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MEASUREMENT AND ANALYSIS OF THE ELECTRICAL PROPERTIES OF REMEDIATED CRUDE OIL IMPACTED SOIL

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ABSTRACT

Soil electrical properties are important parameters to be considered during the design of several electrical installations. This study gives an insight into the impact of crude oil contamination on the soil's electrical behaviors and suitable remediation technique for the contaminated soil. Crude oil was spilled on the soil and this soil was thereafter remediated with poultry (organic) manure and NPK 15:15:15 fertilizer for a duration of 12 weeks; thereafter, some of the soil's electrical properties (electrical dielectric constant, electrical conductivity and electrical resistivity) were measured in accordance with the Institute of Electrical and Electronic Engineers standard guidelines. Results obtained revealed crude oil had negative impacts on the soil electrical properties; but the remediation agents alleviated these poor electrical properties of the contaminated soil samples. After the remediation programme, the dielectric constant of the contaminated soil treated with 0.5 kg manure (AXT 2) and 1 kg manure (AXT 3) declined by 56.38% and 47.21% respectively; while the contaminated soil treated with 200 g fertilizer (AXT 4) and 400 g fertilizer (AXT 5) declined by 57.49% and 64.54%respectively. The electrical conductivity of AXT 2, AXT 3, AXT 4 and AXT 5 soil samples increased by 46.48%, 50.89%, 32.84% and 41.70% respectively. Furthermore, the AXT 2, AXT 3, AXT 4 and AXT 5 electrical resistivity declined from 1362 Ωm to 579 Ωm, 1362 Ωm to 483 Ωm, 1362 Ωm to 719 Ωm, and 1362 Ωm to 594 Ωm respectively. This study's revealed the relevance of remediating crude oil contaminated soil to preserve the electrical integrity of electrical installations.

Keywords: Crude Oil, Electrical Design, Organic Matter, Remediation, Soil Electrical Properties

1. INTRODUCTION

Soil is a heterogeneous material that comprises of both organic and inorganic materials, produced mainly by rocks weathering and other anthropogenic actions. The solid, liquid and air components of soil have relatively high electrical and magnetic fields. Soil has a lot of engineering applications, and its intended engineering utilization is governed by its engineering properties. Soil quality is an essential parameter that the performance of several engineering tasks; mostly telecommunication and electrical earthing installation rely on. Joffe and Kai-Sang, (2009) stated that high soil resistance, which can be associated with lower moisture level, oil pollution and other extrinsic factors tend to hinder telecommunication operations. The electrical properties of soil are influenced by several factors such as: soil porosity, moisture level, salinity, and presence of contaminants. These factors either increase or lower the soil resistance and dielectric properties, which could possibly limit the utilization of the soil for electrical engineering applications. According to Tashpolat et al. (2015), the dielectric properties of a soil mass are principally controlled by the soil's moisture and salinity levels since there is a strong correlation between the soil salt content and the coefficient of dialectical loss. Lasne et al. (2008) reported that the soil dielectric constant is inversely proportional to the soil salinity level and the volume of water in the soil. Concerning soil resistivity, it was reported in Oyubu (2015) that while high alkalinity lowers soil resistivity, it increases soil corrosivity. Studies have revealed that oil pollution has significant impact on the soil's electrical properties. In a study carried out by Odoh et al. (2022) on the impact of transformer oil on soil's electrical properties, the authors observed that oil significantly increased the soil electrical resistance. According to a research team report, the electrical resistivity of the soil varied between 374Ωm and 877Ωm, as the oil contamination rate increases Odoh et al. (2022). Igboama and Ugwu (2016) investigated the effect of oil pollution on various soil samples electrical properties, and reported that the contamination initiated significant alterations in the soil electrical conductivity and electrical resistivity. Uguru and Udubra (2021) observed that petroleum products increased the petroleum aromatic hydrocarbons, which can possibly cause serious reduction in the soil electrical conductivity, since petroleum has poor (low) electrical conductivity potential. Similarly, Fakunle et al. (2021) studied the impact of oil contamination on the electrical properties of virgin soil; and interestingly, they noted that the soil's resistance increased in a non-linear pattern, as the quantity of the oil in the soil mass increases. Yodrot *et al.* (2023) examined the impact of diesel on soil's electrical properties, and reported that the soil dielectric constant increased unevenly, as the diesel volume in the soil increases; while the electric field intensities of the soil samples declined inconsistently as the diesel content in the soil increases.

Oil spills are rampant in many oil producing countries, and various remediation methods are being applied for the remediation and the cleaning up of the environment. Therefore, studies on the best remediation method that will not only improve the soil physicochemical properties but also the soil electrical properties have become a paramount concern. According to Obukoeroro and Uguru (2021), soil's electrical behaviours are important factors that influence the performance of electrical grounding system; hence, their values should be maintained around the allowable limits used for the electrical design, in order to maintain the electrical integrity of the buildings/structures. While the impact of oils on the soil electrical properties has been extensively investigated, very little studies have been done to restore the depreciated electrical properties of contaminated soil. Arising from the necessity of improving the soil electrical properties after degradation caused by oil pollution; this research aims to develop a good remediation programme for contaminated soil. The remediation method will not only degrade the oil content in the soil, but also try to restore the electrical properties of the contaminated soil.

2. MATERIALS AND METHODS

The crude oil was obtained from an oil spill site in Delta state, Nigeria; the soil (0 – 0.4 m depth) was collected from a virgin land, with no recorded history of oil spill. The poultry manure was compost from poultry waste collected from poultry farms; while the NPK 15:15:15 fertilizer was purchased from agro-allied shop. The soil was sun-dried and filtered with a 0.60 mm size metal sieve.

The sieved virgin (uncontaminated) soil was contaminated with crude oil at the ratio of 9:1 (9 parts of oil to 1 part of oil), and left to stabilize for 10 days under ambient environmental conditions. At the 10th day, the soil was thoroughly mixed to have a near homogenous mixture, and filled into plastic containers at the rate of 10 kg per pot. Thereafter the contaminated soil was remediated with the following therapies, as presented in Table 1. All the experimental pots were kept in a shady environment for a period of 12 weeks, under normal environmental condition. 1 Litre of borehole water was uniformly added to all the containers once in a week.

Table 1

Table 1 The Remediation Setup

Sample code	Constituents
AXT 1	Control
AXT 2	CS + 0.5 kg poultry waste manure
AXT 3	CS + 1 kg poultry waste manure
AXT 4	CS + 0.2 kg of NPK 15:15:15 fertilizer
AXT 5	CS + 0.4 kg of NPK 15:15:15 fertilizer

CS = Contaminated soil

The soil samples dielectric properties were analyzed by using the vector network analyzer (VNA), at a frequency of 800 MHz, as explained by Yodrot*et al.* (2023). The digital electrical conductivity meter (model DDS-11C, manufactured in China) was used to measure the electrical conductivity of all the soil samples in accordance with ASTM D1125 guidelines.

The electrical resistance (R) of the soil samples was measure using the apparatus described by Igboama and Ugwu (2016). During the laboratory analysis, the soil samples were dried to a moisture content of 20% (wet basis), crushed and sifted with a 2 mm gauge sieve. The soil was poured into the hollow pipe and rammed 20 times, by using a 2-inch ramming rod. Thereafter, the pipe (with it's soil content) was carefully inserted into the apparatus, and the current and potential difference across the soil were read from the ammeter and voltmeter. The soil electrical resistance of the soil sample was calculated, by using Equations 1.

$$R = \frac{V}{I} \quad (1)$$

With the knowledge of the soil column length (L) and soil cross-sectional area (A), the soil electrical resistively was calculated with the aid of Equation 2.

$$\rho = \frac{RA}{L} \quad (2)$$

The results obtained from the laboratory analysis were subjected to statistical analysis, using tables and charts to further evaluate the findings made in this study.

3. RESULTS AND DISCUSSIONS

The results indicate that the crude oil has substantial effect on the soil electrical properties; likewise, the remediation therapies showed their effectiveness in remediating the corrupt electrical properties of the soil.

Figure 1

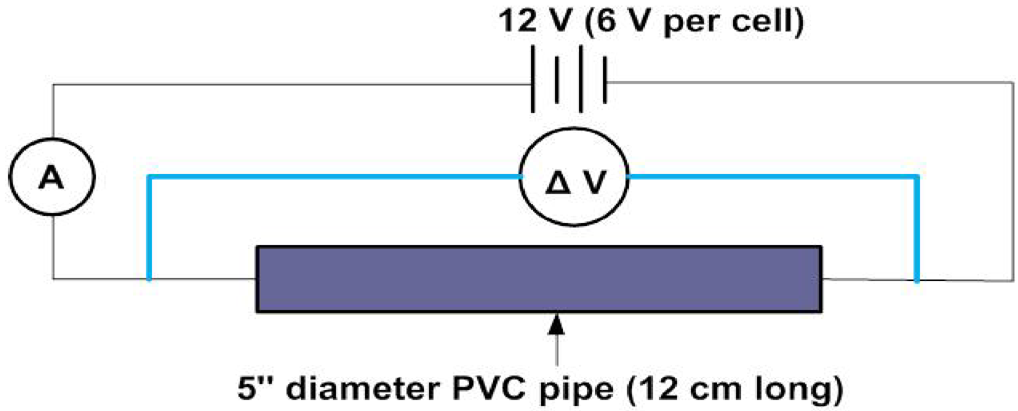

Figure 1 Schematic Diagram of the Soil Electrical Resistance Testing System

3.1. IMPACT OF THE CRUDE OIL ON THE SOIL ELECTRICAL PROPERTIES: DIELECTRIC CONSTANT (Ɛ')

The results of the dielectric constant ***(ε')*** of the contaminated and uncontaminated soil samples are presented in Figure 2. Figure 2 shows that the ε' of the soil increased drastically from 3.77 to 6.92, indicating 83.55% increment in the soil ε' after the crude oil pollution. This increment observed in the soil dielectric constant after petroleum pollution, is similar to observations previously made by Yodrot *et al.* (2023), for petroleum products contaminated soil. Yodrot *et al.* (2023) reported that dielectric constant of soil samples increased from 2.0 to 3.7 (85% increment) after being impacted with gasoline. Furthermore, Abdelgwad and Said (2016) in their investigation into the dielectric properties of oil spill sandy soils, noted that the dielectric constant of the soil increased by approximately 80% after the oil impaction. The reduction observed in the contaminated soil dielectric constant, may be associated with decline in the water holding capacity of the oil contaminated water. According to Shao et al. (2003), soil moisture constant played a significant role in the dielectric behavior of soil sample, especially on the dielectric constant and permittivity.

3.2. IMPACT OF THE CRUDE OIL ON THE SOIL ELECTRICAL PROPERTIES: ELECTRICAL CONDUCTIVITY (EC) AND ELECTRICAL RESISTIVITY

The results of the impact of the crude oil on the soil electrical conductivity and resistivity are presented in Table 2. As shown in Table 2, the soil's electrical resistivity increased from 275Ωm to 1362Ωm, after the pollution using the crude oil. Likewise, the EC values of the soil declined from 3.52dS/m to 1.37dS/m. This signified that the oil caused about 400% increase in the soil resistivity and approximately 62% increment in the soil electrical conductivity. Common observations of an increment in soil electrical properties, probably due to the presence of oil in the soil were made by Igboama et al. (2016). Guan et al. (2018) stated that soil pollution has adverse effects on the soil electrical properties, as the pollutants can increase the soil resistivity to current flow. The surge in the soil EC after the crude oil pollution could be attributed to decline in the soil salinity caused by the presence of the oil in the soil voids. The alterations to the soil electrical properties, which can be linked to the oil contamination, are similar to previous researchers' observations (Wang et al. (2010), Akpokodje and Uguru (2019)), one the effect of oil spills on other engineering properties of the soil. Abosede (2013) and Onyemauche et al. (2018) reported that crude oil or its derivatives negatively affect the soil physiochemical and mechanical properties.

Figure 2

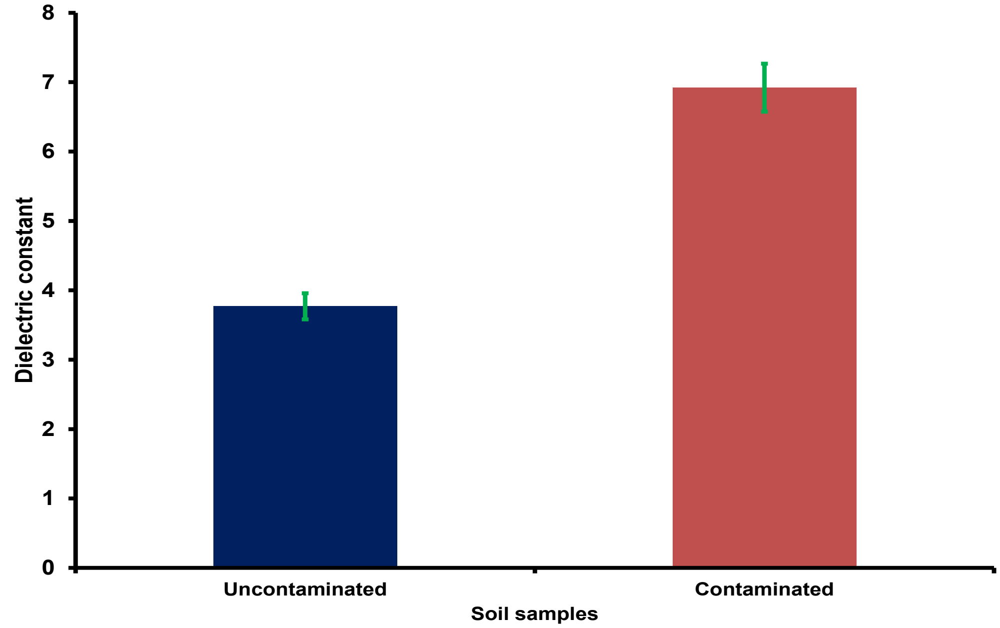

Figure 2 The Dielectric Constant of the Soil Samples at a Frequency of 800 MHz

Therefore, to reduce the environmental and infrastructural hazards, associated with crude oil spill in the soil, appropriate remediation practices should be carried immediately after oil pollution.

Table 2

Table 2 Effect of the Crude Oil on the Soil Electrical Conductivity and Resistivity

Soil Condition	Electrical Conductivity (dS/m)	Electrical Resistivity (Ωm)
Uncontaminated	3.52	275
Contaminated	1.37	1362

3.3. EFFECT OF REMEDIATION ON THE SOIL ELECTRICAL PROPERTIES: DIELECTRIC CONSTANT

The results of the remediating therapies on the dielectric constant of the contaminated soil samples are presented in Figure 3. It can be seen by comparing Figure 2 and Figure 3 that the remediating agents have significant effect on the contaminated soil dielectric constant. At the end of the remediation programme, the control programme had dielectric value of 5.81, the contaminated soil treated with 0.5kg poultry manure and 1kg poultry manure developed ε' values of 594 and 719 respectively, while the contaminated soil treated with 200g of fertilizer and 400g of fertilizer recorded ε' values of 579 and 483, respectively. This portrayed 16.04%, 56.38%, 47.21%, 57.49% and 64.54% reduction in the dielectric constant value of the control, AXT 2, AXT 3, AXT 4 and AXT 5 soils respectively. This depicted that the remediating materials had substantial impact on the soil dielectric constant during the remediation period.

Remarkably, it was noted from the study's findings that the contaminated soil remediated with organic material (AXT 2 and AXT 3) developed higher dielectric constant, when compared to the results recoded for the contaminated soil treated with inorganic material (AXT 4 and AXT 5). This is an indication that organic manure has higher potential of increasing the soil dielectric properties, when compared to inorganic fertilizer. This is similar to the observations made by NavarKhele et al. (2009), in their research findings on the effect of organic and inorganic products on the dielectric constants of soil samples. Palta et al. (2022) reported slight non-linear increment in the soil dielectric constant as the organic matter (sewage) volume in the soil increases; a situation that is attributed to higher alkali concentration in organic manure, which aids electrolyte formation in the soil. The higher dielectric constant values recorded in the CS samples treated with organic materials can be linked to the higher moisture content in the AXT 2 and AXT 3 soil samples. Organic materials have the ability of increasing soil water holding capacity Akpokodje and Uguru (2019); thus increasing the dielectric constant values of the soil mass. Soil dielectric properties are not influenced by the soil moisture content, but by the soil particle size grading and distribution.

Figure 3

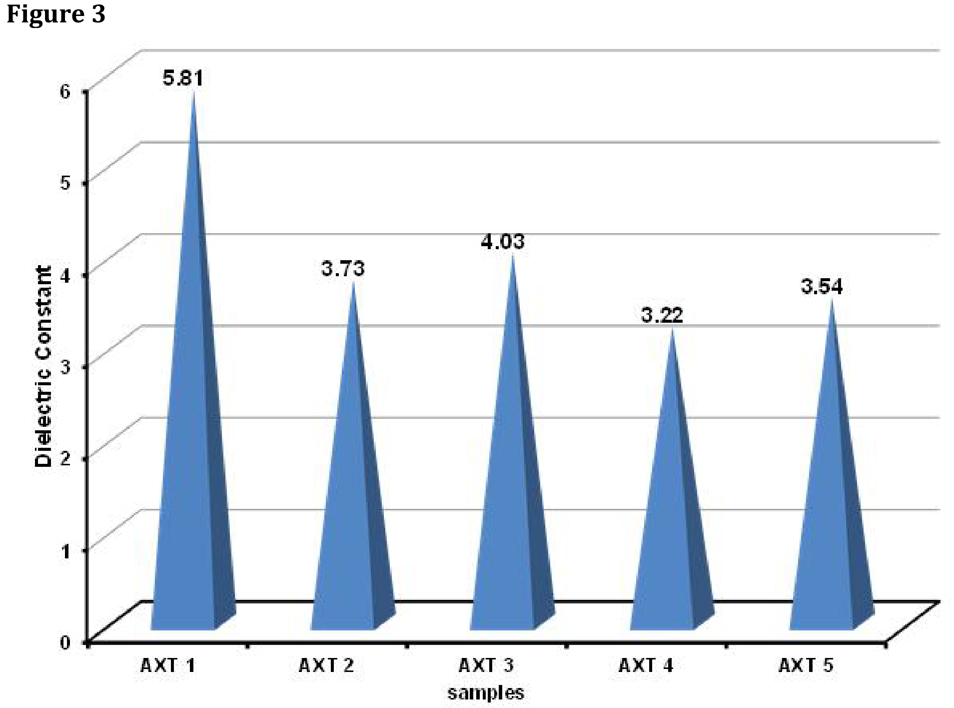

Figure 3 Impact of the Remediation Programme on the Soil Dielectric Constant

3.4. EFFECT OF REMEDIATION ON THE SOIL ELECTRICAL PROPERTIES: ELECTRICAL CONDUCTIVITY

The result of the soil electrical conductivity after the remediation is presented in Figure 4. Figure 4 revealed that both the manure and fertilizer increased the electrical conductivity of the contaminated soil remarkably. At the end of the remediation programme, the AXT 2, AXT 3, AXT 4 and AXT 5 soil samples recorded electrical conductivity of 2.56, 2.79, 204 and 2.35dS/m respectively. This is an indication that the organic manure increased the electrical conductivity by 46.48% and 50.89%, as the manure quantity increased from 50 g to 1kg; while as the NPK

15:15:15 fertilizer quantity increased from 200g to 400g, the contaminated soil electrical conductivity was increased by 32.84% and 41.70% respectively.

Figure 4

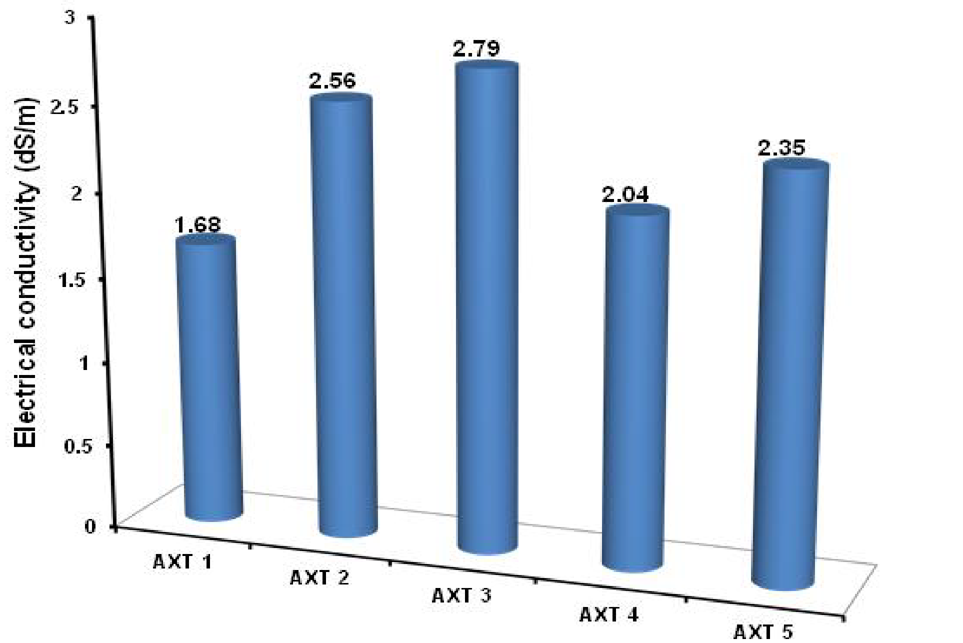

Figure 4 Effect of Remediation on the Soil Electrical Conductivity

3.5. EFFECT OF REMEDIATION ON THE SOIL ELECTRICAL PROPERTIES: SOIL ELECTRICAL RESISTIVITY

The result of the impact of the remediation programme on the soil resistivity of the contaminated soil samples is presented in Figure 4. It was observed from the results that the electrical resistivity of the soil was a function of the remediating materials. At the end of the remediation duration, the resistivity of the soil declined remarkably; with a higher remediation efficiency observed in the soil treated with organic matter. It was noted in the results that at the 12th week of remediation, the soil resistivity declined from 1362Ωm to 1275Ωm in the control experimental setup, in the AXT 2, AXT 3, AXT 4 and AXT 5 experimental setups, the soil resistivity value declined from 1362Ωm to 579Ωm, 483Ωm, 719Ωm and 594Ωm respectively. This finding depicts that the soil electrical resistivity declined by 06.39%, 57.48%, 64.53%, 47.21% and 56.38% in the AXT 1, AXT 2, AXT 3, AXT 4 and AXT 5 experimental setups respectively.

Interestingly, the poultry (organic) manures (AXT 2 and AXT 3) reduced the resistivity of the CS, at a higher rate when compared to the results obtained for the AXT 4 and AXT 5. This could be attributed to the higher electrical conductivity potential of organic manure. According to Igbologe and Okieke (2022), organic materials have higher prospect of enhancing the soil electrical conductivity; thus lowering the soil resistivity in the process. Additionally, petroleum products contaminated soil with appropriate amount of humus (organic manure) tends to accumulate more moisture – higher moisture content Akpokodje and Uguru (2019); hence, the higher water presence in the soil will reduce the soil resistance and increase the soil electrical conductivity Siow et al. (2013). According to Nigeria Industrial Standard (NIS), soils having low electrical resistivity are recommended for electrical grounding as they provide higher electrical protection, during the occurrence of voltage surge Idoniboyeobu et al. (2018)

Figure 4

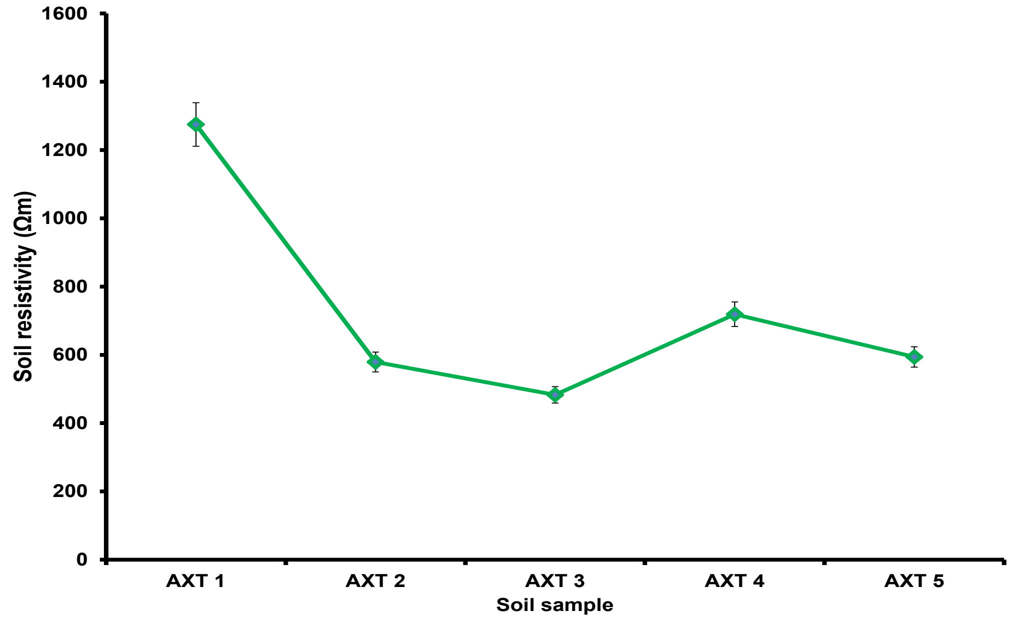

Figure 4 Soil Electrical Resistivity of the Soil Samples

4. CONCLUSIONS AND RECOMMENDATIONS

The impact of crude oil on the soil electrical properties, and appropriate remediation methods were investigated in this study. Crude oil spill stimulation was carried out on uncontaminated soil using standard procedure, and thereafter bio-remediated with organic manure and inorganic fertilizer. The electrical dielectric constant, electrical conductivity and electrical resistivity of uncontaminated, contaminated and remediated soil samples were evaluated in accordance with Institute of Electrical and Electronic Engineers laboratory procedures. Findings obtained from the laboratory tests and data analysis revealed that crude oil had negative consequences on the soil electrical properties; but these electrical hazards were alleviated through suitable remediation programmes. The results further depicted that the organic matter remediated the contaminated soil better than the inorganic matter (fertilizer); hence, the use of organic materials should be encouraged in the remediation of crude oil spill environment.

CONFLICT OF INTERESTS

None.

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