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Assessment of Soil Resistivity and Earth Electrode Resistance for Power System Grounding in Alimosho, Lagos State, Nigeria

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ABSTRACT

Earthing systems safely redirect high currents into the ground. For example, lightning can produce high-magnitude transient currents and voltages with rapid rise times that must be effectively discharged to avoid electrical shocks. Therefore, a well-designed earthing system that can safely disperse large currents is essential for safety. The study is aimed at carrying out a comprehensive interpretation of the soil resistivity of Agbado-Okeodo and AKESAN towns in Alimosho, to estimate the soil resistivity values in order to site substations and transformers within the study area and identify ways to improve soil quality, provide the lowest ground resistivity over an extended time using the current guidelines for grounding electrodes and earthing procedures. Using the Wenner Array method, we measured soil resistivity along a 330 kV transmission line to assess its influence on earth-electrode grounding. The findings showed earth electrode resistance between 4.90 and 22.40 Ohms and soil resistivity from 94.26 to 391.61 Ohm-meters across the two locations. The results indicated a strong link between earth electrode resistance and soil type, highlighting the importance of soil resistivity for more effective grounding systems.

INTRODUCTION

Assessing soil resistivity is a crucial step in designing a reliable, safe power-system grounding grid. Grounding manages abnormal voltages or currents by applying Ohm's law (He *et al.*, 2012). This process is crucial for designing effective earthing systems, which play a vital role in electrical protection. Soil resistivity analysis involves measuring and interpreting soil electrical resistivity at a specific location. It reflects how well soil conducts electrical current and depends on moisture levels, soil composition, temperature, and mineral content. This process protects personnel from electric shock or electrocution, safeguards equipment and facilities from failures and fires, and prevents damage to electrical cables. Different soil types have varying resistivity; for example, moist, conductive soil has lower resistivity than dry, less conductive soil, which can be measured using a low-resistance connection to earth and is influenced by factors such as soil resistivity, stratification, electrode type and size, depth, moisture, and chemical composition. An earth electrode's ability to conduct effectively depends on soil resistivity and burial depth (Gabriel & Kehinde, 2011). Most national and international lightning protection standards specify an earth resistance of 10 Ω (BSEN 2006, AS1991). According to AEMC (2019), soil resistivity measurements serve three main purposes: to conduct subsurface geophysical surveys and locate ore deposits or bedrock, to assess corrosion risk in underground pipelines (since lower resistivity increases corrosion activity, thus influencing protective measures), and to determine the resistance and depth required for grounding electrodes to achieve low resistance.

Proper grounding enables a power system to withstand power surges and minimize potential harm. It provides a common voltage reference and a low-impedance path for fault currents, allowing protection systems to clear faults efficiently, limit grid voltage rise, and maintain earth potentials within safe limits. Grounding is achieved by driving electrodes into the earth. Soil resistivity varies widely globally and seasonally, mainly because of electrolyte content, including moisture, minerals, and salts, making the electrical resistivity method suitable for measurement. Dry soils can have

high resistivity if they lack soluble salts. Because resistivity relates to moisture and temperature, the grounding system's resistance fluctuates seasonally. Below the surface, temperature and moisture are more stable, so deeper grounding systems, preferably to the water table, perform more consistently. Combining resistivity surveys with soil properties such as texture and water content yields valuable insights into subsurface conditions and helps determine the optimal installation depth for grounding rods. This study aims to evaluate soil resistivity and earth electrode resistance at selected locations in Alimosho, Lagos State, Nigeria, and assess their implications for effective power system grounding

MATERIALS AND METHODS

The Study Area

Alimosho Local Government Area is one of 20 LGAs in Lagos State, Nigeria. It is the largest LGA in Lagos and one of Nigeria's most populous LGAs. Located in the northeast of Lagos State, it borders Ogun State. The area includes several towns and communities, including Egbeda, Ikotun, Igando, Ayobo, and Ipaja. Known for its diverse population, lively markets, and social amenities, Alimosho also has numerous educational institutions, healthcare facilities, and recreational centers. It was recently divided into multiple Local Community Development Areas (LCDAs). This restructuring began after Bola Ilori's administration, the last of the former single Alimosho Local Government. The six new LCDAs formed from the former Alimosho are Agbado-Oke-odo, Ayobo-Ipaja, Alimosho LG, Egbe/Idimu, Ikotun/Igando, and Mosan Okunola. The LG also encompasses the urban area of Egbeda/Akowonjo. Alimosho was founded in 1945 when it was part of the old Western Region.

Location and geology of the Study area

This study examines the geography, history, population, infrastructure, economy, social and cultural aspects, and trends of Agbado/Okeodo and Akesan towns in Alimosho. Alimosho, a large local government area in Lagos State, Nigeria, is known for its diverse population and vibrant economy. It borders Agege, Ifako-Ijaiye, and Ojo and is near major transport routes, which improves connectivity. The towns have a rich history, with indigenous and immigrant communities, and have experienced urbanization and population growth, creating a cosmopolitan environment. Infrastructure has improved with roads, schools, hospitals, markets, and recreational facilities, though some areas still need development. Economically, these towns are active trade centers with many small and medium enterprises, markets, and industrial zones serving local needs (Asaju, 2023). The geological succession in Lagos ranges from the Cretaceous Abeokuta Formation, which unconformably overlies the Basement Complex rocks, to the Quaternary deltaic Plain Sands. Alimosho, where the survey area is located, lies directly on the Benin Formation (Figure 1). This formation consists mainly of sands and sandstones, with lenses of shale and clay. It provides a straightforward solution to groundwater issues across much of Lagos State, particularly in areas with pebbly beds. However, the Benin Formation's sandy nature makes it vulnerable to contamination from human activities. The Ilaro Formation contains fine- to coarse-grained sands interbedded with shale and clay. Although it hosts aquifers, these are often limited to poor boreholes. The Ewekoro, Akinbo, and Oshosun formations comprise sequences of sandstone, shale, limestone, and clay. While the Ewekoro Formation may contain multiple aquifers, its clay-rich makeup suggests limited groundwater potential. The Abeokuta Formation, composed of arkosic sandstones and grits that tend to become carbonaceous at the base, has good groundwater potential. Nonetheless, bituminous materials in the sands could pose water quality issues. All these formations are multi-aquiferous.

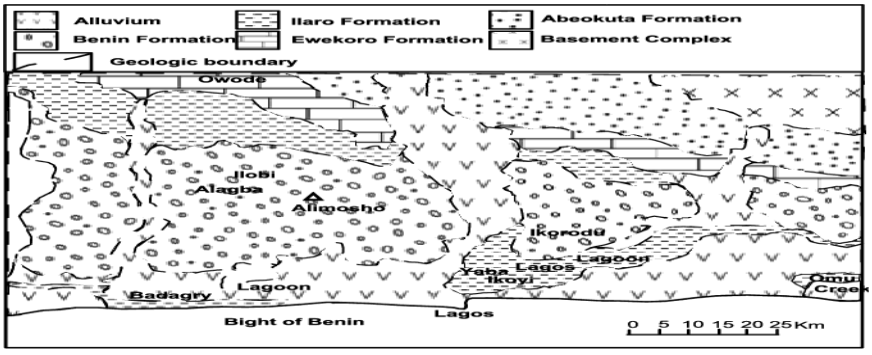


Figure 1: Geological map of Lagos showing Alimosho, within which the study area is located (modified after Offodile, 2002

Soil Resistivity Analysis

Resistance is a conductor's property that opposes electric current flow when a voltage is applied across its ends. Resistance is the ratio of the applied voltage (V) to the resulting current flow (I), as defined by the well-known linear equation from Ohm's Law (Nagrath, 2001):

$$V = I \times R \quad (1)$$

Where

V is the Potential Difference across the conductor (Volts)

I is the current flowing through the conductor (Amperes)

R is the resistance of the conductor (Ohms)

The resistance (R) of a conductor can also be derived from the resistivity as (Nagrath,2001):

$$R = \frac{\rho \times l}{A} \quad (2)$$

Where;

L is the Length of the conductor (m)

A is the cross-sectional area (m^2)

ρ is the Resistivity (Ω-m) of the conductor material

Soil resistivity is the resistance between opposite faces of a one-meter cube of soil, measured in ohm-meters. It affects the charging electrode's resistance and how deep it must be driven to reduce ground resistance. Resistivity varies widely and seasonally, depending mainly on soil electrolyte content, moisture, minerals, and salts, which affects substation resistance and earth electrode requirements. Lower resistivity means you need fewer electrodes. Knowing resistivity during planning helps estimate electrode needs. When choosing a testing method, consider probe depth, cable length, efficiency, cost, and how you interpret the data. The Wenner array method is the most efficient and was used here to measure soil resistivity, with apparent resistivity calculated using Nigel's formula.

$$\rho = 2\pi aR \quad (4)$$

Where

ρ is the resistivity of the local soil (Ω-cm)

ΔV is the voltage measured (V)

a is the distance between probes(m)

R is the resistance determined by the testing device or instrument (Ω)

The resistivity of the surrounding soil influences the earth resistance of any earth electrode. This resistance largely depends on the soil's nature and moisture content. Because soil resists the flow of electrical current and is not an ideal conductor, there is always some resistance (which can never be zero) between the earth electrode and "true Earth". This resistance is called the electrode's earth resistance, and it depends on soil resistivity, electrode type and size, and burial depth. A digital earth meter (UT522) was used for high-accuracy, reliable measurements, with 0.01 resolution and a 4000ω maximum. This UNI-T product, a four-terminal digital earth meter, used a 1.22m copper ground electrode.

The Wenner four-point method is the optimal technique for testing soil resistivity. It uses a 4-pole digital ground resistance meter (e.g., a Megger), along with probes, conductors, a measuring tape, and a hammer. These probes establish electrical contact with the earth. The Megger meter then sends a constant current through the ground via the outer probes (C1 and C2). As the current passes through the resistive soil, it develops a voltage (potential difference) between the inner probes (P1 and P2). The meter indicates the current flowing through the earth, and the voltage drop across the two center probes is recorded. The Megger meter's resistance reading is then used to calculate soil resistivity using equation (4).



Figure 2: Megger Earth tester

In this study, soil resistance was measured for the Agbado-OkeOdo and Akesan transmission lines in Alimosho Local Government. To investigate soil resistivity, the Wenner 4-point technique was used, which uses electrical conductors (electrodes) and a 4-pole electronic earth resistivity meter, called a Megger meter. In this study, the electrodes were arranged in a single line, spaced 1 meter apart, and buried 0.5 meters deep; also, the distance D is more than five times the probe length (L), as shown in Figure 3. Here, the electrodes were electrically connected to the ground. After injecting a steady current through the earth via the test instrument and the two outermost probes (C1 and C2), the Megger meter measured the potential difference as the current passed through the earth:

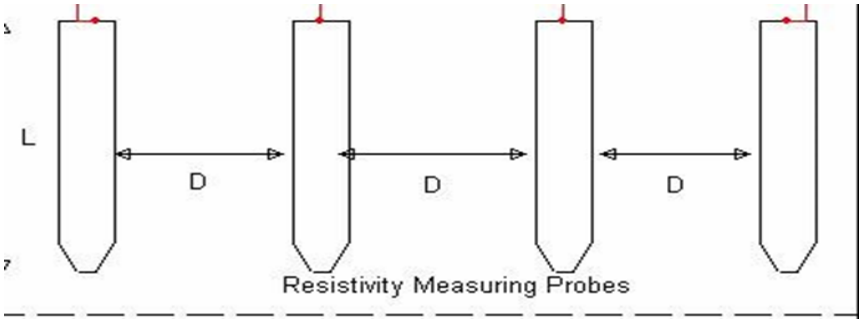


Figure 3: Resistivity measuring probes using four electrodes

To measure soil resistivity, the four-probe (electrode) method will be used. For one electrode, four probes of equal distance and diameter (D > 5*L) are used. This method uses a current source between the outer probes and a voltmeter between the inner probes, as shown in Figure 4:

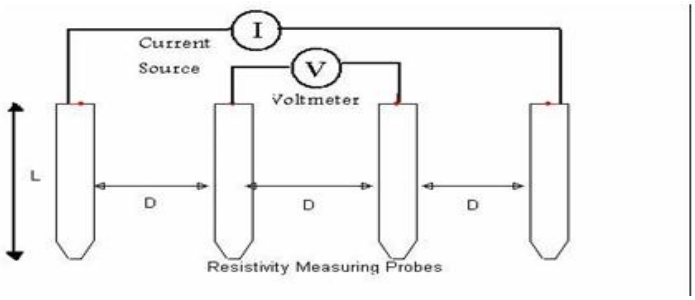


Figure 4: Resistivity measuring probes with current and voltage source

The current source is constant and known from the design. The probe length and diameter are also known. The measured voltage will indicate the soil resistivity according to the relation. Fig.3 shows the general measurement setup. The four earth probes should be driven into the ground in a straight line, at a distance 'a' meters apart and driven to a depth of 'P' cm. The testing depth of a soil resistivity test is determined by the spacing between the four Test rods connected to tester terminals C1, P1, P2, and C2. The recommended practice is to test the soil at various depths to determine the optimal depth for the grounding (earthing) electrode system. For instance, if the test rods are 1 m (3.28 ft.) apart, the measurement averages the soil from the surface to 1 m (3.28 ft.) deep. As the spacing between the rods increases, results for correspondingly deeper samples are obtained directly

RESULTS AND DISCUSSION

Soil resistivity varies with depth because soil properties are not uniform from the surface downward. To determine this, we performed the four-point method at various depths and locations across the site to obtain a combined resistivity measurement. The testing depth is linked to the spacing between the four rods, which correspond to terminals C1, P1, P2, and C2. Conducting tests at different depths usually helps identify the optimal depth for grounding electrodes. For instance, if the rods are spaced 1.52 m (5 ft.) apart, the measurement reflects the average resistivity from the

surface to that depth. Larger spacing allows direct measurement at greater depths. Table 4 lists the soil depths associated with each rod spacing. At each site, the four-electrode setup was used with spacings of 1, 2, 3, and 4 m to chart soil resistivity at different depths. These spacings, based on a logarithmic scale, help sample both surface and deeper soil layers.

Measured Soil Resistance and Resistivity

The soil resistance measurements (in ohms) for the Agbado-OkeOdo and AKESAN transmission lines were taken while the lines were properly grounded as they traversed various terrains. The megger readings for the lines are shown in Tables 1 and 2. Figures 5 and 6 present the earth electrode resistance and soil resistivity for Agbado/Oke Odo, while Figures 7 and 8 show these parameters for Akesan.

Table 1: Measured soil resistance and Resistivity in Agbado/Oke Odo

Depth (m)	Earth Resistance (Ω)	Soil Resistivity ((Ωm)
1.00	19.20	120.65
2.00	7.58	94.26
3.00	5.50	103.70
4.00	4.90	123.16

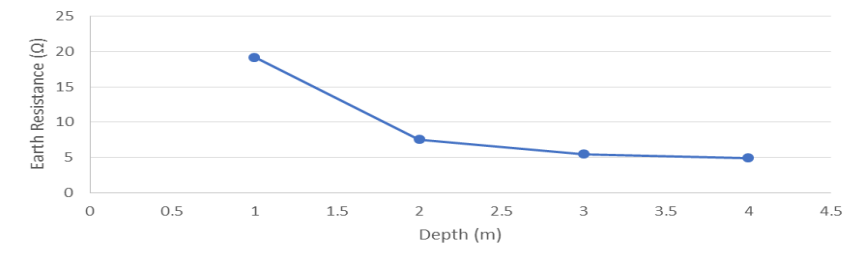


Figure 5: Measured soil resistance in Agbado/Oke Odo

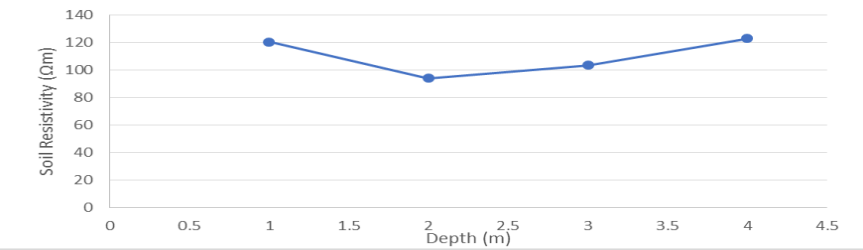


Figure 6: Measured soil resistivity in Agbado/Oke Od

Table 2: Measured soil resistance and Resistivity in AKESAN

Depth (m)	Earth Resistance (Ω)	Soil Resistivity ((Ωm)
1.00	33.40	209.89
2.00	24.80	311.69
3.00	11.20	211.14
4.00	6.40	160.87

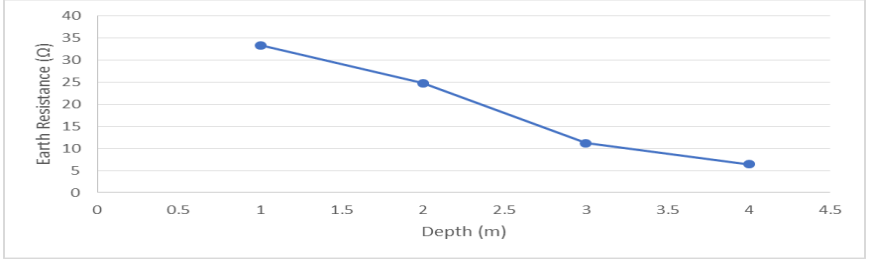


Figure 7: Measured soil resistance with depth in AKESAN

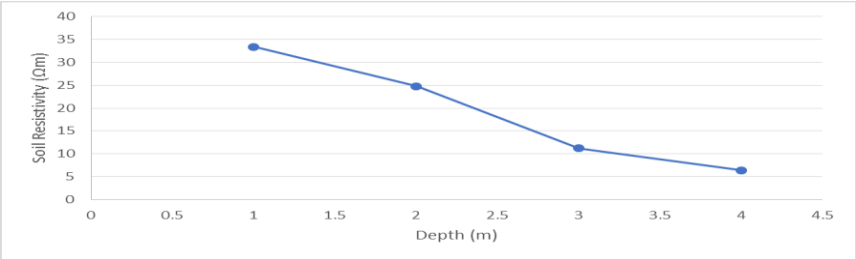


Figure 8: Measured soil resistivity with depth in AKESA

Table 3: Soil Types and Resistivity Values

Soil Types	Resistivity (OhmMeter)	
	Minimum	**Maximum**
Clay	5	100
Sand/Clay	6.28	346.83
Limestone	36.40	95.80
Gravel/ Sand	800	10,000
Laterite	961.30	1528.7
Rock	1557	19,012.92

(Source: Siow et al., 2013)

Compared with the standard resistivity values for different soil types in Table 3, Agbado-Oke Odo ranges from 94.26 to 123.16 Ωm, while Akesan ranges from 160.87 to 209.89 Ωm; both indicate sand/clay. The results align with Lagos State geology, and the resistivity range is considered suitable for an electrical grounding system. This sand-and-clay mixture provides a stable environment for a grounding electrode; soil resistivity directly determines how easily fault currents dissipate into the earth. The lower the resistivity, the easier it is to achieve a low-resistance ground loop. High soil resistivity can increase transmission line footing resistance, making it difficult for electrical and lightning fault currents to dissipate safely into the ground and thereby increasing safety and operational risks. The results align with findings by Adegboyega and Odeyemi (2011) and Akwukwaegbu and Gerald (2017).

Storm Response of October 30, 2003

In Bahir Dar, relative humidity at 600 hPa exhibited a notable increase during the storm peak, with moderate post-storm decline. At 850 hPa, relative humidity remained relatively stable, showing minor fluctuation. In contrast, humidity at 1000 hPa showed an early increase followed by stabilization, suggesting surface-layer moisture accumulation likely influenced by convection.

Temperature trends at 600 hPa indicated a steady decrease, becoming more pronounced post-storm. At 850 hPa, similar cooling was observed, with less variability. The 1000 hPa level exhibited moderate thermal oscillations with a cooling trend toward the end of the storm period, implying downward propagation of storm-induced thermal anomalies.

CONCLUSION

This study examines the earthing system design for the transmission line in the Agbado-Oke Odo and Akesan areas within Alimosho Local Government. Earth resistance was measured at locations within the study area. The resistivity values indicate sandy/clay soils; therefore, the sand-to-clay ratio is important, as sand typically provides poor earthing because it drains quickly and retains little moisture. In contrast, clay generally provides good earthing.

To improve safety and performance, modify the soil by burying earth rods and digging deeper to reduce sand content. Regular earth resistance testing is vital. Poor earthing risks lives and equipment during faults or lightning strikes. These strategies can help existing and new systems meet standards. The study recommends soil resistivity testing at various sites and efforts to reduce resistivity in high-resistance areas.

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