



Evaluation of the Dielectric Properties of Soil in the Vicinity of Delta State University of Science and Technology, Ozoro, Nigeria

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Abstract

A comprehensive understanding of soil electrical properties, particularly dielectric characteristics, is essential for the effective design and implementation of electrical and telecommunication systems, as well as for improving agricultural productivity. This study aims to determine the dielectric properties of soil within the premises of Delta State University of Science and Technology (DSUST), Ozoro, Nigeria. Soil samples were collected from nine strategic locations covering an area of approximately 0.5 km² within the university community. The dielectric constant (ϵ'), dielectric loss (ϵ''), and relaxation time (τ) of the samples were evaluated using ASTM-approved standard procedures. The results revealed that the dielectric constant (ϵ') ranged from 2.9 to 4.6, with the highest values observed in the central part of the study area. Similarly, dielectric loss (ϵ'') values varied between 0.8 and 1.15, with peak values also recorded in the central region. The relaxation time (τ) ranged from 3.72 to 4.59, with higher values predominantly observed in the northern part of the study area. These findings indicate significant spatial variability in the dielectric properties of soil within the study area. The results provide valuable insights for applications in agricultural management, geophysical studies, and the design of electrical and communication systems.

Keywords: Soil dielectric properties, Dielectric constant, Dielectric loss, Relaxation time, Soil electrical conductivity, Soil resistivity, Electromagnetic wave propagation, Grounding systems, Soil moisture

1.0 Introduction

Soil electrical properties are fundamental characteristics that play a crucial role in various soil processes and functions. These properties include electrical conductivity (EC), dielectric permittivity (ϵ), soil resistivity, and chargeability, all of which depend on factors such as moisture content, mineral composition, and organic matter (Gustavo Fano, 2019). With advancements in technology, soil electrical properties have found wide applications in telecommunications, electrical engineering, geophysics, and agriculture (Pradipta et al., 2022). In particular, these properties significantly influence the propagation of electromagnetic waves within soil media, making them essential considerations in the design and implementation of wireless communication systems.

In electrical engineering, soil properties are critical in the design of effective grounding (earthing) systems. Key influencing factors include soil electrical conductivity, moisture content, resistivity, texture, and structure (Edeko & Omorogiwa, 2022). Soil texture and structure directly affect moisture retention and permeability, which in turn influence conductivity and resistivity. Fine-grained soils, such as clay, typically retain more water and exhibit lower permeability than coarse-grained soils like sand. Consequently, clay soils generally have lower electrical resistivity and higher conductivity compared to sandy soils (Long et al., 2012).

Accurate knowledge of soil dielectric parameters is therefore essential to minimize capacitive coupling and other electrical interactions between underground cables and surrounding soil. This ensures proper insulation design and enhances safety in electrical and telecommunication installations (Chanzy et al., 2012; Li et al., 2023).

The dielectric constant of soil is strongly influenced by soil texture and moisture content, both of which are closely linked to the level of organic matter present. Soils with high organic content typically exhibit finer textures, greater moisture retention, lower resistivity, and higher dielectric constants (Martini et al., 2017). Organic materials generally possess higher dielectric constants than inorganic components, making their presence significant in electrical and telecommunication system design (Sahu et al., 2018). Understanding these dielectric properties is essential for ensuring efficient propagation and distribution of electromagnetic waves in underground communication infrastructure (Banaseka et al., 2021).

In agricultural engineering, soil electrical properties serve as important indicators for evaluating groundwater depth, assessing water quality, and estimating soil resistivity (Gustavo Fano, 2020). These properties can also provide indirect insights into soil fertility, crop growth, and yield potential. When integrated into predictive models and decision-support systems, they aid in optimizing agricultural productivity (Corwin & Lesch, 2003; Sui, 2019).

Although several studies have investigated the dielectric properties of agricultural soils (Navar Khele et al., 2009; Chaudhari, 2015; Syeda et al., 2020; Muhammad et al., 2022; Khan et al., 2023), findings consistently highlight the significant influence of soil physicochemical and mechanical properties on electrical behavior. However, despite extensive research in this area, there is limited information on the dielectric characteristics of soils in the Ozoro community of Delta State, Nigeria.

Therefore, the primary objective of this study is to assess the dielectric properties of soils within the premises of Delta State University of Science and Technology (DSUST), Ozoro, Nigeria. The findings from this research are expected to provide valuable data for the design and optimization of electrical installations and telecommunication systems within the university environment and beyond.

2.0 Materials and Methods

2.1 Study Area

The study was carried out within the premises of Delta State University of Science and Technology (DSUST), Ozoro, Nigeria. The area of investigation was the Agricultural Engineering Research Center of the university, covering a landmass of approximately 0.5 km². The site is characterized by a high-water table during the rainy season and is prone to seasonal flooding.

The study area is located within the tropical rainforest region of Nigeria, which is characterized by two major climatic seasons: the rainy (wet) and dry seasons. The region receives an average annual rainfall of approximately 1,800 mm (Uguru et al., 2022).

2.2 Sample Collection and Preparation

Soil samples were collected from nine strategically selected locations within the study area at a depth of 0.4 m using a soil auger. Each sample was properly labeled and transported to the laboratory for further analysis. In the laboratory, the samples were air-dried under ambient environmental conditions (temperature: 30 ± 5°C; relative humidity: 80 ± 10%). Sampling was conducted in April 2022, at the onset of the rainy season.

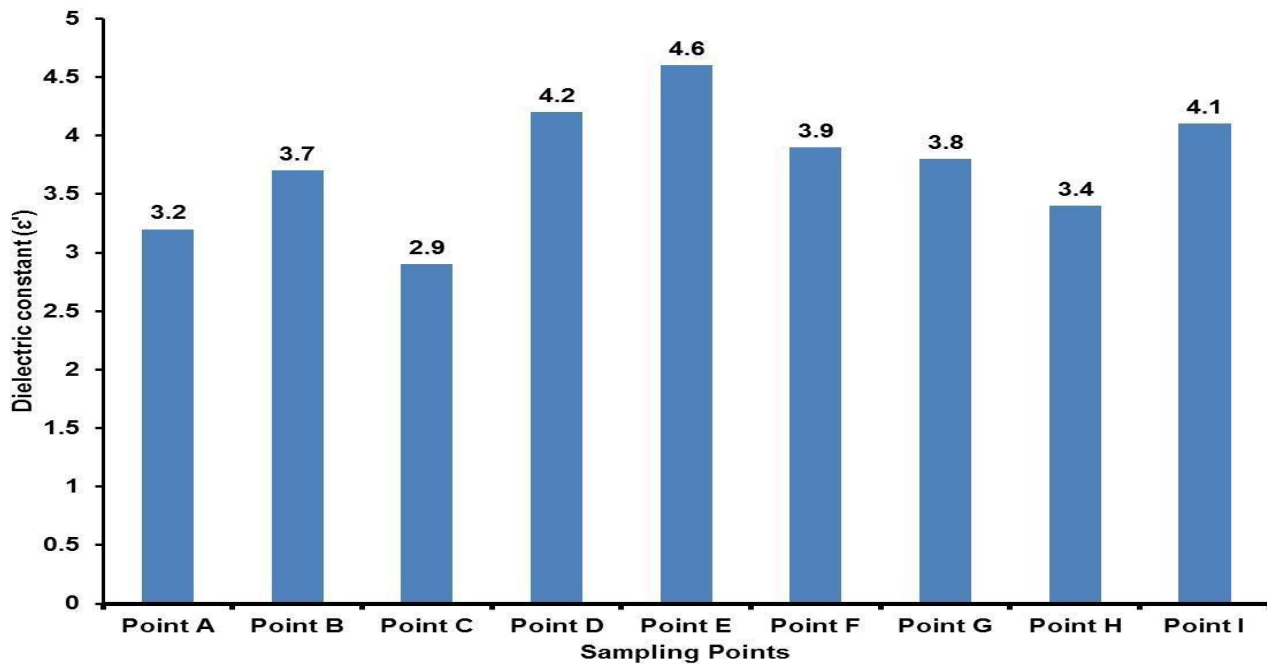
2.3 Laboratory Analysis

Dielectric Constant and Dielectric Loss

The dielectric constant (ϵ') and dielectric loss (ϵ'') of the soil samples were determined in accordance with ASTM D150 standard procedures at a microwave frequency of 7.0 GHz (ASTM D150, 2018).

After each measurement, the dielectric constant (ϵ') of each soil sample was calculated using Equation 1:

$$\text{Dielectric Constant} = \frac{C_a}{C_v}$$



Where C_a and C_b are the soil specimen capacitance and free air capacitance, respectively.

Relaxation time

The relaxation time (τ) was calculated through Equation 2.

$$\tau = \frac{\epsilon''}{\omega \epsilon'}$$

Where $\omega = 2\pi f$

3.0 Results and Discussion

3.1 Dielectric constant

The results of the dielectric constant of the soil sampled from the region are presented in Figure 1: Figure 1 indicated that the dielectric constant of the area ranged from 2.9 to 4.6, with the central part of the research station (studied area) having the higher dielectric constant, when compared to the southern and northern parts of the research station. The higher dielectric constant recorded at the middle of the study region (Points D, E and F) could be attributed to the higher organic content of the sub-region, resulting from agricultural activities that added humus to the soil. This addition of humus-rich organic material can influence the dielectric properties of the soil (Zhao *et al.*, 2023). Similarly, Harish (2023) stated that humus, which is the organic component of soil formed by the decomposition of agricultural materials, tends to have a higher dielectric property compared to mineral soils; hence, its presence increased the ϵ' of the soil to a considerable level.

3.2 Dielectric loss

Figure 2 presents the dielectric loss (ϵ'') results of the various soils sampled from the study region. It was observed from the results that the soil ϵ'' values ranged from 0.8 to 1.15 across the research station, with the soil samples collected from the central part of the area recorded the highest dielectric loss results. The lower results obtained in the northern parts (Points A, B and C) can be linked to poor organic matter content in this sub-region's soil. The specific characteristics of soil and their dielectric properties vary widely depending on factors such as soil type, land use, and environmental conditions (Tsolis and Barouchas, 2023). The dielectric loss of soil is greatly influenced by the volume and composition of both inorganic and organic materials present in the soil. Soil with higher inorganic solute tends to have lower dielectric loss when compared with soil with organic solute/solution. According to the report of Chaudhari *et al.* (2013), soil with a higher content of organic solutes or solutions, such as those resulting from decomposition of organic matter, may experience higher dielectric losses due to the increased presence of

polar molecules that can absorb and dissipate electrical energy. Soils with very high dielectric loss tend to have negative impact of the performance of electrical and electronic components and devices, which can be linked to the high energy lost to the environment (Yuan *et al.*, 2023).

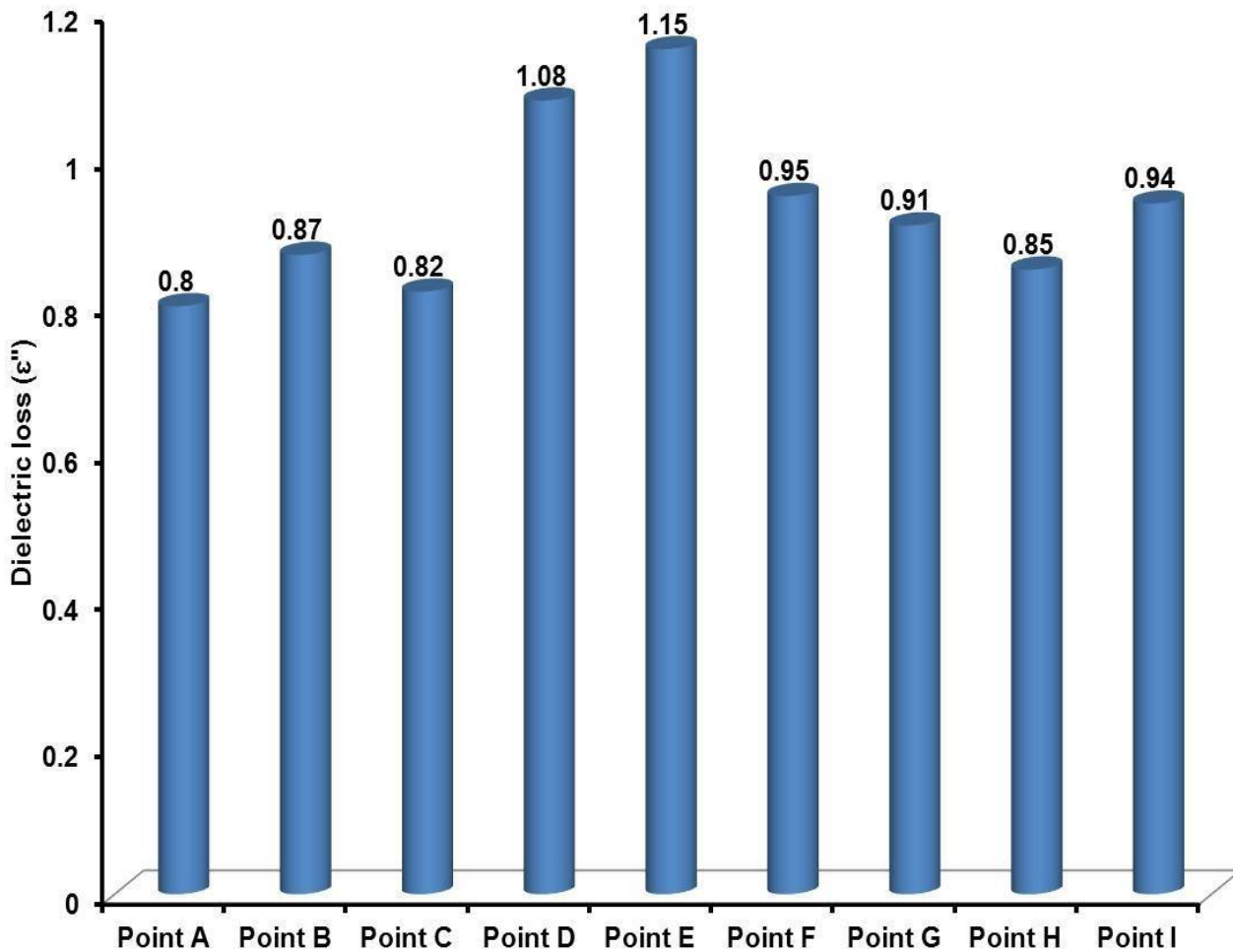


Figure 2: The dielectric loss of the soil samples

3.3 Relaxation time

Figure 3 displays the outcomes derived from the relaxation time analysis of the soil samples. The relaxation time of soil samples collected from the study area varied between 3.72 and 4.59. Soil from the northern part of the region exhibited a higher relaxation time compared to soil from other locations within the region. This difference could be attributed to variations in soil composition, moisture content, or other factors that affect the dielectric relaxation behavior of the soil. Syeda *et al.* (2020) stated that relaxation time is the time taken for the dipoles in a soil to return to their equilibrium state after being perturbed by an external electric field; and it is dependent on the organic matter content, moisture content, mineral composition and temperature of the soil. obtained from the laboratory testing indicated that the values of soil's ϵ' , ϵ'' , and τ are significantly influenced by the sampling location. In particular, the soil in the central region of the study area exhibited the highest values for ϵ' and ϵ'' , while concurrently displaying the lowest.

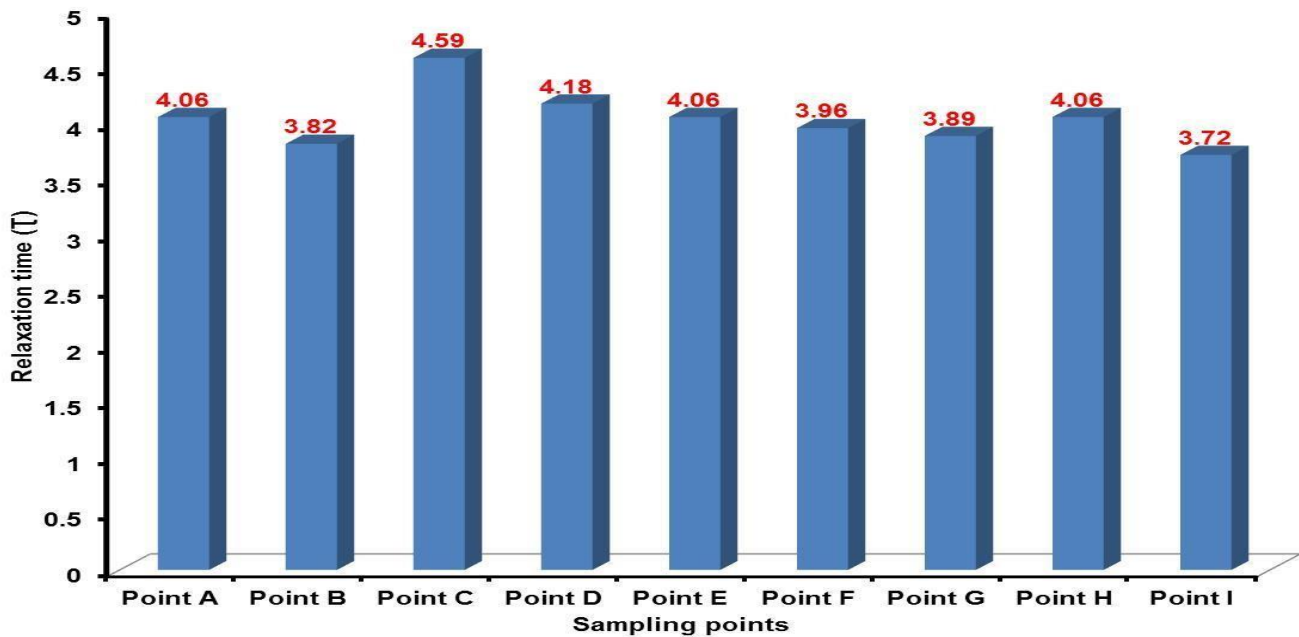


Figure 3: The soil samples relaxation time

4.0 Conclusion

This study was conducted to assess the dielectric properties of alluvial soils located within the Delta state of Nigeria. Nine soil samples were collected from the DSUST Ozoro campus, and their dielectric constant, dielectric loss, and relaxation time were determined following the guidelines outlined by ASTM. The results values for relaxation time. These results have affirmed the heterogeneity of soil electrical properties, offering valuable insights applicable to various agricultural and electrical engineering contexts.

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