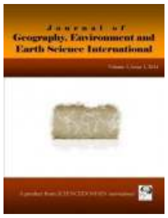

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Application of Geotechnical and Geophysical Methods for Engineering Site Evaluation of Emure-Ile, Southwestern, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Authors OOF and OEB designed the study, wrote the protocol. Authors MPO and VO analyzed the data and managed the experimental processes. Author EGI managed the literature searches. All authors read and approved the final manuscript, which was written by author OOF.

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ABSTRACT

Subsoil competence evaluation was carried out in Emure Ile area of Ondo State, Southwestern Nigeria, with the aim of evaluating the competence of the subsurface geology in hosting civil engineering structures. Geotechnical investigation involved analysis of six soil samples for mechanical strength and soil classification test. The geophysical methods used were magnetic, Very Low Frequency Electromagnetic and Electrical resistivity. The geotechnical characteristics of the sampled soils showed that the subsoil is clay-sand with medium plasticity/compressibility at moderate compaction and strength characteristics. The magnetic and VLF – EM showed a correlated fairly conductive subsoil indicating a clayey material with few structural features. The

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VES interpretation results delineated four subsurface layers which included the topsoil, weathered Basement, partly weathered/fractured basement and the fresh basement. The layer resistivity values for the topsoil used in this study ranged from 30 – 5220 ohm-m with layer thicknesses of between 0.5 m and 6.1 m. The depth to bedrock was generally 20 m, but could be thicker at the central part of the town i.e. greater than 20 m. Corrosivity potential of the soil was generally minimal at 10 m; therefore this depth would suit the burial of metallic objects. The competency map of the area classified the area into moderate competence (40%) and low competence (20%). Most parts of the area were underlain by moderate competent subsoil (65%), while low competence (35%) was prominent around the northwestern – southwestern parts of the study area. Therefore this work has showed the importance of integrated geophysical and geotechnical techniques in engineering subsoil characterization.

Keywords: Corrosivity; competence; evaluation; subsoil; geotechnical; site investigation.

1. INTRODUCTION

All important Civil Engineering projects like dams, reservoirs, tunnels, roads, bridges and buildings etc. are constructed on rocks or on soils. It is, therefore, essential that the engineer should have fullest knowledge possible of the strata or soil through which works of construction are carried out or on which these have to rest. When the geological characters of the site or of alignment are not properly investigated or properly interpreted, the structures might involve considerably higher costs. Not only that, their stability might be in question [1].

Many dam disasters, foundation failures in buildings, collapse of bridges and tunnels were found to be closely related to ignorance of geological conditions that existed in and around these structures. Therefore one of the priority considerations in the design of such structures is the pre-construction investigation of the subsurface at the proposed site in order to ascertain the fitness of the host earth material [2].

Therefore geotechnical and geophysical methods are routinely used in engineering site characterization, as they provide subsurface information that assists civil engineers in the design of foundation of civil engineering structures. The primary purpose of all site investigations is to obtain the data needed for analysis and design. In present day Civil engineering construction, it is almost mandatory to decide about the location; design and construction of all major structures only after geological characters of the area have been investigated and recorded to the last detail. The necessity for site characterization for construction purposes has therefore become very vital so as to prevent loss of valuable lives and properties that always characterized structural failure [3].

Subsequently, this research work aims at integrating geophysical methods with geotechnical data to proffer solutions to the collapse of buildings in the studied area and the possible precautions to avoid this devastating incidence. Partial defects are noticeable on building and fence walls around the area.

This is a deviation from the conventional engineering soil characterization methods that lack complete imaging of the subsurface. Geophysical data interpretation can image the subsurface to the depths of competent layer and evaluate the real distribution of geological earth material [4].

Thus, to thoroughly investigate the study area - Emure-Ile town of Ondo State, It was decided to use integrated geophysical methods with geotechnical analysis of sampled soils within the study area with the aim of delineating the subsurface geologic layers and determining the nature of the identified layers; determine the overburden thickness or depth to competent bedrock; delineating any existing geologic structures such as faults, fractured zones, basement depression, cavities etc; mapping the bedrock topography; and determine the geotechnical characteristics of the soil at a depth not less than 5 m.

2. DESCRIPTION OF THE STUDY AREA

2.1 Geographic Location, Physiographic Features and Drainage

The study area is Emure Ile town which is situated in Owo Local Government area of Ondo State. It is approximately 30 km away from

Akure, along Akure – Owo highway. It is one of the major towns that bordered Owo town (Fig. 1). Emure Ile lies within Latitudes 07° 00' and 07° 30'N and Longitudes 05°15' and 05° 45'E.

The surrounding topography is gently undulating with gently rising isolated hills attaining heights of over 350 m, whereas the intervening topographic lows are about 300 m (Fig. 2).

The temperature of the area ranges from 24°C to 27°C. The annual rainfall of the area varies from 1000 mm to 1500 mm [5]. Ajangbasa stream and Aboludo stream which are tributaries of Ogbese river drained the area. The directions of flow of the streams are toward the North and Northeast directions in the town.

2.2 Geology and Structures

Field observations revealed exposures of rocks underlying the area along the stream channels and on the slopes bordering the channels. The rocks are mainly migmatite and granite gneiss classified by GSD [6] as undifferentiated Basement rocks of Nigeria (Fig. 3).

The migmatite consist of biotite gneiss, granite, and gneiss as members. The granite is weakly foliated and appears to have resulted from granitization of biotite gneiss and gneiss members. The gneiss in the migmatite has well developed leucocratic/melanocratic banding.

The major structural elements in the rocks are foliation, fractures, lineation, microfolds, veins and microdykes. Fractures on migmatite and gneiss in the study area trend mostly in Northeastern – Southwestern and East – West directions. There are three major soil associations around the area (Fig. 4). These include Iwo, Ondo and Okemesi Associations [7]. The study area is located on Ondo Soil Formation Group which is a well drained, medium to fine textured, Orange to Brownish Red, Fairly clayey soils overlying orange, yellow and white motted clay.

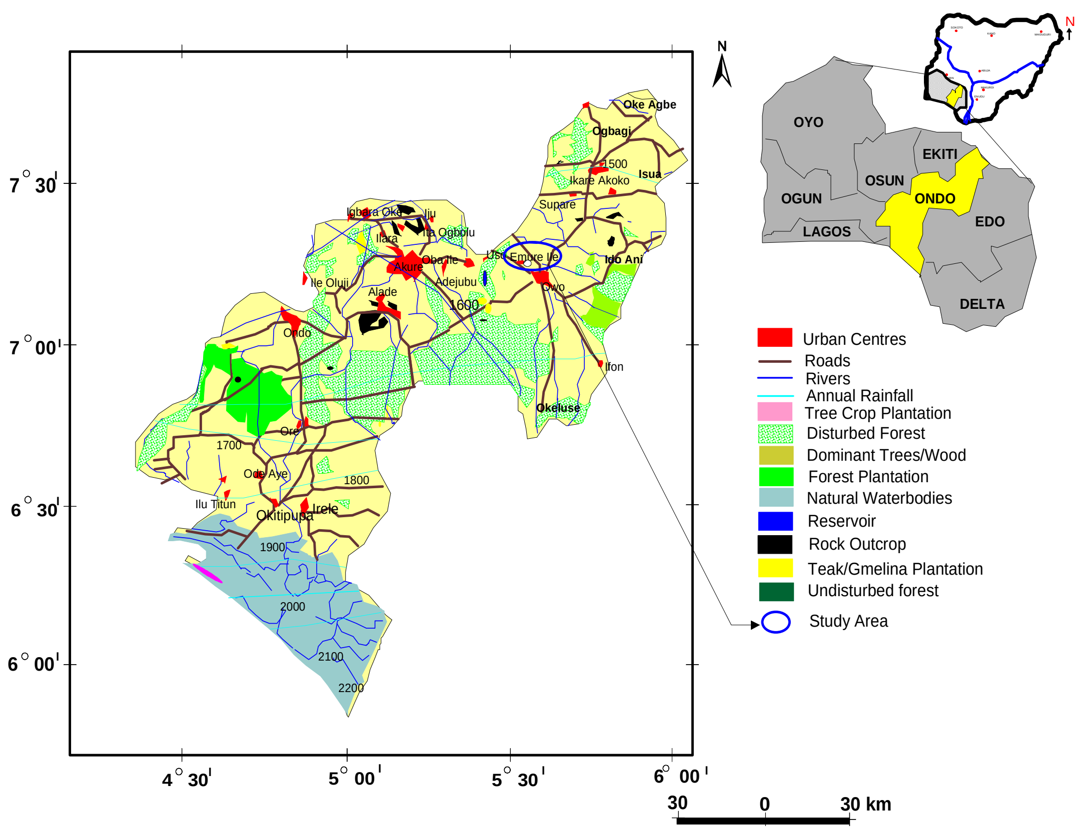


Fig. 1. Land use map of Ondo State showing the study area

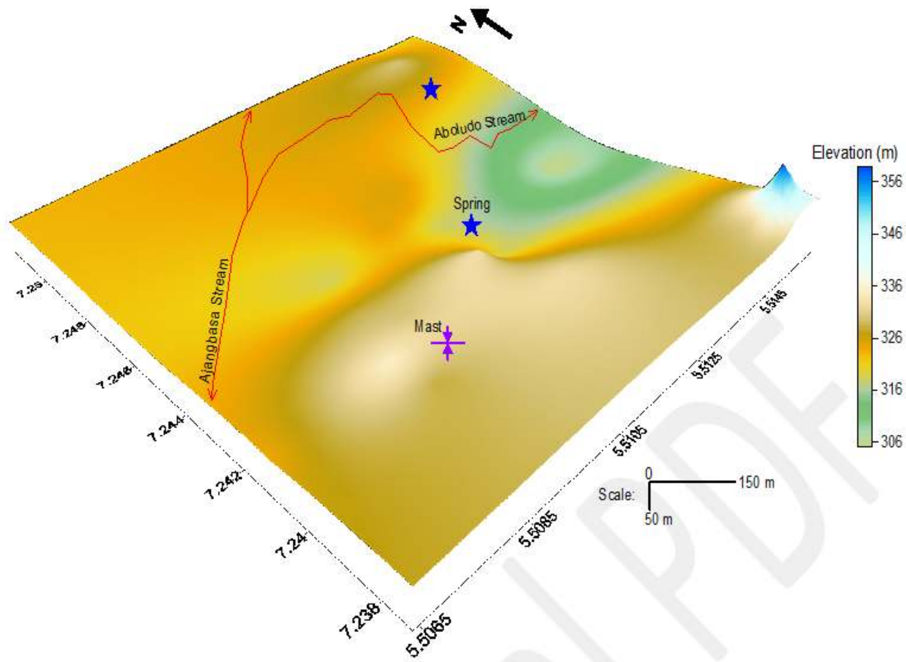


Fig. 2. 2-D surface map of the study area

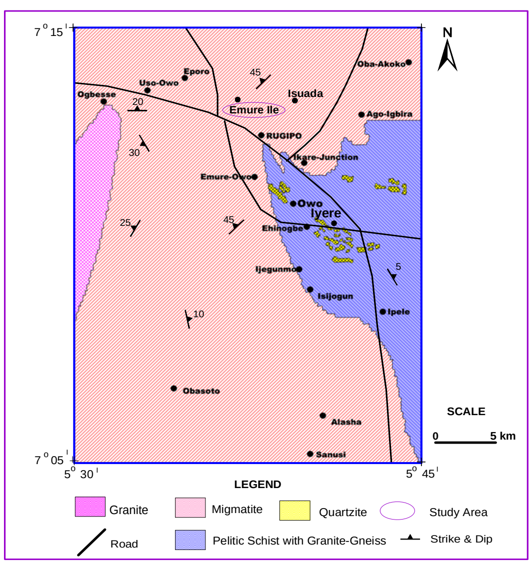


Fig. 3. Geology map of Emure Ile and environs [6]

3. METHODS OF STUDY

For the purpose of the investigation, four traverses were established (Fig. 5) in East – West and Northeast – Southwest directions. The lengths of the traverses are 120 m, 130 m, 250 m, and 360 m respectively. The research work employed both geotechnical and geophysical surveying methods in delineating regions that are fit for erecting foundation of civil engineering structures. There was a reconnaissance survey before the area was mapped out to determine the number of profiles and where geotechnical sampling survey would be carried out.

3.1 Geotechnical Investigation

Generally, geotechnical investigation method involved observing the soils/rocks below the surface (to obtain information about the soil conditions), obtaining samples, and determining physical properties of the soils and rocks below the surface. In view of this, six geo-referenced soil samples were collected from the study. The samples were analyzed for natural moisture content, specific gravity, liquid and plastic limits, plasticity index, linear shrinkage, percentage clay content, compaction characteristics, and undrained triaxial test using Standard equipment and test procedures in accordance to British Standard.

3.2 Geophysical Survey

The geophysical survey involved Magnetic method, Very Low Frequency Electromagnetic method, and Vertical Electrical Sounding (VES).

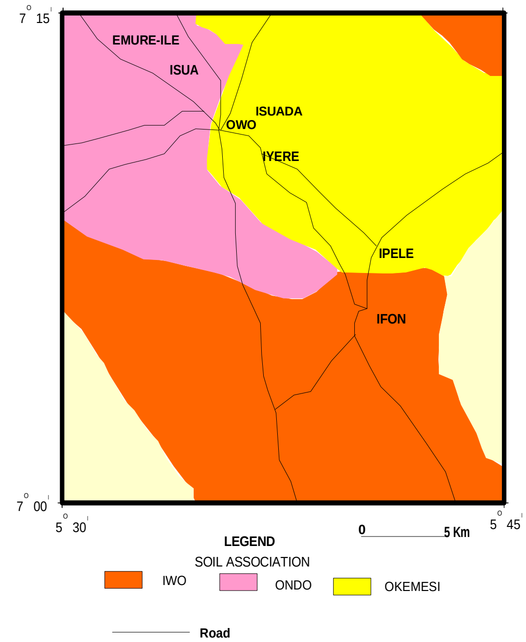


Fig. 4. Soil Map of the study area [7]

The 1-D vertical electrical resistivity sounding data (VES) was obtained using the Schlumberger electrode array with the Allied Ohmega Resistivity meter. Electrode spread (AB) was varied from 1m to a maximum of 225 m. Twenty four (24) vertical electrical sounding were acquired. Every VES station was appropriately geo-referenced using Geographic Positioning System (GPS). 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 Resists software. The interpretation results (layer resistivities and thicknesses) were used for geoelectrical characterization. The choice of the VES stations was constrained by the geology, terrain, accessibility and representativeness of the spread of the stations. Quantitative interpretation of VES curves assume 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% [11].

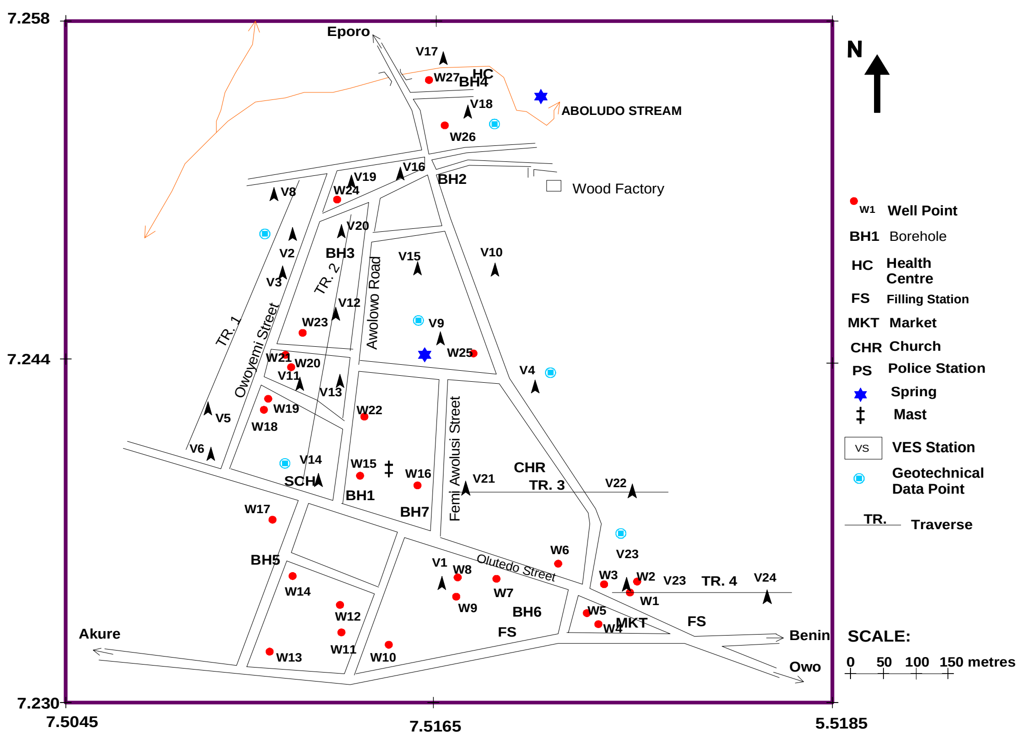


Fig. 5. Data acquisition map for the survey showing the geophysical and geotechnical data points

Magnetic measurements were made at 10 m interval along traverses 1 and 2. The survey cannot be conducted along traverses 3 and 4 due to high level of noise arising from electric wire lines, household magnetic materials, etc. The survey utilized GSM 8 Proton Precession Magnetometer (PPM). Two magnetic measurements with sensor height at 1.5 m were taken per station and the mean of the magnetic measurements adopted for each observed station. A set of readings was taken at an established base station close to each traverse before the commencement and immediately after data acquisition. The base station readings were used for diurnal and offset corrections. Corrected magnetic data were plotted against station positions.

The Very Low Frequency Electromagnetic (VLF – EM) method utilized the inline profiling technique. VLF-EM measurements were also taken at 5 m interval along each traverse with Geonics EM 16 VLF. The real and quadrature components of the vertical/horizontal magnetic field ratio were recorded at each observation station. The receiver unit was tuned to Rugby in Great Britain. The real and filtered real components were plotted against station positions using 'KHFFILT' software version 1.1. A 2-D inversion of the real component data was carried out using the same software.

4. RESULTS AND DISCUSSION

4.1 Engineering Geotechnical Investigation

The summary of the geotechnical characteristics of all sampled soils is displayed in Table 1.

The natural moisture content gives information on the moisture condition of the soil. The entire soil samples have moderate moisture content ranging from 10% to 20.2% with an average of 15.5%. The results of the grain size distribution analyses of the samples show percentage finer (percentage passing 0.075 mm) 30.3 to 43.2% and an average of 38% indicating a high percentage of clay/silt content. However, all the soil samples have high % (greater than 50%) of coarse material (sand) than the fine (clay) fraction and can be categorized as Clay-sand soil (SC) using Unified Soil Classification System (USCS). The USCS is based on the characteristics of the soil that indicate how it will behave as a construction material. The soils that are largely made up of fines (silt and clay) are likely to have poor geotechnical properties. The specific gravity varies from 2.64 to 2.69 with an average value of 2.66 indicating sandy clay.

The consistency (degree of firmness i.e., soft, firm, stiff) of a fine grained soil varies significantly with the water content. The Liquid limit and plastic limit varies between 30.1and 39.5%, and 13 and 25.2% with an average values of 35.3 and 21.9% respectively. The average value of the plasticity index of the soil samples is 13.8%.

According to the range of plasticity index in Table 2, the soils can be classified as medium plastic soil. The average value obtained for the linear shrinkage is 11.2% indicating a poor soil quality (Table 3). Activity of the soil varies between 0.29 and 0.44 with average of 0.37. Soil activity is a good indicator of the potential swell-shrink problems associated with specific clay. Higher the activity, higher is the swell-shrink potential.

Therefore from Table 4 the soils fall within threshold of inactive soil in terms of quality. The Casangrade plasticity chart (Fig. 6) showed that the soil fall within CI-Group which implies that they would exhibit intermediate/ moderate swelling potential. The compaction characteristics of the soil samples showed high Maximum Dry Density (MDD) at moderately low Optimum Moisture Content (OMC) of an average of 1704 Kg/m³ and 15.8% respectively. The results of the triaxial test showed a high cohesive bond and shear strength properties.

Consequently, the geotechnical results showed an inactive clay dominated soil moderate swelling potential under impose load; and moderate compaction and shear strength characteristics. The soil can be regarded as moderately competent soil (Table 5).

4.2 Subsurface Geoelectric / Geologic Sequence

The curve types identified in the study area include A, HA, KHA, H, KH, and QH. The H and KH signatures are the most predominant accounting for 63% and 17% (Figs. 7 and 8).

The interpreted twenty four sounding curve types indicate four distinct subsurface geologic layers. The layers are the topsoil, the weathered layer, the partly weathered/fractured basement, and the basement.

Table 1. The summary of geotechnical results obtained for the sampled soils

Sample	1	2	3	4	5	6	Avg.
Natural moisture content (%)	10.0	13.1	16.5	18.4	20.2	14.7	15.5
% of fines (Silt/Clay content)	43.2	38.9	42.9	40.2	32.7	30.3	38.0
Specific gravity	2.69	2.66	2.65	2.64	2.64	2.66	2.66
Liquid limit (%)	39.5	30.2	36.3	30.1	38.4	37.2	35.3
Plastic limit (%)	25.2	13.0	22.4	18.3	25.2	24.8	21.5
Plasticity index (%)	14.3	17.2	13.9	11.8	13.2	12.4	13.8
Linear shrinkage (%)	9.6	10.3	12.4	12.2	12.0	10.4	11.2
Soil activity	0.33	0.44	0.32	0.29	0.40	0.41	0.37
MDD (Kg/m³)	1816	1852	1604	1743	1502	1707	1704
OMC (%)	15.8	12.2	15.1	17.3	19.2	15.3	15.8
Cohesion (Kpa)	86.2	80.1	85.2	88.1	82.3	80.6	83.8
Angle of friction (˚)	28.8	32.8	32.5	30.8	31.4	32.6	31.5
Shear strength (Kpa)	119.2	118.8	123.4	123.9	118.9	119.0	120.5
Soil plasticity characteristics							
Classification	CI	CL	CL	CI	CI	CI	CI
USCS classification	SC	SC	SC	SC	SC	SC	SC

Table 2. Classification of soil according to plasticity index [8]

Plasticity index	Plasticity
0	Non – Plastic
<7	Low – Plastic
7-17	Medium – Plastic
>17	Highly Plastic

Table 3. Classification of soil according to linear shrinkage [8]

Linear shrinkage (%)	Quality of soil
<5	Good
5 – 10	Medium good
10 – 15	Poor
>15	Very poor

Table 4. Classification of soil based on activity number [8]

Activity number	Quality of soil
< 0.75	Inactive
0.75 – 1.4	Normal
>1.4	Active

The topsoil has resistivity values that vary from 30 to 5220 ohm-m, with the most occurring frequency in the range of 100 – 200 ohm-m indicating clay and sandy clay material, and thicknesses of between 0.5 and 16.5 m. The weathered layer is characterized by low resistivity values ranging from 7 to 101 ohm-m, and thicknesses varying from 2 to 85 m. The low resistivity values (< 105 ohm-m) are symptomatic of clay. The resistivity values of the third layer vary from 180 to 587 ohm-m. The depth to the geoelectric bedrock varies from 4.5 m to over 85 m.

Figs. 9 and 10 displayed the 2-D modeling of the VLF –EM, the geoelectric section and the magnetic profile along traverse 1 and 2 respectively.

Along traverse 1, the VLF – EM model displays a fair conductive subsurface layering in the upper 20 m, in correlation with the geoelectric section. However, the magnetic profile showed gently undulating anomalies indicating the degree of heterogeneity within the subsoil.

Along traverse 2, fairly resistive dominated the 2-D model except at distances between 100 m and 150 m which represented a conductive target but shown as fractured zone within the basement on the geoelectric section. The magnetic profile displayed positive (resistive) magnetic intensity.

Figs. 11 and 12 showed the VLF – EM model and geoelectric section along traverse 3 and 4 respectively. The VLF – EM models displayed conductive features widely spread along the traverses. These features are correctly represented by low resistivity weathered layer on the geoelectric sections.

Therefore, it can be concluded from the above that the subsoil along the traverses are generally clay-sand in the upper 10 m depth as they are represented with resistivity values less than 100 ohm-m. This result correlated very well with geotechnical analyses of the samples which classified the soil as clay-sandy material.

4.3 Geoelectrical Maps

Fig. 13 showed the depth of weathering/ overburden thickness (depth to the basement rock) map obtained from the VES sounding curves in the area. From the map, the area generally has an overburden thickness varying between 0 and 20 m. However, the depth of weathering is thicker at the center of the town with thickness ranging from 20 to 40 m.

Corrosivity of the subsoil was evaluated at different depths (5 m and 10 m) shown in Figs. 14 and 15. A soil may be corrosive depending on its mineralogical composition and structure [10]. Clay soils tend to be corrosive because they usually retain water, which can favour oxidation of metals embedded in them. Other factors that may make a soil corrosive include reduced aeration and high level of electrolyte saturation or high concentration of salts dissolved in the water contained in the pore spaces. All these factors generate low electrical resistivity. The corrosivity of the subsoil in the area at 5.0 m showed high corrosivity. But at depth of 10 m, the Northeast – Southeast are extremely/mildly corrosive, while Northwest – Southwest and North – South directions are essentially non-corrosive.

Subsequently, the competency of the subsoil was calculated using the criteria presented in Table 6. The thematic maps of the topsoil resistivity, lineament density of the area which was adapted from [12], plasticity index, and soil classification were integrated to generate a subsoil competence map for the study area (Fig. 16). 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.

Table 5. Engineering classification using plasticity index [9]

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

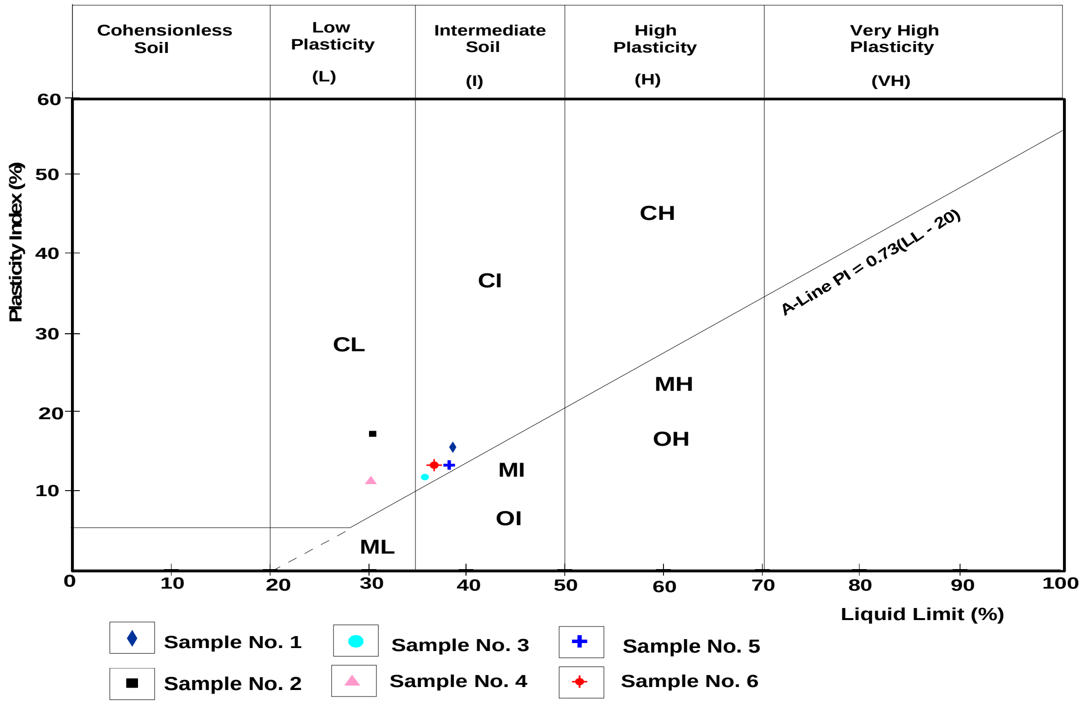
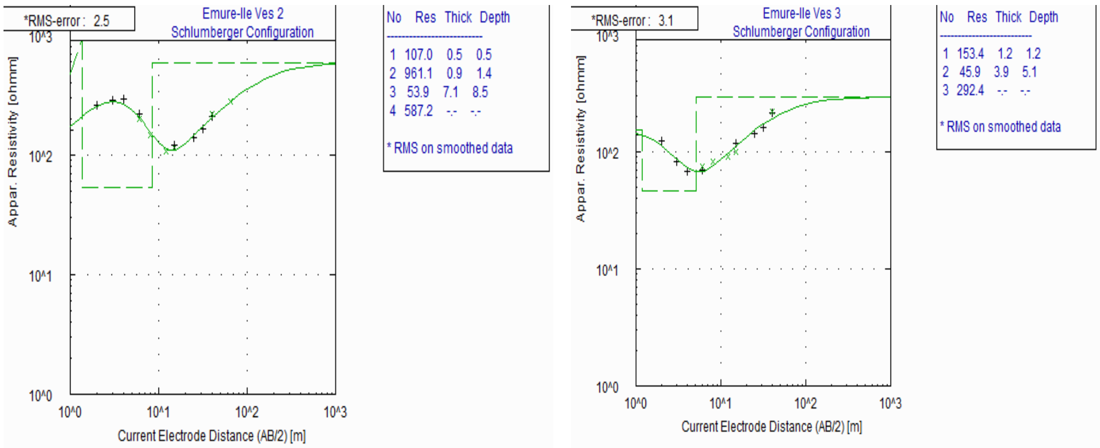


Fig. 6. Casangrade chart classification of the studied soils

The competency map of the area classified the area into moderate competence (40%) and low competence (20%). Most parts of the area (65%) are underlain by moderate competent subsoil, while low competence (35%) is prominent around the northwestern – southwestern parts of the study area.



(a) **(b)**

Fig. 7. Sounding Curves obtained from the study area: (a) KH- Curve type (b) H- Curve type

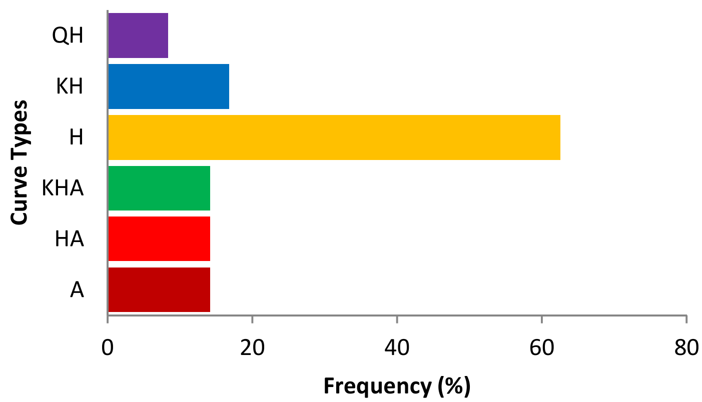
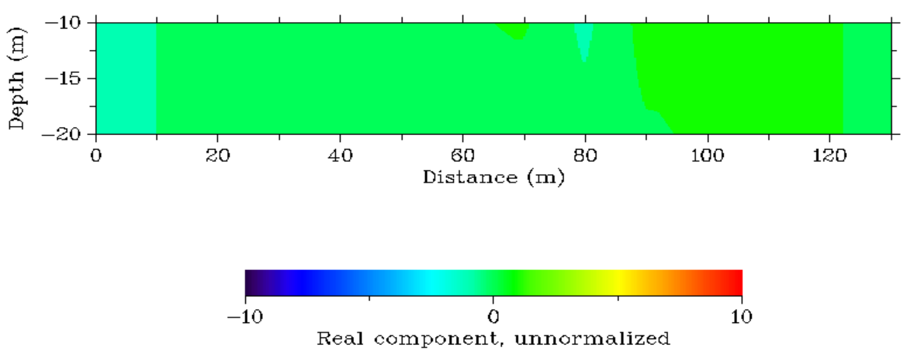


Fig. 8. Bar chart of the curve types in the study area



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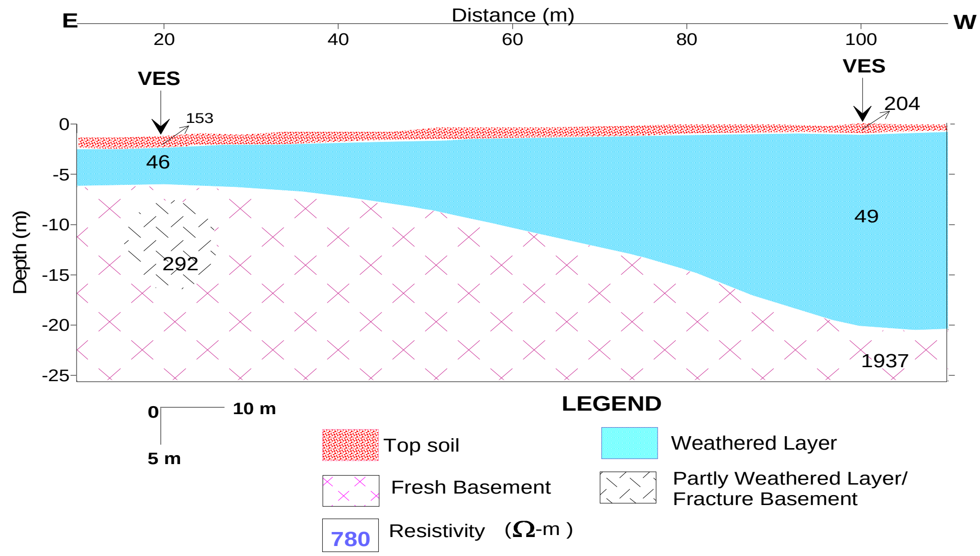

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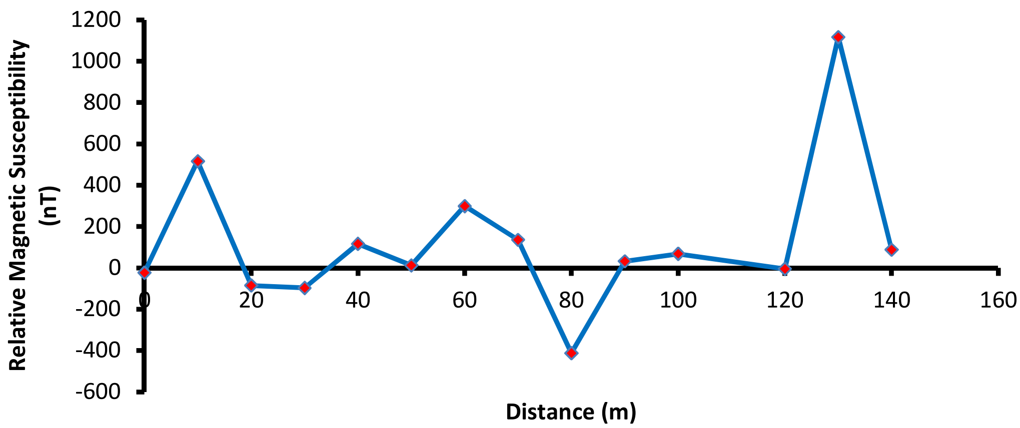
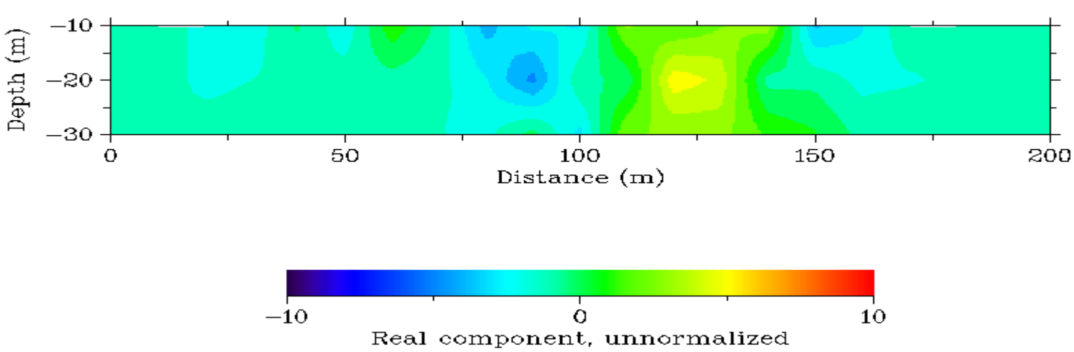


(c)

Fig. 9. (a) VLF – EM 2-D Inversion model, (b) Geoelectric section, and (c) Magnetic profile along traverse 1



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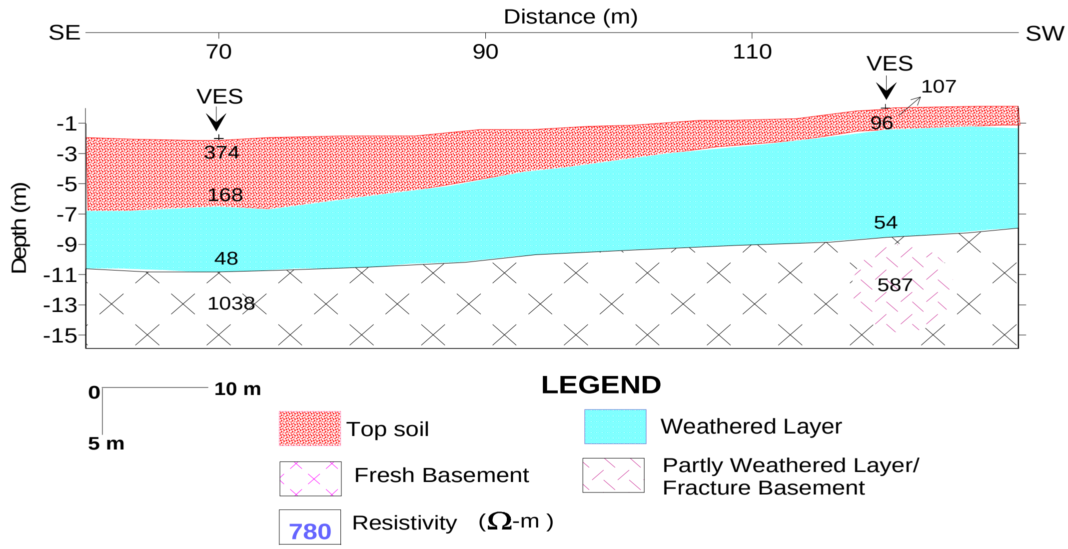

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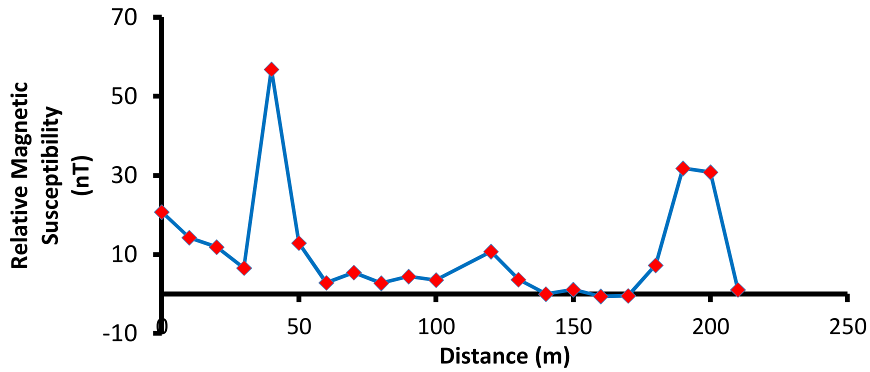
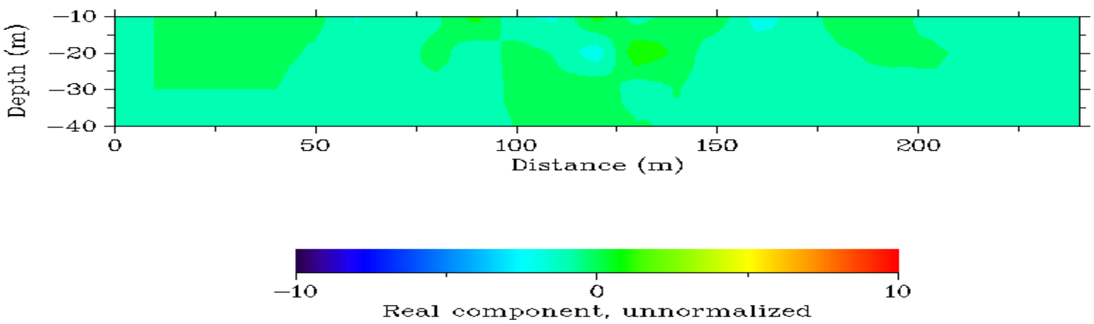


(c)

Fig. 10. (a) VLF – EM 2-D Inversion model, (b) Geoelectric section, and (c) Magnetic profile along traverse 1



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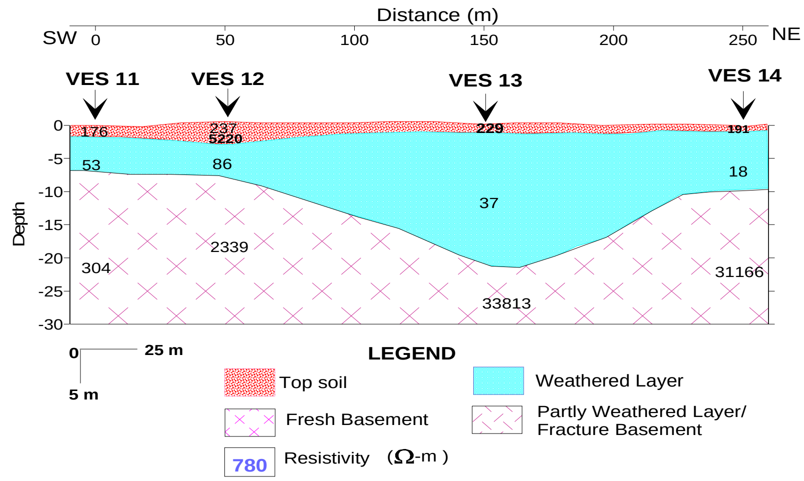
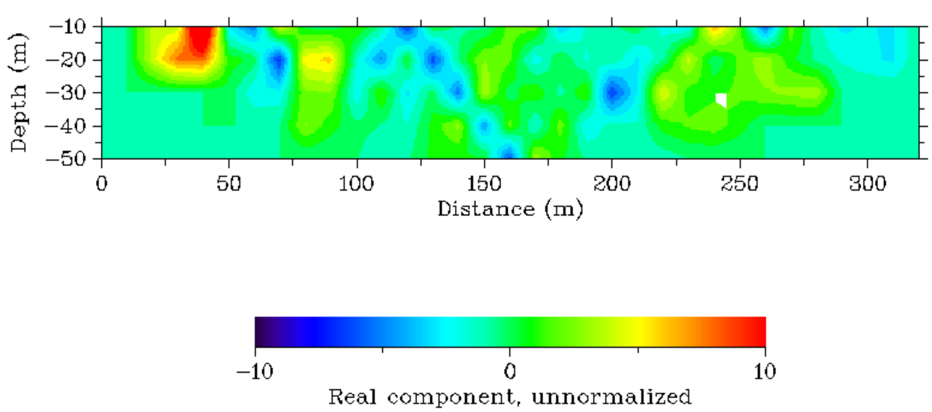


(b)

Fig. 11. (a) VLF – EM 2-D Inversion model, and (b) Geoelectric section along Traverse 3

Table 6. Multi-criteria evaluation (MCE) parameters for the subsoil competence map (Modified after [11])

S/N	Thematic map layer	Attribute	Rating	Weightage (%)	Overall Weightage (%)
1	Topsoil resistivity (ohm-m)	1 - 100	1	10	
		100 - 200	2	20	
		200 – 300	3	30	50%
		300 – 700	4	40	
		>700	**5**	50	
2	Soil	Itagunmodi	1	4	
		Ondo	3	10	20%
		Iwo	5	16	
3	Plasticity index	< 10	1	6	
		10 – 20	2	3	20%
		> 20	3	1	
3	Lineament density	0 – 0.19	5	8	
		0.19 – 0.52	4	6	10%
		0.52 – 0.90	2	4	
		0.90 – 1.96	1	2	



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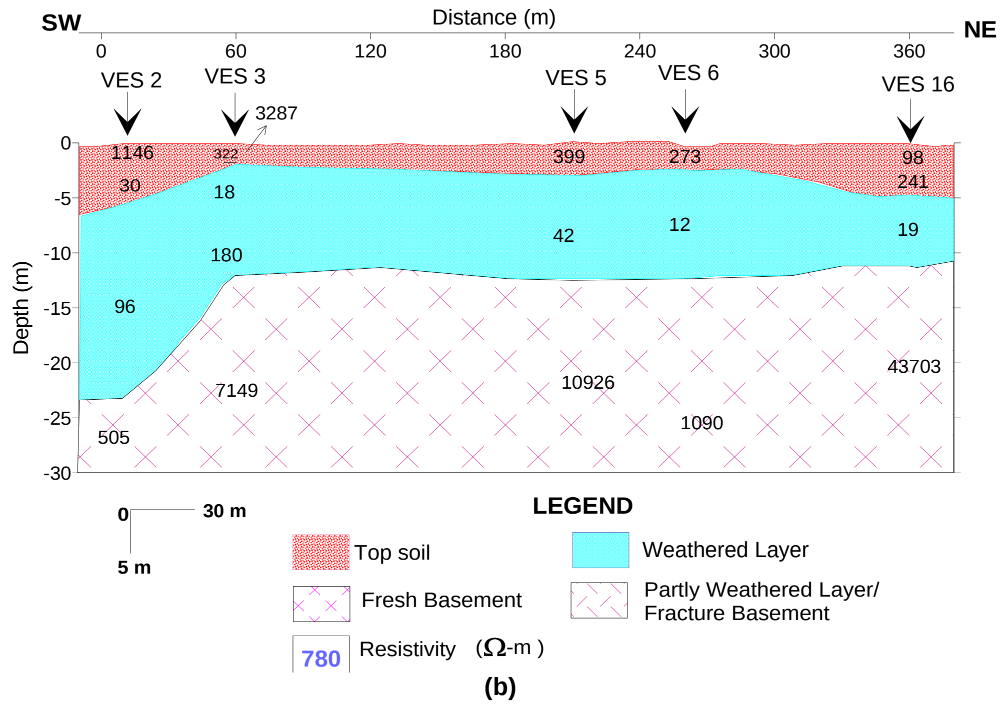

Fig. 12. (a) VLF – EM 2-D inversion model, and (b) Geoelectric section along traverse 4

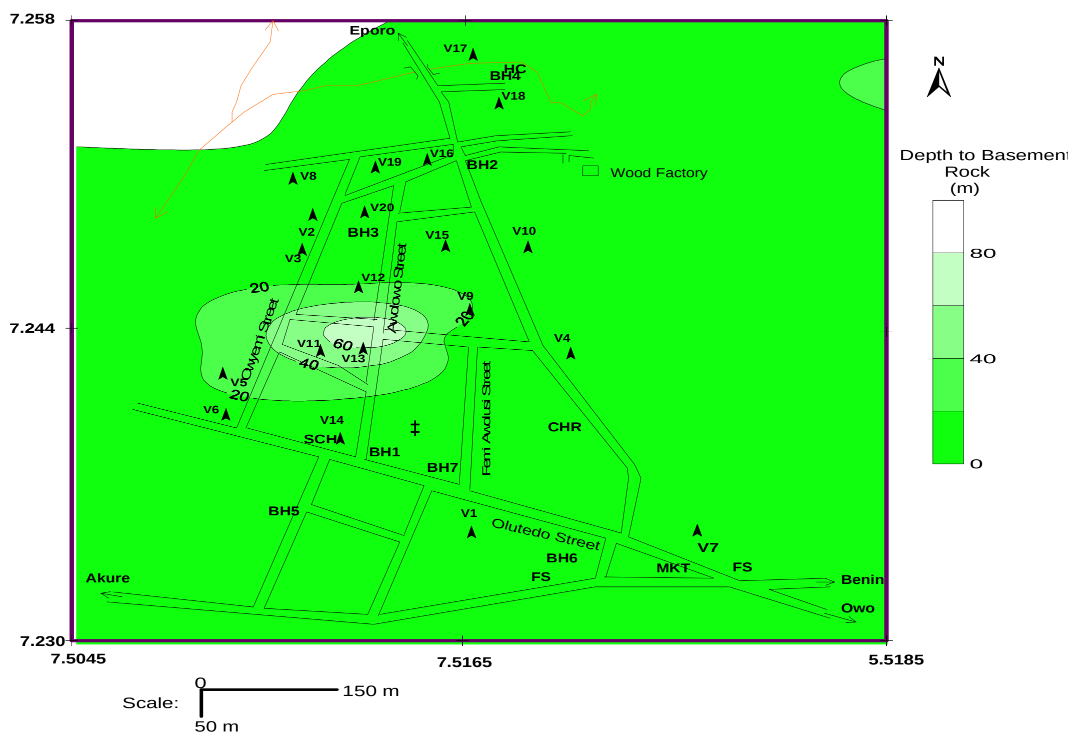

Fig. 13. Depth to basement map of the study showing predominance range of 0 – 20 m

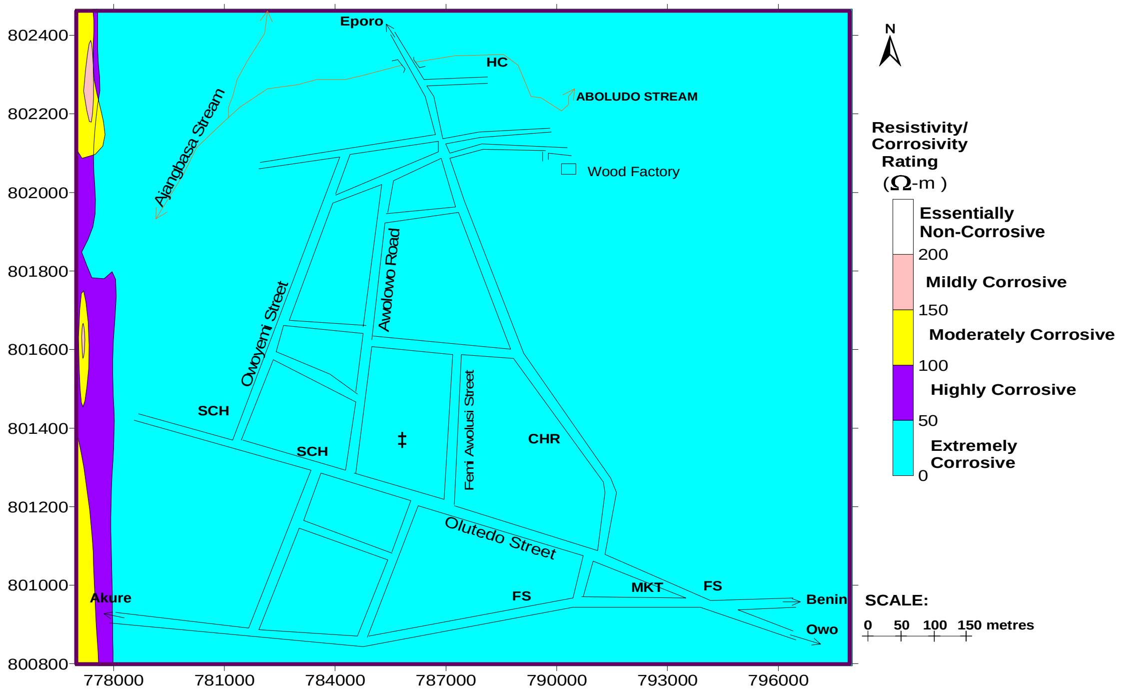

Fig. 14. Subsoil corrosivity evaluation map at 5 m depth

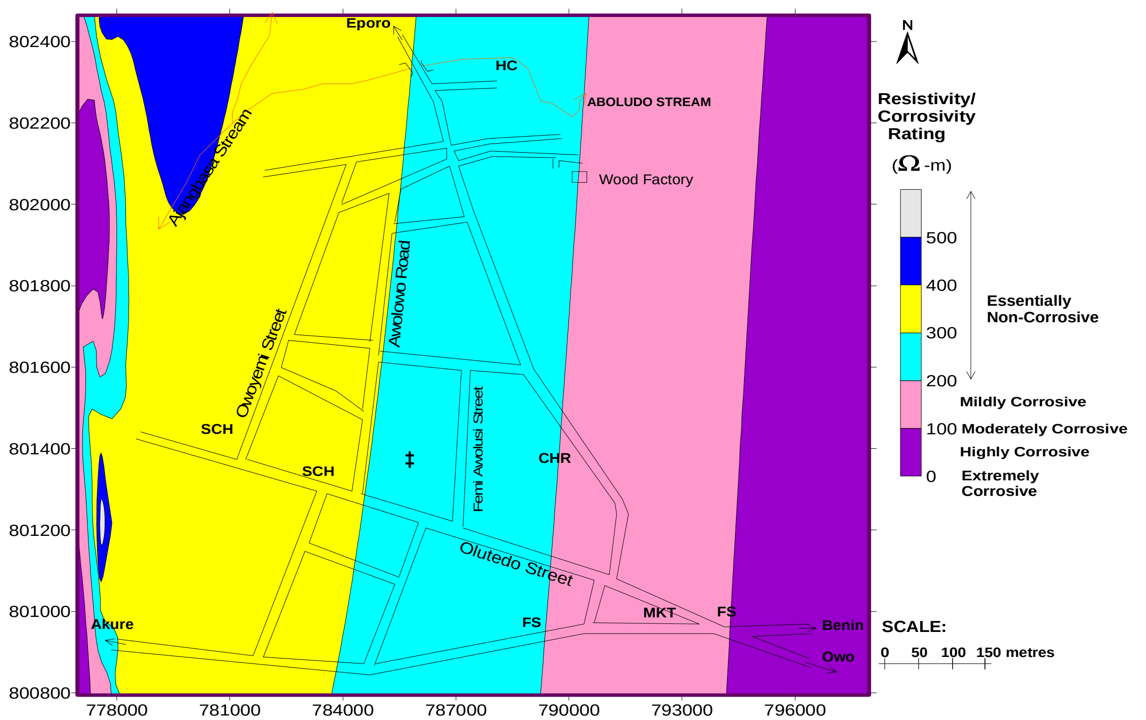

Fig. 15. Subsoil corrosivity evaluation map at 10 m depth

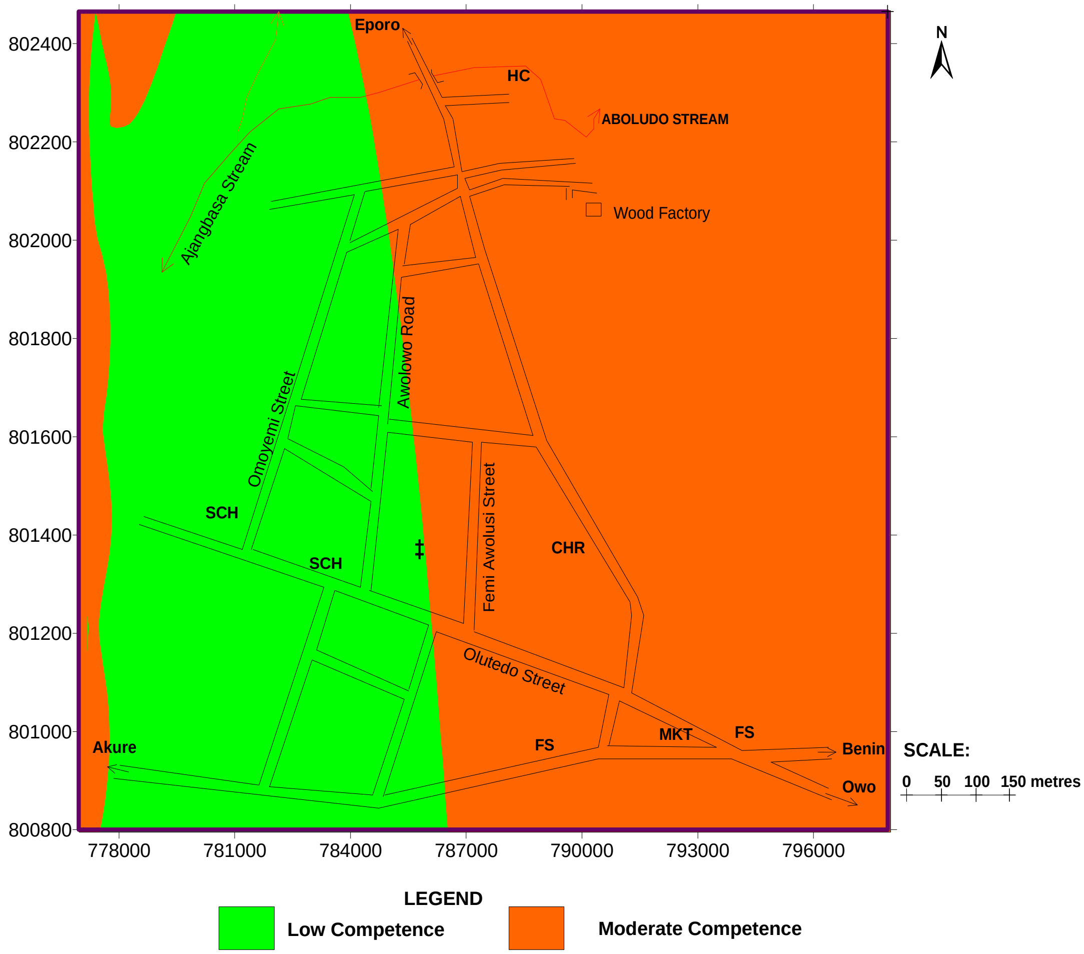

Fig. 16. The subsoil competence map which classifies the study area into moderate competence (40%) and low competent (20%) subsoil

5. CONCLUSION

Based on the results of the investigations, the geotechnical characteristics of the sampled soils showed that the subsoil is clay-sand (SC) using USCS Classification. The clay fraction would exhibits medium plasticity / compressibility at moderate compaction and strength characteristics. Geophysical results revealed a clayey/sand/lateritic topsoil underlain by low resistivity (<10 ohm-m) weathered layer, indicative of clay which corroborate the geotechnical result. The depth to bedrock is generally 20 m, but could be thicker at the center part of the town i.e. greater than 20 m. Corrosivity is generally minimal at 10 m; therefore this depth would suit the burial of metallic objects. The competency map of the area classified the area into moderate competence (40%) and low competence (20%). Most parts of the area (65%) are underlain by moderate competent subsoil, while low competence (35%) is prominent around the northwestern – southwestern parts of the study area. Hence, civil engineering construction should be concentrated around the classified high competence areas with little soil stabilization or reworking processes where possible. Therefore this work has showed the importance of integrated geophysical and geotechnical techniques in engineering subsoil characterization.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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