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Geophysical Characterization of the Subsurface Using Electrical Resistivity Method: A Case Study of Fountain University, Oshogbo, Osun State.

Rafiu Adegbola[1], James Whetode[1], Oluwakemi Adeogun[2], Busuyi Akeredolu[3], Olajuwon Lateef[1]

[1]*Department of Physics, Faculty of Science, Lagos State University, Nigeria*

[2]*Department of Geosciences, Faculty of Science, University of Lagos, Nigeria*

[3]*Department of Biochemistry, Faculty of Science, University of Lagos, Nigeria*

Correspondence
Whetode James, Department of Physics, Faculty of Science, Lagos State University, Nigeria.
Email: James.whetode@lasu.edu.ng

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Abstract:

Introduction: This technical paper will demonstrate the importance of subsurface characterization for engineering purposes such as construction and road failure.

Aims: Geoelectrical method was deployed at Fountain University located at Oshogbo, Osun state with the aim of characterizing the subsurface geological layers within the premises.

Materials and Methods: Seventeen (17) VES were acquired with PASI 16-GL along three 100-meter traverses. Electrical resistivity data was plotted on a log-log graph, curve matched and subjected to computer iteration software.

Results: The interpreted results showed that the entire region generally consists of four to five sublayers; topsoil with resistivity values ranging between 27.5 Ωm and 967.1 Ωm at maximum depth of 0.9 m beneath the earth surface, weathered layer with resistivity values ranging between 60.8 Ωm and 505.1 Ωm at a maximum depth of 15.8 m and partly weathered layer with resistivity values ranging from 150.8 Ωm – 1130.0 Ωm at maximum depth of 26.9 m beneath the earth surface, clay with resistivity values ranging between 4.0 Ωm and 42 Ωm at maximum depth of 16.9 m beneath the earth surface, fractured basement with resistivity values ranging between 103 Ωm – 460.0 Ωm at maximum depth of 92.6 m and fresh basement with resistivity values ranging from 931 Ωm – 5432.0 Ωm.

Conclusion: This study can be used as a reconnaissance material for groundwater, engineering, and environmental purposes in the surveyed area, it can also serve as a template in other similar terrain.

Keywords: Geoelectrical method, Vertical electrical resistivity, Traverse, Subsurface layers, Fountain university

1. INTRODUCTION

Subsurface characterization is one of the most important evaluations needed for understanding every terrain and could be achieved by the application of geophysical methods. Different geophysical methods have been used in the past and are still relevant in providing detail information revealing the subsurface heterogeneity. Subsurface characterization is extremely important for evaluation of engineering structures based on the subsoil competence [1], mapping out the groundwater formation based on fractured zones, and subsurface environmental studies. Due to human interactions with the subsurface of the earth, it is important to have a good knowledge of the geologic layers thereof to avoid geological related challenges such as failed boreholes, cracked foundations, and groundwater contamination prior to any site development [2].

Different Geophysical approach are conventionally used use in characterization of the subsurface, for instance, electrical resistivity (ER), electromagnetic (EM), ground-penetration radar (GPR) and seismic. Geotechnical approach such as core penetration test (CPT) and standard penetration test (SPT) are also used for characterisation [3].

The electrical approach adopted in this study is the application of vertical electrical sounding (VES) method which measures the average resistance along the path of travel [4]. The electrical resistivity of earth materials is determined by parameters such as fluids, porosity, permeability, temperature, degree of fracturing, grain size, rock type, and the extent of weathering of the medium, all of which are distinguishable contrasting properties and can easily be differentiated from one material to another [5]. It is therefore assumed that changes in resistivity values correspond to changes in the subsurface character [6]. Electrical resistivity technique can be applied in various fields, for example, the engineering field where the subsurface information obtained could be used to determine suitable locations for construction of houses, bridges, dams, and roads [7,8]. It is cheap and easy to perform [9]. Several studies have applied electrical resistivity techniques for subsurface investigations for numerous purposes and the obtained results have provided fresh insights [10]. There is need to have good knowledge of the subsurface strata at Fountain University campus located at Oshogbo in Osun state for effective planning and development of the site [11]. This informs the use of the electrical resistivity method to characterize the subsurface layers for future developments on campus [12].

Location and Geological Setting

The study area is located within Fountain University campus in Oke-Osun, Oshogbo, Osun State, southwestern Nigeria as shown in Fig. 1. It lies between latitude 07º 44' 30'' N to 07º 44'40'' N and longitude 04º 32' 30'' E to 04º 32' 40'' E. The terrain of the study area is moderately undulating, with topographic elevation ranging from 294 m – 309 m. The Oke-Osun area of Oshogbo local government is characterized by a few landmarks including Fountain University, the Osun shrine, and a large industrial farming site. There are also small villages with an average of 50 - 70 inhabitants near the school campus. Geologically, the study area lies within the Precambrian Basement Complex of Southwestern Nigeria and belongs to the Pan African mobile belt east of West African Craton [19]. The major rock groups in the study area are migmatite complex (including banded and augen gneisses as well as pegmatites) and metasediments (consisting of schists quartzites and amphibiolites in places). The dominant basement rocks in Osogbo area are schist and migmatites, associated with quartzite ridges forming the characteristic undulating terrain. Mostly, the topsoil is made up of fine sand medium-grained granite [18].

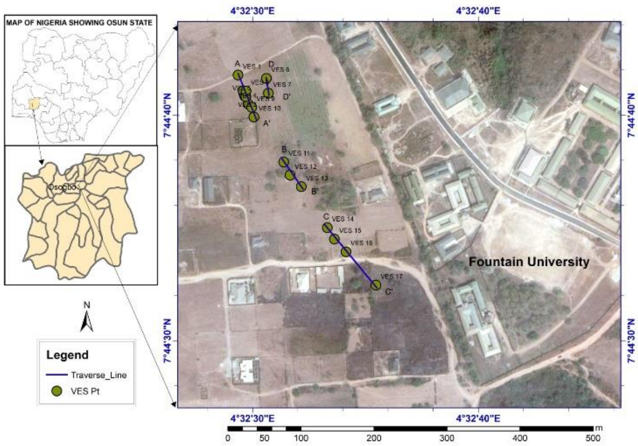

Fig. 1: Map of the Study Area

2. MATERIAL AND METHODS

Three (3) traverses of about one hundred meters each were surveyed, and seventeen (17) VES (1D) were subsequently conducted using Schlumberger electrode array as shown in Fig. 1. The apparent resistivity of each point was measured and recorded using a 16GL PASI-Earth resistivity meter while the coordinates of the points were recorded using a mobile handheld Global Position System (GPS). The setup for the VES survey is described in Fig. 2. The formula for calculating the apparent resistivity for the Schlumberger array is expressed in eq. 1.

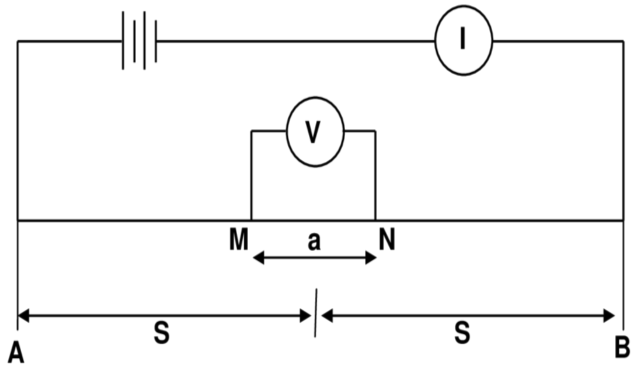

Fig. 2: Schlumberger Electrode array for VES Geoelectrical survey [20].

$$\rho_a = \pi\left[\frac{s^2}{a} - \frac{a}{4}\right]\frac{v}{I} = \pi a\left[\left(\frac{s}{a}\right)^2 - \frac{1}{4}\right]\frac{v}{I} \qquad (1)$$

Were.
A & B = current electrodes
M & N = voltage electrodes
S = AB/2 (current electrode distance)
a =voltage electrode distance
V = Applied Voltage
I = Current flow.
ρ_a = *Apparent resistivity*
π = *3.14*

The maximum current electrode distance AB/2 varied from 65 m to 200 m. The apparent resistivity values were calculated from the product of the apparent resistivity and the geometric factor (K-factor) of the Schlumberger array used. These resistivity values were plotted on a log-log graph against the electrode distance (AB/2) and curve matched. Curve marching involves the comparison of VES curves obtained in a resistivity survey with Master Curves obtained from past experimental studies [14]. The comparison is based on the values of apparent resistivity of the geoelectric layers detected in a resistivity curve. The Master Curves include H type where ρ1> ρ2 < ρ3; K type where ρ1< ρ2 > ρ3; A type where ρ1< ρ2 < ρ3; and Q type where ρ1> ρ2 > ρ3 [4]. The geoelectric parameters obtained from curve matching were then fed into Winresist software for computer iteration to produce the resistivity values of the sublayers, geoelectric layers, thicknesses, and respective depths and the geoelectric section for each tranverse were further generated using Rockworks version16 [15].

3. RESULTS AND DISCUSSION

The geoelectric parameters obtained from the sounding curves of the study area are presented in Table 1 and were in turn used to generate subsurface models, profiles and 2D sections. Table 1 reflects the inferred geoelectric layers, their depths, thicknesses, curve types and lithologic unit for each VES points [21]. The curve types are H, HA, HAA, HAK, HKH, A, AK, KH, QH, and QHA. The dominant curve type in the area is HA type having percentage occurrence of 42%. This HA-type is typical of pronounced weathering effect characterized by low to intermediate high resistive clay to lateritic topsoil (27.5 to 967.1 Ωm); saturated weathered layer to partly weathered layer (60.8 to 1130 Ωm); and fractured to fresh basement (103 to 5432 Ωm). In most case the topsoil is thin with maximum thickness of 0.9 m, while the overburden thickness ranges from (9.9 to 92.6 m). However, some shallow zone of low resistivity values especially at VES (8, 9, 10, 11, 12, and 13) show a weak clayey layer with probable depth less than 16.9 m.

Table 1: Summary of VES Results

VES No	LAYERS	RESISTIVITY (Ωm)	THICKNESS (m)	DEPTH (m)	CURVE TYPE	LITHOLOGY
	1	27.5	0.7	0.7	KH	Topsoil
	2	182.9	13.2	13.9	$\rho_1 < \rho_2 > \rho_3 < \rho_4$	Weathered Layer
1	3	103.9	12.2	26.1		Fractured Basement
	4	931.1	---	---		Fresh Basement
2	1	91.0	0.7	0.7	HA	Topsoil
	2	82.8	9.8	10.6	$\rho_1 > \rho_2 < \rho_3 > \rho_4$	Weathered Layer
	3	354.9	18.8	29.4		Fractured Basement
	4	3385.5	---	---		Fresh Basement
3	1	188.6	0.9	0.9	HA	Topsoil
	2	67.4	5.9	6.7	$\rho_1 > \rho_2 < \rho_3 > \rho_4$	Weathered Layer
	3	354.8	22.4	29.1		Fractured Basement
	4	3093.4	---	---		Fresh Basement
4	1	337.0	0.6	0.6	HA	Topsoil
	2	38.0	5.3	5.9	$\rho_1 > \rho_2 < \rho_3 > \rho_4$	Clay formation
	3	339.8	27.4	33.3		Fractured Basement
	4	5432.6	---	---		Fresh Basement
5	1	203.4	0.8	0.8	HA	Topsoil

	2	60.8	7.0	7.8	$\rho_1 > \rho_2 < \rho_3 > \rho_4$	Weathered Layer
	3	313.9	22.2	30.0		Fractured Basement
	4	2924.9	---	---		Fresh Basement
6	1	300.4	0.5	0.5	**HAA**	Topsoil
	2	139.2	2.4	3.0	$\rho_1 > \rho_2 < \rho_3 > \rho_4 < \rho_5$	Weathered Layer
	3	548.7	5.0	8.0		Partly weathered layer
	4	149.0	31.6	39.6		Fractured Basement
	5	1341.6	---	---		Fresh Basement
7	1	164.7	0.7	0.7	**HAK**	Topsoil
	2	135.0	3.3	3.9	$\rho_1 > \rho_2 < \rho_3 < \rho_4 > \rho_5$	Weathered Layer
	3	1130.9	14.9	18.9		Partly weathered layer
	4	4336.9	17.0	35.9		Fresh basement
	5	222.2	---	---		Fractured Basement
8	1	54.2	0.7	0.7	**HA**	Topsoil
	2	42.1	3.5	4.2	$\rho_1 > \rho_2 < \rho_3 > \rho_4$	Clay formation
	3	413.8	17.0	21.2		Fractured Basement
	4	1572.4	---	---		Fresh Basement
9	1	85.3	0.7	0.7	**QH**	Topsoil
	2	18.6	2.3	3.0	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	Weathered Layer (Clay)
	3	5.6	14.0	16.9		Clay formation
	4	121.1	---	---		Fractured Basement
10	1	187.4	0.6	0.6	**QH**	Topsoil
	2	21.6	1.9	2.6	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	Weathered Layer (Clay)
	3	4.0	12.0	14.6		Clay formation
	4	43.5	---	---		Weathered Layer
11	1	190.5	0.6	0.6	**QH**	Topsoil
	2	24.2	2.2	2.8	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	Weathered Layer (Clay)
	3	4.5	7.1	9.9		Clay formation
	4	134.5	---	---		Fractured Basement
12	1	179.5	0.5	0.5	**QHA**	Topsoil
	2	20.8	1.5	2.1	$\rho_1 > \rho_2 > \rho_3 < \rho_4 < \rho_5$	Weathered Layer (Clay)
	3	8.5	5.7	7.7		Clay formation
	4	52.8	14.5	22.2		Weathered Layer
	5	396.6	---	---		Fractured Basement
13	1	120.4	0.6	0.6	**QH**	Topsoil
	2	38.7	2.2	2.8	$\rho_1 > \rho_2 > \rho_3 < \rho_4$	Weathered Layer (Clay)
	3	17.1	5.3	8.1		Clay formation
	4	183.7	---	---		Fractured Basement
14	1	468.6	0.7	0.7	**QHA**	Topsoil
	2	150.8	2.7	3.4	$\rho_1 > \rho_2 > \rho_3 < \rho_4 < \rho_5$	Partly Weathered Layer
	3	64.4	12.5	15.8		Weathered Layer
	4	460.5	37.5	53.3		Fractured Basement
	5	4919.0	---	---		Fresh Basement
15	1	261.1	0.6	0.6	**HKH**	Topsoil
	2	253.8	2.8	3.5	$\rho_1 > \rho_2 < \rho_3 > \rho_4 < \rho_5$	Weathered Layer
	3	791.4	22.4	25.9		Partly weathered layer
	4	258.6	66.8	92.6		Fractured Basement
	5	3298.6	---	---		Fresh Basement
16	1	967.1	0.6	0.6	**HA**	Topsoil
	2	505.1	5.6	6.2	$\rho_1 > \rho_2 < \rho_3 > \rho_4$	Weathered Layer
	3	692.8	20.6	26.9		Partly weathered layer

	4	2609.8	---	---		Fresh Basement
17	1	629.4	0.6	0.6	**HKH**	Topsoil
	2	391.5	4.1	4.7	$\rho_1 > \rho_2 < \rho_3 > \rho_4 < \rho_5$	Weathered Layer
	3	1647.4	14.5	19.3		Fresh Basement
	4	328.2	55.9	75.2		Fractured Basement
	5	3969.5	---	---		Fresh Basement

The geoelectric model (Fig. 3) shows the lithological variation and thickness of layers based on the geoelectric parameters of these sublayers (resistivity, thickness, and inferred lithology). The earth model was built with the aid of Rockworks geostatistical software. The study area is characterized by the presence of very thick weathered – fractured layers and occurrence of the clay formation. This reflects the intense degree of weathering profile in the study area. The suitable conductive zone for groundwater exploration is located toward the northern and southern part of the study area which could also be used for erection of structures. However, the clay layer identified at shallow depth in the central part makes the region not suitable for engineering construction though it could be excavated, or deep foundation could be considered.

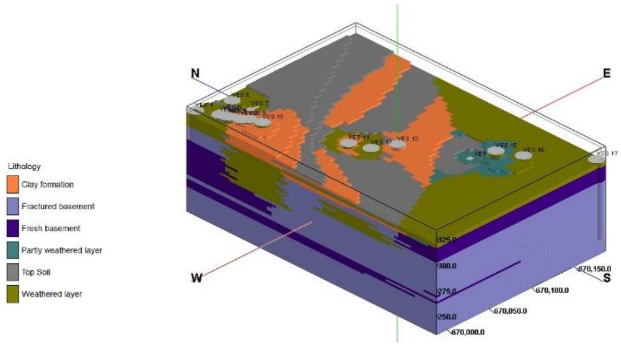

Fig. 3: Geoelectrical model of the study area.

Geoelectric section A – A' (Fig. 4) shows the subsurface variation of VES (1-10) which were all conducted along the boy's hostel. Along the traverse, the observed weathered zone lies between the start point of the traverse A and terminate at 45 m away into a more conductive zone of clay formation. The section reveals the maximum overburden thickness of 39 m, with two distinct geoelectric profiles of topsoil, weathered layer, fractured basement, and fresh basement with thicknesses of 0.6 m, 9 m, and 18 m, respectively. Also, the second profile has topsoil, clay formation, weathered layer, and fresh basement with thickness of 0.6 m, 9 m, and 32 m, respectively.

Geoelectric section B – B' (Fig. 5) shows the subsurface variation of VES (11-13) which were conducted along the road section of the school between the boy's hostel and the clinic area. Along the traverse, presence of clay layer at shallow depth was observed as a continuous low resistive layer of appreciable thickness of about 15 m. This is inimical to engineering structures such as road and buildings. In other way, this could be used as open landfill waste site, due to the presence of highly impermeable clay layer.

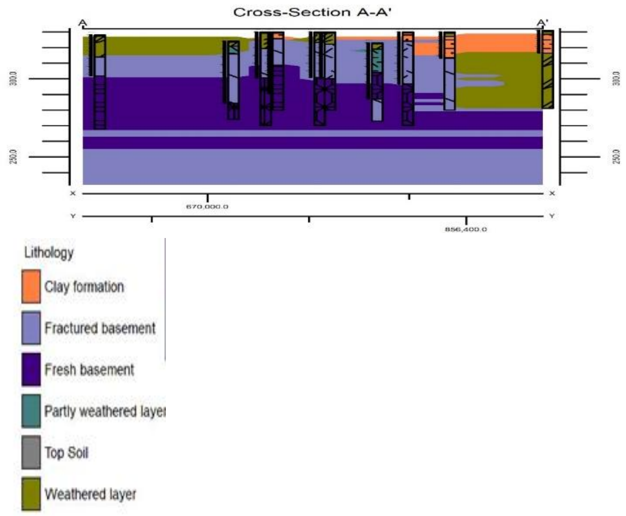

Fig. 4: Geoelectric section A – A' showing the subsurface variation of VES (1-10)

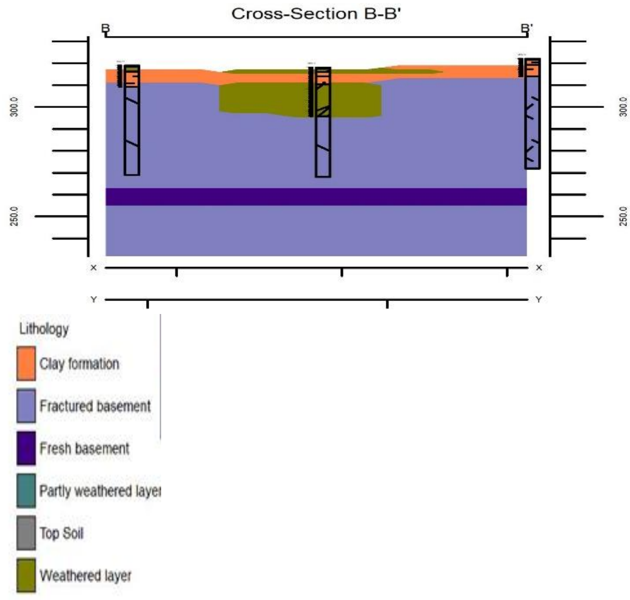

Fig. 5: Geoelectric section B – B' showing the **subsurface variation of VES (11-13)**

Geoelectric section C – C' (Fig. 6) shows the subsurface variation of VES (14-17). The profile is beside the school fence. Along the traverse, the observed weathered zone lies between the start point of the traverse C and terminate at 24 m away into a more resistive zone of partly weathered layer. From this section, the two adjacent layers; fracture bedrock and shallow fresh bedrock share boundary in the southern region of the survey.

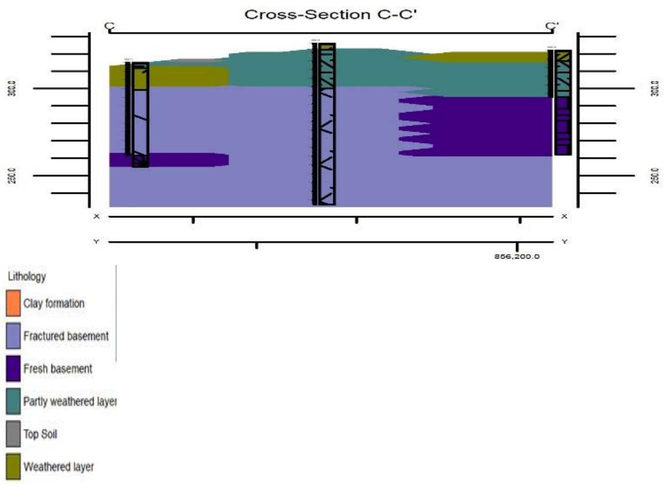

Fig. 6: Geoelectric section C – C' showing the subsurface variation of VES (14-17)

4. CONCLUSION

The geophysical survey conducted within Fountain University campus in Oke-Osun, Oshogbo, revealed the subsurface geoelectrical properties of the earth materials in the study area. The interpretation of the VES data shows the varying degree of weathering occurrence within the study area. Four to five geoelectric layers were delineated. The topsoil which is composed of the sand/clayey sand and laterite with resistivity values that ranges from 27.5 – 967.1 Ωm and maximum thickness of 0.9 m. The presence of a localized clay layer identified with resistivity values ranging from 4.0 – 42 Ωm and thickness ranging from 3.5 – 14 m. The weathered product of migmatite/gneiss with resistivity values that ranges from 60.8 – 505.1 Ωm and thickness ranging from 2.4 – 13.2 m. Also, the partly weathered layer with resistivity values ranging from 150.8 – 1130.0 Ωm and thickness ranging from 2.7 to 20.6 m. The fractured bedrock with resistivity and thickness range 103 – 460.0 Ωm and 20.6 m to 66.8 m respectfully indicates presence of potential fractured zone that could be considered for groundwater extraction. The fresh basement is characterized with high resistivity values ranging from 931 – 5432.0 Ωm with infinite thickness. The survey was able to reveal the resistivity information that can guide future engineering construction development within the study area, and it was found that the second layer (weathered layer) is suitable for several types of foundations at distinct locations within the study area, due to its thickness which is up to 26.9 m.

COMPETING INTERESTS

Authors have declared no conflict of interest.

AUTHORS' CONTRIBUTIONS

Authors contributed collectively.

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