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Measurements of soil resistivity and moisture content in four selected locations within Iwo town for grounding installation

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ABSTRACT

In Nigeria, Grounding Systems Installation (GSI) were carried out without prior knowledge of Soil Apparent Resistivity (SAR) and Soil Moisture Content (SMC) of a location, which strongly influence its effective functioning when fault current builds up in the electrical circuit. Therefore, these two factors were measured in four locations: P(Latitude: 7°37` 46.074 and Longitude: 4°12` 2.250), Q(Latitude: 7°37` 14.886 and Longitude: 4°11` 10.608), R(Latitude: 7°37` 26.964 and Longitude: 4°11` 6.552) and S(Latitude: 7°39` 18.312 and Longitude: 4°10` 57.552) in Iwo town, Osun State, Southwest, Nigeria. To measure SAR values of each location, five different Vertical Electrical Soundings (VES) were conducted randomly using a Schlumberger arrangement. IPWin2 computer software was used to analyse the data. Soil Samples (SS) of each VES station were taken and analysed at the Civil Engineering Laboratory. VES results showed that P, Q, R and S had different lithologies, SAR, depths, and Lowest Soil Apparent Resistivity Values (LSARV) ranging from 1.47-51.98Ωm. 40.40-73.60Ωm, 27.00-67.40Ωm, and 18.40-88.00Ωm while their respective depths were 2.06-26.40m, 7.13-11.8m, 9.65-11.60m, and 6.23-8.20m. LSARV of each location were attributed to the presence of conductive and moisture-rich minerals, which made the fault current cause the breaker/fuse to cut off, thereby safeguarding electrical appliances, animals, and humans. SS results indicated that P, Q, R, and S, on average, had 33.38%, 38.40%, 27.06%, and 29.68% SMC, respectively, which agrees with VES results. R^2 values of SAR and SMC indicated ranges from 0.2357 to 0.7064. Thus, correlations between SAR and SMC values were established. This research has revealed ranges of SAR, depth and SMC that electrical engineers need for GSI.

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Introduction

Grounding or earthing is the connection between the electrical equipment and the soil mass. When electrical appliances or facilities, or equipment are grounded, the purpose is to protect these facilities from damage, fire, electrical shocks, or electrocution of personnel, or even the death of animals and humans in the vicinity of the equipment. Grounding is the process of safely diverting fault currents into the soil, thereby preventing the buildup of static electricity and reducing the risk of electrical hazards [1]. Therefore, grounding becomes an inevitable process in electrical installation. An improper grounding installation can therefore harm both man and animals and equipment. Different researchers have shown that soil resistivity, moisture content, soil compositions, the presence of impurities, as well as temperature are factors that affect grounding [2]. The effectiveness of grounding, therefore, depends on any of these factors. Consequently, this research focused on the importance of soil resistivity measurement and moisture content determination in a few locations of Iwo town before carrying out grounding installation.

Researchers have demonstrated that different soil types have different resistivity values, with sandy soils generally having lower resistivity than clayey soils, and that clayey soils have higher retention capacity

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than sandy soils. Grounding installation is achieved when ground electrodes are inserted into the soil. The ground electrodes can be in the form of a metal plate, pipe, or cable, while the materials used could be mild steel, copper, aluminium, and galvanised iron. The chemical makeup of the nearby soil moisture content, electrode depth, and soil temperature are the variables that affect the electrode soil resistance. Therefore, it is important to carry out soil resistivity measurements and moisture measurements by geophysicists before the installation of grounding systems. Therefore, proper knowledge and understanding of soil resistivity and moisture content on the effectiveness of the grounding system should be carried out both during the dry and wet season before installation of the grounding to meet safety standards The principle behind soil resistance measurement is based on the fact that different materials have different electrical resistivities which can be used to map subsurface features such as rock formation, soil types, ground water levels and buried objects [3]. It had been established that soil type affects the movement of water in the soil and the conductivity of the soil, and that clay soils have higher water retention capacities when compared to the sandy soils, an indication that clay soils have smaller particles and higher moisture content and lower resistivity values when compared to sandy soils [4]. The presence of water in any soil type dissolves the mineral compositions of that soil so that it becomes an electrolyte. The presence of water in a soil helps in the increase in moisture content of that soil and thereby leads to a decrease in resistivity [4]. The resistivity of the soil had been described by researchers as a measure of the soil's ability to conduct current [5].

Several studies have been conducted in Nigeria to investigate the soil resistivity of different parts and geological formations using different arrangements of electrodes. A Schlumberger array was used to determine the subsurface resistivity of the Benin Formation in the southeastern part of the country [6]. Their results revealed that low resistivity zones were associated with clayey and sandy formations, which are indicative of potential groundwater resources. Wenner electrode configuration was used to investigate the resistivity characteristics of the basement complex rocks in Southwestern Nigeria [7]; their finding reveals that granite rocks exhibit higher resistivity. The study that was carried out on the measurement of the resistivity of sedimentary basins of the Niger Delta Region using dipole-dipole electrode arrangement was carried out using dipole-dipole electrode arrangements revealed that the resistivity value of the region varied with different lithological structures and the fluid (hydrocarbon) content of the sediments [8].

The study conducted on the measurement of the resistivity of the sandy soil formation using the Wenner arrangement showed that the resistivity of the sandy soil decreased with depth, indicating a decrease in the soil moisture content [9]. The research on the resistivity measurement on clay-rich soil within contaminated zones was conducted using the Schlumberger method, and the outcome of their findings revealed high resistivity values in areas with elevated levels of contaminants and an indication of a contaminant plume [10]. The soil resistivity measurements were taken in a mixture of sand and gravel using the dipole-dipole array method. The results showed variations in resistivity values across the site, indicating differences in grain size and porosity [11]. In all these, previous studies have demonstrated the importance of soil resistivity measurements in different soil types for various geochemical and environmental applications. These measurements have helped soil engineers and geologists to have valuable insight into the composition, moisture content, and contaminated levels of the soil and allow them to make informed decisions regarding installations, construction, environmental remediation and groundwater management, and development. Therefore, this research aims at the measurement of soil resistivity and moisture content in four locations within Iwo Town, Southwestern Nigeria, for grounding installation using the Schlumberger Configuration due to enough spacing.

The study site description

The four locations, P, Q, R, and S, used for this research were specifically within Iwo Town (Fig. 1) Southwestern Nigeria. These locations could be found on the Latitude: 7°37`46.074 and Longitude: 4°12`2.250 (P), Latitude: 7°37`14.886 and Longitude: 4°11`10.608 (Q), Latitude: 7°37`26.964 and Longitude: 4°11`6.552 (R) and Latitude: 7°39`18.312 and Longitude: 4°10`57.552 (S). The elevation of the four locations varied from 300 to 500 metres above sea level. Nigeria's population census of 2022 estimated the town's population to be 248,400, which makes it the most populous town among other towns in Osun West Senatorial District [12]. The population density of Iwo was approximately

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1,015/km² [12]. The square kilometres of land of Iwo span approximately 245km². The presence of a major network of tarred roads makes it accessible from

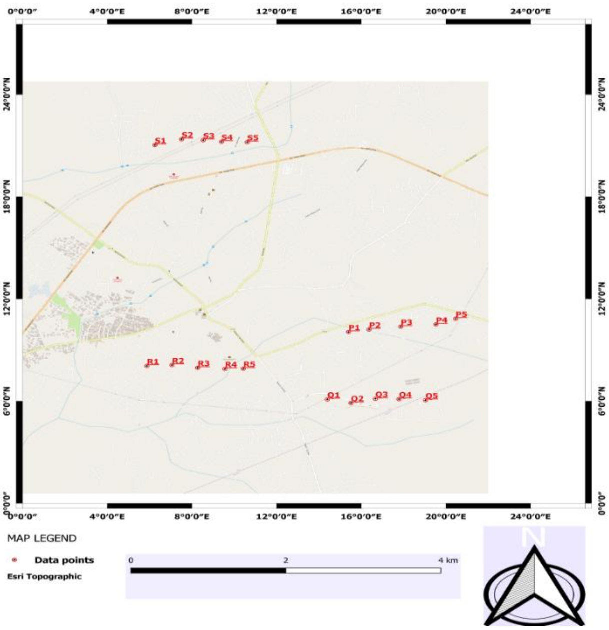

Fig.1: The Study Area Map Showing Locations P, Q, R, and S

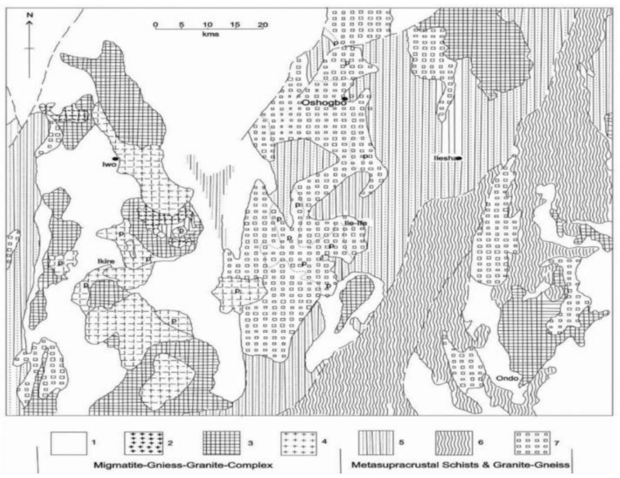

Fig. 2: Geologic map of the Iwo region modified after 1: 250,000 sheet 60 (Iwo) of the Geological Survey of Nigeria (GSN). 1, Migmatite-gneiss complex; 2, charnockite; 3, early granitic phases of Older Granite Cycle; 4, younger granitic phases of Older Granite Cycle; 5, amphibolite, amphibolite schist, and pelitic schist; 6 quartzite, quartz-schist, and quartzo feldspathic gneiss; 7, granitic-gneiss-dominated regions; p, pegmatite; T, tonalite. Thick broken lines indicate major faults [13].

other adjoining towns. The existence of minor tarred roads and footpaths within the town makes the connection of every part of the town possible. In addition, movement to every section of the town is also easy and possible. Annually, Iwo experiences two seasons of climate (Wet and Dry). The average annual temperature is 29.66°C (85.39°F). In general, Iwo experiences 248.57 wet days (68.1%) of the year annually. Iwo experiences 248.57 wet days (68.1% of the year) annually with average precipitation of 133.63 millimetres (5.261m) [14].

Geology of the study area

The four sites selected for this research were located within Iwo town southwestern part of Nigeria. So the geology of the study area is that of southwestern Nigeria. The rock of south-western Nigeria is the Precambrian basement complex and Cretaceous-Palaeocene sediments 6. The greater parts of Iwo are occupied by the Precambrian basement (Fig.2). Iwo and its region are located in the southern part of the Pan African reactivated terrain referred to as Dahomeyide by Iwo town and its environs are bounded by the African Craton (East), Cogon Craton (Southeast), and Saharan Metacraton (Northeast) [16]. Sheets 60 on a scale of 1:250,000 cover the geology of most of Iwo and its environs, which reveals that it comprises migmatite genesis, granite complex, and metasupracrustal sequences (Fig. 1a) (Geological Survey of Nigeria). In addition to the metasomatism feature of Iwo and its region, rocks like migmatite, granite, gneiss, schist, and quartzite, early tonalitic and syenitic, diapirs, late magmatic, granitic, pegmatite, and aplitic intrusions in the large Iwo-Ikire complex were present [13].

Theoretical background

The measurements of soil resistivity are purely based on the electrical resistivity method. Various methods could be used to measure the soil resistivity of a location. One of such methods used is to collect soil samples and put them in cylindrical PVC pipes of measured length L and seal them at both ends with metal plates; then a milli-ammeter (mA) is connected in series with the sample. Across the sample, a voltmeter is connected. When a voltage is applied, the flowing current is recorded by the ammeter and the corresponding potential is recorded by the voltmeter. The cross-sectional area of the plastic cylinder is also determined. From all these measurements, the resistivity of the soil sample used can be determined [17]. Another method of determining the resistivity of the soil is called a three-point or fall-of-potential. In this method, the ground resistance test was carried out several times, and each time, the depth of burial of the tested electrode was increased by a particular

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increment. But the most accurate practical method of measuring the average soil resistivity of a large volume of soil is the Four-Point Method [18]. Wenner and Schlumberger arrays are examples of the Four-Point method. Among the drawbacks of the Wenner method is that while measuring the soil resistivity at large spacing, the voltage between the potential probes decreases very rapidly, and the instrument is unable to measure such low voltage. Therefore, to measure the apparent soil resistivity at large spacing/depth, the spacing probes Schlumberger method is recommended. Fig. 3 shows the Four-Point method using the Schlumberger method, where the potential probes are placed very close together and the current probes are placed further apart, unlike the Wenner method, where all four probes are placed at equal distances. In the Schlumberger method, the outer probe (current probes) are required to be reinstalled for each measurement, while in the Wenner method, all four probes are to be reinstalled for each soil measurement.

If the depth to which all four probes is small compared to their spacing p and q and p>2q, then the apparent resistivity is given by

$$\rho_a = \pi R p \left(\frac{p+q}{q} \right) \qquad (1)$$

where

p = spacing between the current probes,

q = spacing between the potential probes and

h = the depth of burial of the four probe

Equation (1) indicates the soil resistivity at the approximate depth of $\left(\frac{2p+q}{2} \right)$ which is the distance of the current probe from the centre axis.

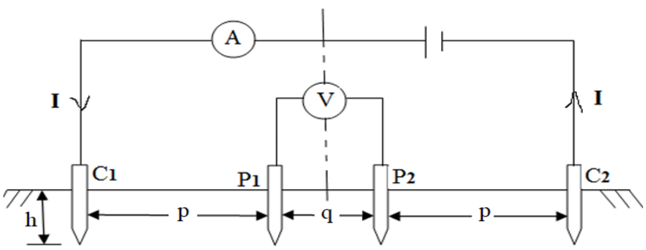

Fig. 3: Unequal Arrangement of Probes in Schlumberger-Array

The derivation of equation (1) is as follows:

If the current sent into the ground follows a hemispheric path, then the potential at probe P_1 is

$$V_1 = \frac{\rho I}{2\pi} \left(\frac{1}{p} - \frac{1}{p+q} \right) \qquad (2)$$

Similarly, the potential at electrode P_2 is

$$V_2 = \frac{\rho I}{2\pi} \left(\frac{1}{p+q} + \frac{1}{p} \right) \qquad (3)$$

Then the potential difference (V_{12}) between $P_1$and P_2 is given by

$$V_{12} = \frac{\rho I}{2\pi} \left(\frac{1}{p} - \frac{1}{p+q} - \frac{1}{p+q} + \frac{1}{p} \right) \qquad (4)$$

But

$$\text{Resistance} \quad R = \frac{V_{12}}{I} = \frac{\rho}{\pi} \left(\frac{q}{p(p+q)} \right) \qquad (5)$$

Therefore,

$$\rho_a = \pi R p \left(\frac{p+q}{q} \right) \qquad (6)$$

Materials and methods

Vertical electrical sounding (VES) data acquisition and analysis

In this research Schlumberger arrangement of electrodes was used to measure the apparent resistivity of the soil in the four locations, P, Q, R and S. A total of five vertical electrical soundings were conducted in each of the four selected locations of Iwo town using the IGIS DDR-3 Digital Resistivity meter. To carry out a VES in one location, an artificial current from the instrument was introduced into the ground by hammering current electrodes that were connected by means of cables to the resistivity meter into the ground and in the presence of various conductive materials in the subsurface; the current flow paths were altered. As a result, the potential distribution is affected, and the resulting potential differences were recorded [19]. The instrument then applied Ohm's law (R = V/I) to calculate the resistance. Then the apparent resistivity of the soil is now displayed on the instrument after multiplying the resistance by the geometric factor. A tape rule was laid down alongside the current and potential cables to measure the spacing between the two current electrodes and the two potential electrodes. It is assumed theoretically that the charges move radially outward from a point source and radially inward toward a negative point source, as shown in Fig. 4 [20]. The current lines represent a sampling of the infinite many paths followed by the current paths that are defined by the condition that they must be everywhere normal to the equipotential surfaces [21] and [22]. The instrument is programmed in a way that it filters self-potentials and

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noises from the incoming signals so that the output is actually the apparent resistivity of the subsurface. Each VES data was processed and analysed using IPwin2 computer software. The output of the analysis of each VES data was a curve where apparent resistivity was plotted with the current electrode spacing.

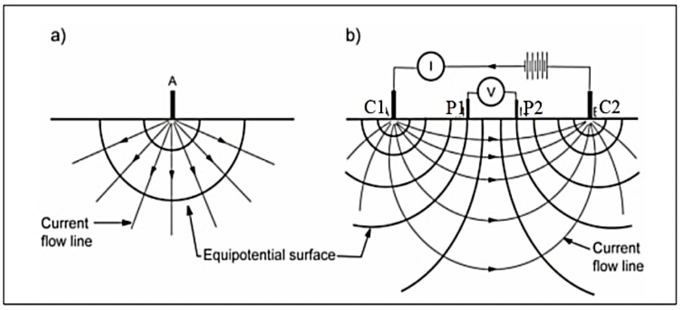

Fig.4: Simplified current flow lines and equipotential surfaces arising from (a) a single current source and (b) a set of current electrodes (a current source and sink)

Moisture content data acquisition

The weight of water in the soil, rather than the volume of water, determines the moisture content value in the soil. So, soil samples were collected from the four study locations in Iwo town. A soil sample from each VES station of each location was collected, making a total of twenty soil samples collected altogether. These soil samples were taken to the University Civil Engineering laboratory for analysis, where they were moistened with a certain volume of water at a temperature of 105°C. At the expiration of twenty-four (24) hours, the samples were allowed to cool so as to remove the excessive heat and to allow the soil samples to be in their natural dried state. Finally, the oven-dried samples were reweighed to quantify the difference between the wet and dry samples. Then the moisture content was calculated using the expression

$$\text{Moisture Content (MC)} = \frac{\text{B - C}}{C - A} \text{ x } 100 \qquad (7)$$

where
A = Weight of empty beaker (g)
B = Weight of wet sample (g) and
C = Weight of oven-dried sample (g)

Results and discussions

The results of the process and analysis of all the twenty VES points were shown in Table 1 and Figures 4(a-d) when apparent resistivity is plotted against current electrode spacing. The curves (fig. 5a- d) were of different shapes (HA, QH, KHA and HKHA). The apparent resistivity distribution of the subsurface of Location P showed that the subsurface consists of three to five layers and that these layers were of different resistivity values, thicknesses and depths. The layers with the highest apparent resistivity values ranged from 1577-12518.0 Ωm, which occurred at the depth of infinity. This is an indication that these layers contain hard or compacted rock formations or even non-conductive materials. When these layers were selected by electrical engineers/contractors for grounding installation, it can pose a serious threat to life and damage the electrical equipment because when fault current builds up, the possibility of it to reverse its paths so that breaker or fuse can cut is uncertain The layers with low resistivity values (VES 1 layer 2, VES 2 layer 4, VES 3 layer 4 VES 4 layer 3 and VES 5 layer 4) ranged from 1.47 Ωm to 51.20 Ωm at depth range of 2.06 m to 26.4 m should be selected for grounding installation purposes by electrical contractors and engineers since these layers could be adjudged to contain wet, conductive materials such as clay or water saturated soil. These low apparent resistivity layers, when selected, will help in the effective dissipation of electrical fault current, lightning surges, and other electrical discharges, thereby protecting electrical facilities since the fault current will rupture the fuse and breaker. The moisture content of the layers in location P varied from 29.2 to 36.1%. These values of moisture content are in tandem with the low values of apparent resistivity of location P.

The apparent resistivity distribution of location Q showed that there is variation in the subsurface layer distribution. The resistivity distribution of VES 6 Layer 3, VES 7 Layer 2, VES 8 Layer 2, VES 9 Layer 4 and VES 10 Layer 2 showed low apparent resistivity values from range from 40.4 to 73.6 Ωm at this depth range of 10.3 to 11.8m is an indication that these layers contain high moisture-rich materials such as clay and water saturated soil which greatly improves the conductivity of the soil and making them suitable for grounding installations. If these layers were chosen for grounding installations by electrical contractors, electrical equipment will be safe because there will be effective dissipation of electric fault current and other electrical discharges. So, the range of the depth scales of this location should be selected for effective grounding installation. The

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Table 1: Results of the analysis of all VES in the four locations

S/N	Type of VES Sounding Curve	Resistivity (Ωm)	Thickness (m)	Depth (m)	FORMATION
VES 1	HA	360.0	0.524	0.524	Lateritic Topsoil
		1.87	9.82	10.3	Weathered layer
		1577	-	-	Basement
VES 2	QH	668.0	0.403	0.403	Lateritic Topsoil
		48.2	15.2	15.6	Weathered layer
		23.2	10.8	26.4	Saturated soil
		9140	-	-	Basement
VES 3	HA	1136	0.621	0.621	Lateritic Topsoil
		1.47	1.44	2.06	Weathered layer
		3884	-	-	Basement
VES 4	HA	645.0	0.766	0.766	Lateritic Topsoil
		9.46	0.683	1.45	Saturated soil
		51.2	23	24.5	Weathered layer
		5695;0	-	-	Basement
VES 5	HA	1091.0	0.3943	0.3943	Lateritic Topsoil
		39.02	0.2392	0.6336	Saturated soil
		103.5	12.02	12.65	Weathered layer
		51.98	10.71	23.36	Weathered fracture
		12518	-	-	Basement
VES 6	KHA	14.5	0.204	0.204	Lateritic Topsoil
		255	6.62	6.83	Weathered layer
		43.9	5	11.8	Weathered fracture
		46060	-	-	Basement
VES 7	KHA	360	6.09	6.09	Topsoil
		58.6	4.21	10.3	Weathered layer
		1197	-	-	Basement
VES 8	KHA	208	5.32	5.32	Lateritic Topsoil
		40.4	5.74	11.1	Weathered layer
		40717	-	-	Basement

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		1007	0.75	0.75	Lateritic Topsoil
		144	0.926	1.68	Weathered layer
VES 9	HKHA	1061	1.91	3.59	Weathered/Basement
		59.6	3.54	7.13	Saturated soil
		1057	-	-	Weathered/Basement
		394	6.73	6.73	Topsoil
VES 10	KHA	73.6	4.98	11.7	Weathered/Basement
		1602	-	-	Weathered/Basement
VES 11	KHA	268	1.15	1.15	Lateritic Topsoil
		29.6	8.74	9.88	Weathered layer
		189	-	-	Basement
		233	1.13	1.13	Lateritic Topsoil
VES 12	KHA	28.9	10.5	11.6	Weathered layer
		234	-	-	Basement
		254	1.43	1.43	Lateritic Topsoil
VES 13	HA	67.4	8.89	10.3	Weathered layer
		195	-	-	Basement
		260	1.22	1.22	Lateritic Topsoil
VES 14	HA	31.4	8,41	9.63	Weathered layer
		206	-	-	Basement
		260	1.14	1.14	Lateritic Topsoil
VES 15	HA	27	9.1	10.2	Weathered layer
		209	-	-	Basement
		146	1.77	1.77	Lateritic Topsoil
		363	1.1	2.88	Weathered layer
VES 16	KHA	22.2	3.35	6.23	Saturated soil
		264	-	-	Basement
		172	4.7	4.7	Lateritic Topsoil
		18.4	2.83	7.53	Weathered layer
VES 17	HA	395	-	-	Weathered Basement

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		203	3.98	3.98	Topsoil
VES 18	KHA	27.9	4.22	8.2	Weathered layer
		501	-	-	Basement
		315	1.73	1.73	Lateritic Topsoil
VES 19	KHA	88	5.89	7.62	Weathered layer
		610	-	-	Weathered/Basemen
		291	4.93	4.93	Topsoil
VES 20	HA	31.8	2.29	7.93	Weathered layer
		655	-	-	Weathered/Basement

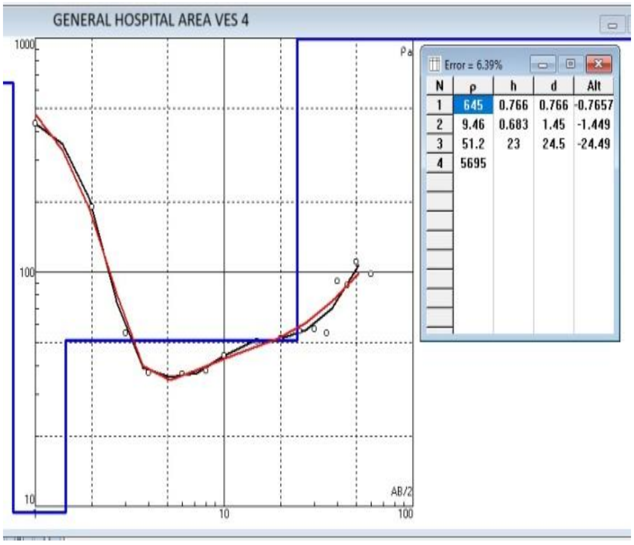

Fig.5a: Sample of log-log plot of VES in location P

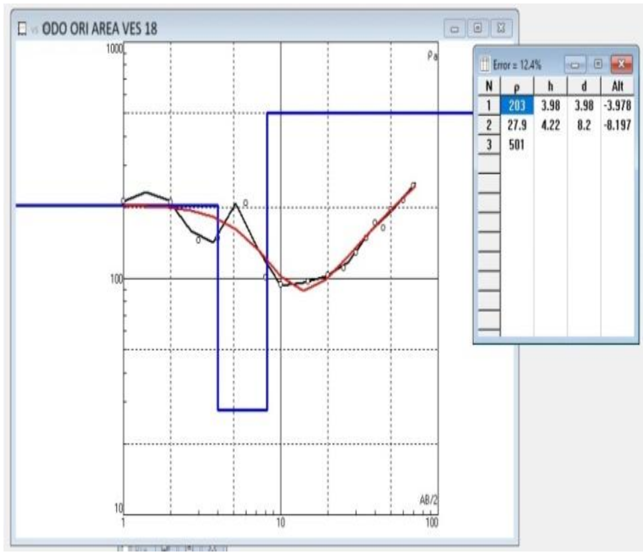

Fig.5c: Sample of log-log plot of VES in location R

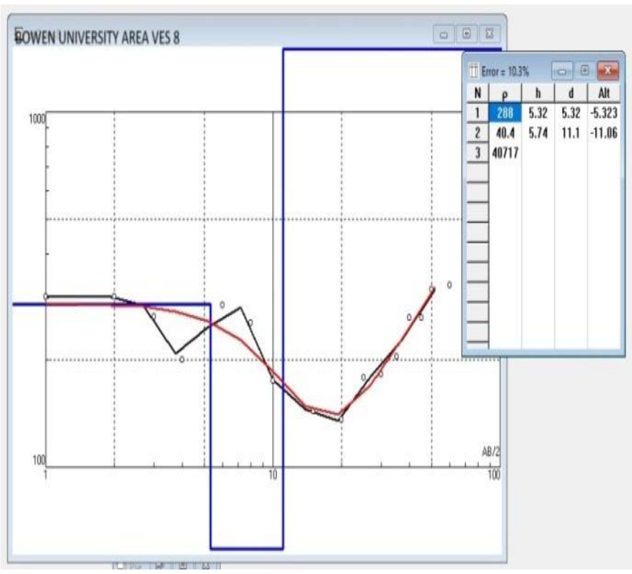

Fig.5b: Sample of log-log plot of VES location Q

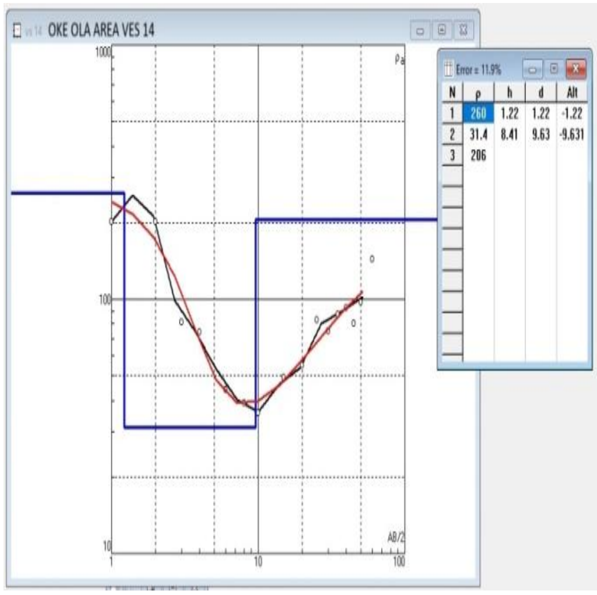

Fig.5d: Sample of log-log plot of a VES in location S

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A higher resistivity distribution of this location, Q ranged from 10615 Ωm to 46060.0 Ωm at infinite depth. The high resistivity values were indicative of the presence of compacted rock formations, which are non-conductive. These layers and depths with high apparent resistivity value when selected by electrical contractors/engineers for grounding installation because their high resistivity will impede the efficient dissipation of electrical energy. The variation of moisture content value in location Q is 34.4% - 47.7%. The average of which is 38.4%. This is an indication of the presence of clayey materials that will bind the conduction of fault current. The distribution of apparent resistivity of the subsurface layers of Location R indicated that layer 3 of VES 11, 12, 13, and 15 had the lowest values of apparent resistivity in the range 27.0 to 67.4 Ωm. The depth scale of these resistivity values ranged from 9.63 m to 11.60 m. The low values of apparent resistivity of layer 3 indicate that these layers consist of high moisture-rich materials like clay and water-saturated soil, which enhances the conductivity of this layer, making these layers ideal for grounding installation. Electrical Engineers and contractors should select the depth range of these layers for grounding installation to ensure the safe dissipation of electrical fault currents, lightning surges, and other electrical discharges. High apparent resistivity values of this location, which range from 189.0 Ωm to 234.0 Ωm, occurred at an infinite depth. At this depth, installation of the grounding system by electrical engineers and contractors could not be effective because, when fault currents build up, they might not be able to reverse their path to cause the breaker or fuse to cut off. The materials at these depths could be hard rocks, dry soil, or non-conductive types. Grounding installation at these depths can pose a serious threat to life and damage electrical equipment/facilities. The moisture content results varied from 22.1 to 30.6%, and the average is 27.06%. This could be an indication of clayey sand, and this might also favour the installation of a grounding system.

At location S of the study site, VES 16, 17, 18, 19, and 20 had their lowest resistivity values, ranging from 18.4 Ωm to 88.0 Ωm (layer 3). The depth range of occurrence of these lowest apparent resistivity values is from 6.23 m to 8.20 m. The lowest resistivity values were indication of the presence of highly conductive materials such as clay and water-saturated soil. To achieve effective grounding installation and safety of personnel and electrical equipment/facilities, electrical contractors and engineers should select this depth range in this layer for effective dissipation of fault currents and lightning surges when they occur. At this location, high apparent resistivity of the site occurred at the last layer and at infinite depth. The apparent resistivity values of this layer ranged from 264.0 Ωm to 655.0 Ωm. This layer is tagged as the basement. The basement is the hard rocks, which are not conductive, and it will not help in grounding installation. The moisture content results of this location ranged from 27.1% to 31.7%. The average value of it is 29.68%. These values indicate that the site consists of clay material, which will help in ground installation. Lastly, soil resistivity is inversely related to soil saturation. As the moisture content increases, the soil becomes more saturated, resulting in a decrease in soil resistivity as shown in Fig. 6(a-d). This suggests that when moisture content increases, soil saturation increases, and soil resistivity decreases. This relationship is important in grounding penetration radar (GPR) surveys, electrical resistivity tomography (ERT), soil moisture monitoring for agricultural and environmental purposes, hydrogeological and groundwater research, and so on.

Conclusion

The study has successfully highlighted the critical importance of accurate soil resistivity measurements for effective grounding systems in Iwo, Osun State, Nigeria. Grounding is a fundamental aspect of electrical safety, providing a pathway for fault currents to dissipate safely into the soil, thereby preventing electrical shocks, equipment damage, and potential fires. The research has demonstrated that the resistivity of the soil is a key determinant in the performance of grounding systems, with various factors such as soil composition, moisture content, and temperature significantly influencing resistivity values.

Acknowledgement

On behalf of the remaining authors, I appreciate the Civil Engineering Department for allowing us to use their laboratory to carry out the determination of the soil moisture content of the soil samples.

Conflict(s) of interest

On behalf of the remaining authors, I want to state that potential conflicts of interest do not exist.

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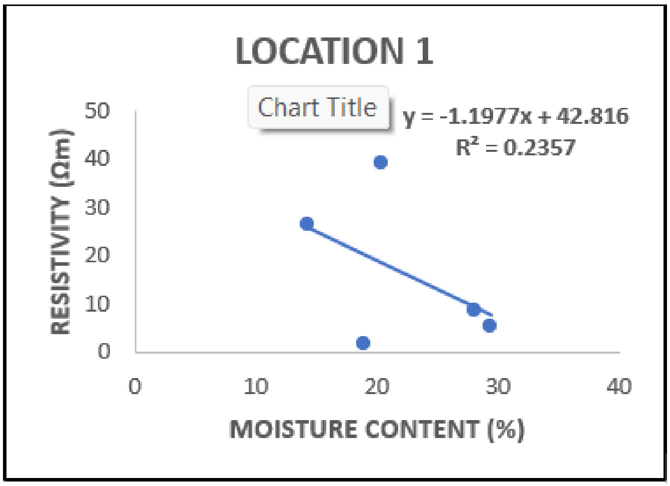
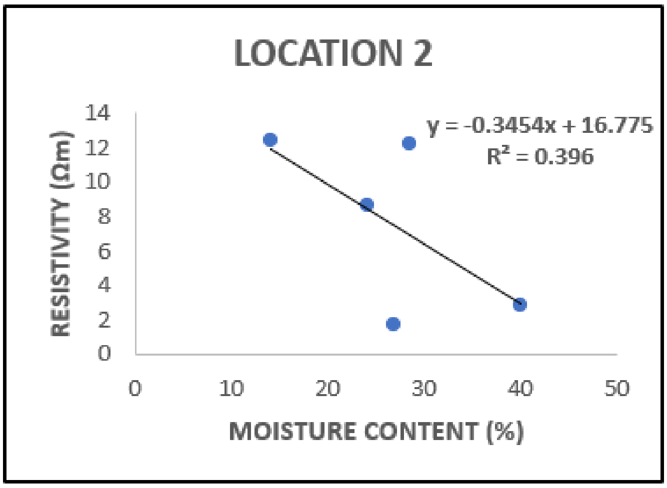
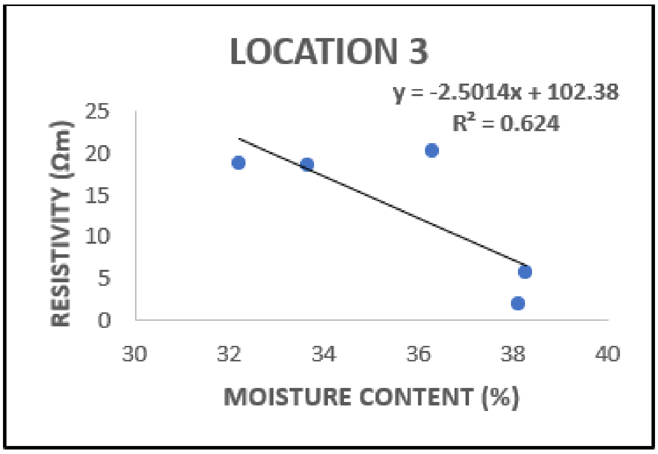


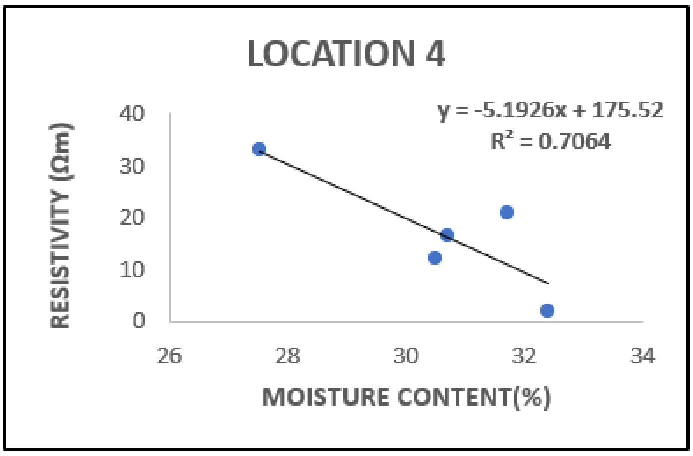
(a)



(b)



(c)



(d)

Figs 6(a - d): Correlation between resistivity and moisture content

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