Soil Resistivity, its Impact on Optimum Depth of Electrodes in Earthing System– Case Study University of Port Harcourt Residential Staff Quarters

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***Abstract*: A well-designed earthing system plays a vital role in any Electrical Facility.**

Soil resistivity measurement is an important parameter when designing earthing system. However, it is a known fact that the resistance of an earth electrode which is a component of earthing system is heavily influenced by the resistivity of the soil in which it is driven to. A knowledge of the soil resistivity at the intended site, and how this varies with parameters such as moisture content, temperature and depth, provides a valuable insight into how the desired earth resistance value can be achieved and maintained over the life of the installation with the minimum cost and effort. One of the main objectives of earthing electrical systems is to establish a common reference potential for the power supply system, building structure, plant steelwork, electrical conduits, cable ladders and trays and the instrumentation system. To achieve this objective, a suitable low resistance connection to earth is desirable. In this research paper, soil resistivity was investigated in three different residential staff quarters of University of Port Harcourt Choba, Abuja and Delta Campuses during the wet and dry season of 2022 using the relevant IEEE standards and International best practices for determining Electrical substation and residential buildings earthing system designs. To determine the optimum depth of grounding electrodes that will have the acceptable values of earth resistance and resistivity for earthing system designs, the Wenner four pin method of measuring soil resistivity was employed. The findings of this research paper show the optimum depth the grounding electrodes will get to in order to obtain the best earth resistance and resistivity values that is suitable for substation and residential earthing system designs. The outcome of this study is also useful for purposes of estimating the number of grounding electrodes, ground resistance and potential gradients including step and touch voltages of substation grounding installations around the three locations of study in university of Port Harcourt residential staff quarters.

***Keywords*: Earth Electrodes, Grounding systems, Soil Resistance, Soil Resistivity, Apparent Resistivity.**

I. INTRODUCTION

Soil resistivity and earthing system plays a key role in generation, transmission and distribution for safe and proper operation of any electric power system. Soil resistivity directly affects the design of a grounding system. When designing an extensive grounding system, it is advisable to locate the area of lowest soil resistivity in order to achieve the economical grounding installation. Neither very low resistivity nor very high resistivity is safe for human safety under power system fault conditions. The earthing or grounding is mainly affected by soil resistivity [1]

A fault in a power plant or a substation for instance, consists of soil resistivity measurement and its interpretation, fault current distribution computations, and grounding system analysis. Safety assessment includes GPR (Ground Potential Rise) and ground resistance of the substation grounding grid, touch and step voltages in the substation area, body current when a person is subjected to a touch or step voltage under fault conditions. The grounding system performance and safety are closely related to soil characteristics. This is logical that the highest soil resistivity results in the highest GPR (Ground Potential Rise). The faults in any electrical system are unavoidable. Every electrical equipment, appliance, system must be earthed or grounded to obtain a low resistance path for dissipation of current into the earth.

Soil resistivity data is the key factor in designing an earthing system for a specific performance objective. The greatest single factor determining the quality of an earth is the resistivity of the soil surrounding the electrode. All soil conducts electrical current, with some soils having good electrical conductivity while the majority has poor electrical conductivity.

The resistivity of soil varies widely throughout the world and changes dramatically within small areas. Soil resistivity is mainly influenced by the type of soil (clay, shale, etc.), moisture content, the number of electrolytes (minerals and dissolved salts) and finally, temperature. When designing an earthing system for a specific performance objective, it is necessary to accurately measure the soil resistivity of the site where the earth is to be installed.

In this research paper, soil resistivity was investigated in three different residential staff quarters of University of Port Harcourt Choba, Abuja and Delta Campuses during the wet and dry season of 2022 using the relevant IEEE standards and International best practices for determining Electrical substation and residential buildings earthing system designs.

To determine the optimum depth of grounding electrodes that will have the acceptable values of earth resistance and resistivity for earthing system designs, the Wenner four pin method of measuring soil resistivity was employed. The findings of this research paper show the optimum depth the grounding electrodes will get to in order to obtain the best earth resistance and resistivity values that is suitable for substation and residential earthing system designs.

The outcome of this study is also useful for purposes of estimating the number of grounding electrodes, ground resistance and potential gradients including step and touch voltages of substation grounding installations around the three locations of study in university of Port Harcourt residential staff quarters.

Objectives of the Study

(1) To determine soil resistivity in depth of (2, 4, 6, 8, 10 up to 20m) in three different residential staff quarters in University of Port Harcourt Choba, Abuja and Delta campuses during wet and dry seasons using relevant IEEE standards.
(2) To determine the optimum depth of earth electrode in three different residential staff quarters in University of Port Harcourt Choba, Abuja and Delta campuses
(3) To investigate how resistivity varies with electrode depth and spacing.
(4) To provide resistivity profile table in the areas under study to serve as reference guide at a glance for earthing system design engineers.

Soil characteristics

Soil is one of the most important natural resources. It is indispensable for the existence of plants and animals. Soils are formed by the combined work of rocks, topography, climate and plants. Soils of different country may be different. Soils are classified based on their colour structure and place where they are found. The wetter the soil, the lesser the resistance it will have. This is the reason buildings have their own earth connection and do not rely on earth point at the distribution transformer.[1]

There are various reasons of measuring soil resistivity.

These are:

i. Such data is used to make sub-surface geophysical surveys as an aid in identifying core locations, depth to bed rock and other geological phenomena.
ii. Soil resistivity directly relates to an increase in corrosion activity and therefore dictates the protective treatment to be used.
iii. Soil resistivity directly affects the design of a grounding system. When designing an extensive grounding system, it is advisable to locate the area of lowest soil resistivity in order to achieve the most economical grounding system.

When a grounding system is designed, the fundamental method to ensure the safety of human beings and power apparatus is to control the step and touch voltages in their safe regions. In different seasons, the resistivity of the surface soil layer would be changed, which would affect the safety of grounding system, and the grounding resistance, step and touch voltage would move to the safe side, or to the hazard side. In rainy season, the low resistivity soil layer leads the grounding resistance and the step voltage smaller than the respective values in normal condition, it is good for safety of human beings, but the raining season perhaps leads the touch voltage higher than its limit value, so the influence of raining on the safety of grounding grid should be considered. The touch voltage of the ground surfaces increases with the thickness or the resistivity of the freezing soil layer. When the thickness of the freezing soil layer exceeds the burial depth of the grounding system, touch voltage sharply increases. If the resistivity of the freezing soil layer reaches 5000Ω-m, then the touch voltage will increase to 12 times of the respective value in normal condition. Then high resistivity soil layer would lead step voltage higher than the respective value of the grounding system in normal condition. The step voltage increases with resistivity of the freezing soil layer. Even if a granite layer is added, the limit of touch voltage is still smaller than the actual touch voltage. Adding vertical grounding electrodes can effectively decreases the touch voltage to improve the safety of grounding system. In high freezing areas, the design of grounding grid should strictly analyze the influence of freezing soil layer on the safety of grounding system. [2]

Resistance And Resistivity Values For Several Types Of Soil Layer [3]

Table 1 Resistance and Resistivity for Types of Soil Layer

Type of Soil	Soil Resistance 3 – 20m depth (Ω)	Soil Resistivity (Ω-m)
Swamp Soil	3 - 10	2 - 50
Farming Clay And Loaming soil	10 - 33	100
Sandy clay soil	15 - 50	150
Moist Sandy Soil	20 - 66	300
Concrete 1:5	N/A	400
Moist Gravel	48 - 160	500
Dry Sandy soil	100 - 330	1000
Dry Gravel	100 - 330	1000
Stoney Soil	300 - 1000	30000
Rock	N/A	10^7

(Source:[3]: *M. O. Oyeleye and T. D. Makanju march 2020)*

II. THE LOCATIONS UNDER STUDY

The research work on the analysis of soil resistivity and its impact on determining optimum depth of electrodes in earthing system designs was carried out in the university of Port Harcourt residential staff quarters, namely: Abuja, Choba and Delta staff quarters in Port Harcourt Rivers state.

The University of Port Harcourt is located in Choba in Port Harcourt, Rivers state, Nigeria. It was established in 1975 as University College, Port Harcourt and was given university status in 1977. [4]

The University of Port Harcourt is of three campuses, namely: Choba, Delta and Abuja, all located in Obio-Akpor. The three campuses are within the coordinates of 4.9069 0 N and 6.9170 0 E. [4]

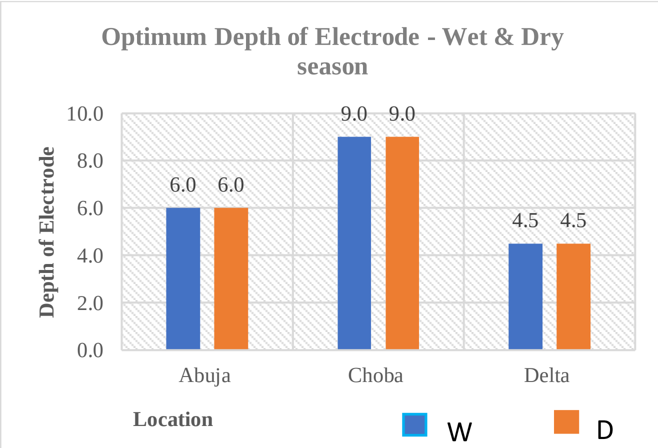

Fig 1 Optimum Depth of Electrode in Uniport staff quarters – wet & dry season

III. MATERIALS AND METHODS

The best method for testing soil resistivity is the Wenner Four Point method. It uses a 4-pole digital ground resistance meter, probes, and conductors. It requires inserting four probes into the test area. The probes are installed in a straight line and equally spaced. The probes establish an electrical contact with the earth. The four-pole test meter injects a constant current through the ground via the tester and the outer two probes. The current flowing through the earth (a resistive material) develops a voltage potential difference. This voltage drops resulting from the current flow is then measured between the two inner probes. The meter then knows the amount of current that is flowing through the earth and the voltage drop across the two center probes. With this information the meter uses Ohms law (R=V/I) to calculate and display the resistance in ohms This displayed resistance value is in ohms and must be converted to ohms meter, which are the units of measurement for soil resistivity. Ohms-meter is the resistance of a volume of earth that is 1m x 1m x 1m.

To establish the average resistivity of the soil in ohm/meters (Þ) between the surface and the depth (D), the megger reading must be converted by employing the following formula: $\rho = 2\pi ar$ where ρ = resistivity in ohm/meters a = the interval between probes, r = the megger reading in ohms readings are usually taken at probe spacings of 2, 4, 6, 8, 10m, etc as shown in the following Field Sheet. The spacing of the probes; distance "a" MUST always be equal.[5]

The calculated soil resistivity is the average of the soil resistivity from the surface to a depth equivalent (D) (0.75xa) of the probe spacing. A probe spacing of 4m (a) between each probe will provide the average soil resistivity between the surface and a depth of 3m(b).

Several readings at the different probe spacing and at different areas of the site are required. The more data available the more accurately will be the design of the grounding system.

(1) Readings should be taken along at least two sides of the site and diagonally from one corner to another. A pipe or some underground structure could influence the readings. The more data available and used in the design provides more confidence in the outcome.[5]

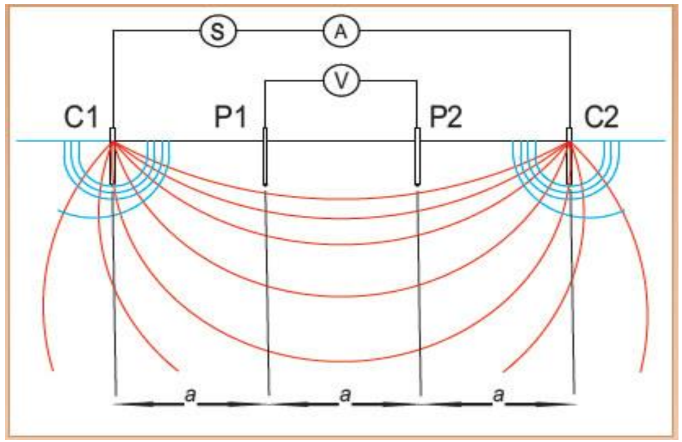

Fig 2 Wenner Four Pin method showing current propagation pattern

Equipment And Tools Required

The following equipment and tools were used in carrying out the resistivity measurement as seen in Fig 3 below:

- 4-Pole Digital - Earth Resistance / resistivity Tester Meter
- Hammer (to drive probes)
- Measuring tape
- Test Electrodes
- Four insulated wire conductors
- User's Manual for Meter

Fig 3 Resistivity Measurement / Test Equipment

The test equipment used in this research work is 4Pole Digital Electrical earth / resistivity meter while the analytical tool is a newer version of spreadsheet application software.

3.1 Experimental determination of soil resistivity

Resistivity (ρi) of layer i of a given soil can be determined experimentally and different methods have been developed in achieving this.

These methods are: the Wenner method, the Schlumberger palmer method and the fall-off potential method. Of the three methods, the Wenner technique is the simplest and the most popular method. This is because, it obtains deeper layer of soil resistivity without having to deep the pins down into the layers. Therefore, this method shall be adopted in determining the soil resistivity of the various locations to be considered in this project.

3.1.1 Wenner Method:

In Wenner method, the soil resistivity is commonly measured by four points as depicted in Fig. 1. [6]. The resistivity of the soil (p) for a given layer i in Ω-m using this wenner technique can be determined as:

$$\rho = \frac{4\pi aR}{1 + \frac{2a}{\sqrt{a^2+4b^2}} - \frac{a}{\sqrt{a^2+b^2}}} \quad (3.1)$$

Where:

R is the measured resistance in ohms and is determined from the measured value of voltmeter (V) and the ammeter (I) from the experiment as shown in Fig.4,

a = Represents the distance between adjacent electrodes in meter

b = Represent the depth of the electrodes in meter

When b is far less than a, equation 3.1 becomes equation 3.2

$$p = 2\pi aR \quad (3.2)$$

3.1.2 Grounding Electrode Resistance

Resistance to the earth of any earth electrode is influenced by the resistivity of the surrounding soil. This depends to a large extent on the nature of the soil and its moisture content. Since soil exhibits a resistance to the flow of electrical current and is not an ideal conductor, there is always some resistance (can never be zero) between the earth electrode and "true Earth". This resistance is called earth resistance of an electrode and it depends on the soil resistivity, the type and size of the electrode and the depth to which it is buried. The most commonly used method of measuring the earth resistance of an earth electrode is the Fall-of-Potential measuring technique [7]. It is the most recognized method for measuring the resistance to earth of a grounding system, or the ground system performance. This method is based on an IEEE standard and when properly performed, it gives a very accurate result. It is normally suitable for use in circumstances such as transmission line structure earths, or areas of difficult terrain, because of the shallow penetration that can be achieved in practical situations.

Earth Resistance (Rg) of a single spike, of diameter (D) and driven length (L) driven vertically into the soil of resistivity (ρ), can be calculated as follows. [8]

$$R = \frac{\rho}{2\pi l}\{\ln\left(\frac{8l}{D}\right) - 1\} \quad (3.3)$$

Where:

- ρ is the soil resistivity in Ω-m
- l is the buried length of the electrode in m
- D is the diameter of the electrode in m

Also, Electrode resistance can be calculated as follows:

$$R = 0.366\frac{\rho}{h}\log_e\left(\frac{4h}{d}\right) \quad (3.4)$$

Where:

- a is probe spacing in m
- d is earth rod diameter in m
- h Depth in m
- r Megger Ohms
- R Resistance Ohm
- ρ Resistivity

3.1.3 Procedure for resistivity measurement (Wenner 4-Point Method)

The following procedure is generic and will work with all meters. The meter's manual should be consulted for operational details.[9]

Step 1. Verify that the metal strip between the meter's C1 and P1 terminals is disconnected (used for 3-Point testing) already Existing Areas.

Step 2. Install the 4 test probes in the ground equally spaced in a straight line. Generally, the shorter spacing is done first. In this research work minimum spacing of 2 meters was considered followed by 4, 6, 8, 10 up to 20 meters spacing.

Step 3. Using the conductors, the C1, P1, P2 and C2 terminals were connected to the electrodes. The electrodes must be connected in an appropriate order from the end, to the C1, P1, P2 and C2 terminals. The test results will be invalid if the electrodes are not connected properly.[9]

Step 4 Carry out resistivity parameter selection from the meter such as: distance of electrodes apart, wiring setting, in this case 4-wire for wenner method, resistance measurement and resistivity measurement.

Step 5. After all connections are done, carefully press the test button and read the digital display. Record the reading on the Field Sheet at the appropriate location. If the reading is not stable or displays an error indication, double check the connections. For some meters, the RANGE and TEST CURRENT settings may be changed until a combination that provides a stable reading without error indications is reached.

Step 6. Place the probes at each of the spacings indicated below fig 5 and record the readings on the Field Sheet. Probes MUST be at EQUAL spacings (distance "a").

Steps 1-6 of this procedure must be repeated at multiple locations on the site to obtain a reliable soil profile.

Stray currents, buried water pipes, cable sheaths and other factors may interfere and distort the readings. Measurements should be taken along 3 directions at each site as a minimum as shown in fig 5 below. Sometimes this may not be feasible, but the more data that can be obtained, the more accurate the generated soil model will be.

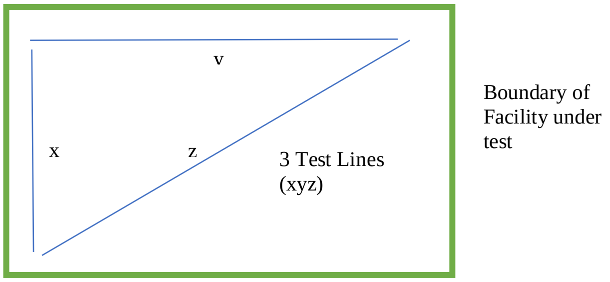

Fig 4 Resistivity test pattern

3.1.4 Resistivity data Measurement / Collection

The resistivity data collections were carried out during the wet season and dry season.

For the wet season, the month of June and July 2022 were chosen for data collection while the month of January and February 2022 was chosen for data collection for dry season.

For data analysis, rain data were obtained from Climate-data.org to ascertain the month with the highest rainfall knowing that moisture content in the soil affect soil resistivity.

The table below shows rainfall data in Port Harcourt.[10]

Table 2 Port Harcourt Rainfall and Temperature data.

Location of study: Port Harcourt			
Period	**Rainfall (Precipitation)**	**Temperature (^{0}C)**	**Peak Month of Rainfall**
June 2022	350mm	35^0 C	June 2022
July 2022	325mm	32.5^0 C	

From the table above [10], Resistivity data collected in the month of June 2022 were used for resistivity analysis as this was the month with the highest rainfall with a precipitation of 350mm at a temperature of 35^0 C.

3.1.5 Obtaining optimum depth of Electrode in ALL Locations

The resistivity data in various locations of study (Uniport Staff quarters in Choba, Abuja and Delta Campus) were collected using the wenner method as described in the outlined resistivity measurement procedure in section 3.1.3 above.

From the 4-pole wenner method and theory in section 3.0, the resistivity measurement is such that the spacing of the probe must always be equal. The calculated soil resistivity according to wenner method is the average of the soil resistivity from the surface to the depth equivalent (D) (0.75 x a) of the probe spacing. An equal probe spacing of 2m between each probe provides an average soil resistivity of 1.5m between the surface and depth. That is, 0.75 x 2m equals 1.5m. Also, An equal probe spacing of 4m between each probe provides an average soil resistivity of 3.0m between the surface and depth. That is, 0.75 x 4m equals 3.0m. while 20m probe spacing being the highest probe spacing provides 15m depth that is, 0.75 x 20 equals 15m.

The results from the resistivity measurement are as shown in tables below:

Location 1 Uniport - Staff Quarters Abuja (Wet Season)

Table 3. Resistivity measurement (Wet-season) – Uniport Abuja

RESISTIVITY SURVEY USING WENNER METHOD - WET SEASON					
LOCATION: UNIPORT - STAFF QUARTERS ABUJA					
Date of Test: 12th June, 2022			Time: 11:00am to 2:45:pm		
Test Meter Details: 4-Point Earth Resistance and Resistivity Tester					
Manufacturer: DUOYI Instruments					
Model No: 4300A			Serial No: 0603191		
Electrode Diameter = 16mm					
Spike Spacing	Depth	Meter Reading resistance	Meter Reading Resistivity	Calculated Electrode Resistance	Calculated Resistivity
(a)	**(D)**	**(r)**	**(ρ)**	**(R)**	**(ρ)**
Meters	Meters	Ohms	Ohm-Meter	Ohms	Ohm-Meter
2	1.5	67.00	842.00	528.83	842.06
4	3	20.00	502.00	176.08	502.72
6	4.5	7.40	279.00	69.24	279.01
8	6	4.80	241.00	46.69	241.31
10	7.5	6.20	389.00	62.13	389.61
12	9	8.00	603.00	82.20	603.26
14	10.5	9.30	818.00	97.49	818.18
16	12	10.00	1,005.00	106.58	1,005.44
18	13.5	9.70	1,097.00	104.93	1,097.19
20	15	10.50	1,319.00	115.03	1,319.64

Location 1 Uniport - Staff Quarters Abuja (Dry Season)

Table 4 Resistivity measurement (Dry-season) – Uniport Abuja

RESISTIVITY SURVEY USING WENNER METHOD - DRY SEASON					
LOCATION: UNIPORT - STAFF QUARTERS ABUJA					
Date of Test: 5th February, 2022			Time: 10:00am to 1:40:pm		
Test Meter Details: 4-Point Earth Resistance and Resistivity Tester					
Manufacturer: DUOYI Instruments					
Model No: 4300A			Serial No: 0603191		
Electrode Diameter = 16mm					
Spike Spacing	Depth	Meter Reading resistance	Meter Reading Resistivity	Calculated Electrode Resistance	Calculated Resistivity
(a)	**(D)**	**(r)**	**(ρ)**	**(R)**	**(ρ)**
Meters	Meters	Ohms	Ohm-Meter	Ohms	Ohm-Meter
2	1.50	80.40	1,010.00	634.34	1,010.47
4	3.00	24.00	603.00	211.51	603.26
6	4.50	8.88	334.00	82.89	334.81
8	6.00	5.76	289.00	55.99	289.57
10	7.50	7.44	467.00	74.59	467.53
12	9.00	9.60	723.00	98.56	723.92
14	10.50	11.16	981.00	116.92	981.81
16	12.00	12.00	1,206.00	127.90	1,206.53
18	13.50	11.64	1,316.00	125.88	1,316.62
20	15.00	12.60	1,583.00	138.05	1,583.57

Location 2 Uniport - Staff Quarters Choba (Wet Season)

Table 5 Resistivity measurement (Wet-season) – Uniport Choba

RESISTIVITY SURVEY USING WENNER METHOD - WET SEASON					
LOCATION: UNIPORT - STAFF QUARTERS CHOBA					
Date of Test: 11th June, 2022			Time: 12:43pm to 3:50:pm		
Test Meter Details: 4-Point Earth Resistance and Resistivity Tester					
Manufacturer: DUOYI Instruments					
Model No: 4300A			Serial No: 0603191		
Electrode Diameter = 16mm					
Spike Spacing	Depth	Meter Reading resistance	Meter Reading Resistivity	Calculated Electrode Resistance	Calculated Resistivity
(a)	(D)	(r)	(ρ)	(R)	(ρ)
Meters	Meters	Ohms	Ohm-Meter	Ohms	Ohm-Meter
2	1.5	62.00	779.00	489.26	779.22
4	3	25.00	628.00	220.28	628.40
6	4.5	10.00	376.00	93.31	377.04
8	6	6.50	326.70	63.30	326.77
10	7.5	4.00	251.30	40.14	251.36
12	9	2.60	196.00	26.72	196.06
14	10.5	4.50	396.00	47.20	395.89
16	12	6.80	684.00	72.54	683.70
18	13.5	9.00	1,021.40	97.70	1,018.01
20	15	10.50	1,320.30	115.14	1,319.64

Location 2 Uniport - Staff Quarters Choba (Dry Season)

Table 6 Resistivity measurement (Dry-season) – Uniport Choba

RESISTIVITY SURVEY USING WENNER METHOD - DRY SEASON					
LOCATION: UNIPORT - STAFF QUARTERS CHOBA					
Date of Test: 6th February, 2022			Time: 11:30pm to 2:30:pm		
Test Meter Details: 4-Point Earth Resistance and Resistivity Tester					
Manufacturer: DUOYI Instruments					
Model No: 4300A			Serial No: 0603191		
Electrode Diameter = 16mm					
Spike Spacing	Depth	Meter Reading resistance	Meter Reading Resistivity	Calculated Electrode Resistance	Calculated Resistivity
(a)	(D)	(r)	(ρ)	(R)	(ρ)
Meters	Meters	Ohms	Ohm-Meter	Ohms	Ohm-Meter
2	1.5	74.40	779.00	489.26	935.06
4	3	30.00	628.00	220.28	754.08
6	4.5	12.00	376.00	93.31	452.45
8	6	7.80	326.70	63.30	392.12
10	7.5	4.80	251.30	40.14	301.63
12	9	3.12	196.00	26.72	235.27
14	10.5	5.40	396.00	47.20	475.07
16	12	8.16	684.00	72.54	820.44
18	13.5	10.80	1,021.40	97.70	1,221.61
20	15	12.60	1,320.30	115.14	1,583.57

Location 3 Uniport - Staff Quarters Delta (Wet Season)

Table 7 Resistivity measurement (Wet-season) – Uniport Delta

RESISTIVITY SURVEY USING WENNER METHOD - WET SEASON					
LOCATION: UNIPORT - STAFF QUARTERS DELTA					
Date of Test: 13th June, 2022			Time: 11:15am to 2:25:pm		
Test Meter Details: 4-Point Earth Resistance and Resistivity Tester					
Manufacturer: DUOYI Instruments					
Model No: 4300A			Serial No: 0603191		
Electrode Diameter = 16mm					
Spike Spacing	Depth	Meter Reading resistance	Meter Reading Resistivity	Calculated Electrode Resistance	Calculated Resistivity
(a)	(D)	(r)	(ρ)	(R)	(ρ)
Meters	Meters	Ohms	Ohm-Meter	Ohms	Ohm-Meter
2	1.5	30.00	277.00	173.97	377.04
4	3	10.00	251.00	88.04	251.36
6	4.5	4.00	150.00	37.22	150.82
8	6	4.50	226.00	43.79	226.22
10	7.5	4.50	282.00	45.04	282.78
12	9	6.80	512.00	69.80	512.77
14	10.5	7.00	615.00	73.30	615.83
16	12	7.00	703.00	74.55	703.81
18	13.5	7.00	791.00	75.66	791.78
20	15	6.80	854.00	74.47	854.62

Location 3 Uniport - Staff Quarters Delta (Dry Season)

Table 8 Resistivity measurement (Dry-season) – Uniport Delta

RESISTIVITY SURVEY USING WENNER METHOD -DRY SEASON					
LOCATION: UNIPORT - STAFF QUARTERS DELTA					
Date of Test: 7th February, 2022			Time: 10:10am to 2:15:pm		
Test Meter Details: 4-Point Earth Resistance and Resistivity Tester					
Manufacturer: DUOYI Instruments					
Model No: 4300A			Serial No: 0603191		
Electrode Diameter = 16mm					
Spike Spacing	Depth	Meter Reading resistance	Meter Reading Resistivity	Calculated Electrode Resistance	Calculated Resistivity
(a)	(D)	(r)	(ρ)	(R)	(ρ)
Meters	Meters	Ohms	Ohm-Meter	Ohms	Ohm-Meter
2	1.5	36.00	452.00	283.88	452.45
4	3	12.00	300.00	105.23	301.63
6	4.5	4.80	180.00	44.67	180.98
8	6	5.40	271.00	52.50	271.47
10	7.5	5.40	339.00	54.15	339.34
12	9	8.16	615.00	83.84	615.33
14	10.5	8.40	739.00	88.07	739.00
16	12	8.40	844.00	89.51	844.57
18	13.5	8.40	950.00	90.87	950.14
20	15	8.16	1,025.00	89.39	1,025.55

IV. RESULT AND DISCUSSION

The analysis of soil resistivity and its impact on determining optimum depth of electrodes in earthing system was carried out in three residential staff quarters (Abuja, Choba and Delta Campus) in University of Port Harcourt. The measurement of soil resistivity was carried using wenner method. The measured soil resistance data were analyzed using relevant IEEE Equations and excel software application to obtain soil resistivity values and optimum depth of earth electrode in the three Locations of study.

From fig 1 below, it can be seen from the graph that the optimum depth for earth electrode 6.0m, 9.0m and 4.5m for Abuja, Choba and Delta Campus respectively. It was also observed that going any deeper, the graph starts to slope upwards thus there is no gain going deeper.

Location 1: Abuja Campus wet and dry season

Resistivity measurement were carried out using wenner method and the readings are presented in Tables 3 and 4.

Location 2: Choba Campus wet and dry season

Resistivity measurement were carried out using wenner method and the readings are presented in Tables 5 and 6.

Location 3: Delta Campus wet and dry season

Resistivity measurement were carried out using wenner method and the readings are presented in Tables 7 and 8.

From fig 1 above, it can be seen from the graph that the optimum depth for earth electrode is 6.0m, 9.0m and 4.5m for Abuja, Choba and Delta Campus respectively. It was also observed that going any deeper, the graph starts to slope upwards thus there is no gain going deeper.

Fig 5 shows the soil resistance at the optimum depth of each location while Fig 6, 7 and 8 shows the relationship between soil resistivity and electrode depth for the three locations for both wet and dry seasons. As spacing increases, the resistivity increases which is an indication that the soil profile is such that the upper soil layer is with high resistivity layer overlaying low resistivity layer.

Table 9 Optimum Electrode depth in Uniport Staff Quarters – (Wet Season)

SUMMARY OF OPTIMUM DEPTH OF EARTH ELECTRODE - WET SEASON							
SN	**Location**	**Probe Spacing**	**Electrode Optimum Depth**	**Meter Reading resistance**	**Meter Reading Resistivity**	**Calculated Electrode Resistance**	**Calculated Resistivity**
		(a)	**(D)**	**(r)**	**(ρ)**	**(R)**	**(ρ)**
		Meters	**Meters**	**Ohms**	**Ohm-Meter**	**Ohms**	**Ohm-Meter**
1	Abuja	8	6.0	4.8	241.00	46.69	241.31
2	Choba	12	9.0	2.6	196.00	26.72	196.06
3	Delta	6	4.5	4.0	150.00	37.22	150.82

Table 10 Optimum Electrode depth in Uniport Staff Quarters – (Dry Season)

SUMMARY OF OPTIMUM DEPTH OF EARTH ELECTRODE - DRY SEASON							
SN	**Location**	**Probe Spacing**	**Electrode Optimum Depth**	**Meter Reading resistance**	**Meter Reading Resistivity**	**Calculated Electrode Resistance**	**Calculated Resistivity**
		(a)	**(D)**	**(r)**	**(ρ)**	**(R)**	**(ρ)**
		Meters	**Meters**	**Ohms**	**Ohm-Meter**	**Ohms**	**Ohm-Meter**
1	Abuja	8.00	6.00	5.76	289.00	55.99	289.57
2	Choba	12	9.00	3.12	235.00	26.72	235.27
3	Delta	6	4.50	4.80	180.00	44.67	180.98

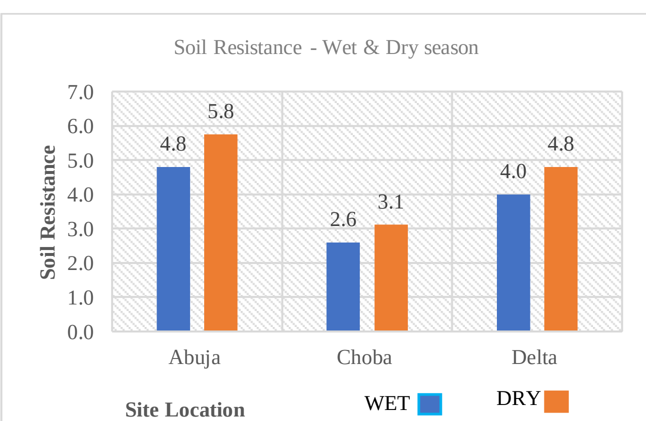

Fig 5 Soil resistance in Uniport staff quarters – wet & dry season

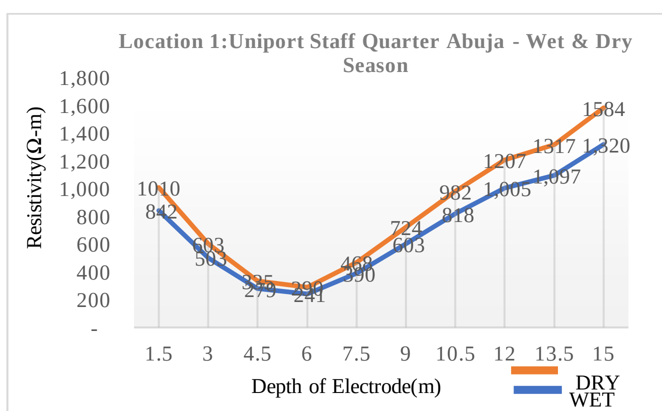

Fig 6 Relationship between Resistivity and Electrode Depth During Wet & Dry Season – Abuja Campus

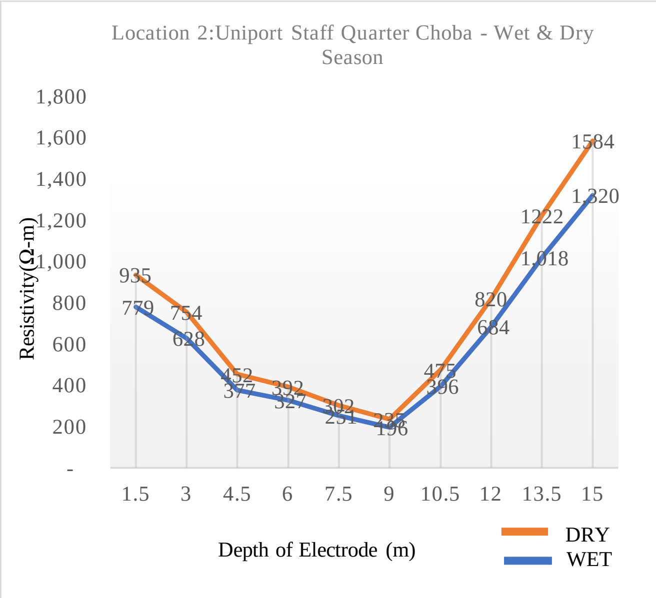

Fig 7 Relationship between Resistivity and Electrode Depth During Wet & Dry Season – Choba Campus

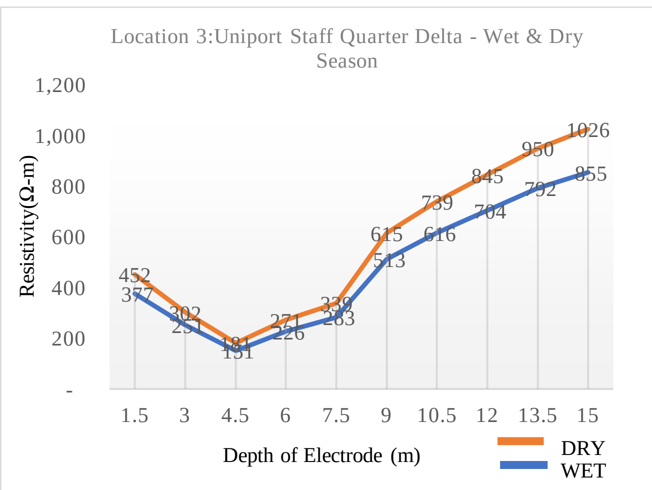

Fig 8 Relationship between Resistivity and Electrode Depth During Wet & Dry Season – Delta Campus

V. CONCLUSION

The analysis of soil resistivity measurement carried out in University of Port Harcourt staff quarters in Abuja, Choba and Delta campus shows that the optimum depth of earth electrode to be buried are 6m depth for Abuja, 9m depth for Choba and 4.5m depth for Delta campus staff quarters during the wet and dry season.

During the wet and dry season, and at the optimum electrode depth of 6m in Abuja campus, the soil resistivity varies from 241 Ω-m to 298 Ω-m.

During the wet and dry season and at the optimum electrode depth of 9m in Choba campus, the soil resistivity varies from 196 Ω-m to 235 Ω-m.

During the wet and dry season and at the optimum electrode depth of 4.5m in Delta campus, the soil resistivity varies from 151 Ω-m to 181 Ω-m. The moisture effect on resistivity from the results obtained in the three locations of study shows that soil resistivity values are lower during the wet season while the soil resistivity values are higher during the dry season. It is therefore recommended that adequate soil enhancement materials / chemicals be considered during design and installation of earthing system in order to lower soil resistivity and improve soil resistance in order to obtain acceptable values.

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