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Comparative Analysis of Soil Resistivity Measurements Using Wenner Four-Point Method: A Case Study in Sabratha, Libya

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Abstract

Accurate soil resistivity measurements are essential for the effective design of grounding systems, particularly in environments where soil properties vary significantly with depth and environmental conditions. This study presents a comparative analysis of soil resistivity measurements using the Wenner four-point method at two test sites in Sabratha, Libya. Measurements were conducted using both Megger and Fluke instruments to evaluate data consistency and identify subsurface variability. Results show that while shallow-depth readings were consistent across devices, significant divergences occurred at greater depths due to heterogeneous soil layering. The analysis reveals a distinct variation in resistivity profiles across different locations and instruments, indicating layered soil structures and fluctuating conductivity due to environmental factors such as rainfall. Results from the Megger and Fluke instruments show consistency at shallow depths but diverge at greater depths, with Fluke detecting a steeper drop in resistivity, potentially signifying a deeper transition to more conductive layers. three-layer soil model derived through CDEGS simulation further validated field observations, indicating a highly resistive intermediate layer overlying a more conductive sublayer. These findings underscore the importance of multi-depth profiling and instrument selection in designing robust and safe earthing systems.

Keywords: Soil Resistivity, Earthing Systems, Wenner Method, Instrumentation Comparison, Sodium Chloride, Bentonite

1. Introduction

Soil resistivity is a key factor that affects how well grounding systems perform. Therefore, accurate soil resistivity measurements and modeling are essential for predicting the behavior of grounding systems in such high soil resistivity [1]. Soil Resistivity significantly depends on soil composition, moisture content, temperature, and other environmental factors [2]. A high soil resistivity can lead to inadequate grounding, which poses safety risks and may cause equipment malfunction. Therefore, understanding and properly assessing soil resistivity helps engineers design grounding systems that are both safe and efficient, ensuring that electrical faults are properly dissipated into the earth. The primary goal of grounding is to provide a safe path for discharging excess currents resulting from electrical faults or lightning strikes, thereby protecting individuals from the risk of electric shock and safeguarding equipment. Grounding theory is based on physical principles such as equalizing electrical potentials between different metallic parts, preventing dangerous voltage differences. Various configurations have been devised for measuring soil resistivity, with the Wenner method illustrated in [3]—being one of the most commonly used techniques. Although it is not typically recommended for power engineering applications [2], soil resistivity can still be assessed in laboratory settings using alternative methods [4].

The motivation for this paper stems from the growing need to design efficient and reliable grounding systems in high soil resistivity sites.

2. Factors Affecting Soil Resistivity

Soil resistivity is a variable characteristic that indicates how much the soil resists the flow of electrical current. It is influenced by a variety of physical, chemical, and environmental factors, making it a critical parameter in fields such as electrical engineering, geotechnical studies, and agriculture. Understanding these factors is essential for designing effective grounding systems, preventing corrosion, and optimizing agricultural practices. Below is an explanation of the key factors affecting soil resistivity:

2.1 Soil Type

The type of soil plays a significant role in determining its resistivity. Soil is composed of various minerals and organic materials, and its resistivity varies depending on its composition. For example, clayey soil contains minerals like montmorillonite or kaolinite, which have a high surface area and can retain water and ions, making it highly conductive and resulting in low resistivity (10–100 Ω.m) [5].

2.2 Moisture Content

Moisture is one of the most critical factors affecting soil resistivity. Water acts as a conductor when it contains dissolved ions, such as calcium (Ca) or magnesium (Mg). As the moisture content in the soil increases, its resistivity decreases significantly [5].

2.3 Salt Content

The type of salt also influences resistivity; highly soluble salts like sodium chloride have a more pronounced effect compared to low-solubility salts like calcium sulfate. In coastal areas or regions with saline groundwater, soil resistivity is typically very low due to the high salt content [5].

2.4 Temperature

Temperature has a direct impact on soil resistivity. At low temperatures (below 0°C), water in the soil freezes, stopping the movement of ions and sharply increasing resistivity. Conversely, at higher temperatures (25–50°C), ion movement increases, reducing resistivity. However, if high temperatures lead to evaporation and drying of the soil, resistivity may increase again due to the loss of moisture [5].

2.5 Soil Stratification

Soil is often composed of multiple layers, each with different properties. For example, a clayey surface layer with low resistivity may overlie a rocky layer with high resistivity. This stratification affects the overall resistivity of the soil and must be considered when designing systems like grounding networks [5].

2.6 Chemical Contamination

Chemical pollutants can alter the resistivity of soil. For example, acids like sulfuric acid can dissolve minerals and increase the concentration of ions, reducing resistivity. On the other hand, oils or petroleum can form an insulating layer on soil particles, increasing resistivity [5].

3. Wenner Four Point Method

Methods for measuring soil resistivity include using an Earth Resistance Meter, which operates based on the four-electrode method. This involves inserting four metal electrodes into the soil and connecting them to the device to measure resistivity. Methods for measuring soil resistivity include using an Earth Resistance Meter, which operates based on the four-electrode method. This involves inserting four metal electrodes into the soil and connecting them to the device to measure resistivity.

Measuring soil resistivity is fundamental in the case of designing an earthing system. The factors that affect soil resistivity have been explored, therefore, by establishing an accurate way of measuring soil resistivity, models can be produced to generate valid simulations and contribute to a good earthing design. Comprehensive studies have been conducted to establish a soil resistivity measurement technique with the main method being the Wenner method [6]. This measurement involves a four-probe array in a straight line that is inserted into the earth of equal depth with a spacing that is constant. The two outer probes are used to inject a test current and the two inner probes are used to measure the potential difference across the two points. A simple rearrangement using Ohm's law gives the resistance of the soil. Figure 1 shows a model of the Wenner arrangement.

It was deduced by Wenner [6,7] that the soil resistivity can be determined by using Equation 1.

$$\rho = 2\pi a R \qquad (1)$$

Where:
a: is the distance between the probes (m)
R: is the measured resistance (Ω)
ρ: is the calculated soil resistivity (Ω.m)

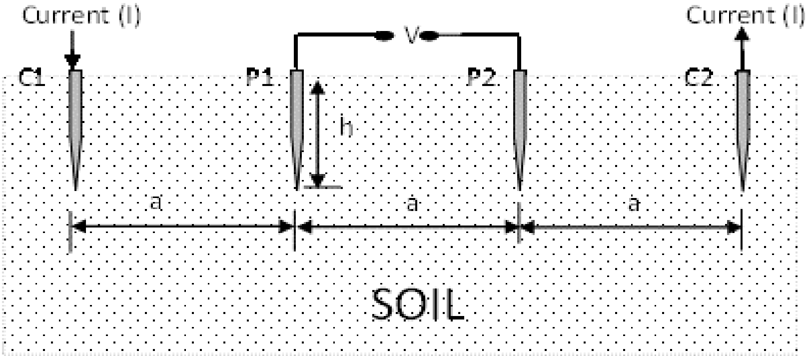

Figure 1: Wenner Four Probe Method [6]

4. Result and Discussion

The test site used to conduct all measurements was on a farm at Sabratha city (Talil). Figure 2 shows an aerial view of the farm detailing the locations of the test sites. The Wenner method was used to measure the soil resistivity for both sites a and b. Two profile tests were performed, and the profile one is perpendicular to profile two and both were measured at the same time and has the same length (39m).

Figure2: Satellite image of measurement location at Sabratha test site

The Megger DET4TR2 was used, and it is an advanced device for measuring earth resistance and features several characteristics that make it suitable for use in various environments. Figure 3 compares the soil resistivity measurements for two distinct profiles. The graph illustrates how soil resistivity (Ω·m) varies with Wenner spacing (in meters), indicating the subsurface soil properties at increasing depths. Both profiles show initial increases in resistivity, suggesting a near-surface resistive layer (e.g., dry or rocky soil). Profile one exhibits higher resistivity and a broader peak compared to profile two, possibly indicating a thicker or more resistive upper

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layer. The decrease in resistivity for both profiles at greater spacings implies the presence of a deeper, more conductive layer (e.g., moist or clayey soil). However, the resistivity in profile two decreases more rapidly than in profile one, which could suggest a thinner resistive layer or a shallower transition to a conductive layer.

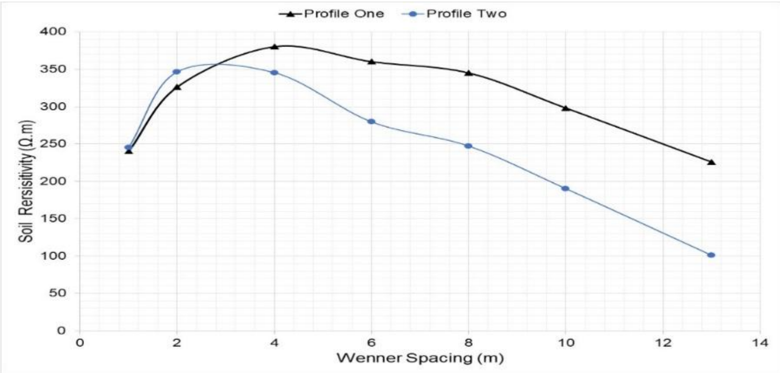

Figure 3: soil resistivity measured by Megger

Figure 4 presents a graph comparing soil resistivity values at Site a and Site b as a function of Wenner Spacing (measured in meters). At Site a, resistivity initially shows an increasing trend, followed by a decline. This pattern suggests the presence of a resistive layer (e.g., dry or rocky material) beneath the surface, which is more pronounced at intermediate spacings. As the spacing increases, the resistivity starts to decrease, possibly indicating a transition to a more conductive layer, such as moist or clayey soil.

In contrast, Site b exhibits a steady decline in resistivity with increasing spacing. This consistent decrease suggests an increase in soil conductivity, likely due to higher moisture content or the presence of clayey materials.

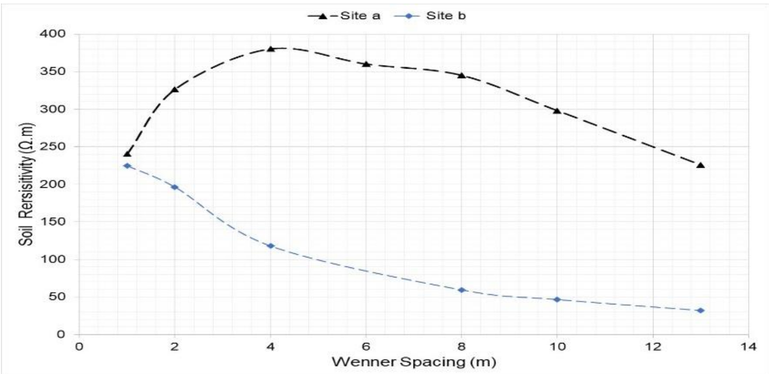

Figure 4: Variation of Soil Resistivity with Wenner Spacing at Different Sites

Figure 5 shows a comparison of soil resistivity measurements taken using two different instruments: Megger and Fluke, across various Wenner Spacing values (in meters). Wener spacing (a) represents the spacing between electrodes in the Wenner method of soil resistivity testing. Greater spacing allows measurements deeper into the ground. As can be seen from figure that both instruments start with very similar readings at smaller spacings (1–2 m), indicating consistency at shallow depths. At the middle-range spacing (4-8m), the readings show some deviation. Fluke instrument shows a small peak at 6m and the its values tend to be higher than Megger instrument, while Megger shows a smoother curve. At the large spacing (14m), Fluke shows a much sharper drop compared to Megger, suggesting it detects a significant change in soil composition or moisture content deeper down.

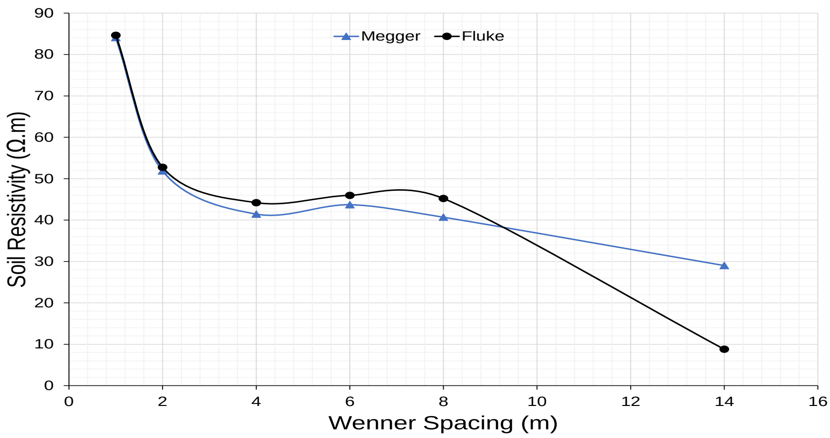

Figure 5: Comparison of Soil Resistivity Measurements Using Megger and Fluke Instruments at Varying Wenner Spacings

4.1 Soil Treatment

To reduce the earthing (grounding) resistance for any type of earth electrode, the low soil resistivity and high conductivity materials are usually used. In the past, the Chloride Sodium was often used, but this type of the salt has some disadvantages such as causing a corrosion for the material of the vertical electrode. Today, a lot of materials were used such as the Bentonite (Clay) which has low resistivity and retain moisture, which can help to increase the conductivity. In this paper, the comparison between the Chloride Sodium and bentonite was performed at the field to reduce the earthing resistance of the vertical electrode, as shown in Figure 6. In this test, a 1m vertical electrode was used, and 3inchs of the Chloride Sodium and Bentonite layers are being used surrounding the vertical electrode.

The results were tabulated in table 1. as can be seen from the table that, using the Sodium Chloride dropped the resistance significantly to 44.10 Ω, resulting in an 85.2% reduction. However, Bentonite reduced the resistance to 58.70 Ω, which is also a strong improvement, with an 80.3% reduction which slightly less effective than NaCl, it is beneficial in environments where long-term moisture retention is needed.

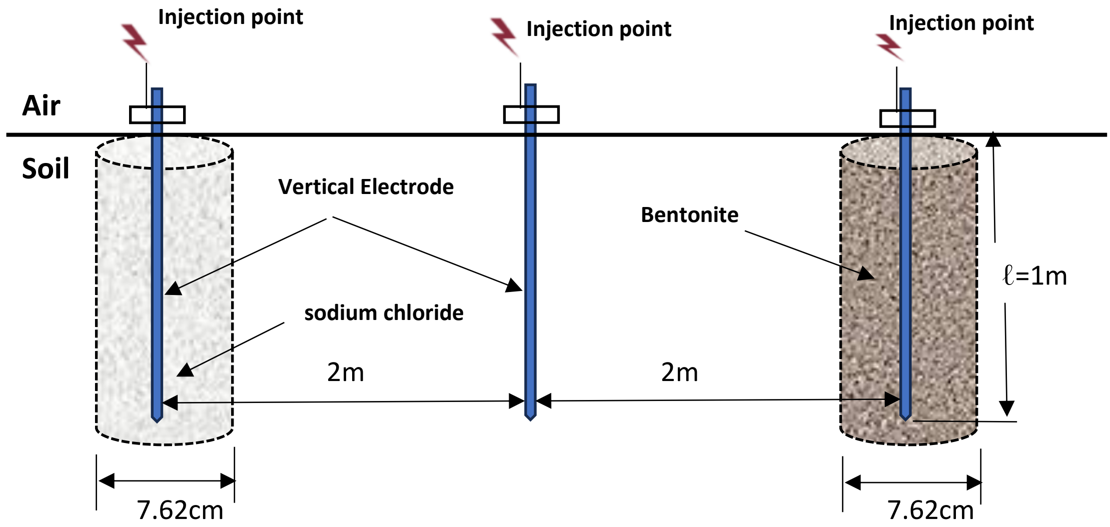

Figure 6: Experimental Setup for Treated Vertical Earthing Electrode in Soil

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Table1 Impact of Sodium Chloride and Bentonite on Earthing Electrode Performance

Configuration	Earthing Resistance (Ω)	Reduction Percentage (%)
Rod only	298.00	-------
Rod with 3inch Sodium Chloride	44.10	85.20
Rod with 3inch Bentonite	58.70	80.30

4.2 Soil Resistivity Simulation

The soil for the resistivity simulation using CDEGDS software (Current Distribution Electromagnetic Grounding Systems) [8] at test site will be used throughout. Table 2 shows the most recently derived soil model. As can be seen from the from the table, it's clear that there are three-layer soil model. The top soil resistivity layer is 196.35 Ω.m with 1.19 m Depth. This represents the uppermost soil layer, often closest to the surface. It could indicate moderately resistive soil, such as dry topsoil or compacted ground. The second layer is the Middle Layer, and the value of soil Resistivity is 2107.62 Ω·m with depth 0.92m. A highly resistive layer, possibly representing a rocky or very dry layer with minimal moisture content. The third layer is called lower layer, and its value is 55.68 Ω·m. A conductive layer likely

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consisting of moist soil, clay, or water-saturated materials, commonly found deeper underground.

Table2 Soil Resistivity Simulation using CDEGS Software

3 Layer Model	**Top**		**Middle**		**Lower**	
	Resistivity (Ωm)	Depth (m)	Resistivity (Ωm)	Depth (m)	Resistivity (Ωm)	Depth (m)
	196.35	1.19	2107.62	0.92	55.68	∞
Uniform Model	**Resistivity (Ωm)**					
	196.35					

5. Conclusion

Soil resistivity, a key property that determines the soil's ability to conduct electrical current, is influenced by a multitude of factors, including soil type, moisture content, temperature, salt content, density, and chemical composition. Understanding these factors is essential for designing effective grounding systems, especially in constrained sites where soil conditions may pose significant challenges.

This study underscores the significance of accurate soil resistivity measurements for the design of reliable grounding systems. By employing the Wenner four-point method and comparing results from the Megger and Fluke instruments, the research identified layered soil structures and the impact of environmental factors such as moisture and rainfall on resistivity profiles. The findings revealed consistent measurements at shallow depths but notable divergences at greater depths, with the Fluke instrument indicating a sharper transition to conductive layers. These variations highlight the necessity of multi-depth analysis and careful instrument selection to account for subsurface heterogeneity. The results provide valuable insights for engineers designing grounding systems in complex soil environments, ensuring safety and operational efficiency. Finally, the findings highlight the necessity of employing multi-depth resistivity profiles and cross-instrument comparisons in order to obtain a comprehensive understanding of the soil structure. Such insights are pivotal for the engineering of reliable and effective grounding systems, especially in high-resistivity or environmentally dynamic regions. Future work could explore seasonal effects and expand testing across diverse soil types to develop adaptable grounding models. Finally, the results show that excellent effectiveness for NaCl's better than Bentonite due to ability to attract moisture and improve ion mobility in the soil.

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