Geophysical Characterization of Subsurface Layers and Soil Competency of Naraguta Campus, University of Jos-Nigeria

Janet Agati-Yakubu   Sunday Sani Daku   Lohfa Wuyep Nimze[*]   Winifred Naanlep Dajilak
Yaba Daniel Douglas   Vincent Santos Anyip
Department of Geology, Faculty of Natural Sciences, University of Jos, PMB 2084, Jos-Nigeria

Abstract
The utilization of geophysical methods can increase the effectiveness of civil engineering works since it can provide the information which the conventional civil engineering method was hard to determine due to the concern of money, time and quality. One of such geophysical methods is the Electrical resistivity using the Schlumberger array which was employed in this study. The study identified three lithological units of top lateritic soil, weathered / fractured basement and the fresh basement. The thickness of the top lateritic soil ranges from 0-4m, the weathered/ fractured basement has an average thickness in the range of 3.0-25 m while the fresh basement thickness ranges from 25 m to infinity. The resistivity values of the sub-surface layers range from 11.40 Ωm to 5896.7 Ωm with most of the lithological units rated competent to highly competent. This study serves as basis for further engineering investigation for the design and construction of proposed buildings and has shown the relevancy of the application of geophysics to civil engineering works.
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1. Introduction
Construction engineering involves the designing, planning, construction, and management of physical infrastructure, which may include roads, bridges, buildings, dams and utilities. All of these types of facilities have a physical footprint that requires some type of modification of the ground, which may involve the insertion of anchors, ground compaction or excavation.

Most construction engineering projects generally require information on subsurface ground conditions to maximum depths of only 50 m or so below the ground surface. This zone can encompass soil, groundwater, unconsolidated sediments, weathered rock, and competent bedrock. It can also contain products of our own invention, including utilities, buried waste, and contaminants. Typical parameters of interest to designers and engineers are the thickness and extent of layers, the physical properties of layers and any variability within them, and any structure within the ground (Alastair *et al.,* 2016). These can be deciphered using geophysical means as the methods are cost-effective and non- invasive. Some of the geophysical methods which are commonly used in civil engineering to characterize the sub- surface are Electrical resistivity, Seismic, Ground Penetrating Radar, Electromagnetic and Gravity surveys. Geophysical techniques also can be of help in locating cavities, backfilled mineshafts and dissolution features in carbonate rocks and can be extremely useful in determining the stiffness properties of the ground (Clayton, 1996). However, since such potentials of geophysics in engineering are yet to be realized, the application of these techniques are still not being fully utilized (Moh'd *et al.,* 2011).

According to Clayton (1996), geophysical techniques offer the chances to overcome some problems inherent in more conventional geotechnical ground investigation which involves drilling, trenching and trial pitting, from which representative disturbed and/or undisturbed samples of the *in-situ* materials may be obtained and analysed and Standard Penetration Test and others which can be correlated with other engineering data. Soupios *et al.* (2007) posited that data obtained through indirect geophysical techniques would contribute to the decision making process for choosing the appropriate footing of a structure based on the subsurface inhomogeneity of the site. The electrical resistivity method in particular, has been employed in studies such as depth to bedrock determination, mapping of superficial deposits, structural mapping, aquifer delineation, saline water mapping, lithological differentiation, and the determination of structural trends etc. In this survey, the conventional resistivity method of Vertical Electrical Sounding (VES) was employed. The VES method was chosen for this study because it has been proven to be a more economical, quick and effective exploration tool for groundwater and engineering geological investigations.

The electrical resistivity survey was embarked upon based on its capability to delineate geological structures such as fractures, faults as well as vertical or near vertical contacts. The delineation of such features is of prime importance in engineering geological site investigation and hydrogeological mapping. This is because any of the features mentioned above can be zones of weakness through which impounded water is lost along dam axis or within reservoir floor. Foundation failure arising from differential movement in the event of tectonic activity along linear features or structures can result in the collapse of civil engineering structures such as dams, buildings and roads. So it is important to investigate these structures to avoid consequent disaster.

The study area falls in the basement terrain underlain by the Precambrian crystalline rocks (600 ± 150 Ma) typical of the Nigeria Basement Complex located on the Naraguta Sheet 168 SW. These rocks exhibit structures like joints, veins, faults and dykes. The rock types found in the study area include; the Jos biotite granite, Aplo-pegmatitic granite gneiss, the Neil's valley granite porphyry, and Naraguta quartz-pyroxene-fayalite porphyry with the dominant rock type being the Aplo-pegmatitic granite gneiss (MacLeod, 1971).

This research study was necessitated by the recent massive infrastructural development works being carried out within the Naraguta Campus of the University of Jos, which falls majorly within area of study. The work will complement directly or indirectly the geotechnical Standard Penetration Test drilling which may not be cost effective.

2. Method of Study

Electrical resistivity method of geophysical prospecting was employed using the Schlumberger electrode configuration with the aid of Omega SAS 3000 Resistivity Meter. This method measures the conductivity of the subsurface materials by passing electric current through the ground. Twenty-four (24) VES points covering four (4) profiles **A- A' and B-B', C-C' and D-D'** respectively (Figure 1) were occupied and the maximum current electrode separation (AB/2) utilized for the Schlumberger sounding was 125 m. In groundwater and engineering studies for instance, the relevance of the method is based on the usually significant resistivity contrast between the weathered zone and or fractured
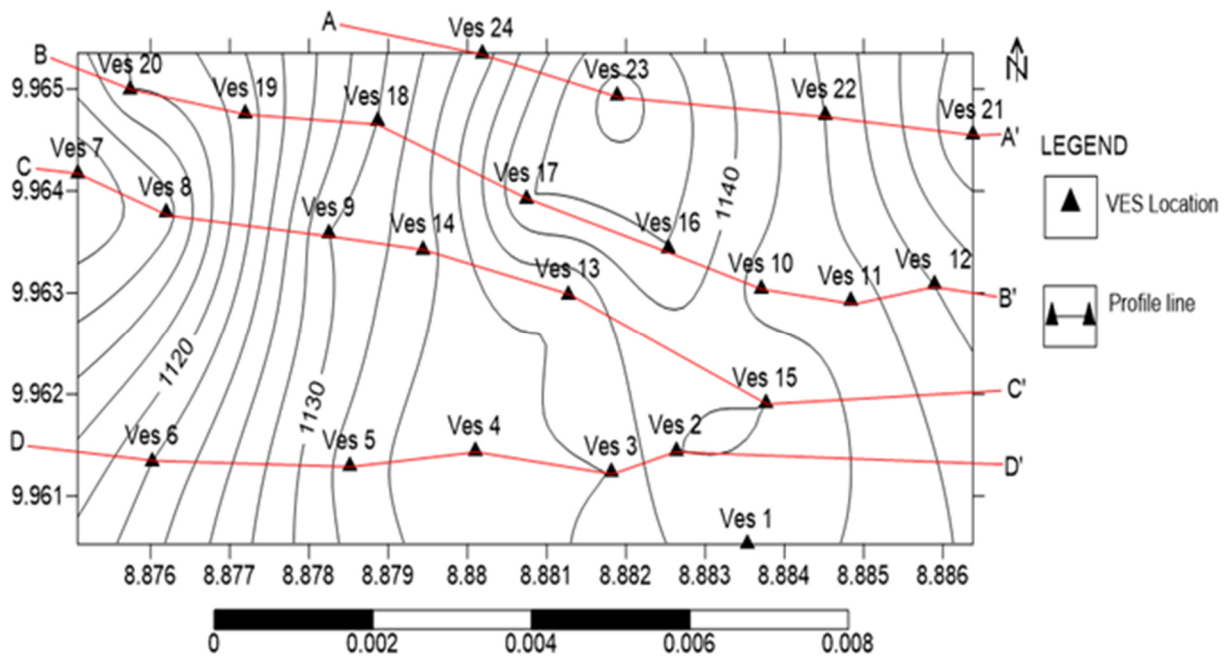

Figure 1: Location Map of the Study Area

column (Olorunfemi and Fasuyi, 1993). The purpose of the vertical electrical sounding method is to investigate the change of the formation resistivity with depth. To achieve this purpose, it is necessary to arrange measurements in such a way that at different measurements, the value of the measured potential difference is affected by the formation resistivity at different depth ranges. This may be accomplished by changing the distance between the current electrodes so that the depth ranges to which the current penetrates is changed. However, the distance between the potential measuring electrodes and their position with respect to the current electrodes also affect the depth range from which information on the formation resistivity is obtained. In the configuration employed in this study (Schlumberger) the four electrodes are positioned on a straight line, with the two current electrodes on the outside of the potential measuring electrodes. The interpretation of the VES data is based on the assumption that the subsurface consists of a sequence of distinct layers of finite thickness and each of these layers is assured to be electrically homogeneous and isotropic (Koefoed,1979), and the boundary planes between subsequent layers are assumed to be horizontal.

The VES is based on the principle that a fraction of the electric current injected into the ground, penetrating below a given depth, increases with the separation of the current electrodes. Thus as the current electrode separation is increased, the depth of penetration will increase.

The field data was processed for easy interpretation by calculating apparent resistivity (ρ_a) value for each layer depth, which was done by multiplying the resistance by their respective geometric constants K, (i.e. $\rho_a = R \times K$).The processed data were interpreted using the computer Software called **IPI2WIN** where the field curves were compared with the computer-modelled curves to deduce the layer thickness (m), true resistivity values (Ωm) for

each layer and the percentage fitting error of each plot model.

3. Results and Discussion

3.1: Sub-surface Lithology

Information on the existing subsurface conditions on site is a critical requirement because it is useful in the planning and design stage of the building foundation and other underground works.

Three lithological geo-electric layers were delineated from the study area consisting of the top soil which is mostly lateritic, weathered/ fractured basement and the fresh basement as seen in Figures 2, 3, 4 and 5 respectively. The top lateritic soil thickness varies from 0.1-4.0 m; the weathered/ fractured basement has thickness that varies from 3.0 -25.0 m while that of the fresh basement ranges from 25.0 m – infinity. The resistivity values of these layers vary from 101 Ωm- 821 Ωm for the top soil, 11.40 Ωm – 99.98 Ωm for the weathered / fractured basement while that of the fresh basement ranges from 442 Ωm- 5896.70 Ωm (Table 1) below. The VES points 13, 15, 19 and 24 have the thickest layers of weathered/ fractured basement while VES 4, 5, 6, 7, 8, 14 and 16 have shallower fresh basement thicknesses which implies that these areas are capable of anchoring heavy implied loads because of the high bearing capacity associated with fresh basement rocks.

Table 1: Resistivity Values, Thickness, Depth and Curve Types of VES Points in the Study Area

| VES Points	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4	Curve Type
1	379.23	51.44	1104.30	25.77		2.8	12.6	16.5		HK
2	95.20	22.35	1421.60	13.41		9.4	5.5	16.5		HK
3	547	80.49	34.34	212.48		0.7	6.8	4.4		QH
4	527.69	119.30	200.24			1.1	15.8			H
5	806.99	50.35	130.43			1.5	1.2			H
6	394.46	101.87	25.40	187.98		2.3	11.6	6.7		QH
7	688.75	134.56	456.01			1.6	3			QH
8	6474.46	137.89	12.89	592.53		0.5	8.0	6.5		QH
9	231.32	127.29	205.61	449.17		1.3	1.1	22.4		HA
10	442.42	202.94	34.03	58957		1.0	12.1	8.2		QH
11	203.66	53.24	14563			1.2	14.4			H
12	389.80	88.90	1523.4	322.48		2.3	7.1	11.6		HA
13	532.72	141.86	3247.7			1.8	42.7			H
14	1060.9	424.17	26.29	2046.3		1.4	2.9	5.6		QH
15	224.08	114.51	226.93	3063.8		1.2	5.8	44.3		HA
16	821.19	223.61	19.10	3110.8	71.32	0.3	7	3.3	22.9	QHK
17	395.07	114.31	616.07			0.3	24.6			H
18	613.94	218.21	60.04	908.45		1.1	7.9	10.6		QH
19	420.53	181.70	137.90	1264.9		1.9	1.2	37.9		QH
20	490.63	104.34	11.4	1534.8		1.0	5.5	5.1		QH
21	468.84	96.39	442.47			2.4	17.3			H
22	101.20	19.33	7952.4			2.6	12.7			H
23	6146.2	342.05	42.13	1235.2		0.3	2.9	14.3		QH
24	461.28	24.27	99.98	2009.8		2.1	1.4	39.1		HA
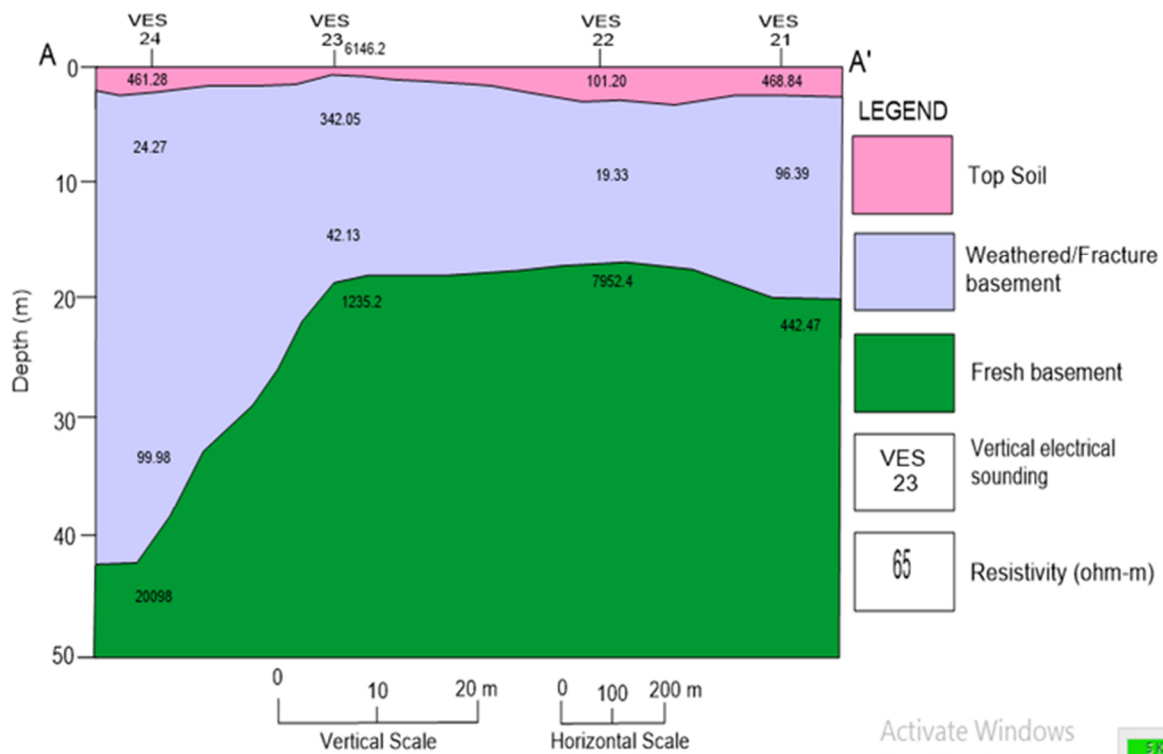
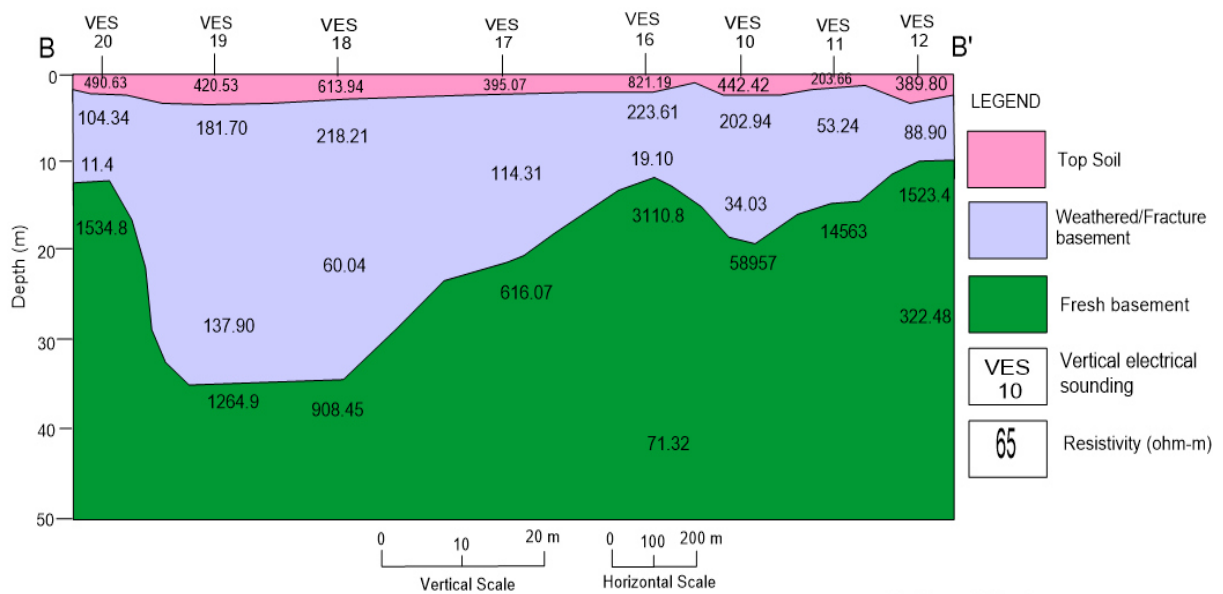**Figure 2: Geo- electric Section of the Study Area Along Profile A-A'**

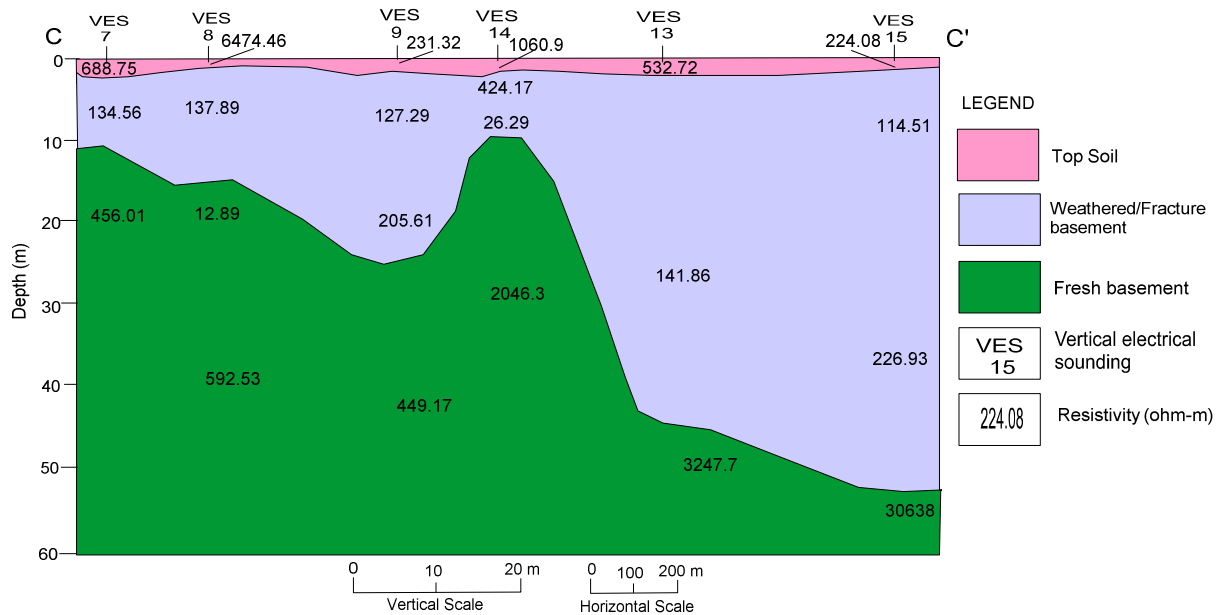**Figure 3: Geo- electric Section of the Study Area Along Profile B- B'**

Figure 4: Geo- electric Section of the Study Area Along Profile C- C'
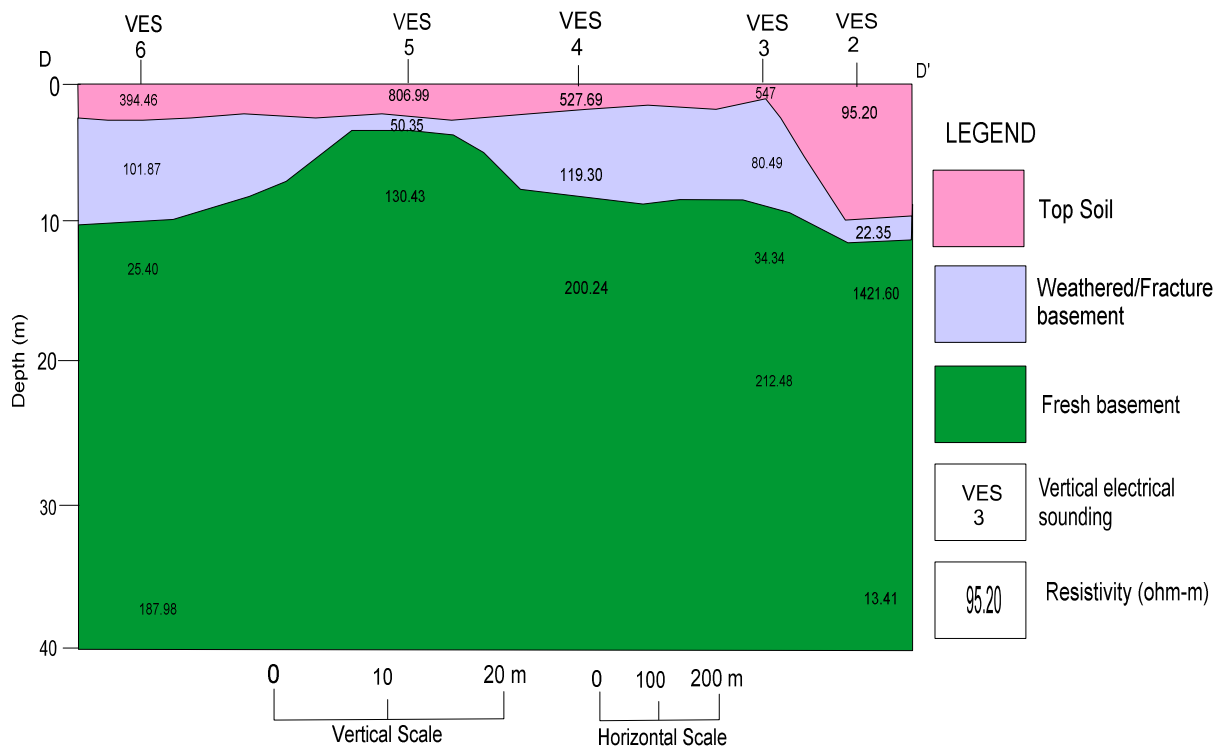

Figure 5: Geo- electric Section of the Study Area Along Profile D- D'

3.2: Soil Competency

The aim of any engineering site investigation whether through direct or indirect means is to determine the nature (competence) of the sub-surface strata that are capable of carrying the load that will be applied to it. Electrical resistivity values have been used by authors such as Sheriff (1991), Idornigie *et al.* (2006) and Bayowa and Olayiwola (2015) to classify earth materials into incompetent, moderately competent, competent and highly competent as shown in Table 2. Clay is characterized by low resistivity usually less than 100 Ωm are regarded as incompetent material as they tend to flow under stress whereas, sands and crystalline rocks are regarded as competent due to the fact that they can withstand stress because of the presence of sands mixed with clay. The sands in this zone would enhance the engineering capacity unlike the purely clayey horizon (Mosuro *et al.,* 2012). Comparing the resistivity values in Table 1 with the standard as proposed by Bayowa and Olayiwola (2015) Table 2, most of the layers are in the range of competent to highly competent.

Table 2: Soil Competence Rating (After Bayowa and Olayiwola, 2015).

Apparent Resistivity (Ωm)	Lithology	Competence Rating
<100	Clay	Incompetent
100-350	Sandy clay	Moderately Competent
350-750	Clayey sand	Competent
>750	Sand/Laterite/Bedrock	Highly Competent

5. Conclusion

Electrical resistivity method of geophysical prospecting has been used in geotechnical and engineering geology, groundwater exploration, contamination studies etc. The cost effectiveness of this method coupled with its suitability in determining the depth to bedrocks, types and thickness of sub- surface materials has made very convenient for use by Civil Engineers and Geotechnical/ Engineering Geologists to characterize the sub-surface before any meaningful construction can commence. Other advantages of the electrical resistivity method are that it saves time and it is environmentally-friendly because of its non-invasive nature. The data obtained in the course of the study identified three lithological units comprising of the top soil which are mostly lateritic, the weathered/ fractured basement and the fresh basement. The sub-surface layers range from competent to highly competent in view of the resistivity values measured. However, this can be complimented with borehole data to arrive at a more convincing conclusion.

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