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ASSESSING EARTHING SYSTEM THROUGH GEOELECTRICAL INVESTIGATION OF SOIL RESISTIVITY ON A SITE IN OYO TOWN, OYO, NIGERIA.

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Abstract

The absence of an effective earthing system can lead to the exposure of electrical power systems to high-magnitude transient currents and voltages with rapid rise times, posing risks of equipment damage and harm to individuals. Soil resistance plays a crucial role in the design of an earthing system. Geophysicists commonly employ the electrical resistivity method, a widely used geophysical technique, to assess subsurface properties and identify suitable locations for earthing installations. This method utilizes principles of electrical conductivity and resistivity to characterize the subsurface. This study focuses on the application of the Geo-Electrical resistivity survey technique to investigate soil conditions and determine earthing properties within Ajayi Crowther University in Oyo State, Nigeria. Ten Vertical Electrical Soundings (VES) were conducted using the Schlumberger Configuration. The VES data were interpreted using the partial curve matching method. The findings revealed the presence of about four unique geo-electric sequences in the surveyed area, namely the topsoil, weathered layer, laterite layer, and bedrock. The thickness of the topsoil layer was found to vary between approximately 0.5 m and 2.9 m. Among the VES measurements conducted, VES 4 and VES 5 exhibited the KH curve type, while VES 9 displayed the QH curve type. Based on the survey results, VES 9 was identified as the most suitable site for an earthing system due to its lowest resistivity value (< 15 ohms-meter). However, further research is recommended to investigate VES 4 for potential alternative locations. Although VES 4 did not exhibit the lowest resistivity value among the surveyed VES points, it may still hold significant potential for earthing system placement.

Keywords: Earthing; Soil resistivity; Geoelectrical Survey; Vertical Electrical Sounding.

1. INTRODUCTION

Earthing Systems are used to divert high current (surges) from power lines or lightning strikes that arises from thunderstorms to the earth. Proper infrastructural earthing plays a vital role in the safety of humans and equipment. The absence of an earthing system can result in the exposure of electrical power systems to high-magnitude transient currents and voltages with rapid rise times. These electrical disturbances need to be safely dissipated to the earth in a controlled manner [1].

There are various stages involved in a good earthing system, this includes; identifying the soil or ground with good resistivity, as well as conductors with very low resistivity, such as copper and earthing materials. These conductors are needed to be connected properly to the frame of the systems being protected, and driven inside the ground. Thus, a properly designed earthing system capable of dissipating large currents safely to earth is required, regardless of the fault type. On high-voltage transmission and distribution systems, such safety measures must minimize damage to electrical power system equipment and protect human beings and animals from harm [2]. One of the main factors that determine the effectiveness of these schemes is the soil resistance.

Materials used for earthing, play a major role in the transmission and distribution for proper operation of an electrical installation. This is done by creating the least path of resistance for the lighting discharges or surges to be dissipated to the

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ground rather than passing through equipment. To determine a conductive medium for the installation of earthing systems, geophysicists often employ the electrical resistivity method, a geophysical technique widely used in subsurface exploration [3]. This method utilizes the principles of electrical conductivity and resistivity to characterize the subsurface properties and identify suitable locations for earthing installations. The electrical resistivity method is based on the concept that different materials possess distinct electrical properties, including their ability to conduct electric current. By measuring and analyzing the electrical resistivity of subsurface materials, valuable information about the composition and conductivity of the underlying geological formations can be obtained [4].

During an electrical resistivity survey, a series of electrodes are placed strategically on the ground surface. Electrical current is introduced into the subsurface through these electrodes, and the resulting potential differences and flow of current are measured and recorded. The collected data is then processed and analyzed to create resistivity profiles or maps of the subsurface [5]. Conductive materials such as moist soils, clayey layers, or aquifers exhibit lower resistivity values compared to resistive materials like bedrock or dry soils. By interpreting the resistivity data, geophysicists can identify regions with low resistivity, indicative of conductive mediums suitable for efficient earthing installations [6&7].

The electrical resistivity method provides several advantages for site characterization and earthing system design. It offers a non-invasive and cost-effective means of gathering subsurface information over large areas. The data obtained from electrical resistivity surveys can help in identifying potential pathways for current dissipation, ensuring effective grounding and minimizing electrical hazards [8]. In addition to the electrical resistivity method, other geophysical techniques such as ground-penetrating radar (GPR) and seismic refraction can also be employed to determine conductive mediums for earthing installations. These methods offer complementary approaches to subsurface exploration and provide valuable insights into the subsurface properties [9].

The Earth resistance of an electrode, which represents the resistance between the electrode and the actual Earth, is determined by various factors including soil resistivity, electrode type, depth of the electrode installation, and electrode size [10]. The resistivity of the soil in which the electrode is installed has a significant impact on the overall resistivity of the electrode. Therefore, accurately measuring soil resistivity plays a crucial role in designing an effective earthing system [6&7]. By employing a 4-point electrode method to measure soil resistivity and considering the specific geometry of the electrode, the earthing resistance Rg of the electrode can be calculated. This calculation takes into account the measured soil resistivity and the characteristics of the electrode used [11].

In this study, the Geo-Electrical resistivity survey technique is used to investigate the soil condition of the studied area and to determine the earthing properties of the affected location. Measurements are made at or near the earth's surface to obtain data that arise from the vertical or lateral variation of the distribution of the subsurface as described by Dobrin and Savit [12].

2. STUDY AREA

The study location is within the premises of Ajayi Crowther University Oyo, in the Atiba Local Government Area of Oyo state, Southwestern part of Nigeria, which lies within latitudes 7°50′N and longitudes 3°56′N with a relative elevation of 300 m above sea level, Figure 1. The area is characterised by two distinct seasons, dry and wet seasons. The wet season usually starts in April and ends in October with a mean annual rainfall between 1000 mm – 1500 mm, while the dry season spans from November to March [13]. The average daily temperature is about 27°C. The study area is generally accessible by a network of minor roads and footpaths connecting all areas within the University. The topography of the study area shows generally undulating with gently rolling lowlands rising to ridges in some parts. The geology of the study area lies within the Precambrian Basement Complex of South-Western Nigeria. The rock types that underlie the area are migmatite, granite gneisses, biotite garnet-schist and quartzite. There are also minor occurrences of doleritic dykes, quartz and pegmatite veins that intruded into the main rock bodies [14].

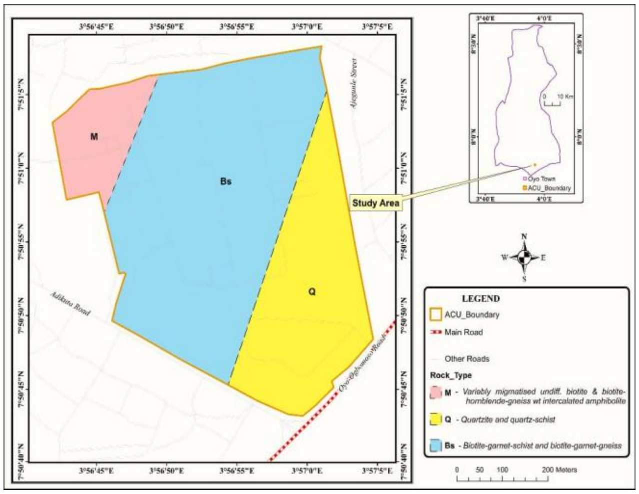


Figure 1: Location of the site, Ajayi Crowther University Oyo, Oyo State, Nigeria.

3. METHODS AND MATERIAL

Vertical Electrical Sounding (VES) was employed in this study. VES is commonly used in electrical resistivity surveys to determine the vertical variation between the earth's bottom of the resistance and the potential field generated by the current [15]. This technique involves the electric current induced into the ground through two implanted electrodes and measures the potential difference between the other two electrodes which is referred to as the potential electrode. The purpose of VES is to examine the fluctuation of resistivity with depth; this technique is best suited to determining resistivity for layered rock structures that are flat-lying [9]. The Schlumberger electrode array was used to perform the VES investigations because it allows for the efficient collection of data at varying depths without having to move the electrodes. This can lead to a more accurate representation of the subsurface resistivity structure than other electrode arrays [16]. The Schlumberger configuration was interpreted using characteristic curves. The Schlumberger array is a four-electrode array that is arranged in a line around a shared midway, Figure 2. The array's midpoint is fixed, while the distance between the current electrodes is gradually increased. The two outer electrodes, A and B, are current electrodes, while, the two inside electrodes, C and D, are close together, these are the potential electrodes [17].

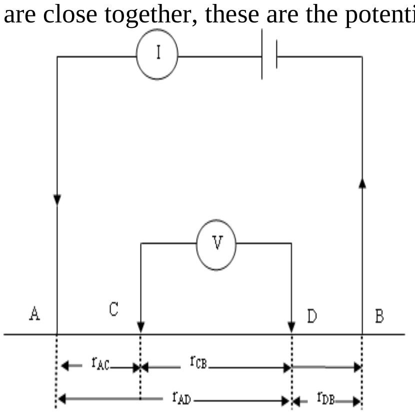


Figure 2: Geometry for Schlumberger configuration

$$r_{AC} = r_{DB} = \frac{(L-a)}{2}$$

$$r_{AD} = r_{CB} = \frac{(L+a)}{2}$$

$$\rho = \frac{\pi}{4}\frac{V}{I}\frac{(L^2-a^2)}{a}$$

Where, L is the distance between the current electrodes A and B, a is the distance between the potential electrodes C and D, r_{AC} is the diatance between A and C, r_{AD} is the diatance between A and D, r_{CB} is the diatance between C and B, r_{DB} is the distance between D and B and ρ is the resistivity. Throughout the survey, the current electrodes A and B in the Schlumberger array are moved outward to greater separation, while the potential electrodes C and D remain in the same position until the observed voltage becomes too small to the source. At the start, the distance between C and D should be equal to or less than one-fifth of the distance between A and B [18]. The Schematic diagram of the Schlumberger array is shown in Figure 3.

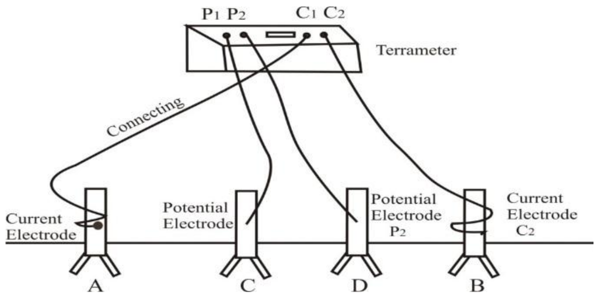


Figure 3: Schematic diagram of the Schlumberger array.

3.1 Measuring Procedure

Resistance measurements were conducted using an Omega resistivity meter. The Geo-electrical Survey involved ten (10) Vertical Electrical Soundings (VES), with a maximum current electrode spacing (AB) of 110 meters (AB/2 = 55 meters). In the field, the resistivity meter was positioned at the midpoint between the potential electrodes (C and D) for VES operation. Its terminals P1 and P2 were connected to electrodes C and D, respectively. The measurements of apparent resistivity at each station were graphed against the electrode spacing (AB/2) on bi-logarithmic graph sheets. The current electrodes (A and B) were connected to terminals C1 and C2. By analyzing the curves, the characteristics and arrangement of the layers were determined. For a detailed interpretation of the curves, the partial curve matching technique was employed, as depicted in Figure 4. The curve matching results, including the resistivity and thickness of each layer, were inputted into the computer as an initial model using the interactive forward modelling technique with Win RESIST Version 1.0 software [19]. The Model was used to determine the final layer resistivity and thicknesses. Resistivity was evaluated, the sea level and VES position longitude and latitude were measured using a Global Positioning System (GPS). The reconnaissance survey of the region was the first step conducted on the field to determine the locations to be sounded.

After identifying the locations, they were marked on the base map, and Vertical Electrical Soundings (VES) were conducted using the Schlumberger array. A total of ten soundings were carried out within the study area. The VES followed the Schlumberger Configuration, where the potential electrodes remained fixed while the current electrodes were symmetrically positioned around the centre of the spread. The distance between the current electrodes was increased when a noticeable potential difference was observed.

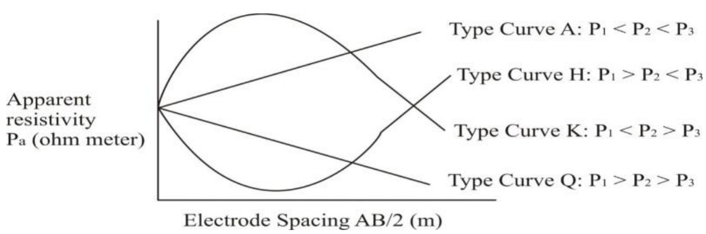


Figure 4 Apparent Resistivity Curve Type.

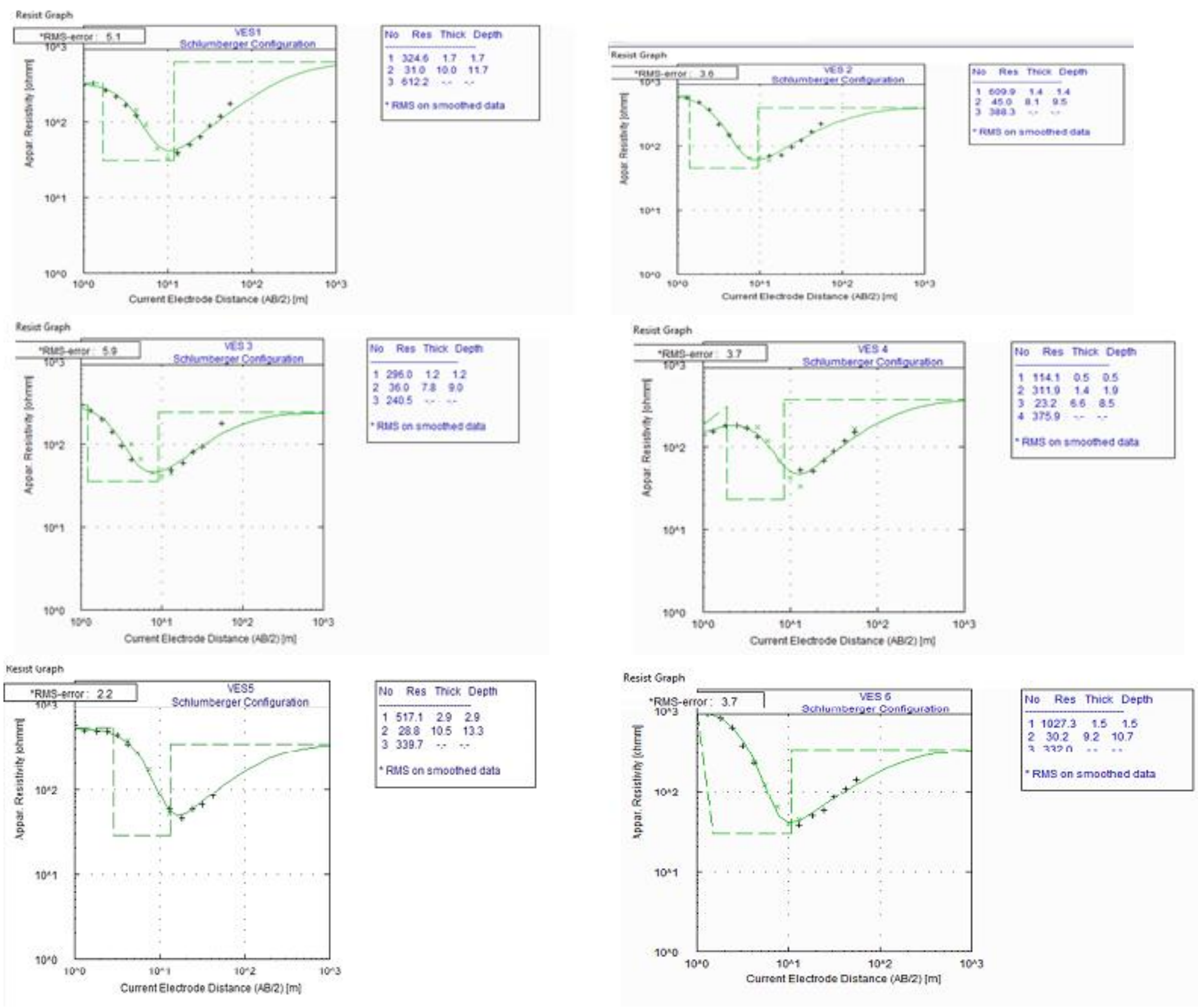
3.2 Data Collection and Analysis

The geo-electric sounding curve was created by analyzing data obtained from Vertical Electrical Sounding (VES) surveys that were carried out using the Schlumberger configuration. The obtained apparent resistivity values were plotted against the electrode spacing on tracing paper. These curves were then overlaid on a log graph sheet to create the geo-electric section sounding curves. To interpret the VES data quantitatively, an iterative process was performed using the WinResist Version 1.0 software package. The software enabled the examination and alignment of the observed curves with the theoretical curves using predetermined thickness values, thereby enhancing the precision of interpreting the subsurface characteristics.

In this study, the partial curve matching method was employed for the interpretation of the VES data. This approach involves comparing the observed curves with a set of standard curves and selecting the best match based on similarities in shape, trends, and resistivity values. By iteratively adjusting the resistivity values and layer thicknesses, a more refined interpretation of the subsurface layers and their properties can be obtained [19]. The combination of the partial curve matching technique and the utilization of the WinResist software facilitated a quantitative analysis of the Vertical Electrical Sounding (VES) data. This approach provided a more thorough comprehension of the subsurface geology and electrical properties. The resistivity data plots were carefully examined, and their attributes, such as the resistivity variation pattern with depth and the specific curve type, were documented. After identifying the resistivity curve as A, H, K, or Q, as illustrated in Figure 4, the estimation of the layer count is performed, and the layer parameters of the corresponding theoretical curve are used for the quantitative interpretation of the field curve. If a match is not achieved, the program automatically adjusts the layer parameters.

4. RESULTS AND DISCUSSION

The VES technique, which employs the electrical resistivity method of geophysical prospecting, was employed to map the underlying layers of the subsurface. The VES Curves displayed a resemblance to the pattern shown in Figure 4 of the geo-electric section. The interpretation results indicated the presence of three geo-electric layers for VES 1-3, 5-7, and 10, while VES 4, 8, and 9 revealed a system of four geo-electric layers. The curves showed a KH, H and QH curve pattern, Figure 5.



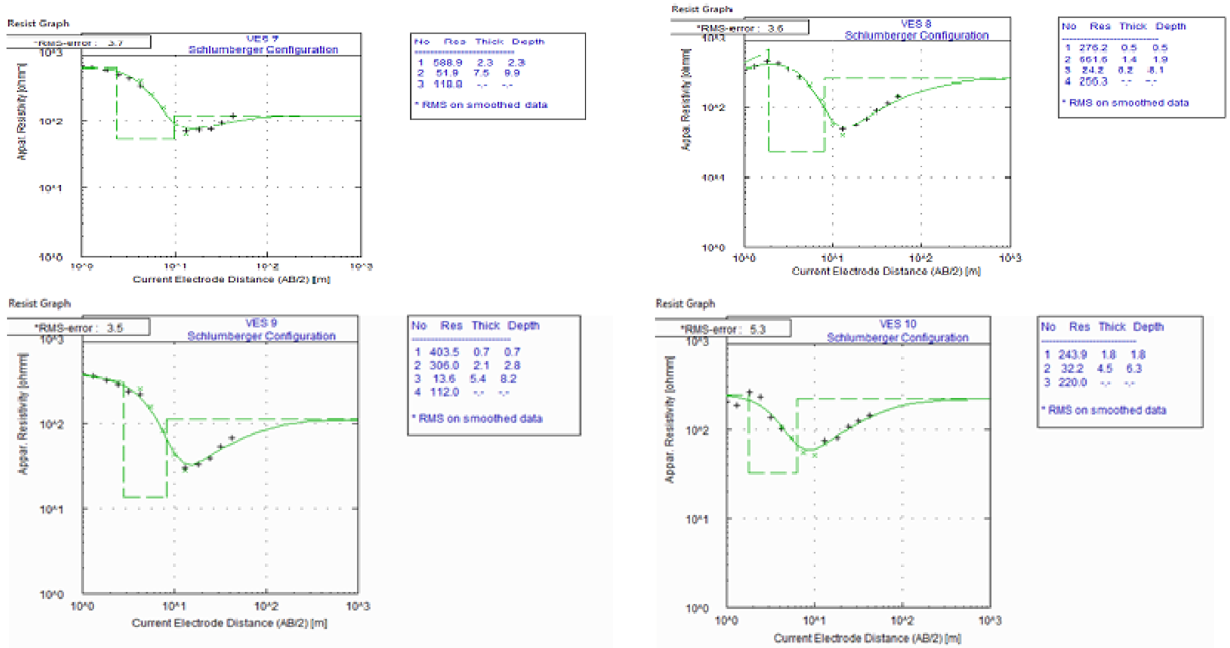


Fig 5: Computer Iterated Graph for VES 1 to VES 10

The major geo-electric sequences that were delineated were: Topsoil (Sandy clay), Lateritic, Clayey (weathered) and Bedrock formation. The first layer is made up of topsoil which has resistivity values ranging from 114.1 to 1027.3 Ωm. The thickness of the layer is between 0.5 and 2.9 m. Beneath the topsoil is the weathered layer which has resistivity values ranging from 28.8 to 661.6 Ωm and the thickness is between 1.4 and 10.5 m. The lateritic layer resistivity ranges from 306 to 661.6 Ωm. The depth is between 1.9 to 2.8 m. Table 2 showed the summary of the result.

The obtained result indicates the presence of three distinct curve types in the surveyed area, with the H-type being the most dominant (70% rate of occurrence), followed by the KH-type (20% rate of occurrence), and the QH-type (10% rate of occurrence).

The H-type curve is associated with a pronounced weathering effect. It is characterized by a relatively low to intermediately high resistivity range within the topsoil layer (243.9 to 1027.3 ohm-m). The weathered layer exhibits resistivity values ranging from 28.8 to 51.9 ohm-m. The fractured bedrock, which underlies the weathered layer, demonstrates resistivity values between 220 and 339.7 ohm-m. The H-type curve signifies the presence of significant weathering and suggests the possibility of a well-developed soil profile.

The KH-type curve indicates the presence of a topsoil layer with resistivity values ranging from 114 to 276.2 ohm-m. This layer is underlain by a lateritic layer with resistivity values between 311.9 and 661.6 ohm-m. Beneath the lateritic layer lies a clayey layer with resistivity values ranging from 23.2 to 24.2 ohm-m. Finally, the fractured bedrock is characterized by resistivity values between 256.3 and 375.9 ohm-m. The KH-type curve suggests a less pronounced weathering effect compared to the H-type, with the presence of distinct layers and variations in resistivity values.

The QH-type curve is diagnostic of a topsoil layer with a specific resistivity value of 403.5 ohm-m. Underneath the topsoil layer, there is a lateritic layer with a resistivity value of 306 ohm-m. Below the lateritic layer, there is a clayey layer with resistivity value of 13.6 ohm-m. The fractured bedrock, in this case, exhibits a resistivity value of 112 ohm-m. The QH-type curve suggests a unique subsurface configuration with specific resistivity values for each layer.

The thickness of the topsoil in the study area is relatively shallow (1.5 ± 0.8) m, with an average overburden depth of 4.1 ± 3.3 meters. At specific locations (VES points 7, 9, and 10), the bedrock shows lower resistivity values, indicating the presence of secondary porosity, likely resulting from fracturing. This is significant for groundwater development. On the other hand, VES point 6, topsoil, exhibits a remarkably high resistivity value of around 1027 ohm-m, as shown in Figure 6. This high resistivity value extends to the clayey and bedrock layers within VES point 6, making it distinct from the other VES points, except for VES 2 (clayey and bedrock) and VES point 1 (bedrock). VES point 1, in particular, shows the highest apparent resistivity value of 612.2 ohm-m compared to the other points, as illustrated in the histogram representation in Figure 8. VES point 2 demonstrates higher resistivity values for both the clayey layer (45.0 ohm-m) and the bedrock layer (388.3 ohm-m), as listed in Table 2. Similarly, the topsoil resistivity value for VES point 2 is also higher

compared to the other points, measuring at 609.9 ohm-m. Consequently, considering the implications, VES points 2 and 6 should be excluded from consideration when selecting a location for earthing in this particular area.
However, some zones of low resistivity values especially at VES points 4, 8 and 9 locations having resistivity values between 13.6 - 24.2 ohm-m will be relevant in the earthing scheme, with probable depth ranging between 8.1 to 8.5 m, these depths correspond to the clayey portion of the soil layers.
TABLE 1: Summary of Vertical Electrical Sounding (VES) Curve Type.

VES STATION	CURVE TYPE	CURVE RESISTIVITY
1	H	$P_1 > P_2 < P_3$
2	H	$P_1 > P_2 < P_3$
3	H	$P_1 > P_2 < P_3$
4	KH	$P_1 < P_2 > P_3 < P_4$
5	H	$P_1 > P_2 < P_3$
6	H	$P_1 > P_2 < P_3$
7	H	$P_1 > P_2 < P_3$
8	KH	$P_1 < P_2 > P_3 < P_4$
9	QH	$P_1 > P_2 > P_3 < P_4$
10	H	$P_1 > P_2 < P_3$

TABLE 2: Summary of Vertical Electrical Sounding (VES) Interpretation.

VES STATION	LOCATION	Layer	App.Resistivity (Ωm)	Thickness (m)	Depth (m)	Probable Lithology
		1	324.6	1.7	1.7	Topsoil
1	$3^0$92.432’E	2	31.0	10.0	11.7	Clayey
	$7^0$83229’N	3	612.2	-	-	bedrock
	$3^0$94.672'E	1	609.9	1.4	1.4	Topsoil
2	$7^0$85131'N	2	45.0	8.1	9.5	Clayey
		3	388.3	-	-	Bedrock
	$3^0$94696'E	1	296.0	1.2	1.2	Topsoil
3	$7^0$85128'N	2	36.0	7.8	9.0	Clayey
		3	240.5	-		Bedrock
		1	114.1	0.5	0.5	Topsoil
	$3^0$94.722'E	2	311.9	1.4	1.9	Lateritic Unit
4	$7^0$851.66'N	3	23.2	6.6	8.5	Clayey
		4	375.9	-	-	Bedrock
		1	517.1	2.9	2.9	Topsoil
5	$3^0$95.0010'E	2	28.8	10.5	13.3	Clayey
	$7^0$850112'N	3	339.7	-	-	Bedrock
		1	1027.3	1.5	1.5	Topsoil
6	$3^0$95.0100'E	2	30.2	9.2	10.7	Clayey
	$7^0$85.0320'N	3	332.0	-	-	Bedrock
		1	588.9	2.3	2.3	Topsoil
7	$3^0$95.0271'E	2	51.9	7.5	9.9	Clayey
	$7^0$85.0391'N	3	118.8	-	-	Bedrock
		1	276.2	0.5	0.5	Topsoil
8	$3^0$950272'E	2	661.6	1.4	1.9	Lateritic Unit
	$7^0$850021'N	3	24.2	6.2	8.1	Clayey
		4	256.3	-	-	Bedrock
		1	403.5	0.7	0.7	Topsoil
	$3^0$94.7001'E	2	306.0	2.1	2.8	Lateritic Unit
9	$7^0$85.097'N	3	13.6	5.4	8.2	Clayey
		4	112.0	-	-	Bedrock
		1	243.9	1.8	1.8	Topsoil
10	$3^0$947410'E	2	32.2	4.5	6.3	Clayey
	$7^0$85.10310'N	3	220.0	-	-	Bedrock

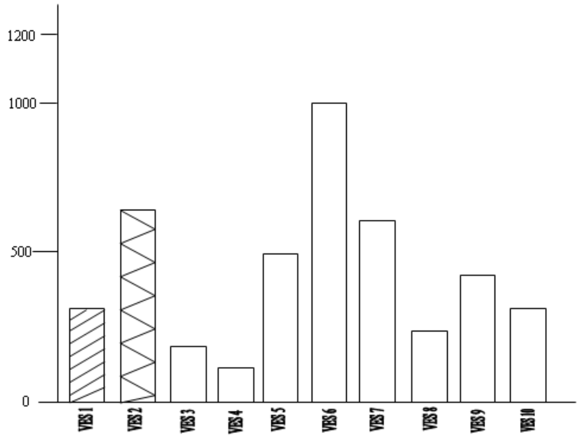


Figure 6: Histogram of topsoil resistivity of the Study area.

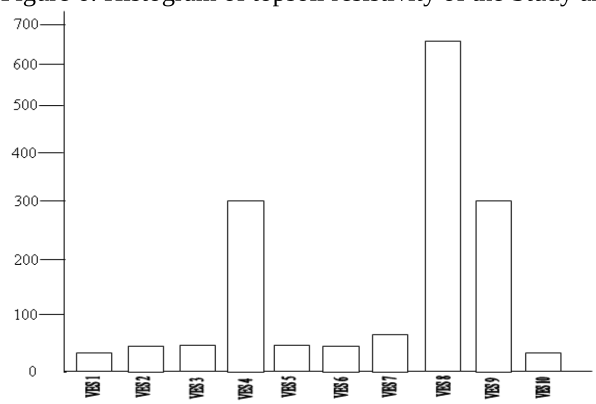


Figure 7: Histogram of weathered layer resistivity of the study area

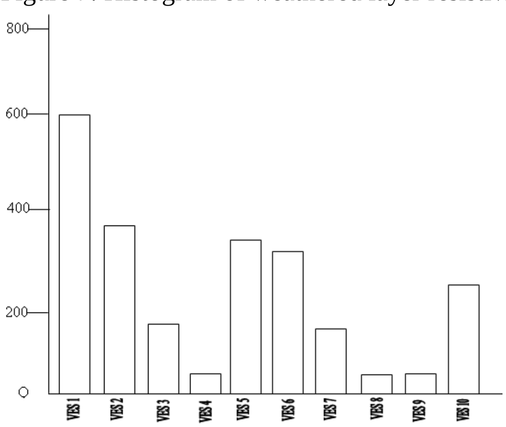


Figure 8: Histogram of Bedrock Layer Resistivity of the study area

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The finding highlights the utilization of surface geo-electrical investigation methods, specifically the electrical resistivity method, to assess the earthing properties in Ajayi Crowther University, located along the Oyo-Ogbomoso expressway in Oyo State, Nigeria. The study successfully employed these methods to delineate the subsurface characteristics within the study area.

The obtained results revealed the presence of three to four distinct geo-electric sequences within the surveyed area. These sequences include the topsoil, weathered layer, laterite layer, and bedrock. The thickness of the topsoil layer was found to vary between approximately 0.5 meters and 2.9 meters.

Among the Vertical Electrical Sounding (VES) measurements conducted, VES 4 and VES 5 exhibited the KH curve type, while VES 9 displayed the QH curve type. These curve types provide additional information about the subsurface composition and resistivity variations within the studied locations.

Overall, the findings suggest the importance of understanding the subsurface geo-electric characteristics, particularly in relation to earthing properties. The information obtained from the geo-electrical investigation aids in determining the appropriate depth for excavation and understanding the layering of different materials such as topsoil, weathered layers, laterite layers, and bedrock. These findings have practical implications for construction projects, foundation design, and electrical grounding systems in the study area.

5.2 Recommendation

Based on the survey results, it is observed that most of the Vertical Electrical Soundings (VES) exhibited low resistivity characteristics. However, the most suitable site for an earthing system was identified as VES 9, which displayed the lowest resistivity value (< 15 ohms-meter). This low resistivity indicates that VES 9 has the potential to effectively discharge high currents, making it a favourable location for an earthing system.

The recommendation to select VES 9 as the site for the earthing system is based on the understanding that low resistivity facilitates efficient dissipation of electrical current, reducing the risk of electrical hazards and ensuring the safety of the electrical infrastructure. By choosing VES 9 for the earthing system, it is expected that the site will provide effective grounding and contribute to the overall electrical safety of the area.

Additionally, the recommendation suggests that VES 4 should be further investigated in future research for the potential selection of another location for an earthing system. Although VES 4 did not exhibit the lowest resistivity value among the surveyed VES points, it may still possess unique characteristics or geological features that warrant closer examination. Further studies on VES 4 can provide valuable insights into its suitability for an earthing system, potentially expanding the options for optimal grounding arrangements in the area.

Overall, the recommendation takes into consideration the survey findings and highlights the most appropriate site (VES 9) for the earthing system based on its low resistivity value. It also suggests the need for future research to explore the potential of VES 4 as an alternative location for grounding purposes. Such considerations demonstrate a proactive approach to electrical safety and the desire to make informed decisions regarding the selection of suitable sites for earthing systems.

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