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Pre-Foundation Investigation Using Electrical Resistivity Method: A Case Study of Proposed Phase II, Faculty of Law Building, Federal University Oye-Ekiti, Nigeria

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Abstract

The proposed Phase II, Faculty of Law Building, was investigated to determine the competence of the sub-soil for building construction. The Electrical Resistivity method was employed for the geophysical investigation. The 2-D Electrical Resistivity Imaging (ERI) and Vertical Electrical Sounding (VES) techniques were adopted using the dipole-dipole electrode and Schlumberger arrays, respectively. Using an electrode spacing (a) of 5 m and expansion factor (n) varying from 1 – 5, electrical resistivity measurements were taken along two profiles having South – North (SN) and East – West (EW) orientations respectively. Thirteen VES stations were occupied within the study area with half-current electrode spacing (AB/2) ranging from 1–65 m. The interpretation of the geophysical data was carried out using DIPRO software. The 2D ERI showed that the sub-soil along profile 1 and northern part of profile 2 has high resistivity values (>900 Ωm) at 4.5 m depth. The geo-electric sections identified three geologic layers comprising topsoil, weathered layer and fresh basement. The electrical resistivity results revealed that the sub-soils on or within the proposed site are found to be fairly competent for engineering structure.

Keywords: Engineering geophysics, VES, 2-D ERI, geoelectric section

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Introduction

Engineering geophysics is a geophysical scientific discipline concerned with the spatial studies of the earth's surface and subsurface [1, 2]. It spans the established disciplines in civil engineering, which are useful application in the construction of structure, geotechnical studies, mining engineering, petroleum engineering and geophysics [3, 2]. These civil engineering structures such as buildings, dams, bridges, roads etc. are constructed on a daily basis and are importance in the socio-economic development site and the world at large. These structures are constructed on land or water, but either ways they are founded on soil, which results from weathered products of rocks type present in that area or directly on the rock. The soil may be competent or incompetent while the rock may be fractured or not. In addition, the soil is indispensable material on which engineering structures are constructed [4, 5].

In Nigeria, incessant incidence of building failures is becoming alarming and these failures have been attributed to factors such as inadequate information about the subsurface geological material, poor foundation design and poor building materials [6, 7]. Therefore, a detailed geophysical investigation of the subsurface materials of any proposed construction site is an important task needed to be considered before the erection of any structure to avoid foundation failure and undue loss of lives and properties. The need for pre-foundation studies has therefore become necessary so as to prevent loss of valuable lives and properties that always accompany such failures. Pre-foundation study is essential before the design of foundation of any engineering construction since every engineering structure is seated on geological earth materials [8].

It is imperative to firstly conduct pre-construction geophysical assessment of the proposed site to find out the quality, and the competence of the subsurface/or earth materials as well as the period to monitor the construction to ensure its integrity. Engineering applications of electrical resistivity include investigating the bridge, dam and building structure foundations for subsurface integrity assessment [9], structural mapping [10, 11]. This study aimed to assess the competence of the subsurface materials of the study area.

Location and geologyof the study area

The study area is the site of the proposed Phase II, Faculty of Law Building within the Federal University Oye-Ekiti, Ekiti State, Nigeria. It lies between the geographic coordinates of $7^{\circ}\ 54^{\prime}$ and $7^{\circ}\ 56^{\prime}$ E and $8^{\circ}\ 59^{\prime}$ and $8^{\circ}\ 60^{\prime}$ N of Zone 31N (Minna datum) in the Universal Profile Mercator (UTM) coordinate system as shown in Fig. 1. It is located opposite the Administration Building of the University. It is accessible. It is accessible through the new PhaseII road of the campus.

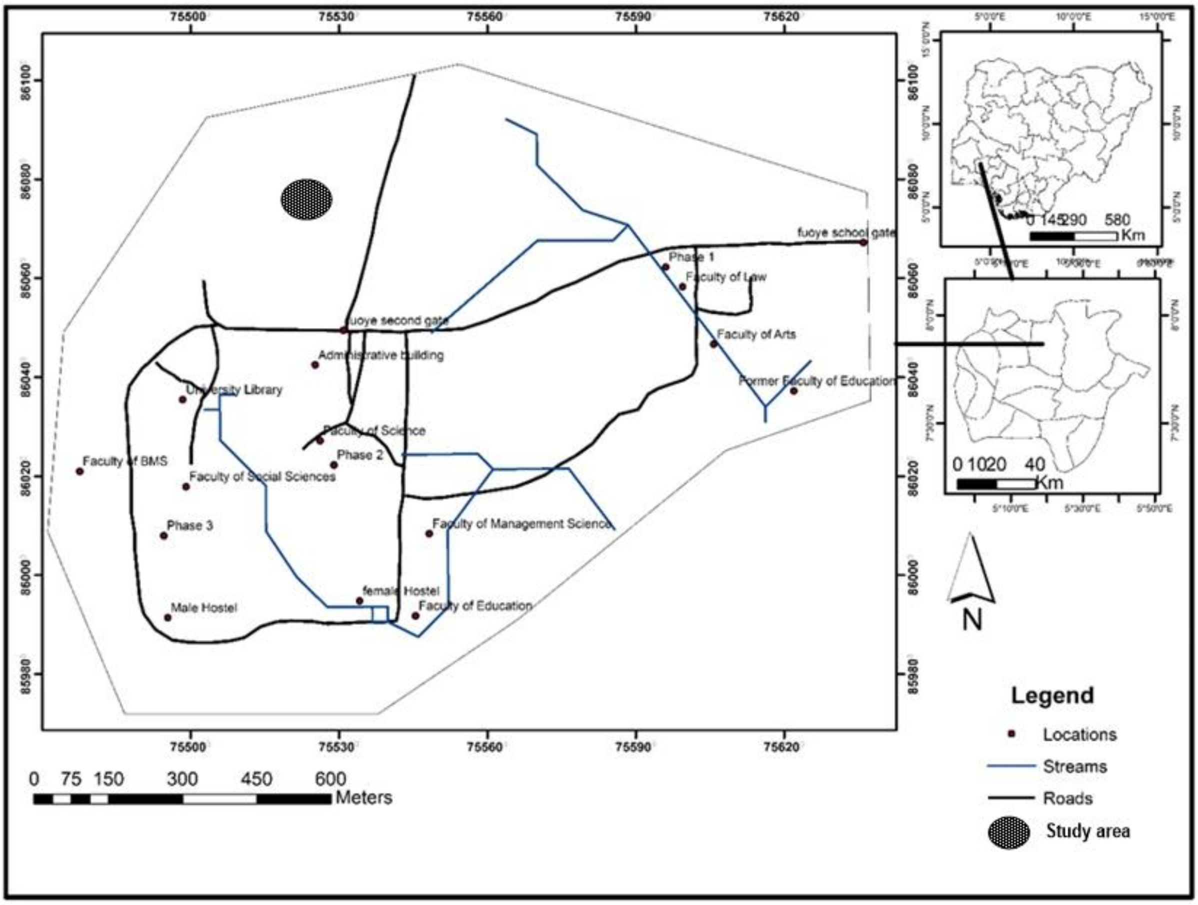

Figure 1: Map of Federal University Oye-Ekiti (Oye Campus) showing the study area

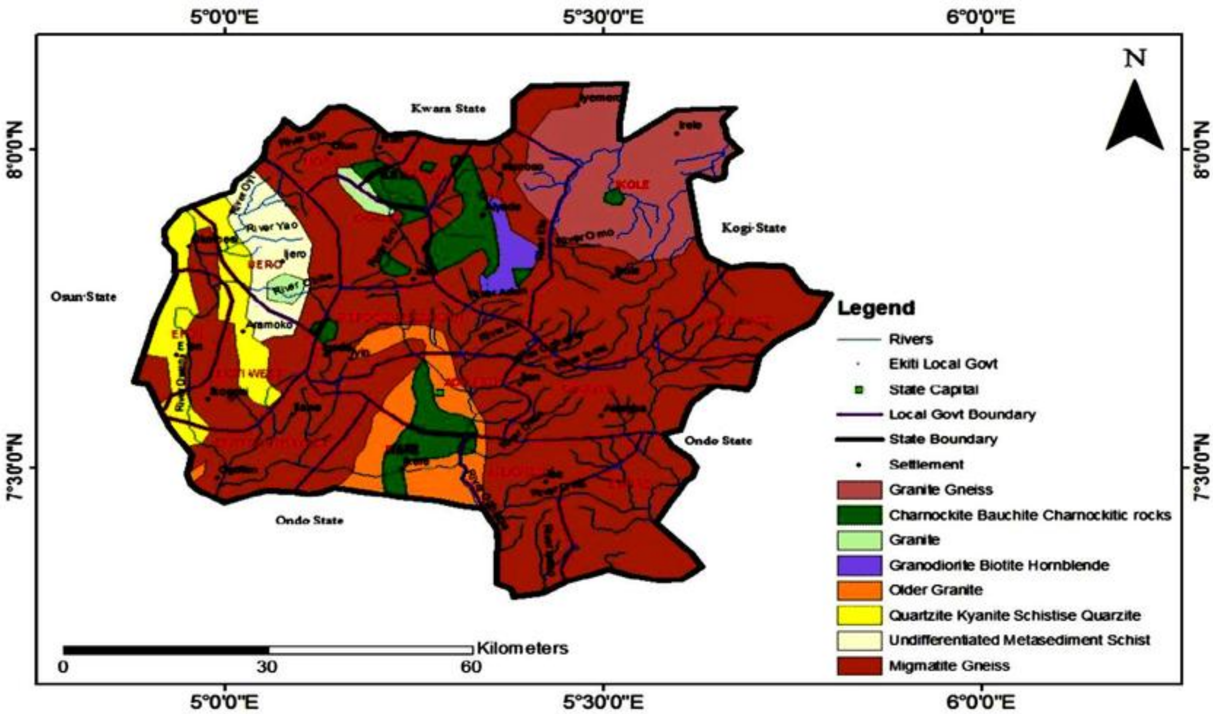

Figure 2: Geological map of Ekiti State and its local government areas [16]

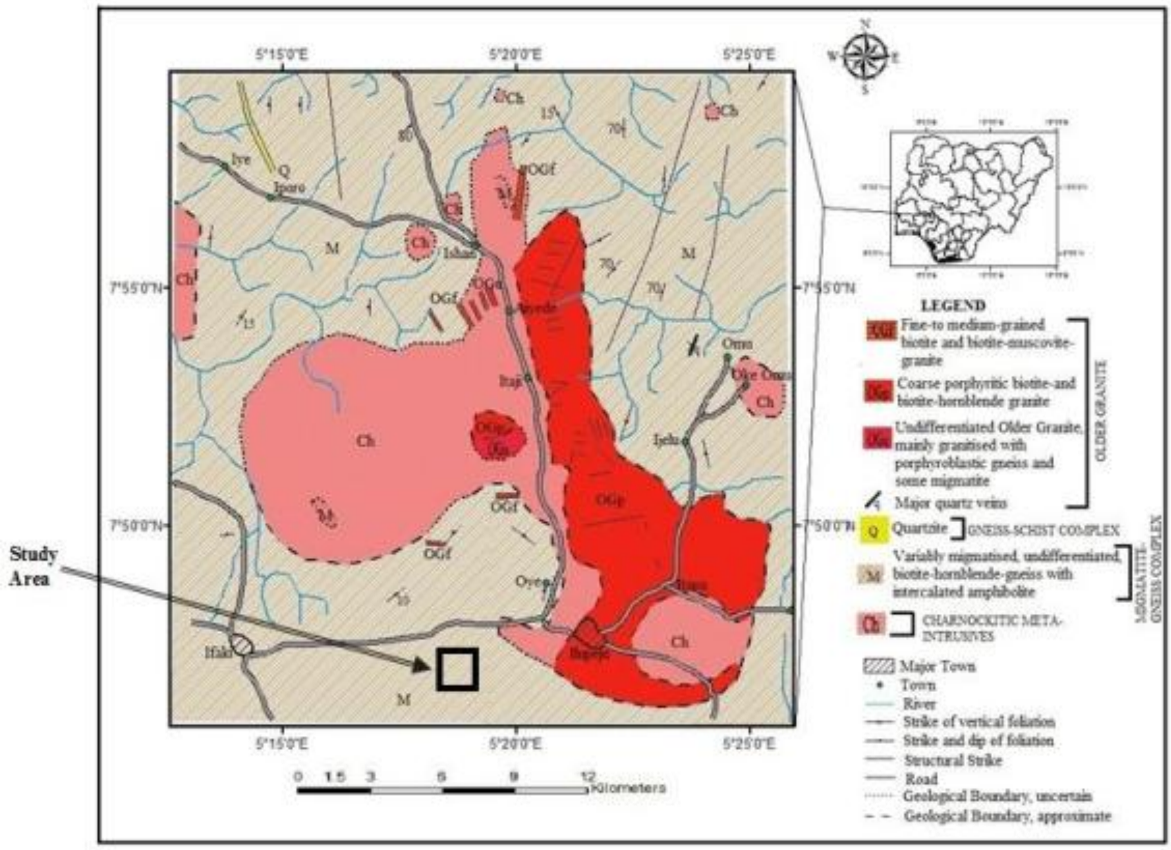

Figure 3: Geological map of Oye-Ekiti and its environs showing the study area [21]

The Precambrian rocks of the Basement Complex in southwest Nigeria underlie Ekiti State (Fig. 2). There are sites where a varying thickness of overburden hides the basement rocks. Rahaman [12, 13] identified the migmatite-gneiss complex, the older granites, the charnockitic rocks, the metaigneous and slightly migmatized to unmigmatized paraschists, and the unmetamorphosed granitic rocks as the main lithologic units. The lithologic unit within the study area is granite whose outcrops are found at the northern and southern parts of the study area (Fig. 3). The topography is gently undulating with elevations ranging between 502 and 547 m. However, some parts are characterized by relatively flat terrain. The prominent geomorphological features include the three (3) valleys being investigated in this study. The drainage pattern in Oye-Ekiti area is dendritic (Fig. 3). The study area enjoys tropical climate with high rainfall of up to 1600 mm by two distinct seasons [14]. These are the rainy season (April – May) and the dry season (November – March). Temperature ranges between 21 and 28^{o}C [15]. The vegetation of the area is the rain forest type with dense evergreen forest of tall trees with thick vegetation.

The hydrogeology of an area is controlled by such factors as geology, structure, and climate of the area [16, 17]. The geological formations underlying the area and the structures determine the type of aquifer and the means of recharging them while the climate determine amount of aquifer [18 – 20].

Materials and Methods

Electrical Resistivity method using Dipole-dipole and Schlumberger arrays were employed for the investigation. The data were acquired using the ULTRA MINI-RES Resistivity meter. Two (2) profiles were established within the study area with Profile 1 (P_1) trending South-North (S – N) direction while Profile 2 (P_2) trends in approximately West-East (W – E) direction (Fig. 4). 2D Dipole-dipole imaging was carried out along the two profiles using the electrode separation of 5 m with electrode expansion factor varying from 1 – 5. Fourteen (14) Vertical Electrical Sounding (VES) stations were occupied within the study area with half-current electrode space (AB/2) ranging from 1 – 150 m. The coordinates of each of the 2D imaging and VES stations were taken using the Garmin 72H GPS equipment. The Dipole-dipole data were inverted into 2D subsurface imaging (resistivity structure) using the DIPRO for windows version 4.0 software. The VES resistivity data were plotted against their respective half-current electrode spacing (AB/2) on a log-log graph and presented as depth sounding curves. The curves were interpreted quantitatively by the method of partial curve matching and 1D computer assisted forward modeling using WINRESIST version 1.0 software. The VES interpretation results (layer resistivities and thicknesses) were used to generate geoelectric sections.

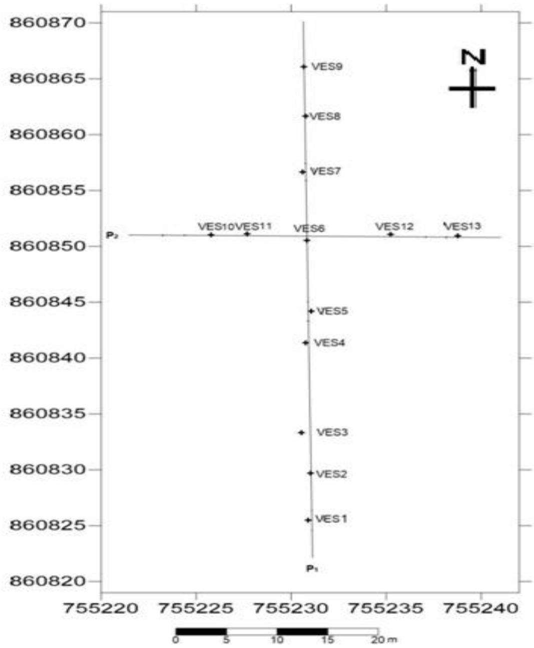

Figure 4: Data acquisition map of the study area

Results and Discussion

2D electrical resistivity imaging

The results of the Dipole-dipole data interpretation showed three 2D pseudo-sections for each profile. The first is the acquired field (raw) data; the second is the algorithm generated theoretical data while the third is the inverted 2-D model. All the interpretations and geologic inferences were made using the inverted 2D resistivity models. These were done with respect to depth. For easy interpretation, colour bands along with contour lines were used to depict various resistivity values from where geologic inferences were made. Two major subsurface layers which are the topsoil and weathered layer were delineated in the inverted 2D pseudo-section, relatively low resistivity values are shown in blue and green colours (mostly depicting the weathered layer), while high resistivity values are shown in yellow, red and purple colours (mostly depicting the basement).

The 2D resistivity model along Profile 1 (Fig. 5) comprises four distinct resistivity layers depicting the subsurface conditions (topsoil, weathered layer, partly weathered layer and basement). The topsoil (blue colour-code) is well pronounced between 0 and 40 m on the profilewith depth of about 4 m and average resistivity ranging from 13.0 to 81.2 Ωm, which is suspected to be a clayey nature area. The weathered layer (green colour-code) is observed throughout the profile with resistivity ranging from 71.9 to 992 Ωm. partly weathered (yellow colour-code) layer is observed between station 39 and 80 with resistivity ranging from 414 to 2952 Ωm. The last layer, which is the basement (red to purple colour-code), is observed between stations 50 and 77 with resistivity ranging from 3419 to 100228 Ωm. The resistivities of the basement is an indicative of strength/competence layer for engineering structures by excavating the incompetent upper layer between the depth of 0 and 2 m and fill it with competent material. But due to high degree of weathering within the basement, this could cause the engineering structures to fail later in the future.

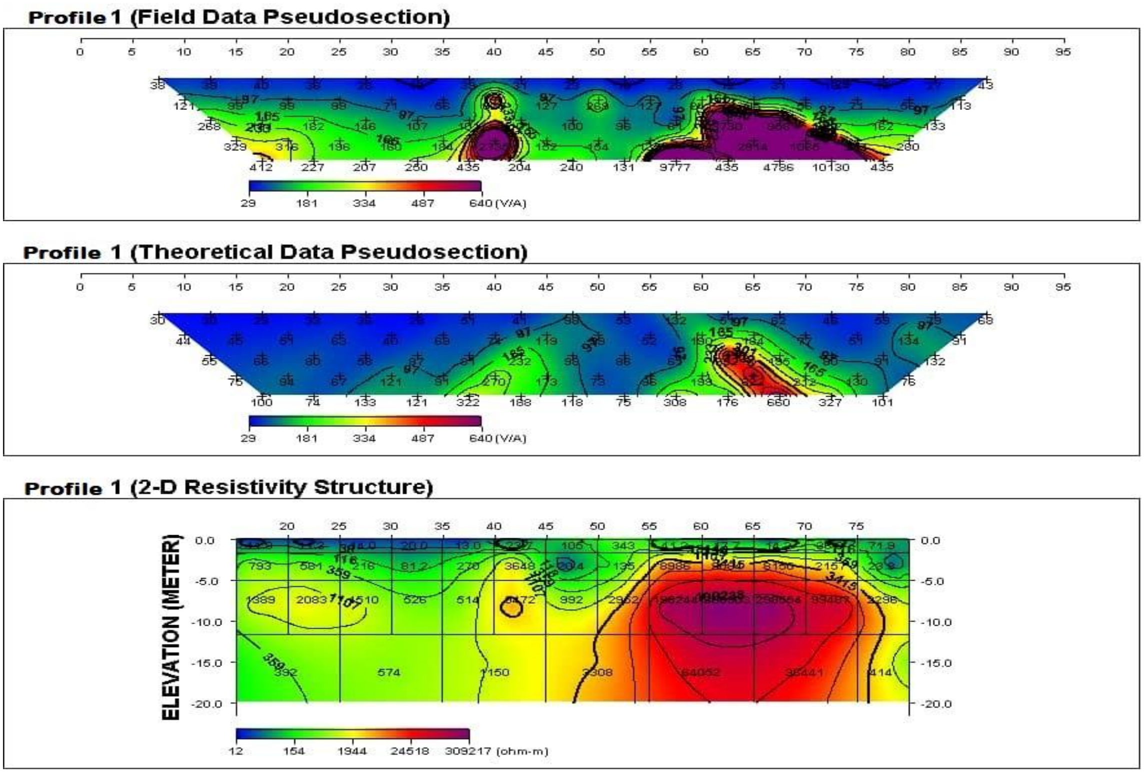

Figure 5: Profile 1 2-D Resistivity Image

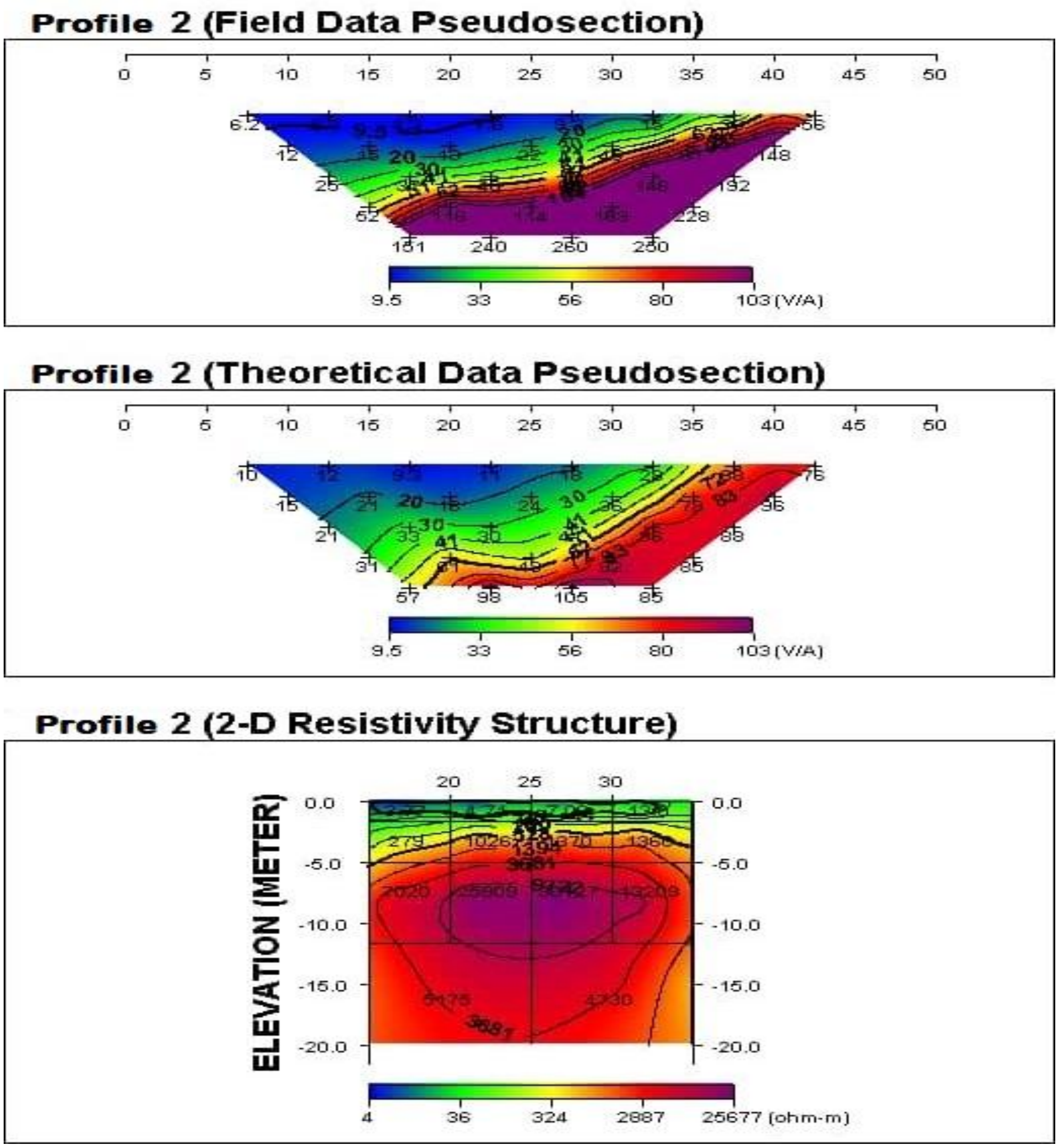

Figure 6: Profile 2 2-D resistivity image

The 2D resistivity model along Profile 2 (Fig. 6) comprises four distinct resistivity layers depicting the subsurface conditions (topsoil, weathered layer, partly weathered layer and basement). The topsoil (blue colour-code) with thin later between distances 0 and 23 with depth of about 1 m and average resistivity ranging from 2.77 to 4.7 Ωm which is suspected to be aclayey nature area. The weathered layer (green colour-code) is observed throughout the profile with resistivity ranging from 7.09 to 13.0 Ωm. The partly weathered (yellow colour-code) layer is a thin layer which is also observed throughout the profile with resistivity ranging from 279 to 1360 Ωm. The last layer, which is the basement (red to purple colour-code) is observed throughout the profilewith resistivity ranging from 1394 to 25909 Ωm. The resistivities of the basement which is observed throughout the profile is an indicative of strength/competence layer for engineering structures by excavating the incompetent upper layer between the depth of 0 to <5 m and fill it with competent material.

Vertical electrical sounding curves

The vertical electrical sounding **(**depth sounding) curve type that were obtained along from the area are the 3-layer H-Type, the 4-layer QH, KH and HA-type and the 5-layer HKH-type. The most prominent curve type is the H-type accumulating 75% of the total depth sounding curves. The result of the depth sounding curves is presented in the Table 1 and was used to generate geoelectric section. For the lithological deductions, the Keary *et al.* [22] classification of resistivity values of common rock typeswas used in the characterization of the various geoelectric layers.

Table 1: Summary of the VES geoelectric parameter and lithologic interpretation

VES No.	Resistivity (Ωm)	Thickness (m)	Depth (m)	Curve Type	Inferred Lithology
1	504	1.2	1.2	QH	Topsoil
	384	4.8	6.1		Lateritic Layer
	79	31.7	37.8		Weathered Layer
	3634	-	-		Fresh Basement
2	406	1.2	1.2	KH	Topsoil
	813	1.7	2.9		Lateritic Layer
	41	8.1	11.0		Weathered Layer
	13371	-	-		Fresh Basement
3	269	1.0	1.0	HA	Topsoil
	265	4.5	5.5		Lateritic Layer
	113	28.7	28.7		Weathered Layer
	5230	-	-		Fresh Basement
4	165	1.4	1.4	H	Topsoil
	72	15.2	16.6		Weathered Layer
	3422	-	-		Fresh Basement
5	98	2.9	2.9	KH	Topsoil
	382	11.1	14.0		Lateritic Layer
	223	34.9	48.9		Weathered Layer
	649	-	-		Fresh Basement
6	227	1.3	1.3	HA	Topsoil
	76	3.2	4.5		Weathered Layer
	105	35.2	39.7		Weathered Layer
	4571	-	-		Fresh Basement
7	220	0.6	0.6	KH	Topsoil
	714	2.0	2.7		Lateritic Layer
	52	6.0	8.7		Weathered Layer
	3208	-	-		Fresh basement
8	171	1.2	1.2	KH	Topsoil
	594	5.6	6.8		Lateritic Layer
	78	31.6	38.4		Weathered Layer
	5308	-	-		Fresh Basement
9	111	1.1	1.1	HKH	Topsoil
	41	2.6	3.7		Clay
	288	2.5	6.2		Lateritic Layer
	80	26.4	32.6		WeatheredLayer
	634	-	-		Fresh Basement
10	89	1.0	1.0	KH	Topsoil
	75	4.5	5.4		Clay
	278	4.7	10.1		Lateritic Layer
	59	-	-		WeatheredLayer
11	71	1.5	1.5	H	Topsoil
	44	6.1	7.6		Clay
	135	-	-		Fresh Basement
12	115	1.0	1.0	KH	Topsoil
	154	2.3	3.3		Lateritic Layer
	73	15.3	18.6		Weathered Layer
	584	-	-		Fresh Basement
13	141	1.0	1.0	KH	Topsoil
	367	3.7	4.7		Lateritic Layer
	93	13.3	17.9		Weathered Layer
	10000	-	-		Fresh Basement

Geoelectric section

A total of two geoelectric sections were generated within the study area using the final VES geoelectric section parameters obtained and presented in Table 1. The geoelectric sections showed a total of three to five geologic layers, which are the topsoil, clay, lateritic layer, weathered layer and fresh basement. The geoelectric section obtained along Profile 1 is shown in Figure 7(Four) geologic layers were delineated), the first layer is the topsoil with the resistivity and thickness that vary between 98 and 504 Ωm and 0 – 1.0 m, respectively. It is composed of clay and lateritic clay. The second layer depicts a lateritic clay with resistivity and thickness that vary 383 to 914 Ωm and 1.0 – 6 m, respectively. It is composed of lateritic clay and laterite. The third layer, which is the weathered layer with resistivity and thickness varying from 52 – 223 Ωm and 6 – 49 m, respectively. It is composed of clay and sandy clay. The fourthlayer which is the fresh basement has resistivity ranges from 649 – 5230 Ωm.

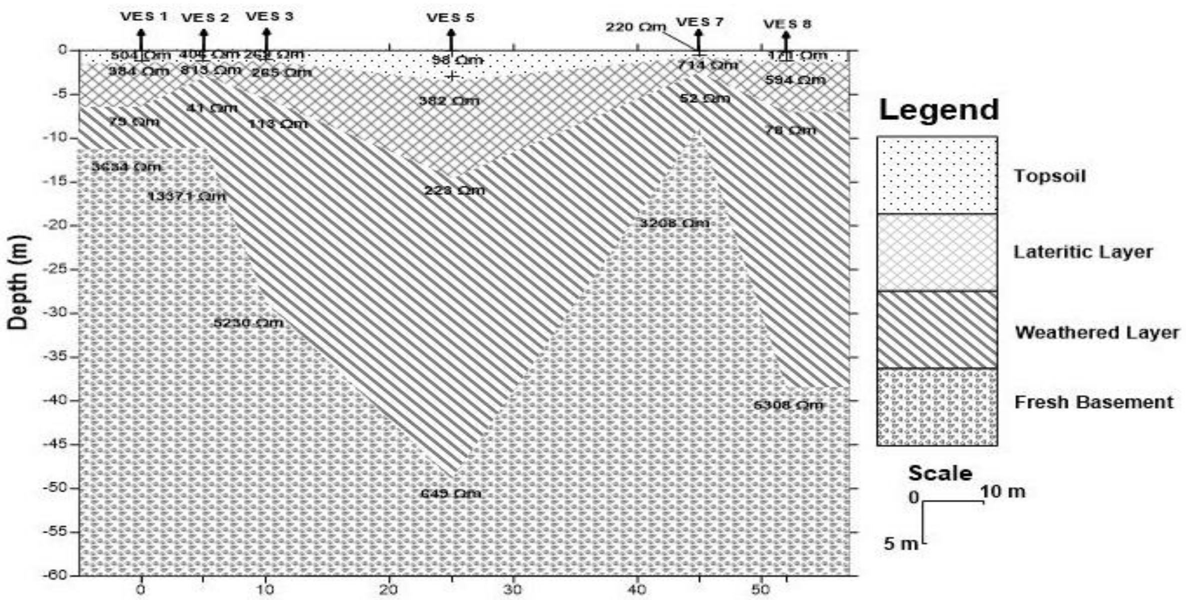

Figure 7: Geoelectric section obtained along Profile One (1) within the investigated area

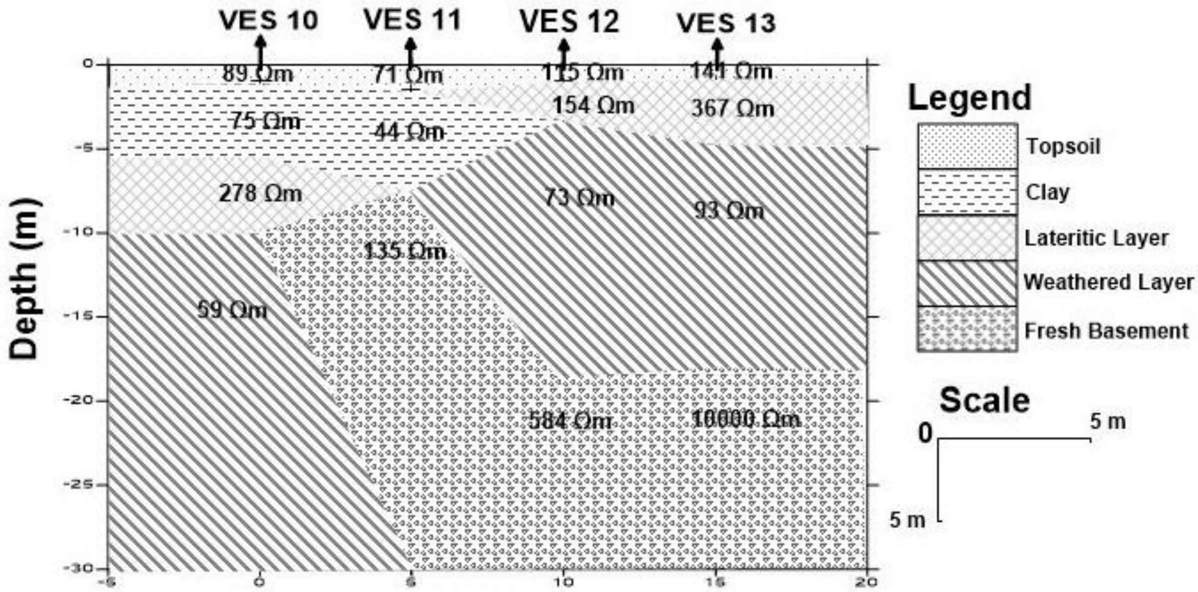

Figure 8: Geoelectric section obtained along Profile One (1) within the investigated area

The geoelectric section obtained along profile 2 in Figure 8 reveals five geologic layers. The first layer is the topsoil with the resistivity and thickness that vary between 71 and 141 Ωm and 0 – 1.5 m, respectively. It is composed of clay and sandy clay. The second layer depicts a lateritic clay with resistivity and thickness that vary 141 to 154 Ωm and 1.0 – 2.5 m, respectively. It is composed of lateritic clay and laterite. The third layer, which is the weathered layer with resistivity and thickness varying from 44 to 93 Ωm and 1.5 – 49 m, respectively. It is composed of clay and sandy clay. The fourthlayer which is the fresh basement has resistivity ranges from 649 – 5230 Ωm.

Conclusions

Major parts of the study area can be inferred to be incompetent for engineering structure due to the low resistivity values of the topsoil typical of clay and lateritic clay, ranging from 98 and 504 Ωm and thickness ranging 0 – 1.0 m along all profile. Few portions within the study area can be classified to be fairly competent for engineering structures due to the high resistivity value. These are distance 0 – 40 m along Profile 1 having resistivity values ranging 13 to 81.2 Ωm and Distance 0 and 23 and depth of 1 m along profile 2 with the resistivity value ranging from 2.77 to 4.77 Ωm. the weathered layer is generally of resistivity (<100 Ωm) typical of a clay and extends beyond 10 m in most places. The partly weathered layer of a fairly high resistivity value (>200 Ωm) is mostly assumed to be laterite formation. Hence, the result shows that the study area is suspected to be fairy competent from engineering structure due to the clayey formation or nature of the topsoil and fair thickness, any region marked for building construction should be investigated prior to construction to avoid failure of structures.

Conflict of interest: No conflict of interest to declare.

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