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Evaluation of sub-soil geo-electric properties in a proposed power sub-station site at Ebubu, Rivers State, Nigeria

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Abstract
Electrical resistivity survey was carried out in a site proposed for the construction and installation of a Power sub-station. The project will involve subsurface installation of cables and other objects that easily conduct electricity. Extant laws including EIA also require knowledge of subsurface distribution of resistivity in construction projects that would involve burial of steel pipes and cables. The imperative of this is emphasized by the location of the project in an area of shallow groundwater conditions. Field resistivity measurements were undertaken using ABEM Terrameter SAS 1000, adopting Schlumberger configuration in vertical electric sounding at 12 locations within the study site. The results were used to generate geo-electric log models. Three geo-electric profile models (pseudo-profiles) were also taken NE-SW of the site. Interpretation of the models shows that the area is characterized by two geo-electric layers to the depth of 30m. The upper layer of lower resistivity occurs to a depth of 2-3m. This layer consists of lateritic to silty sands. The lower layer has a resistivity of between 900 - >2000 Ωm and represents fine to coarse sands and gravels. On the Soil Electrical Resistivity Classification (BS 1377), the subsoil falls within non-corrosive class. Objects installed in the soil are not likely to suffer corrosion soon. Similarly, subsurface electrical installations will pose minimal hazards and would require basic precautions to avoid electrical accidents.
Keywords: Resitivity, subsurface installation, power substation, Rivers State, Nigeria

I. Introduction

Electrical resistivity surveys now enjoy a wide and varied application outside its original applications in geological, mining and geotechnical investigations. It now has wide applications in environmental studies. This is partly as a result of increased environmental awareness and control as well as strict environmental laws and partly as a result of availability of high speed computers capable of processing the usually large volume of data generated during electrical surveys, (Reynolds 1998). The use of electrical survey method in environmental studies derive from the fact that electrical resistivity of earth materials depends on environmental parameters such as mineral composition, fluid content, degree of saturation with water, nature and concentration of the saturating fluid, conductivity, porosity and permeability of the matrix, grain size etc. It is used especially to determine the subsurface resistivity distribution in areas requiring subsurface installation of corrosible components or objects that easily conduct electricity. Environmental Impacts Assessment, EIA, also requires knowledge of subsurface distribution of resistivity in construction projects that would involve burial of steel pipes and cables. This is more pertinent in areas of shallow groundwater conditions like the Niger Delta where this study was carried out.

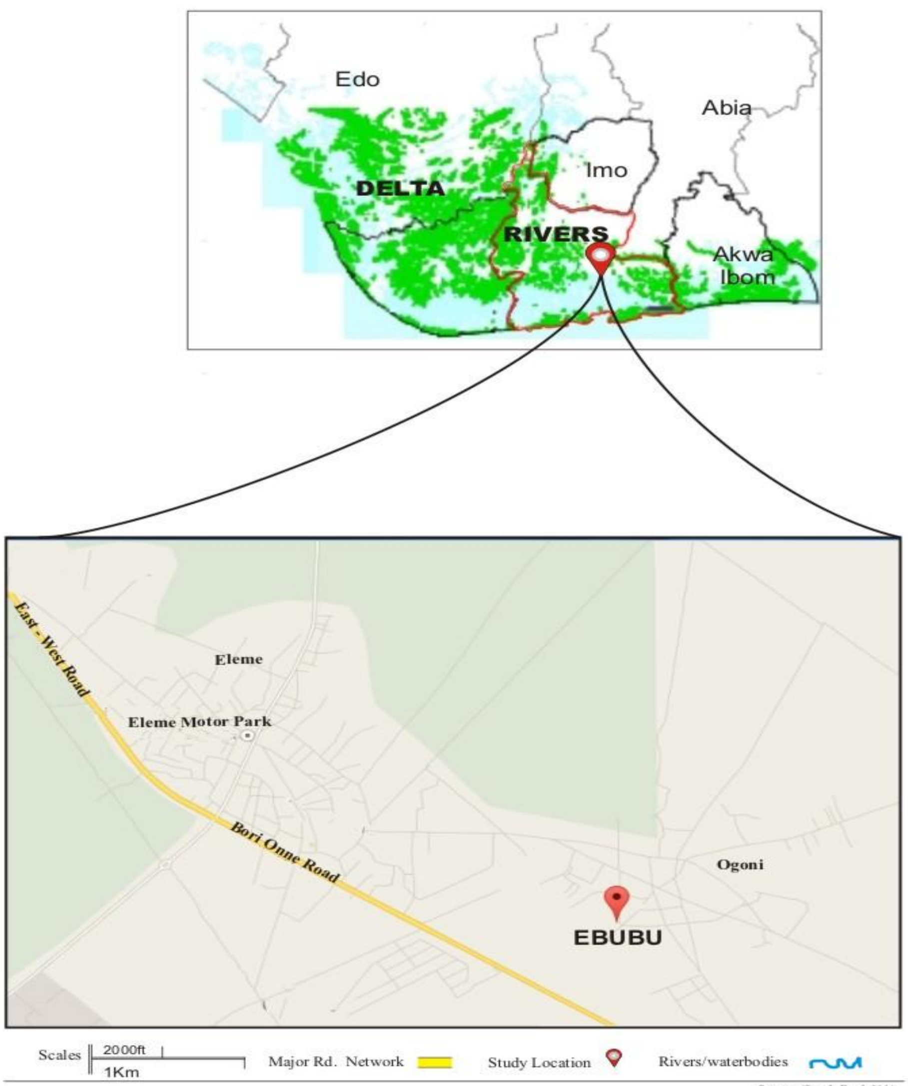
The study site has been marked for construction of an Electrical Power Substation with installation of an effective Lightening Arrestor and Electric Grounding System for safety. The study was commissioned to generate baseline geo-electric characteristics of the area. Shallow resistivity measurements were made at the location with a view to establishing the soil resistivity profile in the area; a knowledge of which is necessary for the design of the project. The level of aggressivity and corrosivity of the sub-soil environment is needed to guide in choice sub-surface installations to avoid electrical accidents, protect sub-surface installations and achieve their expected design life. Extant environmental laws also require that groundwater be protected from pollution resulting from corrosion. Nature of the water bearing units as well as depths to water table will also be investigated.

Soil resistivity measurements were carried out using Schlumberger VES method, (at possible electrical grounding location) at the project site. The data were acquired under fairly favourable weather conditions; sunny and breezy.

II. Geomorphology and Geology of Study Area.

The study area is located in Ebubu, an oil producing community in Rivers State, eastern Niger Delta, Nigeria (Figure 1). The physiography conforms to the geomorphic features of the Niger Delta governed by several factors which influence transport and ultimate deposition of the sediment load, shape and growth of the delta. Present knowledge of the geology of the Niger Delta derives from the works of earlier researchers such as Reyment, (1965), Short & Stauble, (1967), Murat, (1970), Merki, (1970), Hospers, (1971) etc and also from exploration records of oil and gas companies in Nigeria. The formation of the so called proto-Niger Delta occurred during the second depositional cycle (Campanian-Maastrichtian) of the southern Nigerian basin. However, the modern Niger Delta was formed during the third and last depositional cycle of the southern Nigerian basin which started in the Paleocene.

Short and Stauble (1976) explained that the Niger Delta sedimentary basin as made up of three main Formations divided lithostratigraphically and in the order of age into Akata Formation, (Paleocene), Agbada formation, (Eocene) and Benin Formation (Miocene to Recent). These Formations are in turn, overlain by various types of Quaternary deposits, 40 - 150m in thickness (Etu-Efeotor and Akpokodje, 1990), (Table 1).



Geological Unit	Lithology	Age
Alluvium (general) Freshwater Back-swamp, Meander belt Mangrove and salt water/backswamps Active/abandoned beach ridges Sombreiro-Warri deltaic plain	Gravel, sand, clay, silt Sand, clay, some silt gravel Medium-fine sands, clay and some silt Sand, clay, and some silt Sand, clay, and some silt	Quaternary
Benin Formation (Coastal Plain Sand)	Coarse to medium sand with subordinate silt and clay lenses	Miocene
Agbada Formation	Mixture of sand, clay and silt	Eocene
Akata Formation	Clay	Paleocene

Table 1. Various geomorphic units overlying the subsurface geology of the Niger Delta

Ebubu itself is located within the quaternary coastal plain of the lower Niger with extensive alluvium deposits. The alluvium forms the surface blanket for the coastal plain sands. They are sufficiently recharged by precipitation and surface water bodies. Static water levels are generally fairly shallow, varying between 8 and 15m with the water table showing appreciable seasonal fluctuations, rising with the rains and declining during dry season. Groundwater flow is generally in the NE-SW trend in line with the regional trend in the basin. Water quality increases with depth with the thick sequence of sands forming the major aquifers in the area while the clays form the aquitards. The Benin Formation forms the major aquifer in the study area and is exploited for groundwater supply. Although a depth of 100m is most exploited, about 300m depth has been exploited for water supply (Ngah 1990). It consists essentially of massive and highly porous sands and gravels with few clay intercalations

Some studies have previously been carried out at other parts of the Niger Delta to evaluate the subsoil resistivity and geotechnical properties for various other uses, (Osakuni and Abam, 2004, Abam and Ngah, 2013, Ngah and Abam, 2014). The uniqueness of the present study is the application for which it is sought.

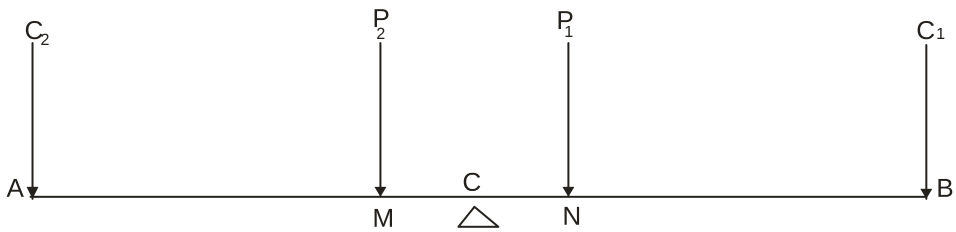
III. Materials and Method

Resistivity is a fundamental electrical property of rock material closely related to its lithology. Its subsurface distribution can be determined from measurements on the surface leading to the generation of a resistivity profile that can be used to characterize subsurface formations. Knowledge of the distribution can guide in choice of locations of earthing electrodes.

To achieve this, field works were undertaken to measure the resistivity of earth materials below the study area. ABEM Terrameter SAS 1000 was used for this investigation. The terrameter itself comprises three main units namely the transmitter, receiver and micro-processor all enclosed in a single casing. The electrically isolated transmitter sends out well-defined and regulated signal currents. The receiver discriminates wise and measure voltage correlated with transmitted signal current while the micro-processor monitors and controls operations and calculates results in running average of repeated readings.

Field resistivity measurement is achieved by passing a current of known value into the ground by means of two electrodes (C_1, C_2) and measuring potential difference between two intermediate points in the ground using another two electrodes (P_1, P. $_2$), Figure 2.

The ground whose mean resistivity is measured is that between the voltage electrodes (P_1, P_2) up to a depth (ID) equal to about 1/3 of the distance between C_1 and C_2 (total electrode spacing) and a width equal to about 2/3 of the distance C_1 and $C_{2.}$ (Reynolds 1998). As the electrode spacing (C1, C2) increases, depth of the probe increases, a process often referred to as electrical drilling. The potential-drop-ratio method is a variation on this procedure used for determining resistivity.



P_1 and P_2 = Potential electrode →

C_1 and C_2 = Current electrode →

Figure 2 Electrode arrangement using Schlumberger Configuration

All resistivity techniques in general use require the measurement of ground resistance (R) which is converted to apparent resistivity (**ρ_a**) by multiplying with a geometric factor which describes the geometry of the electrode configuration such that (Keller and Frechnecht 1970):

$\rho_a = 2\pi.aR.$

Where R = resistance value read on the resistivity meter (Ω)

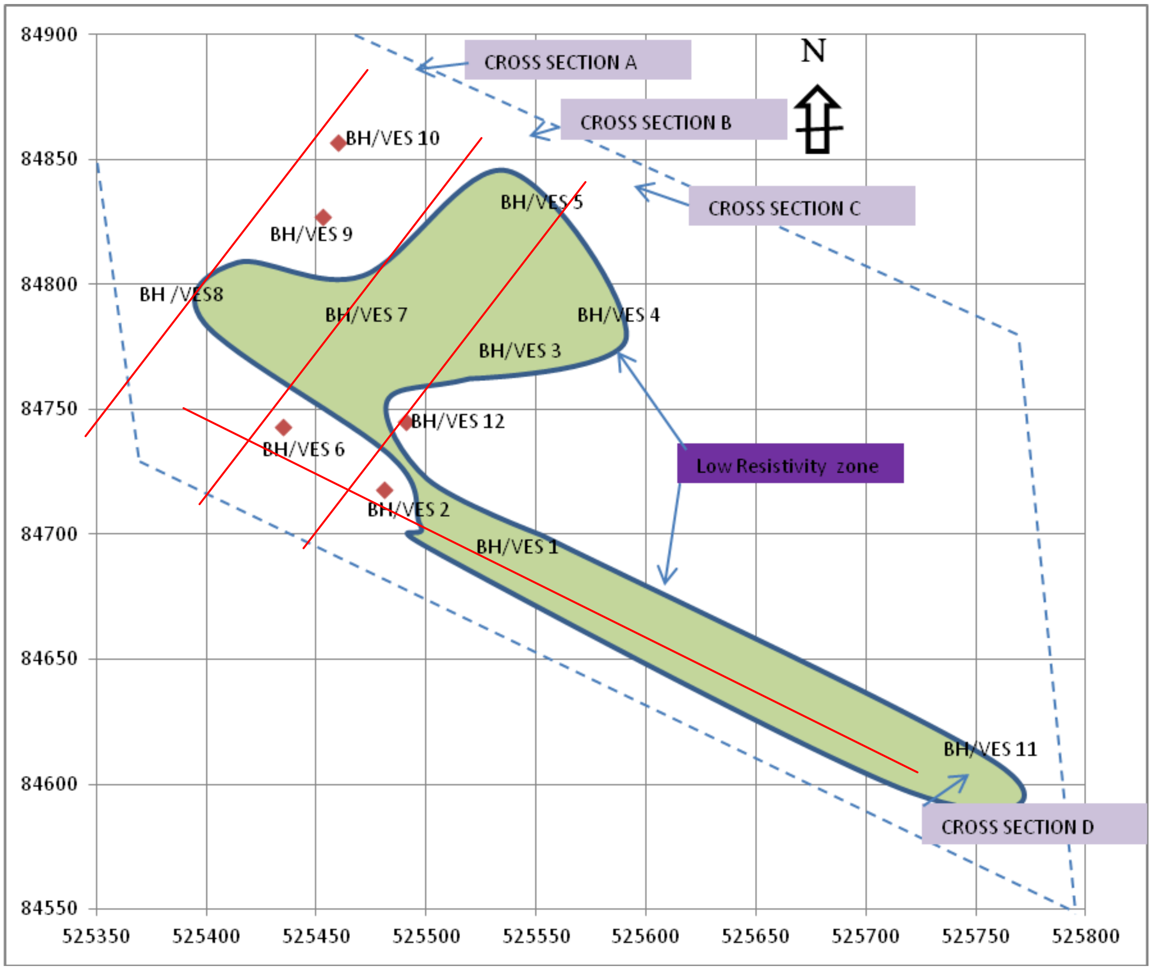
a = electrode spacing (m)

ρ_a = average resistivity (Ωm) of an equivalent soil layer which is equal to 75% of the distance between the inner and outer electrodes (0.756)

Measurements were taken at each pre-determined borehole points. A total of 12 points were measured to assess the subsoil resistivity in the project area (fig. 2). The sounding points were geo-referenced using GPS and presented in Table 2. A sounded depth of 30m was achieved with a total electrode spacing of 90m. Schlumberger electrode configuration was adopted with the following electrode intervals (C_1, C_2): 3m, 4.5m, 6m, 9m, 12m, 15m, 21m, 30m, 45m, 60m, and 90m. The Schlumberger configuration was preferred for its reliability and convenience (Zohdy 1989), and the readings were collected under clement weather conditions. The raw field data was checked for accuracy. Appropriate conversions were made and the field data were later processed using Res2Dinv and IP12Win presenting the VES data as sounding curves obtained by plotting the apparent resistivity versus half electrode spacing.

A graphic plot of A log ρ = f (l) profile was made while pseudo sections trending SE – NW and SW – NE of the study area were also taken. From these, a geo-electric profile model was generated which summarizes the likely subsurface geo-electric layers in the site. Figure 3 shows the layout of the VES/Borehole points

Figure 3. Layout of the VES/Borehole points at the site.



IV. Results and Discussions

The calculated average resistivity of the subsurface layers at various VES points are shown in Table 2. Graphic plots of A log ρ = f (l) profile presented as geo-electric log models are shown in Figures 4- 15 while Figures 16 – 19 are geo-electric profile models (pseudo sections) and summarize the probable subsurface geo-electric layers under the study area.

Table 3 Resistivity Values at various sounding points in the site.

Electrode spacing		Constant	VES 1 @BH 1	VES 2 @BH 2	VES 3 @BH 3	VES 4 @BH 4	VES 5 @BH 5	VES 6 @BH 6	VES 7 @BH 7	VES 8 @BH 8	VES 9 @BH 9	VES10 @BH10	VES11 @BH11	VES12 @BH12	Depth
C_1C_2 (m)	P_1P_2m)	K	$\rho_1(\Omega m)$	$\rho_2(\Omega m)$	$\rho_3(\Omega m)$	$\rho_4(\Omega m)$	$\rho_5(\Omega m)$	$\rho_6(\Omega m)$	$\rho_7(\Omega m)$	$\rho_8(\Omega m)$	$\rho_9(\Omega m)$	$\rho_{10}(\Omega m)$	$\rho_{11}(\Omega m)$	$\ell_{12}(\Omega m)$	(m)
3	0.5	13.74	700.051	1126.156	568.356	774.598	282.151	1421.817	652.62	703.899	1593.342	1052.859	1140.106	1594.167	**1**
4.5	0.5	31.42	961.864	1194.342	523.736	712.483	333.638	1326.918	514.437	654.332	1300.403	906.257	900.1	1337.693	**1.5**
6	0.5	56.16	992.782	1270.923	554.776	805.333	350.88	1174.054	477.646	660.338	1260.534	838.746	723.626	1315.847	**2**
9	0.5	126.84	1369.133	1549.121	663.587	985.689	469.315	1299.116	516.437	812.867	1605.947	929.498	868.207	1300.511	**3**
12	1	112.31	1579.219	1489.145	803.649	1249.471	595.815	1198.706	899.361	1490.268	1382.224	1050.23	1052.262	1302.595	**4**
15	1	175.93	1730.015	1615.204	851.76	1232.84	710.313	1291.812	1140.337	1653.558	1424.55	1081.823	1385.265	1284.88	**5**
21	1	345.58	1947.453	1681.222	1026.842	852.845	944.871	1426.845	1149.866	1580.453	1588.816	938.754	742.883	1368.235	**7**
30	2	351.86	2198.514	1669.355	1113.595	1663.338	1123.342	1114.405	1327.912	1261.341	1320.593	1122.322	1120.316	1079.5	**10**
45	2	793.64	1900.458	1508.557	1293.718	2146.725	1474.668	1203.639	1378.796	1284.511	1373.717	1325.463	857.928	1091.973	**15**
60	2	1412.14	1661.107	1147.736	1270.649	2468.149	1739.481	1049.747	1454.228	1193.136	1436.435	1453.804	723.923	1200.861	**20**
90	10	623.32	984.754	933.233	1141.983	1516.161	1527.069	1013.08	1371.053	894.463	1125.465	1155.633	550.515	987.026	**30**

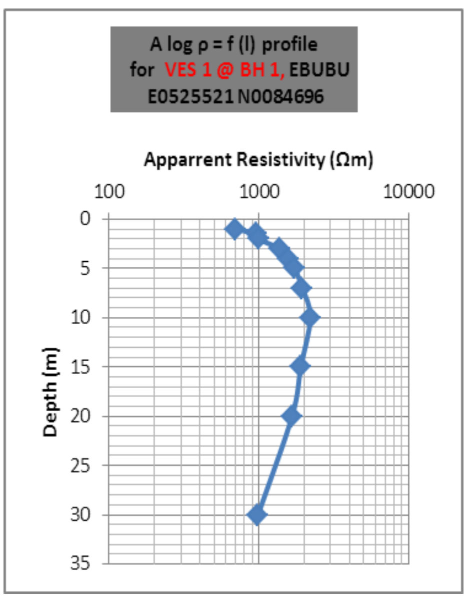


Figure 4. Resistivity log for VES 1

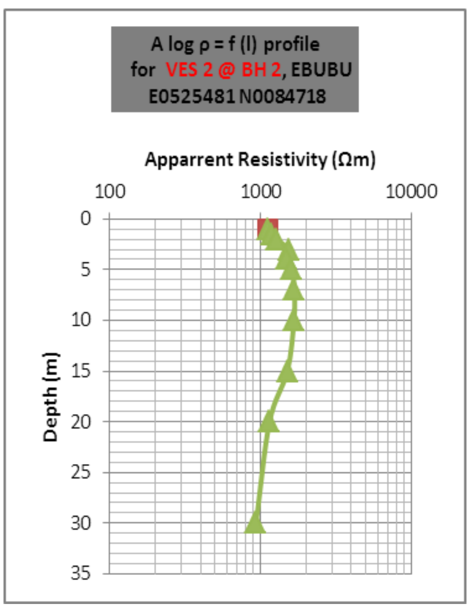


Figure 5. Resistivity log for VES 2

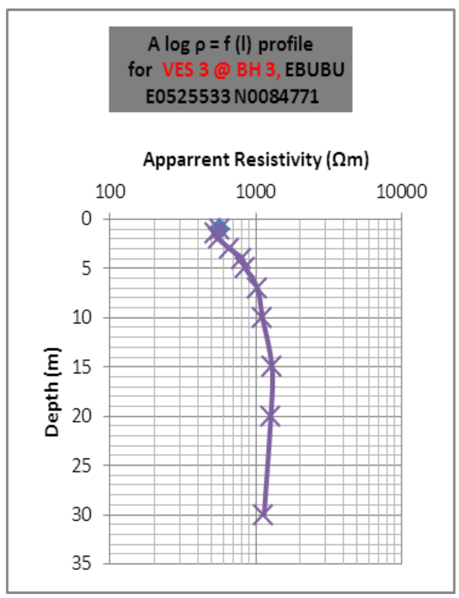


Figure 6. Resistivity log for VES 3

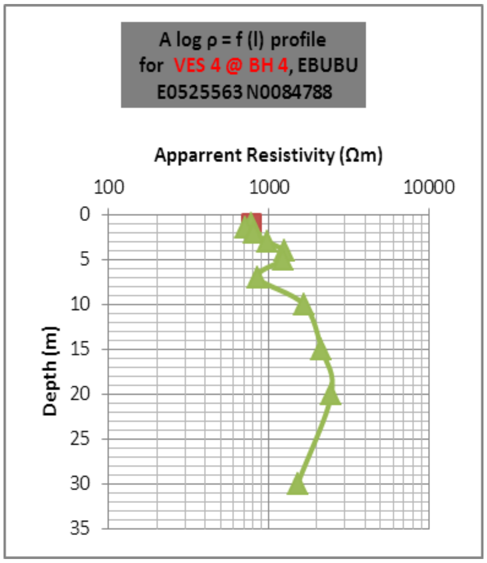


Figure 7. Resistivity log for VES 4

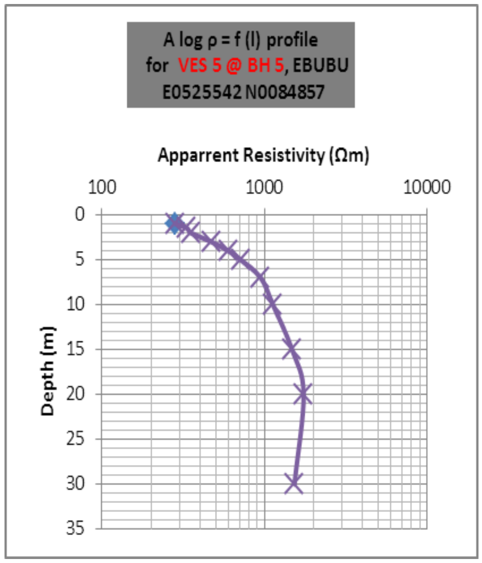


Figure 8. Resistivity log for VES 5

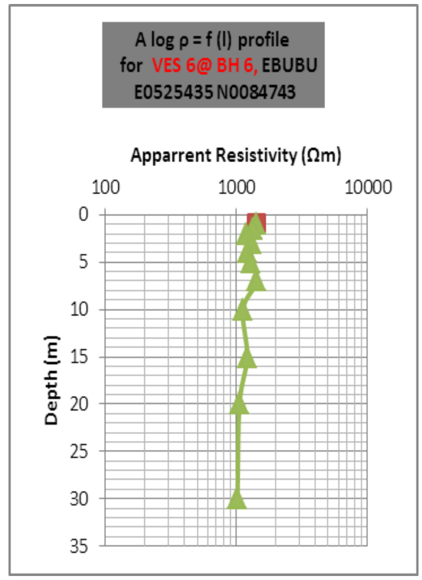


Figure 9. Resistivity log for VES 6

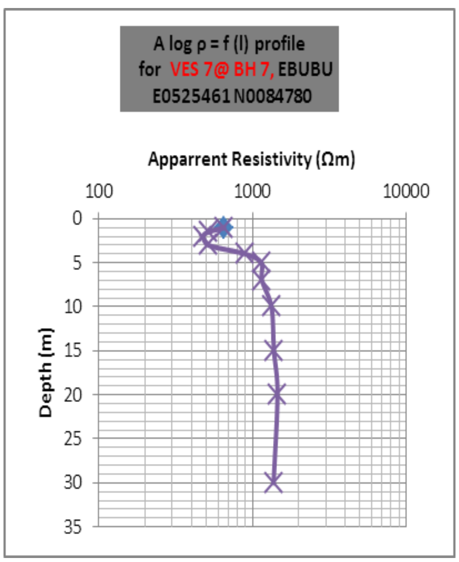


Figure 10. Resistivity log for VES 7

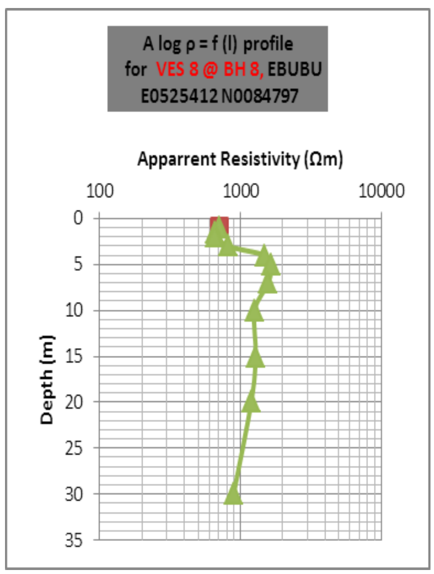


Figure 11. Resistivity log for VES 8

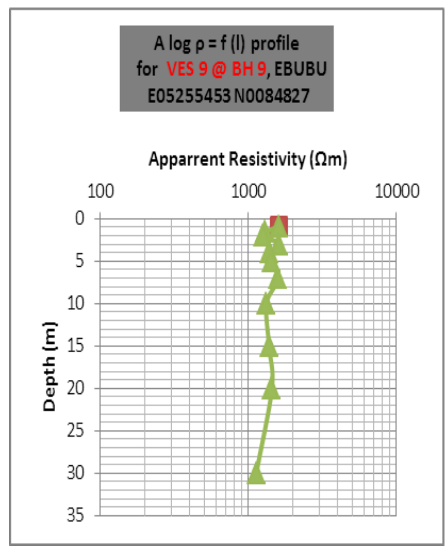


Figure 12. Resistivity log for VES 9

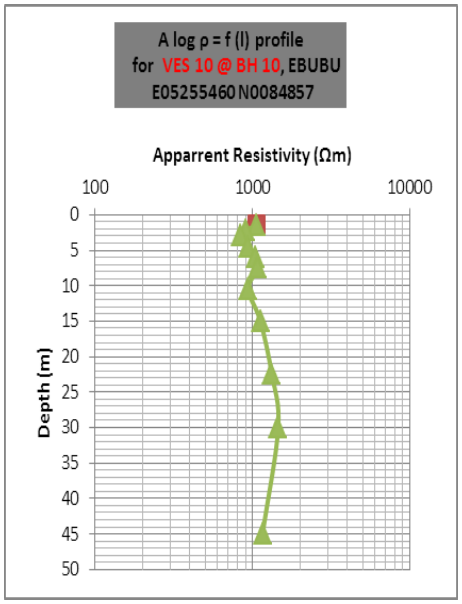


Figure 13. Resistivity log for VES 10

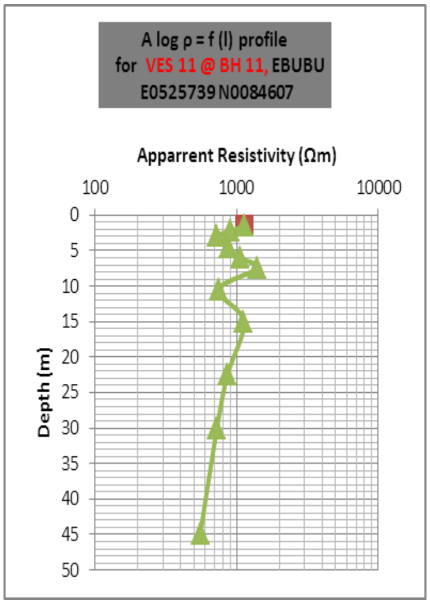


Figure 14. Resistivity log for VES 11

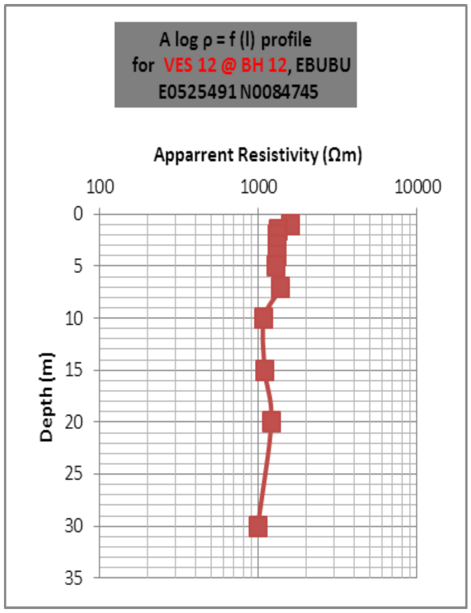


Figure 15. Resistivity log for VES 12

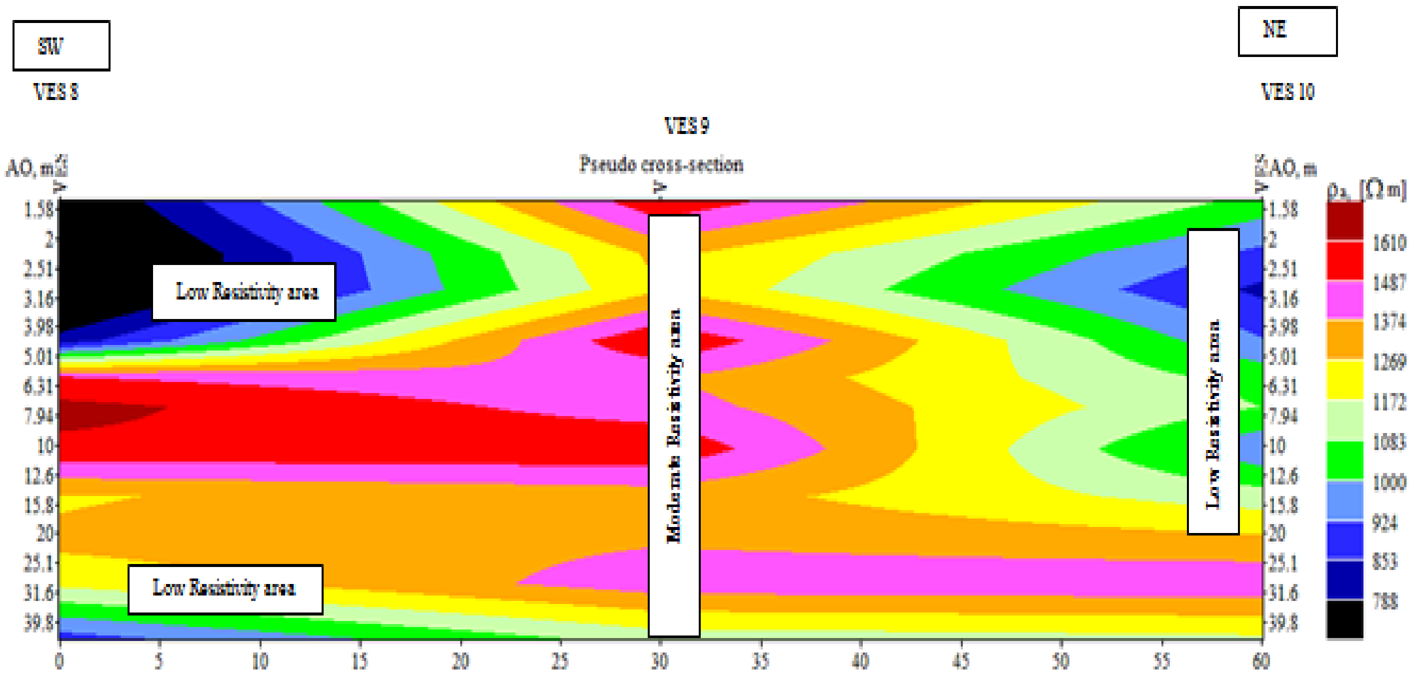


Figure 16 SW – NE Pseudo Cross Section A: (VES points 8, 9 & 10)

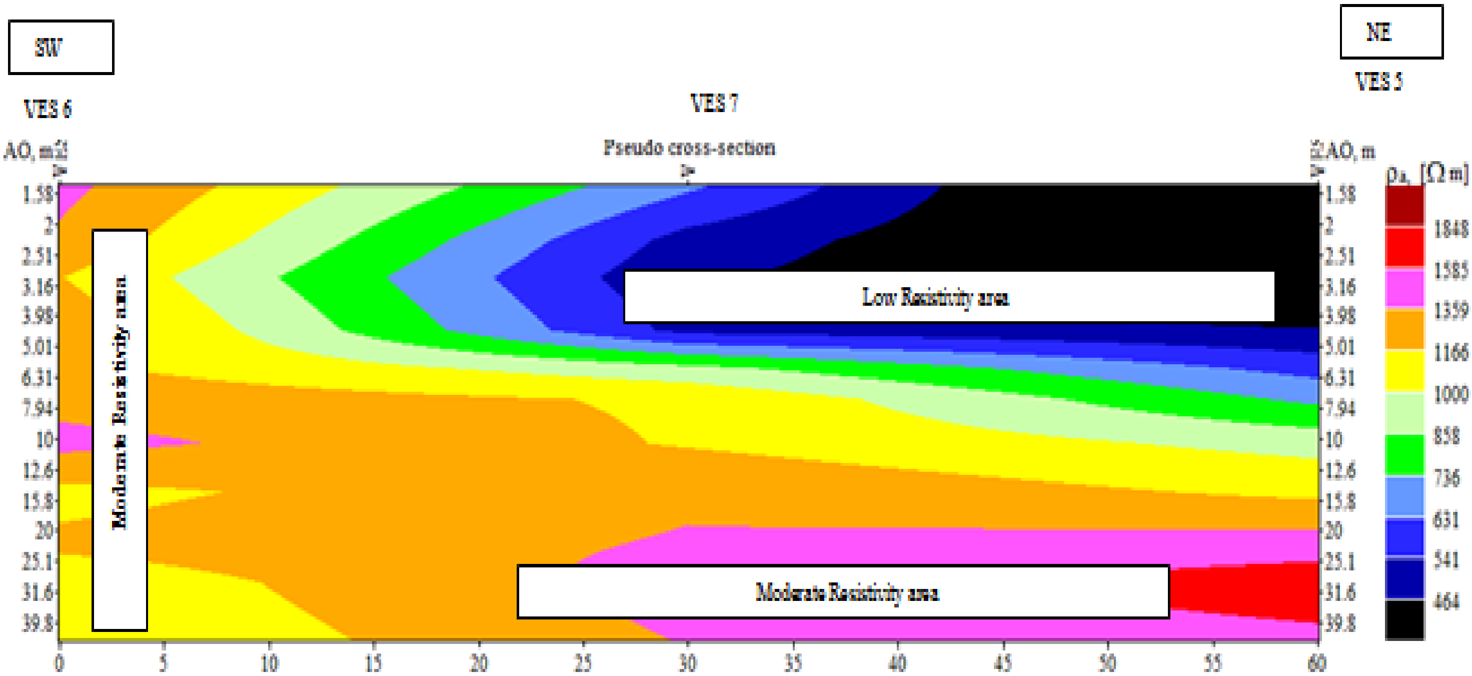


Figure 17 SW-NE Pseudo Cross Section B: (VES points 6, 7 & 5)

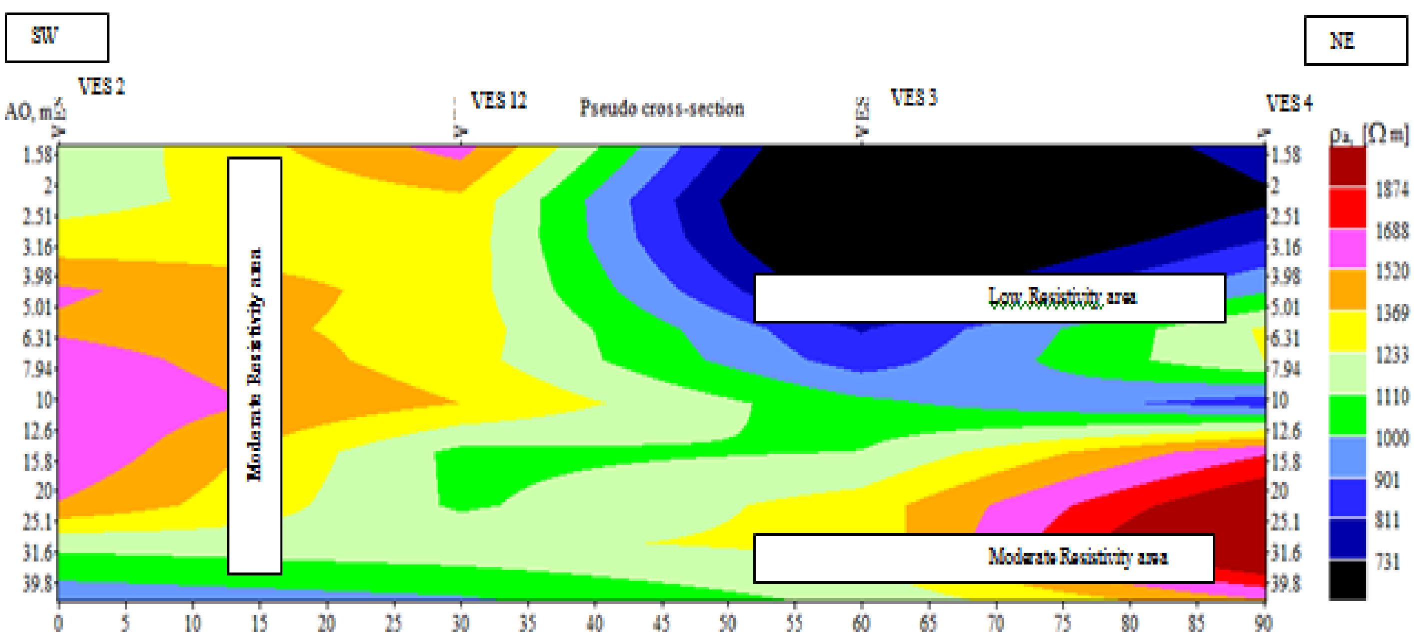


Figure 18 SW-NE Pseudo Cross Section C: (VES points 2, 12, 3 & 4)

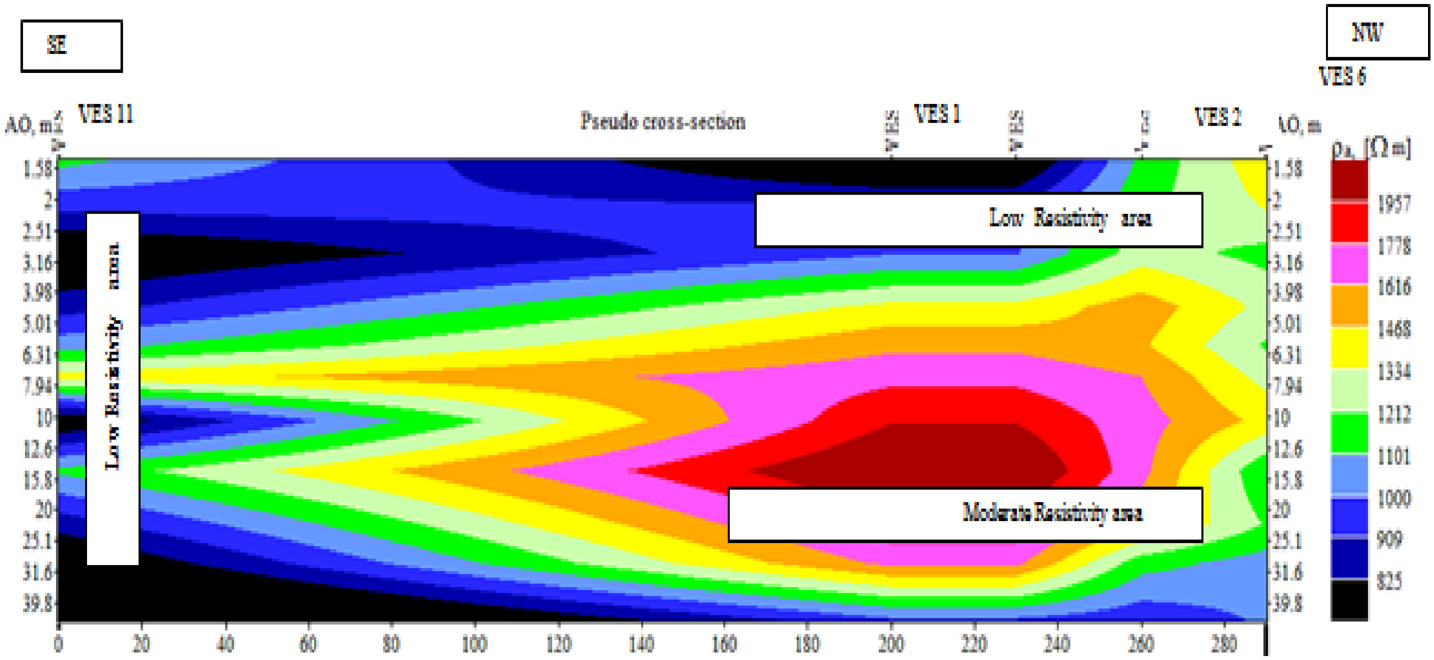


Figure 19 Pseudo Cross Section D: (VES 11, 1, 2 & 6) SE-NW

From the results of the VES, the area is seen to be characterized by two geo-electric layers. The upper layer consists of materials of low resistivity around VES 1,3,4,5, 7 and 8 to a depth of about 2 -3m with the resistivity increasing with depth. Values of ρ_a range from 280 – 700 Ωm The surficial materials of low resistivity are absent in VES 2,6,9,10,11 and 12 where the resistivity is high (1100 - 1600 Ωm) even at near-surface depths. The near surface materials are interpreted as consisting of lateritic to silty sands which forms a less pervious near-surface blanket that will offer resistance to easy infiltration of rainfall and hence result in large run-off . The underlying materials are thought to be coarser materials (sand) which form the aquifers of the area. Values of ρ_a here is high (900 - >2000 Ωm) representing medium to coarse sands and gravels which form major groundwater reservoir in the area. The peculiar values of apparent resistivity at VES 11 is noteworthy and represents localized alternation of sands and clayey sands. The pseudo sections more clearly illustrate the probable succession of the two lithlogic units along the NE-SW trends of the location.

To evaluate how chemically aggressive the reference subsoil is, the apparent resistivity values were compared with the Soil Electrical Resistivity Classification Code, BS 1377, Table 4.

Table 4 Soil Electrical Resistivity Classification (BS – 1377)

Soil Resistivity (ohm-m)	**Soil Corrosivity**
< 10	Severe
10 – 50	Corrosive
50 – 100	Moderately corrosive
>100	Slightly corrosive

The comparison shows that the apparent resistivity of the study site ranges from 280 - >2000 Ωm. It can therefore be concluded that the soil corrosivity potential is extremely low at all the VES points in the site to the depth of 30m. Sub-surface installations are not likely to suffer corrosion. Similarly, subsurface electrical installations will constitute minimal hazard.

V. Conclusions

Electrical resistivity method has been applied in evaluating the geo-electrical properties in a site proposed for the construction of Power substation. The area was found to be characterized by two geo-electric layers; an upper layer consisting of materials of low resistivity around (VES 1,3,4,5, 7 and 8) occurring to a depth of 2 -3m with the resistivity increasing with depth and a lower layer having higher resistivity 900 - > 2000 Ωm). Values of ρ_a in the upper layer range from 280 – 700 Ωm. However, these materials are absent in VES 2,6,9,10,11 and 12 where the resistivity is high even at near-surface depths. Geologically, the near surface materials are interpreted as less pervious lateritic to silty sands while the lower materials represent coarse sands and gravels. The pseudo profile further reveals some alternation of sands and clay at depths. The less permeable cover will resist the percolation of rainfall while the underlying sand and gravel forms the upper parts of an unconfined aquifer in the area. When placed in the Soil Electrical Resistivity Classification (BS 1377), the subsoil in the study site was seen to be non-corrosive. Objects installed in the soil are not likely to suffer corrosion soon. Similarly, subsurface electrical installations will pose minimal hazards and would require basic precautions to avoid electrical accidents.

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