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ASSESSMENT OF OPTIMAL SUBSURFACE CONDITIONS FOR PALM OIL PLANTATION IN ABRAKA USING GEOPHYSICAL DATA AND SOIL ANALYSIS

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ABSTRACT

The study utilized Vertical Electrical Sounding (VES) with a dipole-dipole configuration to investigate subsurface conditions in oil palm plantations in Abraka, Delta State, Nigeria. Complementary soil analysis assessed critical subsurface characteristics for oil palm cultivation. The ABEM SAS 1000 Terrameter was used for data acquisition. Results revealed significant variations in subsurface resistivity and soil properties. At Otorho Road plantation, low resistivity values (116–199 Ωm) indicated high moisture content and fine soil textures, favourable for palm growth. Areas with resistivity exceeding 200 Ωm suggested dry, coarse soils, potentially restricting root penetration and water retention. At Oria, resistivity ranged from low (0.99–45.5 Ωm), indicating high moisture, to moderate (50–300 Ωm), representing well-drained soils. High resistivity zones suggested soil compaction, which may hinder root development. In Erho, low-resistivity zones indicated optimal conditions, while high-resistivity regions suggested compacted soils or geological constraints. Soil analysis revealed differences in nutrient content and pH across locations. Otorho exhibited moderately acidic soil (pH 5.30–6.10), potentially leading to nutrient leaching, with sufficient but lower boron (61.10 mg/kg), nitrogen (0.24%), and phosphorus (24.80 mg/kg). Oria had a near-neutral pH (6.30–6.70), higher boron (84.29 mg/kg), and nitrogen (0.29%), supporting better vegetative growth. Erho showed optimal conditions (pH 6.80) with the highest boron (91.82 mg/kg), nitrogen (0.34%), and phosphorus (61.43 mg/kg), enhancing plant development.

Key word: ***Soil, Dipole-Dipole, Plantation, Subsurface, Geophysical***

INTRODUCTION

Palm Oil production is of Global Economic importance as it significantly contributes to both domestic and industrial applications (Teng *et al.,* 2020). Derived from the fruit of oil palm trees primarily grown in tropical regions, palm oil is the most widely consumed vegetable oil globally, renowned for its high yield per hectare compared to other oil crops (Chew *et al.,* 2021). This efficiency makes it a crucial source of edible oil for numerous countries, playing a pivotal role in food security and economic development (Chiriacò *et al.*, 2024).

Geophysical Method are invaluable for managing oil Palm plantation. These methods assist in site selection by assessing soil properties, and groundwater availability, ensuring new plantations are located in suitable areas (Hussain *et al.,* 2020; Kana 2015). Additionally, geophysical surveys help map soil properties like texture, moisture content, and compaction, aiding in soil management and irrigation planning (Moral *et al.,* 2019). This information is vital for maximizing oil palm tree Yield and identifying areas with unsuitable soil conditions (Wicke *et al.,* 2011). Geophysical surveys play a crucial role in delineating subsurface lithology groundwater resources and assessing aquifer characteristics (Baranwal *et al.,* 2024).

This study aims to assess and characterize the subsurface properties using geophysical data and soil analysis to determine the most viable locations for oil palm cultivation.

THEORETICAL FRAMEWORK

Dipole-Dipole Array

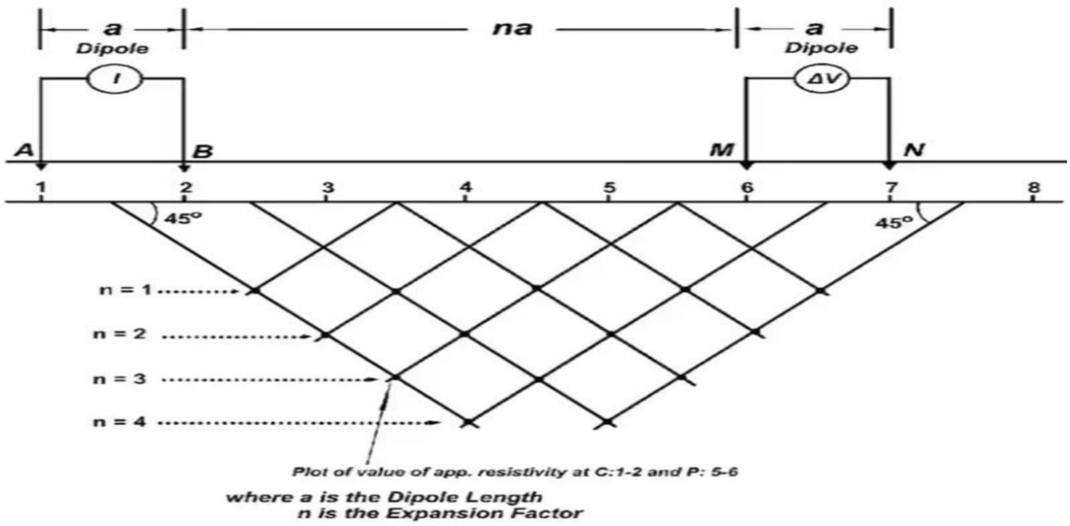

Figure 1 illustrates the dipole-dipole configuration, including the associated electric field, which is essential for understanding resistivity distribution and subsurface characterization in geophysical surveys.

The dipole-dipole array is a common electrode arrangement in electrical resistivity surveys for studying subsurface resistivity changes (Salman *et al.,* 2020). It involves injecting current through two outer electrodes (current electrodes) and measuring potential differences between two inner electrodes (potential electrodes) (Mirzaei *et al.,* 2021). The separation between the current and potential electrodes is fixed and referred to as the "dipole length." The dipole-dipole array is valued for its ability to provide detailed imaging of the near-surface subsurface, offering high resolution (Salman *et al.,* 2020). Users can adjust the dipole length to investigate different depths with varying levels of detail, making it suitable for archaeological, environmental, and geotechnical studies that require detailed shallow subsurface imaging (Parshin *et al.,* 2021). However, the array's effectiveness diminishes with depth, limiting its use for deep subsurface imaging (Salman *et al.,* 2020). Additionally, the need for multiple electrode configurations and the potential for increased data acquisition time can make the dipole-dipole array more time-consuming and resource-intensive compared to simpler arrays like the Wenner array (Mirzaei *et al.,* 2021).

Recall the generalize equation, we have that

$$\rho a = 2\pi \frac{\Delta V}{l} \{\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} - \frac{1}{r_4}\} \quad (1)$$

The apparent resistivity of the Dipole array is give as follow

$$pa = 2\pi \frac{\Delta V}{l}\{\frac{1}{a+na} - \frac{1}{na} - \frac{1}{2a+na} - \frac{1}{a+na}\} \quad (2)$$

$$pa = 2\pi \frac{\Delta V}{l}\{\frac{2}{(n+1)a} - \frac{1}{na} - \frac{1}{(n+2)a}\} \quad (3)$$

$$pa = 2\pi \frac{\Delta V}{l}\frac{n(n+1)(n+2)a}{2n^2+4n-(n^2+3n+2)-n^2+n} \quad (4)$$

$$pa = 2\pi \frac{\Delta V}{l} n(n+1)(n+2)a \quad (5)$$

The Dipole-Dipole array is a flexible electrode configuration where the pair of potential electrodes can be positioned and oriented in various ways relative to the current electrodes (Singh and Sharma 2022). The array's geometrical factor Q, calculated as the ratio of the potential difference to the current multiplied by an array constant, determines the apparent resistivity pa of the subsurface.

$$\Delta V = V_C + V_D = \frac{pl}{2\pi}\left(\frac{1}{r_A} - \frac{1}{r_B}\right) - \frac{pl}{2\pi}\left(\frac{1}{R_A} - \frac{1}{R_B}\right) \quad (6)$$

$$\Delta V = V_C + V_D = \frac{pl}{2\pi}\left[\left(\frac{1}{r_A} - \frac{1}{r_B}\right) - \left(\frac{1}{R_A} - \frac{1}{R_B}\right)\right] \quad (7)$$

Therefore, solving equation 2.18 we have

$$pa = \frac{2\pi\Delta V}{l\{\left(\frac{1}{r_A} - \frac{1}{r_B}\right) - \left(\frac{1}{r_A} - \frac{1}{r_B}\right)\}} \quad (8)$$

Where

$$G = \frac{2\pi}{\{\left(\frac{1}{r_A} - \frac{1}{r_B}\right) - \left(\frac{1}{r_A} - \frac{1}{r_B}\right)\}} \quad (9)$$

Therefore,

$$pa = G \times R \quad (10)$$

Where G is the Geometric factor or known value and R the resistance (Telford *et al.*, 1990).

LOCATION AND GEOLOGY OF THE STUDY AREA

Abraka is a town located in Ethiope East Local Government Area of Delta State, Nigeria, situated at approximately 5.750° to 5.850° N latitude and 6.050° to 6.150° E longitude (Okonkwo and Egbai 2022). It is renowned for its unique geological features, making it an intriguing area (Anomohanran, 2015).

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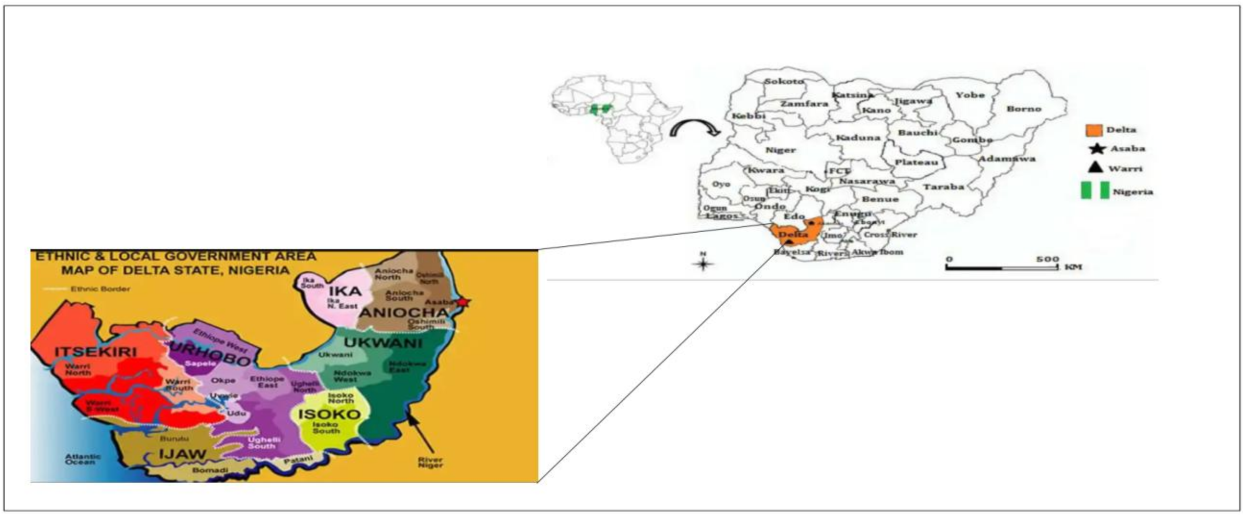

Figure 2 presents a map of Nigeria highlighting Delta State, as adapted from Adjekukor (2020), providing geographic context for the study area.

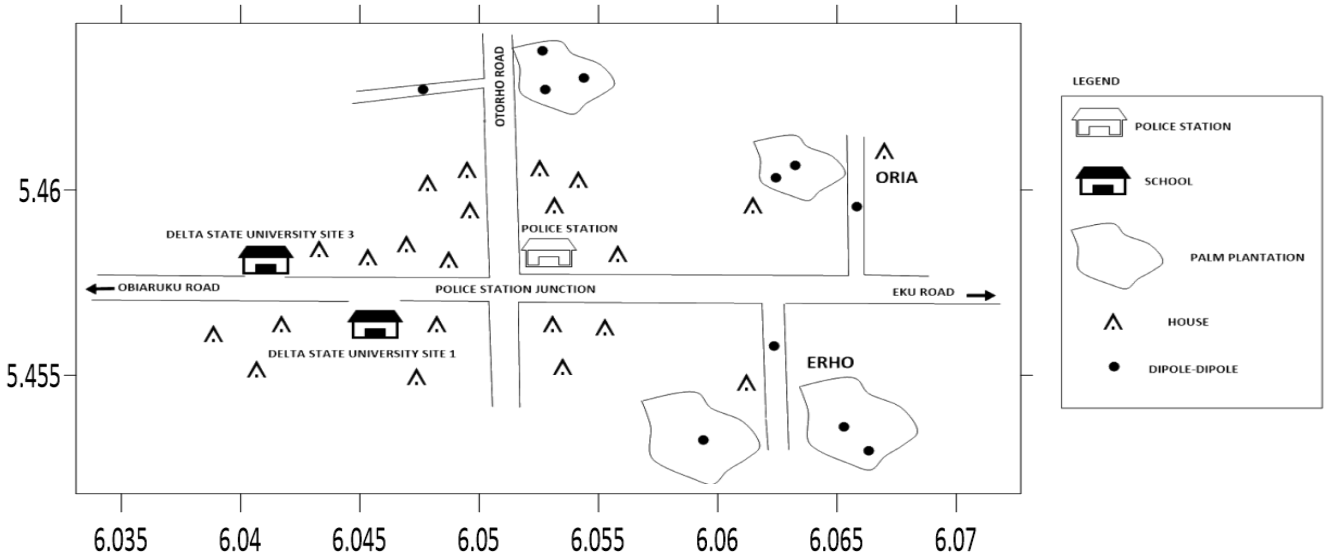

Figure 3 displays the base map of Abraka Town, offering a detailed geographical reference for the study area and its surrounding features.

MATERIALS AND METHOD

The geophysical survey investigated subsurface resistivity variations using the dipole-dipole method with the ABEM SAS 1000 Terrameter conducted at three locations namely Otorho road plantation, Erho, and Oria. These locations were chosen due to the abundance of palm trees and the sufficient land area.The survey covered 11 profiles with 5-meter electrode spacing. Equipment was carefully inspected, and survey lines were cleared for precise data collection. The method involved placing current and potential electrodes along the survey line, systematically moving them to obtain resistivity readings. Data were processed using Dipro Software to generate 2D resistivity models, which were subsequently analyzed for variations in subsurface resistivity. Soil analysis was conducted to understand subsurface properties. Soil samples were collected along survey lines and analyzed in a

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laboratory for pH, boron, nitrogen, and phosphorus levels. This contributed insight into soil composition, fertility, and environmental characteristics.

RESULTS

Otorho road plantation

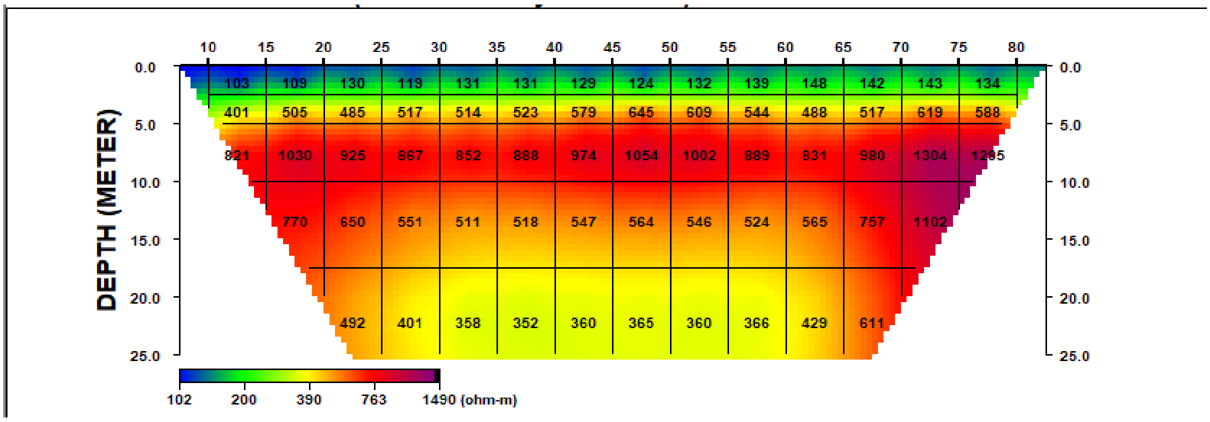

Figure 4 illustrates the 2D resistivity structure of Otorho Plantation Profile 1, highlighting the subsurface variations and potential geological features within the study area.

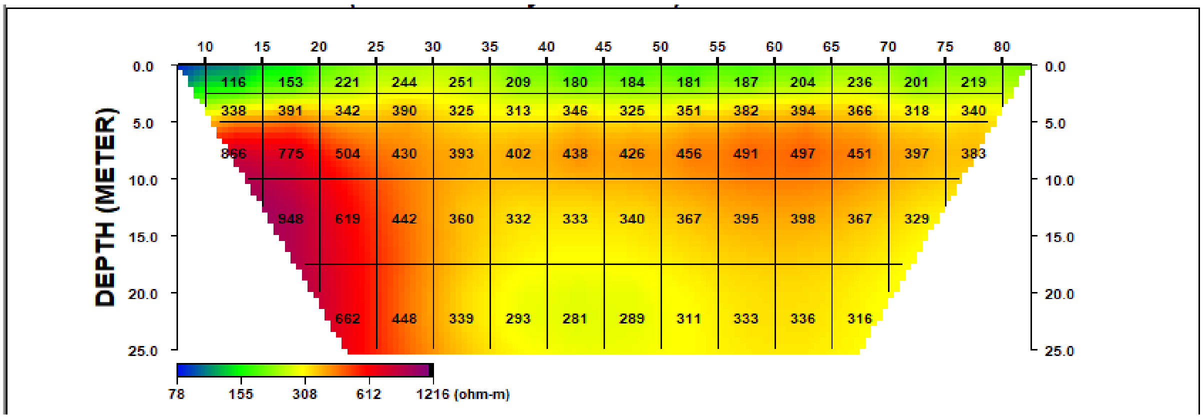

Figure 5 presents the 2D resistivity structure of Otorho Plantation Profile 2, providing insights into the subsurface characteristics of the study area.

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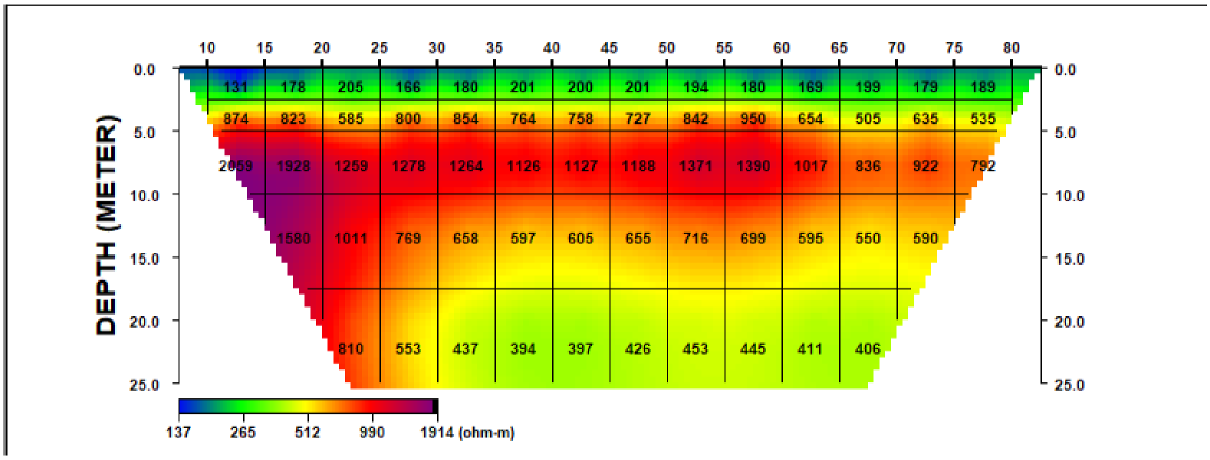

Figure 6 depicts the 2D resistivity structure of Otorho Plantation Profile 3, revealing subsurface resistivity variations that aid in understanding the geological composition of the area.

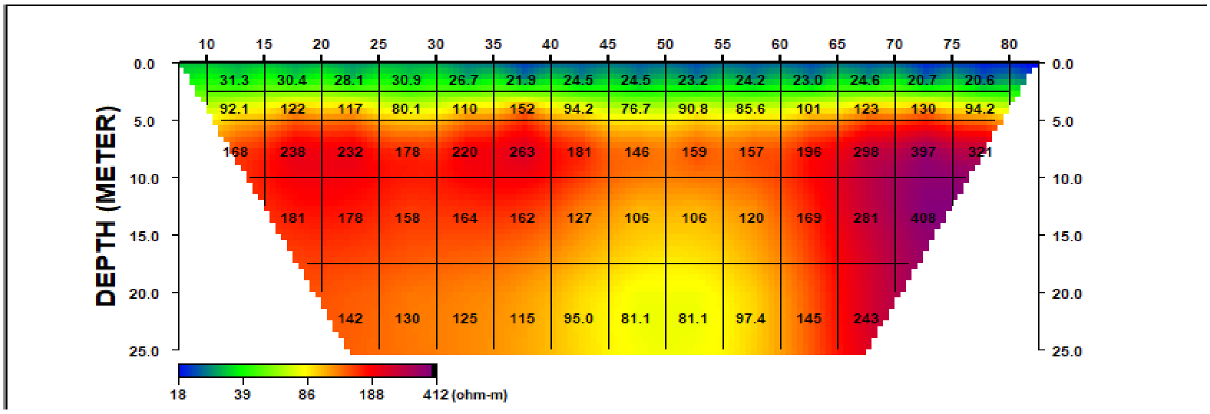

Figure 7 presents the 2D resistivity structure of Otorho Plantation Profile 4 (Control), serving as a reference profile for comparing subsurface resistivity variations across the study area.

Oria

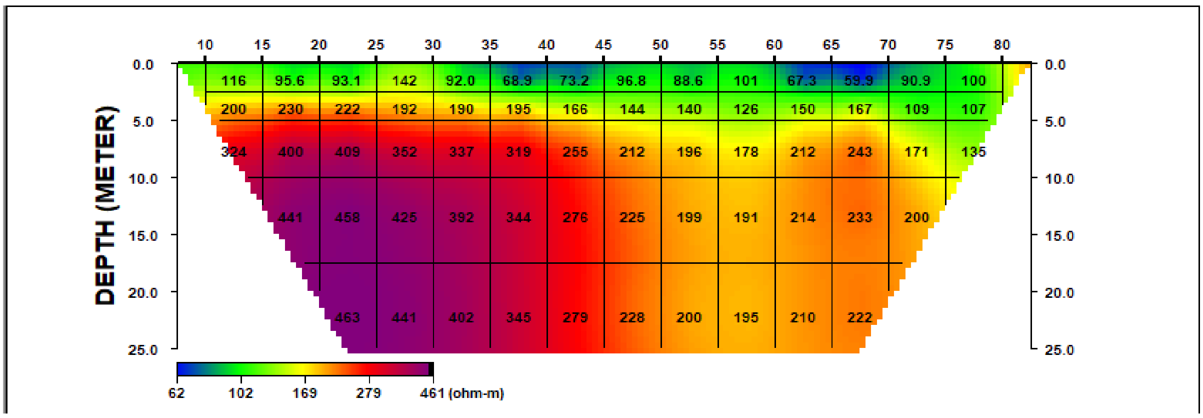

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Figure 8 illustrates the 2D resistivity structure of Oria Plantation Profile 1, providing insights into the subsurface resistivity distribution and geological characteristics of the area.

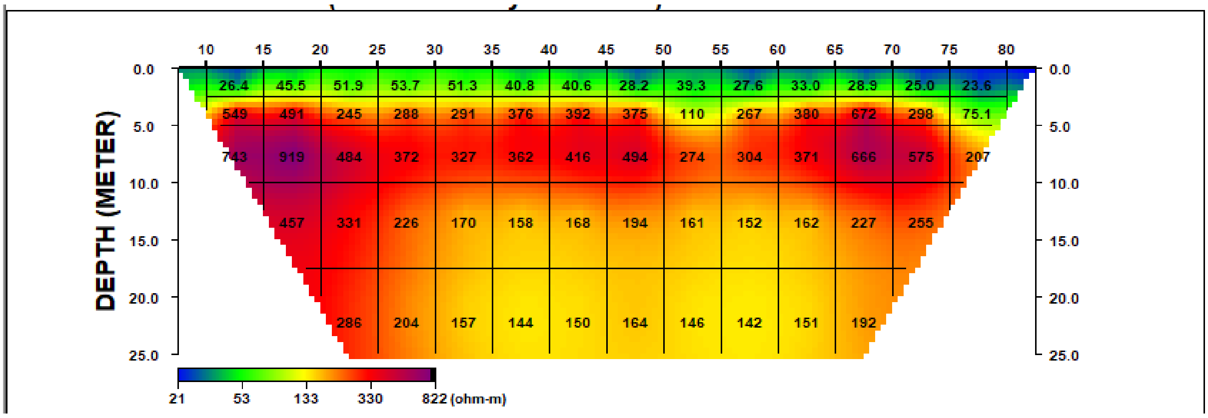

Figure 9 presents the 2D resistivity structure of Oria Plantation Profile 2, highlighting subsurface resistivity variations and geological features within the study area.

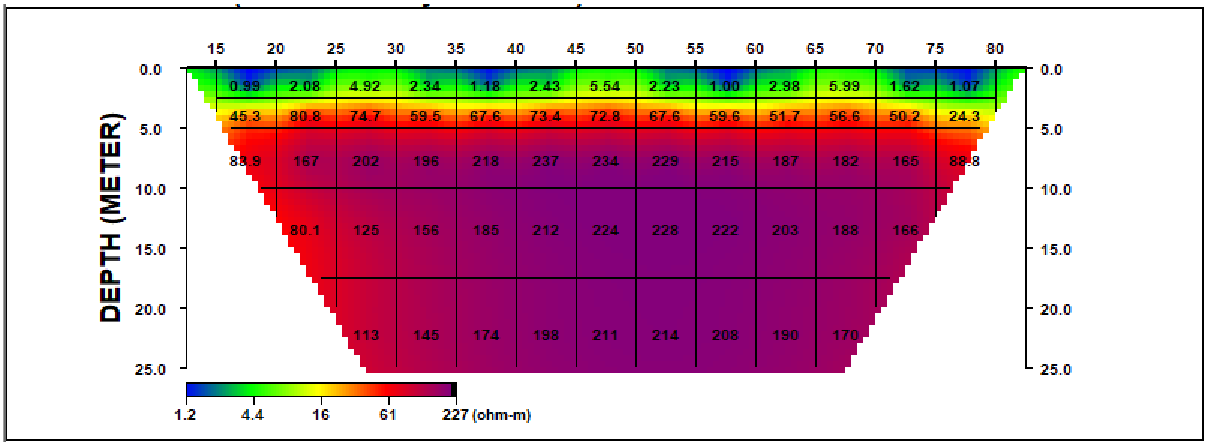

Figure 10 displays the 2D resistivity structure of Oria Plantation Profile 3 (Control), serving as a baseline for assessing subsurface resistivity variations in the study area.

Erho

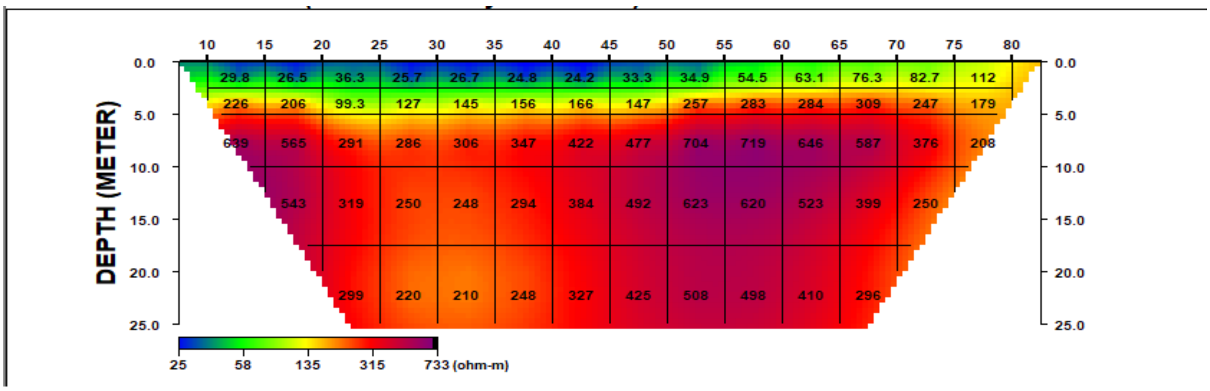

Figure 11 illustrates the 2D resistivity structure of Erho Plantation Profile 1, providing a detailed representation of subsurface resistivity variations and geological features in the study area.

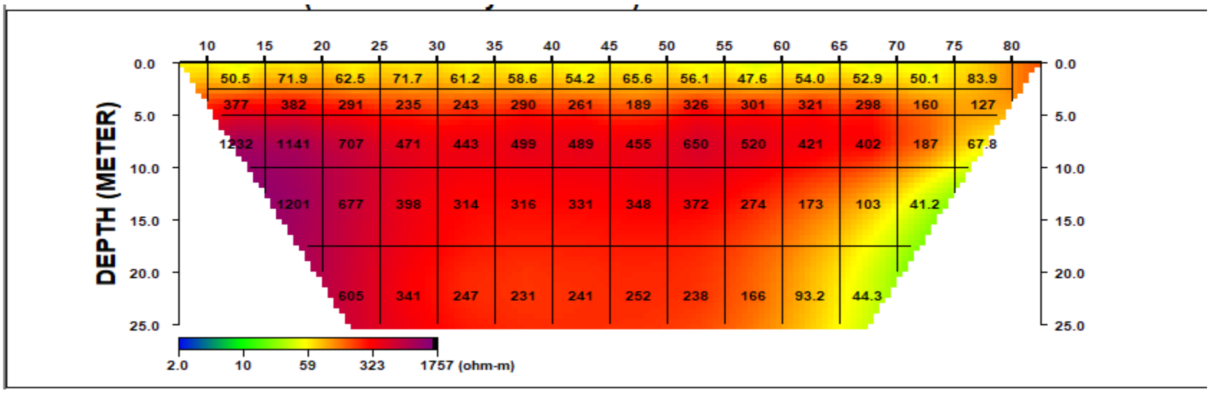

Figure 12 presents the 2D resistivity structure of Erho Plantation Profile 2, offering insights into the subsurface resistivity distribution and geological composition of the area.

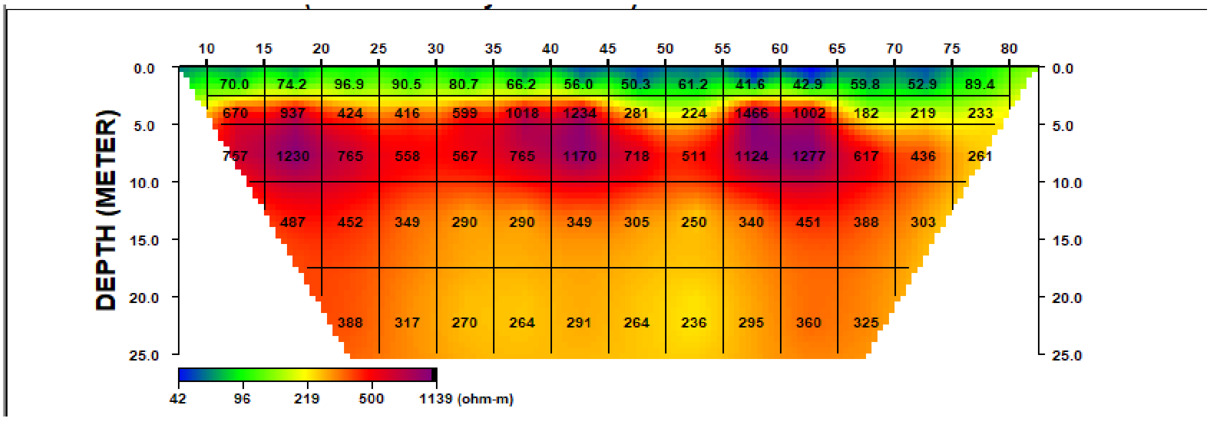

Figure 13 depicts the 2D resistivity structure of Erho Plantation Profile 3, highlighting subsurface resistivity variations and potential geological features within the study area.

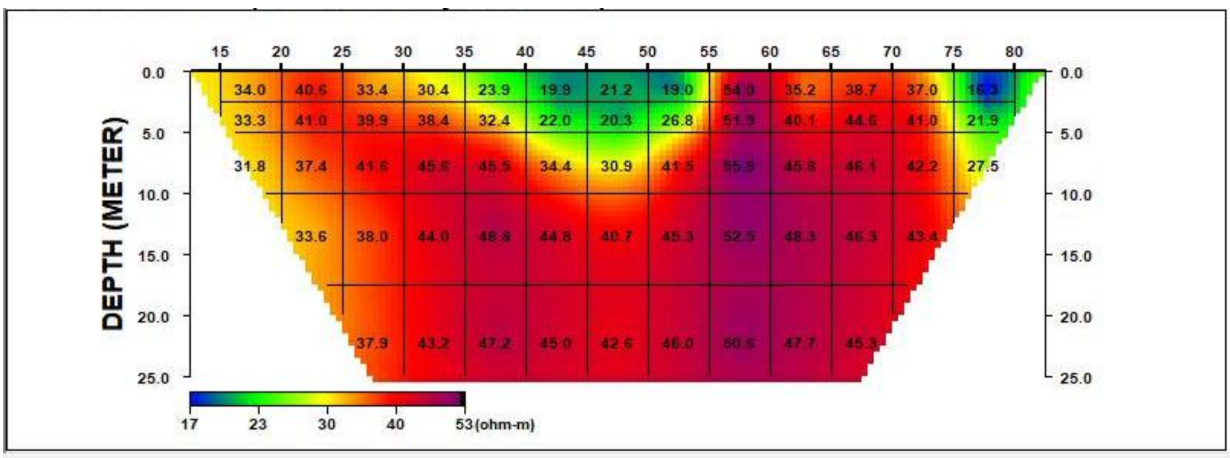

Figure 14 presents the 2D resistivity structure of Erho Plantation Profile 4 (Control), serving as a reference for comparing subsurface resistivity variations across the study area.

Table 1 presents the soil analysis results of the study location, providing key physicochemical properties that offer insights into soil composition.

S/N	Parameters	Otorho	Otorho Control	Oria	Oria Control	Erho	Erho Control
1.	pH	5.30	6.10	6.70	6.30	6.80	6.30
2.	Boron mg/kg	61.10	48.10	84.29	71.60	91.82	63.10
3.	Nitrogen %	0.24	0.18	0.29	0.32	0.34	0.31
4.	Phosphorus mg/kg	24.80	17.80	47.61	28.91	61.43	28.89
5.	Magnesium mg/kg	278.07	209.17	314.63	228.47	281.78	194.78
6.	Potassium mg/kg	0.74	0.62	0.11	0.30	0.16	0.14
7.	Calcium	161.87	124.87	361.10	169.67	284.93	181.93

DISCUSSION

Otorho road plantation Site 1

The dipole-dipole 2D survey results depicted in figure 4 Profile 1 of Otorho road plantaition reveal a structured five-layer subsurface configuration extending to a depth of 25 meters, offering critical insights essential for assessing viable Oil Palm Plantations. The first layer, characterized by resistivity values ranging from 103 to 148 Ωm , likely represents a near-surface zone comprising topsoil or a weathered layer containing

clay or moist materials crucial for palm oil cultivation, influencing root development and nutrient uptake. Moving deeper, the second layer, with resistivity values between 401 and 645 Ωm , indicates a more consolidated and dry stratum potentially composed of sands, gravels, or compacted soils, essential for evaluating water infiltration and drainage crucial for palm oil growth. The third layer, exhibiting resistivity values from 821 to 1304 Ωm , signifies highly resistive and dry material, possibly dense sandstone, impacting water storage and root penetration dynamics critical for Oil Palm Plantation development. Further down, the fourth layer, with resistivity values ranging from 511 to 1102 Ωm , may represent a transition zone with variable moisture or clay-rich materials within partially fractured rock formations, influencing water availability and nutrient transport essential for sustaining palm oil productivity. The fifth layer near the base, registering resistivity values between 401 and 611 Ωm , likely consists of semi-consolidated sediments or weathered rock with mixed materials or some water content, crucial for assessing overall soil stability and potential water storage capacity, both vital considerations for sustainable palm oil cultivation.

The dipole-dipole 2D results in figure 5 Profile 2 of Otorho road plantation which show a five-layer subsurface structure down to 25 meters, the findings contribute to a better understanding of subsurface conditions for oil Palm cultivations in Abraka. The first layer ranging from 116 to 251 Ωm near the surface likely includes topsoil or weathered zones crucial for root growth and nutrient uptake, possibly containing clay, moist materials, or organic matter that influence soil fertility and water retention. The second layer ranging from 313 to 394 Ωm consists of less conductive materials like compacted soils, sands, or gravels, essential for assessing water infiltration and drainage. The third layer ranging from 383 to 866 Ωm is relatively resistive, suggesting more consolidated materials such as sandstone, affecting water storage and root penetration. The fourth layer ranging from 329 to 848 Ωm indicates lithological variability or fractures, including moderately resistive materials with some moisture content or clay minerals, influencing soil stability and water availability. The fifth layer ranging from 281 to 662 Ωm near the base, possibly comprising semi-consolidated sediments or weathered rock, is crucial for assessing soil stability and water storage capacity.

Interpreting the dipole-dipole 2D results in figure 6 Profile 3 of Otorho road plantation, which delineate a five-layer subsurface structure down to a depth of 25 meters, ensure crucial insights essential for optimizing Oil Palm Plantation development. Near the surface, the first layer, with resistivity ranging from 131 to 201 Ohmmeter, likely comprises topsoil or a weathered zone influencing soil fertility and water retention, crucial for palm oil plant growth. Below, the second layer, exhibiting resistivity between 505 and 950 Ohmmeter, consists of less conductive materials such as compacted soils, sands, or gravels, impacting water infiltration and drainage, vital for enhancing palm oil productivity. The third layer, with resistivity values between 792 to 2099 Ohmmeter, suggest lithological variability, potentially including sandstone, shale,or fractured formations essential for understanding water storage capacities and root penetration strategies crucial for sustainable plantation development. Deeper into the subsurface, the fourth layer, ranging from 550 to 1580 Ohmmeter, showcases a wide range of resistivity values, suggesting a complex mixture of materials with varying moisture content or consolidation levels, potentially influencing soil stability and nutrient availability. Near the base, the fifth layer, with resistivity ranging from 394 to 810 Ohmmeter, exhibits moderate resistivity, indicating materials such as semi-consolidated sediments, weathered rock, or a blend of materials with variable moisture content, contributing to a comprehensive understanding of subsurface conditions essential for effective Oil Palm Plantation management and development.

The dipole-dipole 2D results for the Otoroho road Control site in figure 7 , which shows low resistivity, and has five layers down to a depth of 25 meters, reveals a complex subsurface composition. The near-surface layer (20.6 to 31.3 Ohmmeter) likely consists of topsoil or highly weathered material with high moisture content and organic matter, which are favorable for palm oil cultivation. The subsequent layers show a transition to more compacted soils and gravels with decreasing moisture content, indicated by resistivity values ranging from 80.1 to 152 Ohmmeter in the second layer and 146 to 397 Ohmmeter in the third layer. Understanding these layers is crucial for assessing water infiltration and drainage, key factors for palm oil productivity.

The fourth layer (106 to 408 Ohmmeter) displays a wide range of resistivity values, suggesting a mix of materials with varying degrees of moisture content or consolidation, which could influence soil stability and nutrient availability. Near the base, the fifth layer (81.1 to 243 Ohmmeter) indicates a moderately resistive zone, possibly comprising semi-consolidated sediments or weathered rock, which could affect overall soil stability and water storage capacity, important for sustainable palm oil cultivation. These findings highlight the complex geological nature of the site and its hydrogeological implications, which are crucial for optimizing Oil Palm Plantation planning and management in the area.

Oria

The dipole-dipole 2D results from Oria Plantation profile 1 in figure 8 unveil a structured five-layer subsurface profile extending 25 meters deep, demonstrating lower resistivity compared to the Otorho road plantation site, highlighting distinct subsurface characteristics. The first layer, with resistivity values ranging from 59.9 to 116 Ohmmeter, likely comprises topsoil or weathered zone rich in moisture or clay, essential for fostering palm oil root growth and nutrient absorption. Moving deeper, the second layer, with resistivity between 107 and 230 Ohmmeter, suggests more compacted soils, sands, or gravels with reduced moisture content compared to the surface, impacting crucial factors such as water infiltration and drainage crucial for palm oil productivity. The third layer, exhibiting resistivity values from 135 to 409 Ohmmeter, indicates moderate resistivity, possibly due to a transition zone featuring sandy or gravelly materials with varying moisture content, influencing soil stability and water availability critical for plantation health. Moving downward, the fourth layer exhibits resistivity ranging from 191 to 458 Ωm , indicating variability that suggests a mixture of materials with differing moisture content or degrees of consolidation, which may influence nutrient movement and root infiltration.. Lastly, the fifth layer, registering resistivity between 195 and 463 Ohmmeter, signifies a moderately resistive zone likely composed of semi-consolidated sediments, weathered rock, or a mix of materials with varying moisture content, indicating a more conductive subsurface potentially characterized by higher moisture content or different lithologies compared to the Otorho road plantation site.

The dipole-dipole 2D survey results from Oria Plantation profile 2 in figure 9 reveal a complex subsurface structure with five distinguishable layers extending to a depth of 25 meters, offering crucial understanding for optimizing Oil Palm Plantation development. The first layer, characterized by resistivity values ranging from 23.6 to 53.7 Ohmmeter, likely represents topsoil or a highly weathered zone enriched with high moisture content, clay-rich materials, or organic matter, explaining its lower resistivity essential for facilitating palm oil root development and nutrient uptake. Transitioning to the second layer, with resistivity levels from 75.1 to 672 Ohmmeter, indicates a shift towards more compacted soils, sands, or gravels with variable moisture content, suggesting differing degrees of consolidation crucial for factors such as water infiltration and drainage, fundamental for optimal palm oil growth. The third layer, exhibiting resistivity values ranging from 207 to 743 Ohmmeter, displays moderate to high resistivity, likely reflecting a diverse mix of sandy or gravelly materials with varying moisture content and consolidation levels, underscoring lithological diversity impacting soil stability and water availability essential for sustaining plantations. The fourth layer, spanning resistivity from 152 to 457 Ohmmeter, also suggests a mix of materials with diverse moisture content or consolidation degrees, potentially including moderately resistive components such as clay or fractured rock, influencing nutrient transport and root penetration strategies. Finally, the fifth layer, registering resistivity values between 142 and 286 Ohmmeter, indicates a moderately resistive zone comprising semi-consolidated sediments.

ORIA Control in figure 10 shows detailed subsurface insights relevant to oil palm plantation development. The shallow layer (0–5 meters) exhibits low resistivity values (1.2–6.0 Ωm), suggesting clay-rich or water-saturated soil, which could lead to poor drainage and potential waterlogging, detrimental to oil palm growth if unaddressed. The intermediate depths (5–15 meters) show moderately high resistivity values (67.6–89.8 Ωm), indicative of compacted sandy or lateritic soil with reduced water retention, which may limit nutrient availability but improve drainage. At deeper depths (15–25 meters), the resistivity increases significantly (113–227 Ωm), representing highly compacted or consolidated lateritic materials or weathered bedrock that restrict root penetration and water storage. The lateral uniformity in the deeper layers suggests consistent subsurface conditions. For optimal oil palm cultivation, areas in the shallow layer with resistivity between 2–5 Ωm may require soil amendments or improved drainage, while the higher-resistivity zones may necessitate irrigation systems to enhance moisture availability and soil fertility.

Erho

Interpreting the dipole-dipole 2D results in figure 11 Erho Plantation Profile 1, which delineate a five-layer subsurface structure down to a depth of 25 meters, provides detailed insights crucial for optimizing Oil Palm Plantation development in Abraka, Delta State, Nigeria. The first layer, characterized by resistivity values ranging from 24.2 to 112 Ohmmeter, likely represents topsoil or a highly weathered zone rich in moisture, clay, or organic matter essential for palm oil root development and nutrient uptake. Transitioning into the second layer, with resistivity ranging from 99.3 to 309 Ohmmeter, reveals more compacted soils, sands, or gravels with variable moisture content and some degree of consolidation, influencing critical aspects such as water infiltration and drainage crucial for palm oil productivity. Moving deeper, the third layer exhibits resistivity values ranging from 208 to 719 Ωm , suggesting a moderate to high resistivity likely attributed to a combination of sandy materials, varying moisture content and consolidation levels, highlighting significant lithological variability impacting soil stability and water availability. The fourth layer, with resistivity ranging from 248 to 623 Ohmmeter, suggests a diverse composition of materials with fluctuating moisture content or consolidation degrees, potentially incorporating moderately resistive elements like clay or fractured rock that affect nutrient distribution and root penetration essential for palm oil growth. Finally, the fifth layer, registering resistivity between 210 and 508 Ohmmeter, points to a moderately resistive zone.

Results from Erho Plantation Profile 2 in figure 12, which reveal a structured subsurface comprising five distinct layers down to 25 meters’ depth, offers detailed comprehension into the composition critical for optimizing Oil Palm Plantation development in Abraka, Delta State, Nigeria. The first layer, exhibiting resistivity ranging from 50.1 to 83.9 Ohmmeter, likely denotes topsoil or a highly weathered zone enriched with high moisture content or clay-rich materials, explaining its low resistivity and essential role in facilitating palm oil root development and nutrient uptake. Transitioning to the second layer, with resistivity between 127 and 382 Ohmmeter, indicates a shift to more compacted soils, sands, or gravels with varying moisture levels, suggesting some degree of consolidation crucial for assessing water infiltration and drainage, pivotal factors influencing palm oil productivity. The third layer, showing resistivity spanning from 67.8 to 1232 Ohmmeter, displays significant variability, indicative of a heterogeneous mix of sandy or gravelly materials with diverse moisture content and consolidation levels, underscoring the complexity in lithological composition and its impact on soil stability and water availability for the plantations. The fourth layer, characterized by resistivity values from 41.2 to 1201 Ohmmeter, continues to exhibit a wide range, suggesting a diverse material composition potentially including fractured rock or clay, influencing nutrient distribution and root penetration, crucial for sustaining palm oil growth. Lastly, the fifth layer, with resistivity ranging from 44.3 to 605 Ohmmeter, indicates a moderately resistive zone likely comprising semi-consolidated sediments or weathered rock with varying moisture content, further contributing to the comprehensive understanding of subsurface conditions essential for effective plantation management.

Results from Erho Plantation Profile 3 in, which reveal five distinct layers down to a depth of 25 meters in figure 13, offers vital comprehension into the subsurface composition, crucial for enhancing Oil Palm Plantation development in Abraka, Delta State, Nigeria. The first layer, with resistivity ranging from 41.6 to 96.9 Ohmmeter, likely represents topsoil or a highly weathered zone characterized by high moisture content or clay-rich materials, crucial for supporting palm oil root development and nutrient uptake. The second layer, with resistivity ranging from 182 to 1466 Ohmmeter, indicates a transition to more compacted soils, sands, or gravels with significant variability in moisture content and consolidation, vital for assessing water infiltration and drainage. The third layer, with resistivity ranging from 261 to 1277 Ohmmeter, shows substantial variability due to a mix of sandy or gravelly materials, essential for evaluating soil stability and water availability. The fourth layer, with resistivity ranging from 250 to 487 Ohmmeter, suggests a more consistent mix of materials with moderate moisture content or degrees of consolidation, influencing nutrient transport and root penetration. The fifth layer, with resistivity values between 236 and 388 Ohmmeter, suggests a moderately resistive zone likely consisting of semi-consolidated sediments, weathered rock, or a combination of materials with varying moisture content.

The 2-D resistivity inversion model highlights the subsurface characteristics of the oil palm plantation site in Abraka, Delta State, revealing variations critical for land use planning. The shallow subsurface (0–5 meters) shows moderate resistivity values (23.9–41.0 Ωm), suggesting sandy clay or sandy loam with good drainage and moisture retention suitable for oil palm cultivation, though localized low-resistivity zones may indicate water-logged conditions requiring drainage. At intermediate depths (5–15 meters), resistivity increases (32.4–55.8 Ωm), representing compacted soils or lateritic layers that influence water percolation and nutrient availability. The deeper subsurface (15–25 meters) has higher resistivity values (40.6–50.6 Ωm), likely corresponding to consolidated laterite or weathered bedrock, which may restrict root penetration and water storage. Lateral variations in resistivity, particularly higher values around 50–70 meters horizontally, suggest areas with reduced porosity and water-holding capacity. Overall, areas with resistivity below 30 Ωm are most favorable for cultivation, while higher-resistivity zones may require interventions such as irrigation or soil amendments to enhance productivity.

Soil Analysis

In Otorho, the soil exhibits moderately acidic conditions with a pH of 5.30, which could lead to the leaching of essential nutrients like calcium and potassium, though it is still within a tolerable range for Oil Palm Plantation s. The boron level (61.10 mg/kg) supports palm growth, but it is lower than in other areas, suggesting potential growth limitations. Nitrogen content (0.24%) is also low, which could limit vegetative growth. The phosphorus level (24.80 mg/kg) is notably lower compared to Oria and Erho, potentially restricting root development. Magnesium levels (278.07 mg/kg) are moderate but the lowest among the three areas, which may slightly affect chlorophyll production and, consequently, growth rates. Potassium levels (0.74 mg/kg) are sufficient but not optimal, and calcium content (161.87

mg/kg) is the lowest, which could affect soil structure and water retention.

In Oria, the pH is near neutral at 6.70, creating a more balanced environment for nutrient absorption, making the area ideal for Oil Palm Plantations. Boron levels (84.29 mg/kg) are higher than in Otorho, promoting stronger growth and nutrient transport, while nitrogen content (0.29%) is higher, enhancing vegetative growth. Phosphorus (47.61 mg/kg) and magnesium (314.63 mg/kg) concentrations are the highest, supporting root development and photosynthesis, respectively. However, potassium levels (0.11 mg/kg) are significantly low, which could hinder water regulation and fruit quality, despite the high calcium content (361.10 mg/kg), which improves soil structure and root penetration.

In Erho, the pH of 6.80 provides optimal conditions for palm growth, with the highest boron concentration (91.82 mg/kg), suggesting better reproductive potential and nutrient transport. Nitrogen content (0.34%) is the highest, supporting vigorous vegetative growth. The phosphorus level (61.43 mg/kg) is also elevated, promoting robust root development. Magnesium content (281.78 mg/kg) is sufficient for photosynthesis, although not as high as in Oria. Potassium (0.16 mg/kg) is low, which may impact fruit quality and water regulation, requiring soil management interventions. Calcium levels (284.93 mg/kg) are high, contributing to improved soil texture, root penetration, and water movement, ensuring healthy plant growth and stable subsurface conditions.

The control site analysis in the table provides essential baseline data for comparing plantation soils to understand the impact of oil palm cultivation on subsurface characteristics. The slightly acidic pH values (6.10–6.30) reflect conditions that influence nutrient availability and plant growth, which may change due to agricultural practices. Boron levels (48.10–71.60 mg/kg) serve as a reference for this essential micronutrient required for flower and fruit development in palm trees. Deviations in boron levels in plantation soils could indicate nutrient depletion or enrichment caused by fertilizers or other inputs.

Nitrogen content (0.18–0.32%) provides a measure of soil fertility and organic matter availability, critical for vegetative growth. Phosphorus levels (17.80–28.91 mg/kg) are essential for root development and energy transfer, with potential alterations in plantation soils suggesting fertilizer use or the effects of intensive farming. Magnesium values (194.78–228.47 mg/kg) point to strong cation exchange capacity, which is vital for photosynthesis, while the relatively low potassium levels (0.14–0.62 mg/kg) highlight a possible limiting factor for palm oil productivity. These nutrient levels establish a benchmark for identifying nutrient imbalances or deficiencies in plantation soils.

Calcium content (124.87–181.93 mg/kg) supports soil structure and root growth, and variations in plantation areas may indicate the impact of land use or soil amendments. These chemical parameters, in conjunction with geophysical methods such as Electrical Resistivity Tomography (ERT), provide a comprehensive understanding of subsurface conditions. For example, changes in soil chemistry, such as pH or salinity, directly influence resistivity, linking nutrient availability and subsurface moisture distribution to agricultural activities in palm oil plantations.

CONCLUSION

The findings indicate that variations in soil composition and resistivity influence key agricultural factors including water availability, nutrient retention, and soil stability. Erho emerged as the most suitable site, offering balanced soil chemistry and favorable subsurface characteristics essential for oil palm growth. The study demonstrated the effectiveness of combining geophysical survey with soil analysis for subsurface investigations. The study underscores the value of geophysical methods in agricultural planning, enabling informed decision-making for land use and plantation management.

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