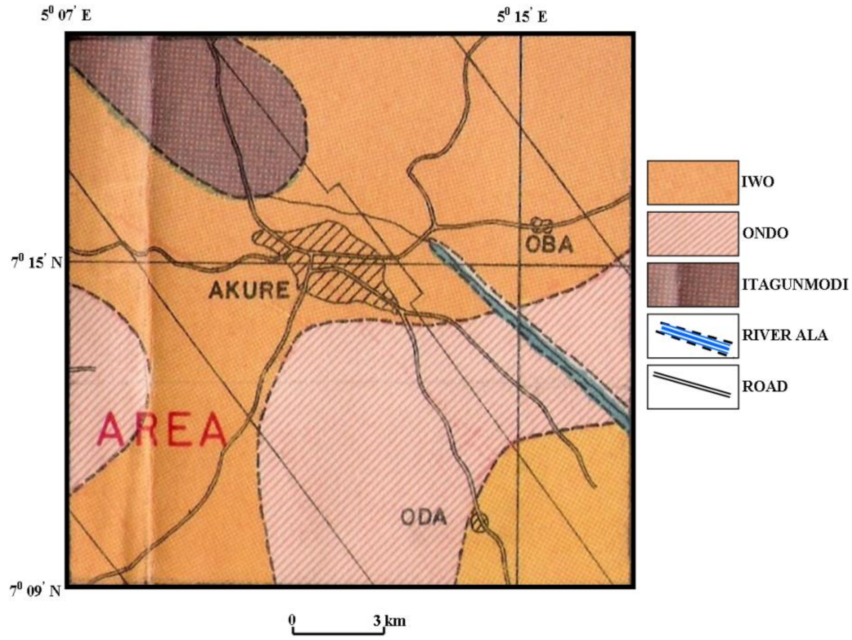


Fig. 3. Soil map of the area around Akure metropolis (Extracted from [23])

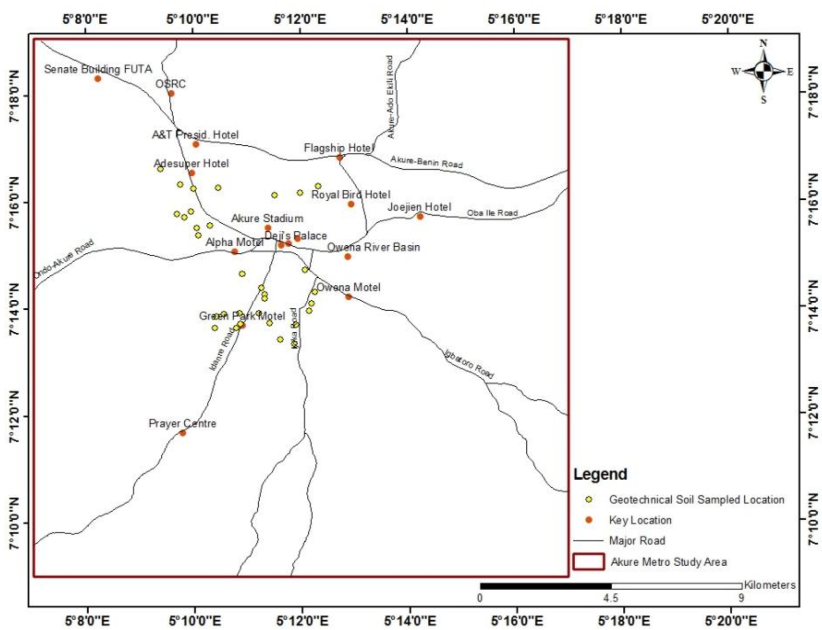


Fig. 4. Geotechnical soil sample location map

The apparent resistivity values were calculated from the equation:

$$\rho_a = \pi \frac{RL^2}{2l}$$

where ρ_a is the apparent resistivity R is the ground resistance (note R=ΔV/I) ΔV is the potential difference I is the energizing current L (AB/2) is half the current-current electrode spacing l is half the potential-potential electrode spacing and π is a constant (22/7).

Every VES station was appropriately geo-referenced. Secondary VES data were assessed, re processed and incorporated.

Four Hundred and two (402) Vertical Electrical Sounding (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 sets from 116 localities were acquired (Fig. 5). 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 (Fig. 6). The interpretation results (layer resistivities and thicknesses) were used for geoelectrical characterization. Subset Topographic map, Aster DEM, Landsat EMT+ surface reflectance image of 2002 of the study area were pre-processed for geometric correction, haze reduction and re-sampling. The input space data utilized are Landsat ETM+ (Fig. 7) and Aster DEM. LandsatETM+ (Fig. 8) exhibit three spatial resolutions; 28.5 m, 57 m and 14.25 m for six spectralbands, one thermal and one panchromatic channel respectively. While Aster DEM has 30 m resolution. 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 3 X 3 window size, histogram equalization, de-correlation stretch, principal component analysis (PCA) and the Aster DEM to topographic analysis such as sink fill and GIS derived hillshade layer (Fig. 9) to generate the lineament map (Fig. 10). The soil map for the study area was extracted from an existing soil map [23] and subsequently digitized.

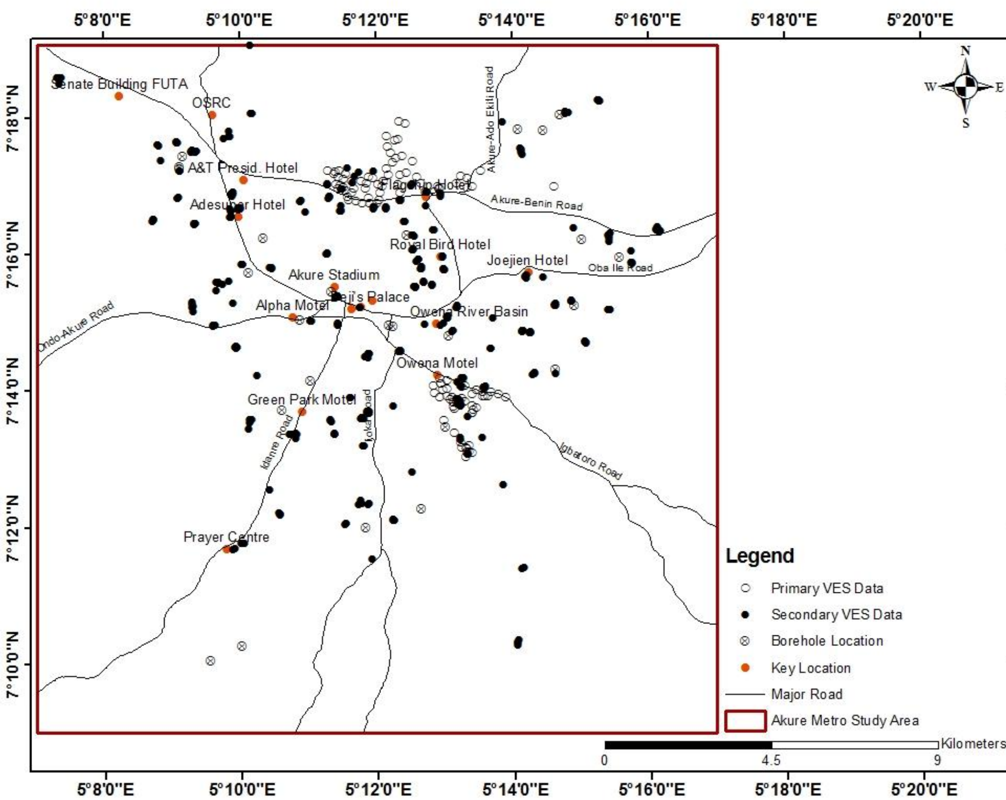
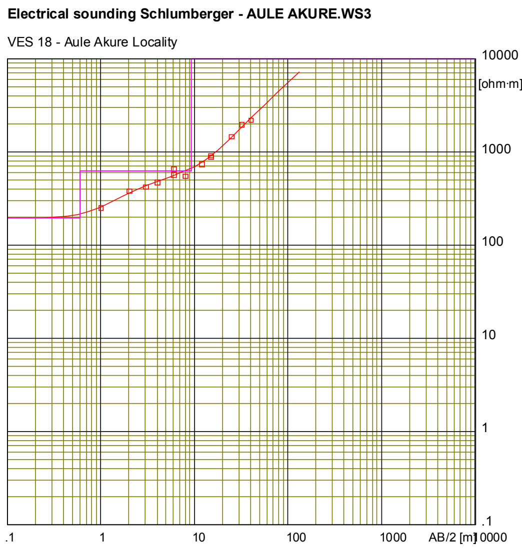
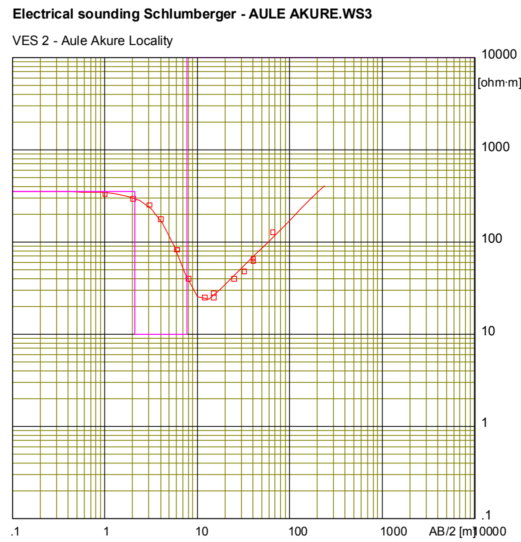


Fig. 5. Geophysical (VES) and borehole data acquisition map



Model Resistivity [ohm·m]	Thickness [m]	Depth [m]
194	.6	
625	8.8	.6
99999		9.4

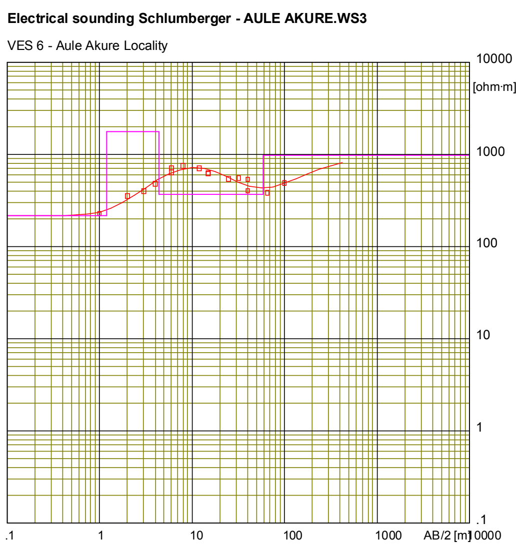
(a)



Model Resistivity [ohm·m]	Thickness [m]	Depth [m]
349	2.1	
10	5.7	2.1
100000		7.8

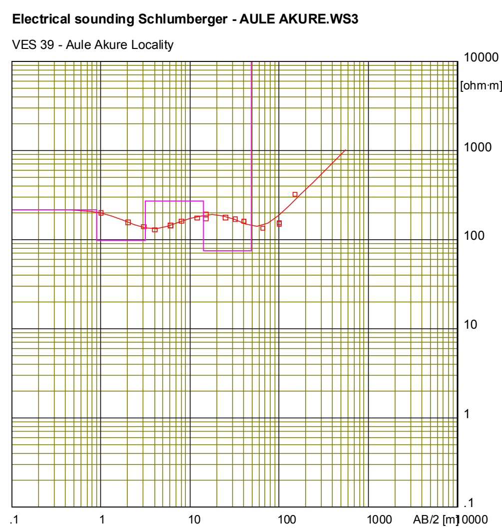
(b)

Fig. 6 (a and b). Typical 'A' and 'H' type sounding curve



Model Resistivity [ohm·m]	Thickness [m]	Depth [m]
214	1.2	
1749	3.2	1.2
368	54	4.4
966		58

(c)



Model Resistivity [ohm·m]	Thickness [m]	Depth [m]
216	.9	
97	2.3	.9
271	11	3.2
74	35	14
99999		49

(d)

Fig. 6 (c and d). Typical 'KH' and 'HKH' type sounding curve

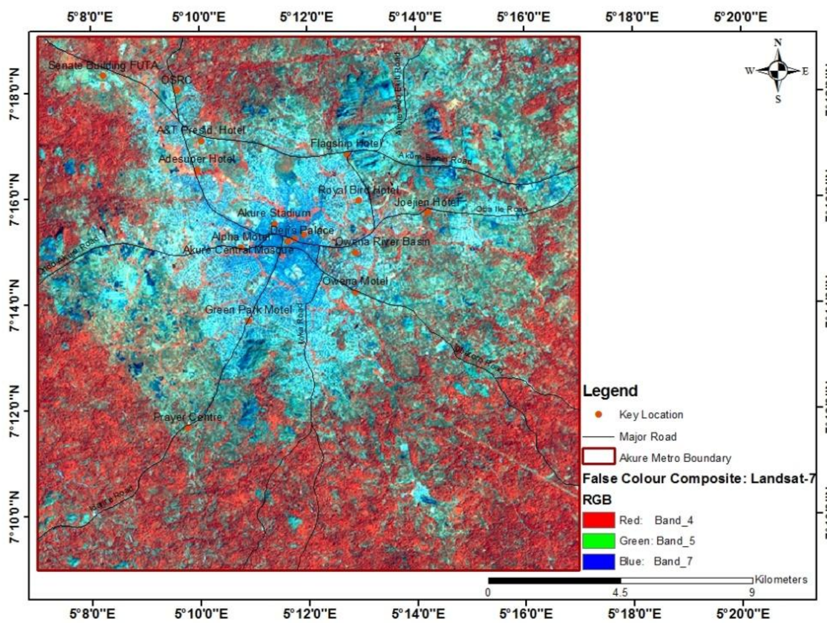


Fig. 7. Landsat ETM+ of the study area

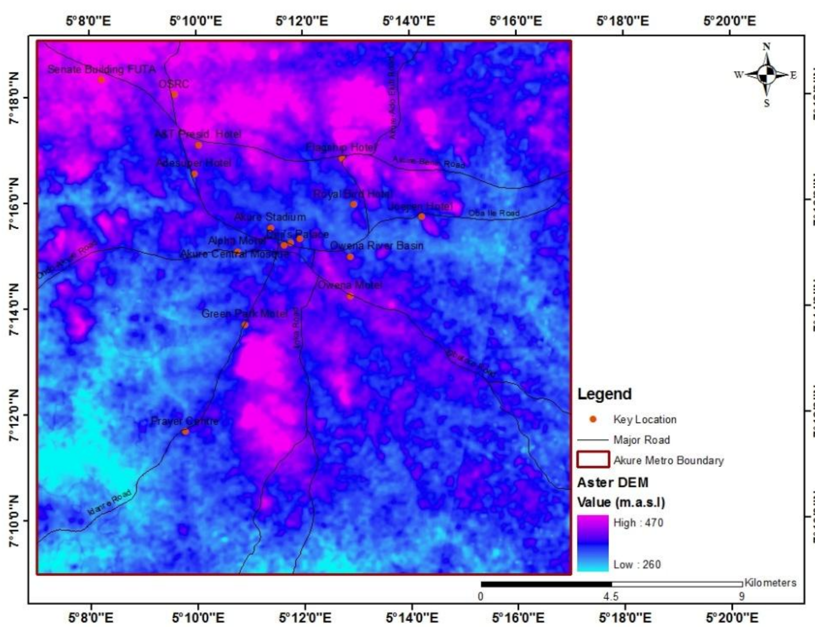


Fig. 8. Digital Elevation Model (DEM) of the study area

3.1 Interpretation Accuracy

Quantitative interpretation of VES curves assumes that the earth is made up of horizontal layers with differing resistivities. Any significant deviation (> 10°) from this planar assumption will distort the VES curve and lead to interpretation error. Other sources of error are lateral inhomogeneity, suppression and equivalence. However, in simple geologic setting with horizontal or near horizontal stratification, VES determined depth-to-geologic interface could be accurate to within 10%.

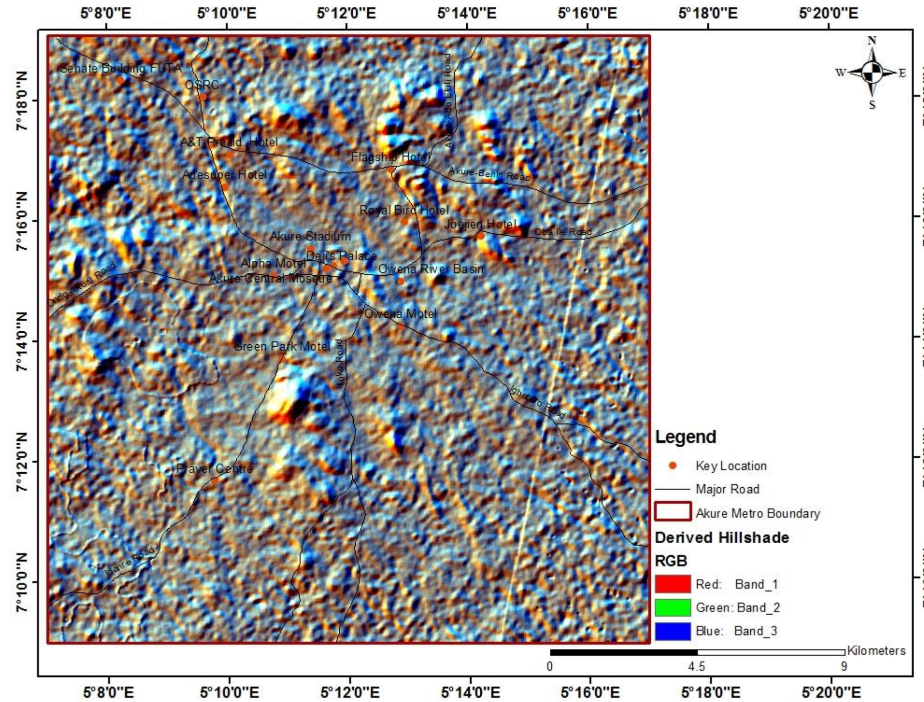


Fig. 9. Derived Hillshade map of the study area

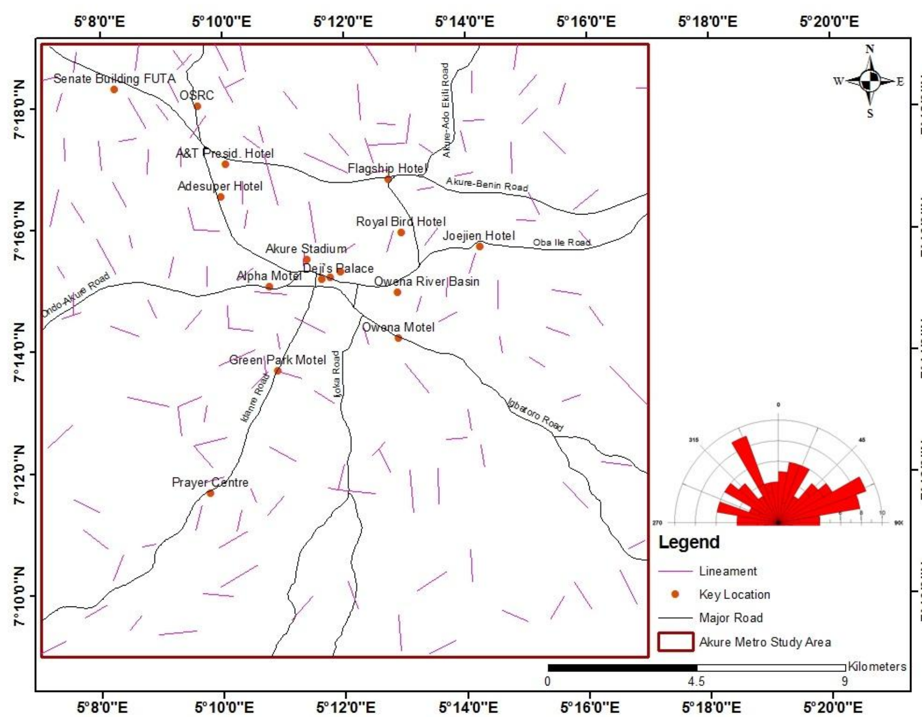


Fig. 10. Lineament map of Akure metropolis

4. RESULTS AND DISCUSSION

4.1 Engineering Geotechnical Investigation

Table 3 displays the consistency results. The charnockite-derived soils exhibit very clayey and silty nature (with % clay content > 18%) and are therefore less competent 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 > 13). The consistency test results were used in conjunction with Table 1 to validate the subsoil competence map generated from integrated topsoil resistivity, soil and lineament density.

4.2 Subsurface Geoelectric / Geologic Sequence

The VES interpretation results delineate four main subsurface geologic units. These include the topsoil, weathered basement, partly weathered/fractured basement and the fresh basement bedrock. The topsoil is the uppermost layer which, at some localities, is underlain by a lateritic layer. The layer resistivity values vary widely between 13 ohm-m and 7133 ohm-m with the highest frequency of occurrence between 13 and 300 ohm-m. The wide variation in layer resistivity depicts variations in composition, degree of fluid saturation (or moisture content) and degree of compaction. The low resistivity (< 300 ohm-m) end of the resistivity spectrum is typical of clay and sandy clay while the high/very high resistivity end (> 300 ohm-m) is diagnostic of clayey sand, sand and laterite. The topsoil thicknesses range in value from 0.3 m to 5.2 m but are generally less than 1.5 m. The topsoil becomes thicker when it is underlain by a lateritic layer or merges, in resistivity, with the underlying weathered basement. The topsoil resistivity values were used in the generation of the subsoil competence map. The weathered layer underlies the topsoil directly in most places unless where the fresh basement rock occurs at shallow depth (nearly outcropping). The layer resistivity values range between 6 ohm-m and 727 ohm-m with the highest frequency in the 6-150 ohm-m range.

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. The weathered layer thicknesses vary between 0.3 m and 106 m. The partly weathered/fractured basement column sometime underlie the weathered layer directly (as unconfined fractured basement) or occurs within fresh basement rock (as confined fractured basement) [24-28]. This geologic layer was only delineated beneath some VES stations.

The layer resistivity values range from 17 ohm-m to 985 ohm-m with the highest frequency in the 17-300 ohm-m range. The thickness of this horizon varies from 0.2 m to 108 m but is generally less than 25.0 m. The fresh basement rock is typically characterized by layer resistivity values greater than 1000 ohm-m. Lower resistivity values (< 1000 ohm-m) were obtained at locations where the overlying layer is very conductive leading to a screening effect and an underestimation of the resistivity of the expectedly infinitely resistive basement rock.

4.3 Geologic Lineament

The satellite-imagery-delineated lineaments (Fig. 10) show predominantly NNW-SSE, ENE-WSW and NNE-SSW trends and subsidiary NW-SE and W-E orientations that are typical of the Basement Complex region of Nigeria [22,14,18].

4.4 Soils

Three major soil associations were identified in the study area. These include the Iwo, Ondo and Itagunmodi Associations. The soil associations have been described in the introductory section.

4.5 Subsoil Competence Map

In this study, thematic maps of the topsoil resistivity, lineament density and soil were integrated to generate a subsoil competence map for the Akure Metropolis The maps (data sets) were imported into the GIS for storage followed by the allocation of weights to each layer and different scores to each attributes within the layers (see Table 4) using reclassification and buffer generation methods.

The subsoil competence map was finally composed using overlay function to combine all the layers. Fig. 11 shows the generated subsoil competence map for the study area. The map was validated using twenty eight (28) plasticity index data and casagrande plasticity classification in Table 1 with a 68% correlation (Table 5).

The subsoil competence map classifies the study area into low competence (3.5%); moderately competent (26.6%) and highly competent (69.9%) subsoil. Most parts (96.5%) of the metropolis are underlain by moderately to highly competent subsoil. The small patches of incompetent subsoil are located in the area around Ade Super Hotel and A&T Presidential Hotel, some parts of FUTA (which already has witnessed spate of structure foundation failures), Alejolowo/Bayduk area and small part of Pelebe-Ilekun.

Table 3. Consistency test results

Station no.	Geographic Co-ordinates		Plasticity index/	% of Clay fraction	Linear shrinkage	Geology
	Northings (m)	Eastings (m)				
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, [14])

Table 4. Multi-criteria evaluation (MCE) parameters for the subsoil competence map

S/N	Thematic map (Layer)	Attribute	Rating	Weightage (%)
1	Topsoil resistivity (ohm-m)	23.47-99.10	1	50
		99.10-348.88	3	
		348.88-750.26	4	
		> 750.26	5	
2	Soil	Itagunmodi	1	30
		Ondo	3	
		Iwo	5	
3	Lineament density	0-0.19	5	20
		0.19-0.52	4	
		0.52-0.90	2	
		0.90-1.96	1	

Table 5. Validation parameters for the subsoil Competence Map

Station no.	Geographic Co-ordinates		Plasticity index/ subsoil competence rating	Rating from subsoil competence map
	Northings (m)	Eastings (m)		
1	804302.666	740076.282	8.11 (HC)	HC
2	804400.871	738768.614	7.72 (HC)	LC
3	804950.720	738090.918	20.41 (LC)	MC
4	803480.841	739141.239	3.6 (HC)	HC
5	803386.419	738672.197	6.81 (HC)	HC
6	803276.903	738902.864	4.88 (HC)	HC
7	802916.444	739346.467	32.03 (LC)	HC
8	802992.392	739806.397	-	-
9	802652.491	739409.102	16.37 (MC)	HC
10	801307.643	740900.798	2.57 (HC)	HC
11	800849.841	741547.443	-	-
12	800604.618	741671.375	3.02 (HC)	HC
13	800481.711	741671.967	2.88 (HC)	HC
14	799958.323	741459.667	9.91 (HC)	HC
15	799622.070	741823.410	0.39 (HC)	HC
16	799040.063	742200.617	-	-
17	798913.318	742679.980	23.21 (LC)	MC
18	799558.939	742750.517	15.84 (M)	MC
19	800058.884	743196.156	3.71 (HC)	HC
20	800299.016	743290.128	5.33 (HC)	HC
21	800705.104	743389.431	4.84 (HC)	HC
22	799605.034	740835.317	2.86 (HC)	HC
23	799456.929	740707.134	3.57 (HC)	HC
24	799453.407	739970.626	14.01 (MC)	MC
25	799859.231	740017.789	26.25 (LC)	MC
26	799934.221	740278.280	13.1 (MC)	MC
27	799955.229	740815.225	5.22 (HC)	HC
28	801459.353	743048.205	4.16 (HC)	HC
29	804047.743	742010.718	-	-
30	804280.167	739229.471	7.34 (HC)	LC
31	804362.259	743500.535	22.07 (LC)	HC
32	804113.485	742894.160	19.66 (MC)	HC

LC: Low Competence; MC: Moderate Competence; HC: High Competence (After [10])

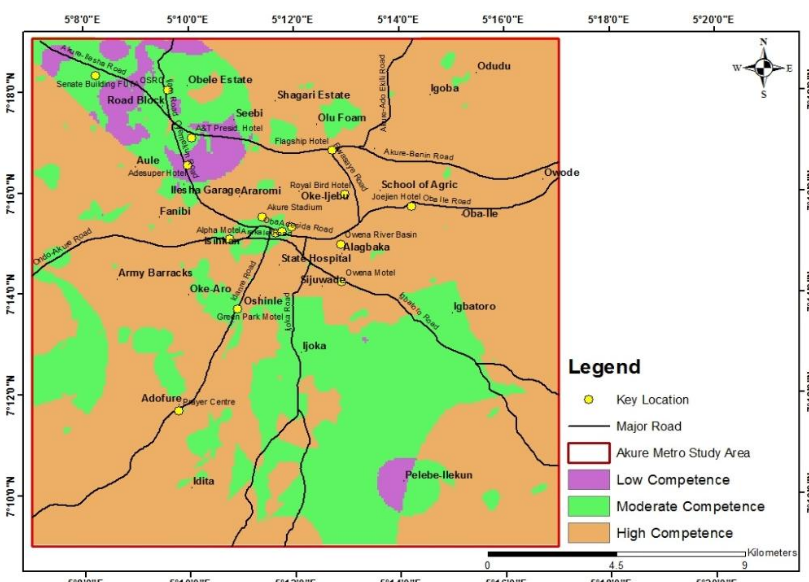


Fig. 11. Subsoil competence map of Akure metropols

5. CONCLUSION

The Akure Metropolis is located on a gently undulating terrain surrounded by isolated hills and inselbergs and drained by several streams and rivers. The area is underlain by the Migmatite

Gneiss-Quartzite Complex, Charnockitic and Dioritic rocks, Older Granites and Unmetamorphosed dolerite dykes. There are three major soil associations in the study area. These include Iwo, Ondo and Itagunmodi associations. Five hundred and thirteen Vertical Electrical Sounding data sets were acquired within the study area, processed and interpreted quantitatively. Geologic lineaments were delineated from satellite imageries acquired for the study area. The VES interpretation results delineate four subsurface layers which include the topsoil, weathered basement, partly weathered/fractured basement and the fresh basement. The layer resistivity values for the topsoil used in this study range from 13–7133 ohm-m with layer thicknesses of between 0.3 and 5.2 m.

The weathered layer resistivity ranges from 6–727 ohm-m with thicknesses of between 0.3 and 106 m. The partly weathered/fractured basement has layer resistivity and thickness ranges of 17–985 ohm-m and 0.2–108 m. the fresh basement bedrock has layer resistivity values that are generally greater than 1000 ohm-m. The satellite-imagery-delineated lineaments show predominantly NNW-SSE, ENE-WSW and NNE-SSW orientations with subsidiary NW-SE and W-E trends and lineament densities that range from 0-1.96. The topsoil resistivity, lineament density and soil thematic maps were integrated in a GIS environment to generate the subsoil competence map. The map was validated using twenty eight (28) plasticity index data and casagrande plasticity classification.

The subsoil competence map classifies the study area into low competence (3.5%); moderately competent (26.6%) and highly competent (69.9%) subsoil. Most parts (96.5%) of the metropolis are underlain by moderately to highly competent subsoil. The small patches of incompetent subsoil are located in the area around Ade Super Hotel and A&T Presidential Hotel, some parts of FUTA, Alejolowo/Bayduk area and small part of Pelebe-Ilekun.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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