Journal of Engineering Innovations and Applications
Volume 2(2), pages 15-27, August 2023
Article Number: E02E98001
ISSN: 2971-673X
https://doi.org/10.31248/JEIA2023.027
https://integrityresjournals.org/journal/JEIA

Full Length Research

Evaluating the effectiveness of various remediation therapies on the engineering properties of oil-contaminated soils

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Received 15th July 2023; Accepted 19th August 2023

ABSTRACT: This study was embarked upon to ascertain the effectiveness of using physical and biological remediation procedures to amend the impact of oil pollution on soil engineering properties. Soil contaminated with crude oil at a mix ratio of 20:1 (percentage by weight), was remediated with charcoal (C2), charcoal + seaweed extract + groundnut plant (C3), and charcoal + wood ash + groundnut plant (C4). During the procedure, the soil's total petroleum hydrocarbon (TPH) level was determined through American Public Health Association (APHA) approved procedures; while the geotechnical (maximum dry density "MDD", optimal moisture content "OMC, and California bearing ratio "CBR") and electrical properties (electrical conductivity "EC", dielectric constant "ε', and electrical resistivity "ρ") were measured in accordance with American Society for Testing and Materials (ASTM) and Institute of Electrical and Electronics Engineers (IEEE) approved procedures. The results depicted that the TPH, ε' and ρ-values of the contaminated soil samples declined by 56.71%, 82.01% and 72.80%; 31.65%, 36.85% and 19.92%; and 56.32%, 62.03% and 60.27%, respectively in the C2, C3 and C4 samples after the remediation program; while the soil EC increased by 103.45%, 145.68% and 135.34% in the C2, C3 and C4 samples, respectively. Likewise, the C2, C3 and C4 samples CBR, MDD and OMC values increased by 29.49%, 34.75% and 50.30%; 7.87%, 11.02% and 4.72; and 12.02%, 28.01% and 40.38%, respectively at the end of the experimental period. These findings portrayed that hybridized remediation therapies are better remediating techniques in remediating contaminated soils; hence sustaining the integrity of the soils' geotechnical and electrical properties.

Keywords: Crude oil pollution, geotechnical properties, hybridized remediation, soil electrical properties, total petroleum hydrocarbon.

INTRODUCTION

Crude oil (petroleum) exploration and production has played a major role in the Nigerian economy, as it accounts for approximately 85% source of Nigeria's export income. Despite the numerous benefits of crude, its production comes with some environmental hazards, which include oil spills and gas flaring (Akpokodje *et al*., 2019; Onwuka *et al*., 2021). Land pollution caused by frequent crude oil spills has become a major problem in most oil-producing nations. In Nigeria, crude oil spills are mainly caused by the activities of oil thieves; though system failures are responsible for an appreciable amount of oil spillage in Nigeria (Uguru and Udubra, 2021). Crude oil (petroleum) and its derivatives spills affect both the biotic and abiotic components of the ecosystems. The vast area of mangrove swamps and arable land in Nigeria has been devastated due to soil spillage, causing serious environmental insecurity (Aniefiok *et al.,* 2018). The environmental hazards associated with oil pollution are dependent on the concentration and volume of oil spilled, the biochemical and physical properties of the soil/water, the presence of natural remediating agent(s), and the prevailing environmental conditions (Ogeleka *et al*., 2017; Akpomrere and Uguru, 2020a; Akpoghelie *et al.,* 2021).

Studies have shown that environmental pollution severely affects the soil's engineering properties (Nazir, 2011; Hewayde *et al*., 2019; Guan et al., 2018; Yodrot *et al*., 2023). Soil engineering properties are essential parameters to be considered during the building design and construction. Obukoeroro and Uguru (2021) in their investigation into the installation of electrical wiring integrity, reported that soil electrical, geotechnical and biochemical properties, greatly determined the type of electrical grounding system to be adopted for a particular structure. According to the study of Akpomrere and Uguru (2020b), crude oil pollution caused significant alterations in the soil and vegetation trace metals and physicochemical properties concentrations. Petroleum hydrocarbon toxicity results in a decline in the microbiological activities of the soil, causing a reduction in vegetative growth and humus formation, thus leading to poor aeration and infiltration rates (Idisi and Uguru, 2020).

Petroleum hydrocarbons and heavy metals contamination have the tendency of causing serious alterations in soils' electrical properties. Tashpolat *et al*. (2015) in their research reported that soil electrical properties are mainly controlled by the concentration of metallic ions in the soil, and a strong relationship existed between the soil's salinity level and its dialectical parameters. According to Yodrot *et al*. (2023), petroleum contamination results in increment of the soil dielectric constant, but a decline in the soil electric field intensity. Fakunle *et al*. (2021) reported in their investigation into the electrical properties of oil-polluted soils that, the soils' electrical resistance ability tends to increase as the oil pollution degree increases. High heavy metals presence in the soil affects its dielectric properties, as the soil permittivity increases considerably with increment in the soil heavy metals concentrations (Dahim *et al*., 2020). Furthermore, Chenaf and Amara (2001) investigated the impact of trace metals on the dielectric parameters of soil samples and observed that the soil dielectric properties increased non-uniformly as the contaminant concentration in the samples increased.

Nazir (2011) reported that petroleum contamination could be linked to the substantial decline observed in the unconfined compressive strength of fine-grained soil; while the soil exhibited a significant increment in its coefficient of permeability, as the oil contamination level in the soil increases. Similarly, Hasan (2021) and Akpokodje and Uguru (2019) stated that the specific gravity, maximum dry density and hydraulic conductivity of soil samples declined in an uneven pattern in the presence of petroleum products. According to the report of Akinwumi *et al*. (2014), oil spillage can lead to serious alterations in the soil's plasticity, load-bearing capacity, and settlement rate; which can result in structural failure of existing structures. Further studies also indicated that oil pollution tends to reduce the shear strength, maximum dry density and consistency limits of poorly graded soils with silt and clay particles (Soltani-Jigheh *et al*., 2018; Akpokodje *et al*., 2022). Recently, there have been several studies on the remediation of crude oil contamination soils, to alleviate the problems associated with crude oil and derivatives pollution (Borah and Yadav, 2017; Gbarakoro *et al*., 2023). These remediation procedures can be achieved through the application of organic materials, inorganic materials, or hybridization of both organic and inorganic materials.

The remediation potential of plants is dependent on their biochemical properties (Anih *et al*., 2019; Akpokodje *et al*., 2019), which are influenced by the cropping system, crop variety and maturation stage (Edafeadhe *et al*., 2020; Rajeev *et al*., 2022; Beautin *et al*., 2023). Salimnezhad *et al*. (2021) reported that beneficial microorganisms' actions help to improve (increase) the angle of internal friction and cohesion of the petroleum products contaminated soils. Amir and Amir (2021) investigated the effects of bioremediation on the geotechnical properties of crude oil-impacted silty clayey soils and reported that the remediation helps to increase the soils' California Bearing Ratio (CBR) values and lower their permeability rate when compared to the results obtained from the un-remediated soil samples.

Though several studies have been done on the remediation of petroleum-contaminated soils (Amir and Amir, 2021; Uguru *et al*., 2022; Gbarakoro *et al.*, 2023), related literatures search revealed little information on the effect of remediation on the electrical and geotechnical properties of contaminated soils samples. Therefore, the main aim of this research is to remediate the impact of crude oil pollution on the soil's geotechnical and electrical properties, through the hybridization of organic matter (charcoal, wood ash and seaweed extract).

MATERIALS AND METHODS

Recovered crude oil from an oil spill site in Warri South West Local Government Area (LGA) of Delta State, Nigeria, was used for this research. The fine-grained soil was obtained from the swamp of Isoko North LGA of Delta State. The groundnut seeds and seaweed extract were procured from a certified agricultural materials shop in Delta State and the wood ash and charcoal were obtained through the burning of softwood.

Sieve analysis

Particle size grading was carried out on the soil in accor-

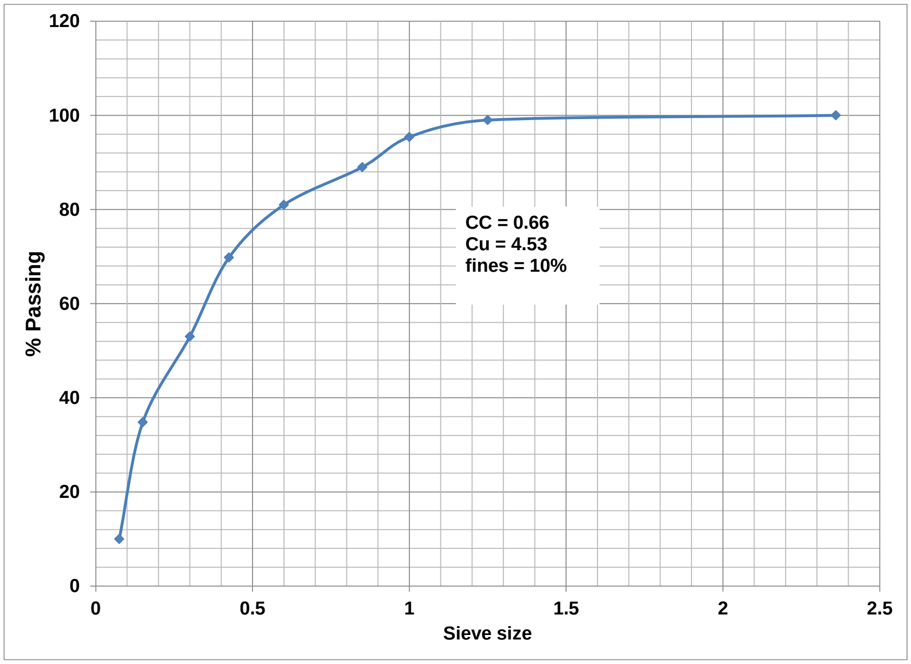

Figure 1. The plot of the soil particle size grading.

dance with ASTM D422 procedures, to ascertain its Unified Soil Classification System (USCS) grading. 500 g of uncontaminated soil was transferred into a set of arranged standard sieves and vibrated for 15 minutes using a mechanical sieve shaker. The weight of soil retained in each sieve is calculated by subtracting the initial sieve weight (W_1) from the final sieve weight (W_2), as shown in Equation 1.

$$\text{Weight of soil retained} = W_2 - W_1 \qquad 1$$

The plot of the particle size grading is presented in Figure 1. The Cu and Cc values coupled with the amount of fines in the soil indicate that the soil was poorly graded with clay particles.

Contamination of the soil sample

The soil was sundried and contaminated with the crude oil at a mix ratio of 20:1 (percentage by weight), and was left to stabilize for five days. Thereafter, it was filled into perforated plastic buckets at the rate of 10 kg per bucket.

Remediation plan

The contaminated soil was remediated with charcoal, wood ash and seaweed extract, as presented in Groups I to IV.

Group I: Control and was tagged “C1”,
Group II: Contaminated soil + 1 kg charcoal and was tagged “C2”
Group III: Contaminated soil + 1 kg charcoal + 500 g wood ash and was tagged “C3”, and
Group IV: Contaminated soil + 1 kg charcoal + 100 g seaweed extract and was tagged “C4”.

Remediation procedures

The wood ash and seaweed extract were thoroughly incorporated into the contaminated soil (C3 and C4), with 1 L of borehole water added to the samples to increase their moisture content. All the buckets (C1 – C4) were ranged in rows, at the rate of three buckets per row (treatment plan) in a shady environment for 10 days. This is to allow some of the nutrients to leach from the wood ash and seaweed extract into the soil (in the case of C3 and C4), which will facilitate the bioremediation process.

On the 10th day, a dried charcoal block was inserted in samples C2, C3 and C4 for 6 hours before its removal. During this period, the soil samples were moistened with distilled water (2 L) to enhance the charcoal adsorption capacity. After which 10 groundnut kernels were planted in C3 and C4 buckets. The kernels were placed in a prepared 20 mm stratum of uncontaminated soil on top of each contaminated soil. This was done to enhance the germination rate of the groundnut kernels and reduce the risk of hydrocarbon toxicity at the initial stage of the groundnut germination.

After germination seedlings were thinned to five stands per bucket. All the buckets – including the control – were kept in a shady environment for a period of ten weeks. During the experiment period (10 weeks), each bucket was watered with 1 L of water per day, and twice weekly. In the case of C2, the charcoal block was inserted into the soil once every week for a duration of 3 hours per week.

At the end of the experiment – in the case of C3 and C4 - the groundnut plants were carefully uprooted from each bucket. The soil remaining in C1, C2, C3 and C4 buckets were poured separately into a tray for sun-drying, before further laboratory analysis.

Laboratory analyses

California bearing ratio (CBR)

The soil samples' CBR values were determined in accordance with ASTM D 1883-05 procedures as explained by Rasheed *et al*. (2014).

Soil compaction test

The proctor compaction test to determine the maximum dry density (MDD) and Optimal Moisture Content (OMC) of the samples was done in accordance with ASTM D698 (2012) guidelines. The MDD of the soil sample was calculated by using Equation 2; while the soil's OMC was determined by plotting the MDD values against their corresponding moisture content values.

$$\text{MDD}\ (\rho d) = \frac{\rho_b}{100+m} \times 100 \qquad 2$$

Where: ρ_b = bulk wet density (kg/m^3), and m= moisture content (%)

Total petroleum hydrocarbon (TPH)

Ten (10) g dried soil sample was poured into a Soxhlet apparatus, and the oil was extracted by using hexane as the solvent. Then the TPH content in the soil was calculated and recorded.

Soil electrical conductivity (EC)

The samples' EC values were measured by using an electrical conductivity meter (model DDS-11C, manufactured in China) in accordance with ASTM D1125 guidelines, as shown in Figure 2.

Electrical resistivity

The soil electrical resistivity (ρ) was determined through the modified laboratory procedures explained by Igboama

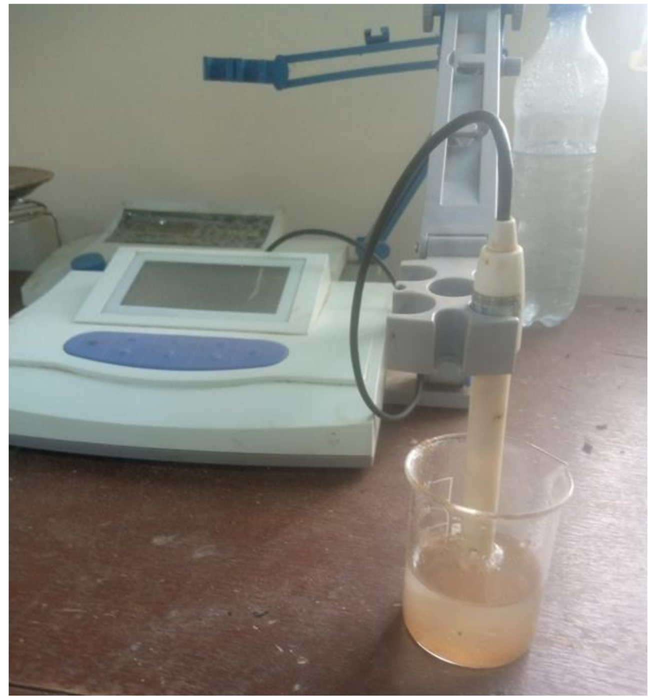

Figure 2. Determination of the sample's electrical conductivity.

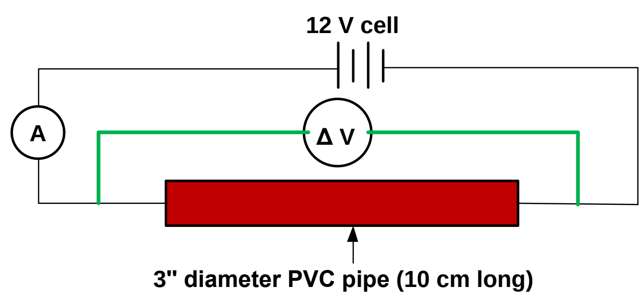

Figure 3. Laboratory soil electrical resistance testing layout.

and Ugwu (2016), with the schematic diagram shown in Figure 3. The electrical resistivity developed by the soil samples was calculated with the expressions presented in Equations 3 and 4.

$$R = \frac{V}{I} \qquad 3$$

$$\rho = \frac{RA}{L} \qquad 4$$

Where R = soil resistance, L = soil's effective column length (length of the tube), A = soil's effective cross-sectional area (area of the tube), ΔV = potential difference across the circuit, ρ = soil electrical resistivity, I = current, and A = Ammeter.

Dielectric constant

The soil's dielectric constant was determined according to the procedures described by Yodrot *et al.* (2023), through the application of the vector network analyzer, at a frequency of 800 MHz.

Data evaluation and analysis

All the data obtained in this research were subjected to statistical analysis, through the use of tables and charts to establish the effect of the oil pollution and remediation, on the geotechnical and electrical properties of the soil.

RESULTS AND DISCUSSION

Effect of crude oil on the soil

Total Petroleum Hydrocarbon (TPH)

The result of the effect of crude oil pollution on the TPH concentration of the uncontaminated soil sample is presented in Figure 4. It was noted that the TPH level in the soil increased from 64 to 1206 mg/kg, which signified a 1784% increment in the TPH concentration in the virgin (uncontaminated soil) after the crude oil impaction. This is consistent with the findings of Gbarakoro *et al*. (2019), where a significant increment was observed in soil samples after crude oil spillage. The concentration of TPH recorded in this study after the pollution was far lower when compared to the concentration recorded by Popoola and Olanbiwonninu (2019) in soil samples after crude oil spillage. This can be attributed to the concentration of petroleum products and the soil-to-oil mix ratio used for the different by the different authors.

Geotechnical properties

The results of the effect of oil pollution on some of the soil's engineering properties are presented in Table 1. The results revealed that the oil contamination significantly decreased the soaked CBR value of the uncontaminated soil from 7.63 to 4.75% (60% depreciation level). This is similar to Akinwumi *et al*. (2014) which reported the CBR of soil samples declined by almost 200% after contamination with 10% (by weight of the soil) of crude oil. Similarly, Rasheed *et al.* (2014) in their investigation into the impact of petroleum derivatives on the CBR values of soil samples reported that 7.5% vehicle oil pollution results in 105% deterioration in the soil samples CBR values.

It was noted that the uncontaminated soil MDD deteriorated from 1.46 to 1.27 g/cm^3 after the oil pollution. This could be linked to the oily component of the crude oil. According to Zhang *et al*. (2021), oils have the capacity to reduce the compaction and maximum dry density of soil samples. Likewise, Oluremi *et al*. (2015) and Nasehi *et al.* (2016) obtained similar results in their research, as the MDD and OMC values of soil samples depreciated significantly in the presence of oil pollution. According to Rasheed *et al*. (2014), oils with higher viscosity tend to reduce the soil dry density and moisture content at a greater rate, when compared to oil with lower viscosity. Additionally, the OMC results revealed that the soil OMC level decreased from 15.53 to 10.82%. This signifies that the oil initiated a 43.53% reduction in the soil OMC after its contamination, which is similar to the reports of Rasheed *et al*. (2014) of soils contaminated with diesel and kerosene respectively.

Electrical properties

Dielectric constant (ε'): The dielectric constant values obtained from the uncontaminated and soil contaminated with crude oil are presented in Table 2. It was observed that the soil's ε' appreciated from 4.01 to 7.33 after the oil spill, which revealed that the crude oil affected the physiochemical properties of the soil. This finding is similar to the observations made by Ahmadian *et al*. (2013), which stated that oil displaces the soil's air and water content from the soil void; thus, affecting the soil's electrical properties. According to Carey and Hayzen (2001), crude oil has poor electric dipole and electrical conductivity ability; hence its presence in a soil mass tends to increase the ε' of the soil.

Electrical conductivity and resistivity: The results of the soil electrical conductivity of both the contaminated and uncontaminated soils are presented in Table 2. It was noted that the electrical conductivity of the soil samples was 3.81 and 1.16 ds/m before and after the oil spill respectively, which is an indication that the crude oil caused 69.55% deterioration in the soil's electrical conductivity. Ebisine *et al.* (2023) reported similar results during their investigation into the impact of petroleum derivatives on the electrical properties of soil samples. According to Onwuka *et al*. (2021), oil pollution causes serious deterioration in the electrical conductivity of different soil types, and the electrical conductivity of soil is a function of the oil hydrocarbon concentration.

Furthermore, Table 2 revealed that the soil resistivity increased from 315 to 1417 Ωm after the oil contamination. This shows that the oil pollution caused a drastic increment in the soil resistance, which results in higher resistivity of the affected soil. The values of soil resistivity recorded in this study were higher than the values obtained by Odoh *et al*. (2023) for transformer oil-contaminated soils. Similarly, Fakunle *et al*. (2021) reported that the presence of oily components of petroleum products in the soil

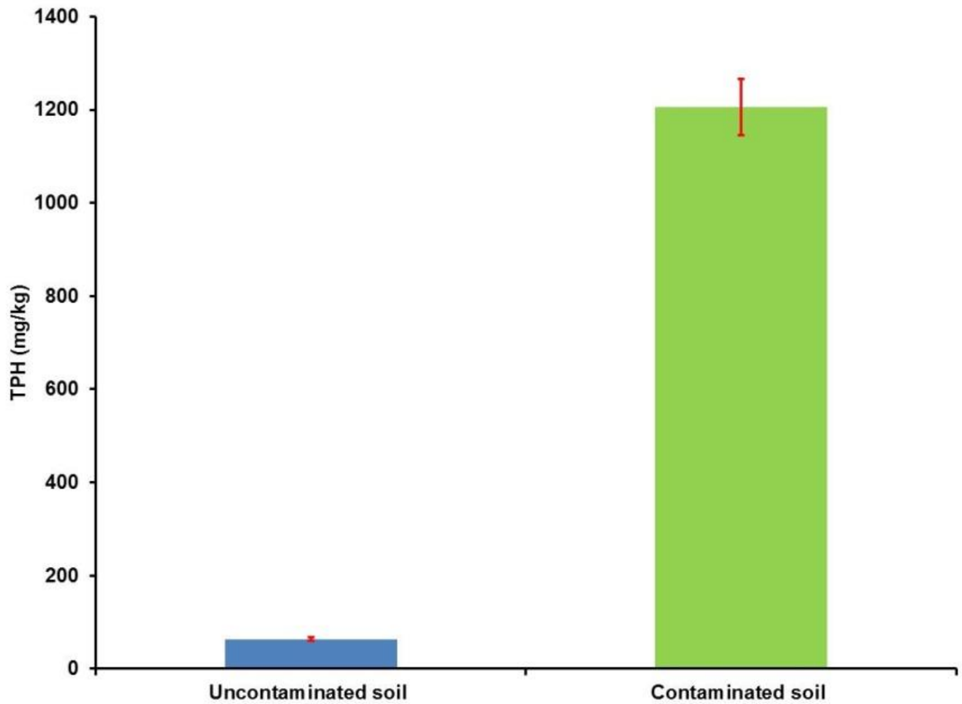

Figure 4. The soil samples TPH value before and after contamination.

Table 1. Effect of crude oil on soil's CBR, MDD and OMC.

Soil sample	CBR (%)	MDD	OMC (%)
Uncontaminated	7.63±0.15	1.46±0.04	15.53±1.73
Contaminated	4.75±0.12	1.27±0.09	10.82±1.10

Values are mean ± standard deviation.

Table 2. The samples electrical properties.

Soil sample	Dielectric constant	Electrical conductivity (dS/m)	Electrical resistivity (Ωm)
Uncon	4.01±0.04	3.81±0.42	315±2.81
Con	7.33±0.97	1.16±0.11	1417±9.22

Uncon - Uncontaminated, Con – Contaminated, values are means ± standard deviation.

significantly increased its resistivity. This could be linked to the formation of insulating layers in the soil by the oil, which will reduce the conductivity of electrons in the soil.

Remediation of the oil-contaminated soil

Total petroleum hydrocarbon

The results of the effect of the remediating agents on the TPH concentration of the soil are presented in Figure 5. This study's findings revealed that after the remediation program, the TPH content in the soil declined from 1206 mg/kg to 1194 mg/kg, 522 mg/kg, 217 mg/kg and 328 mg/kg in C1, C2, C3 and C4 samples, respectively. Gbarakoro *et al*. (2023) reported similar TPH remediation in crude oil-impacted soil through the use of biological materials. It was observed that the soil treated with the hybridization of charcoal and seaweed extract had a better remediation result (C3) when compared to the contaminated soil amended with the hybridization of charcoal and wood ash (C4), or contaminated soil remediated with only charcoal block (C2). The highest TPH remediation efficiency (82.01%) recorded in the C3

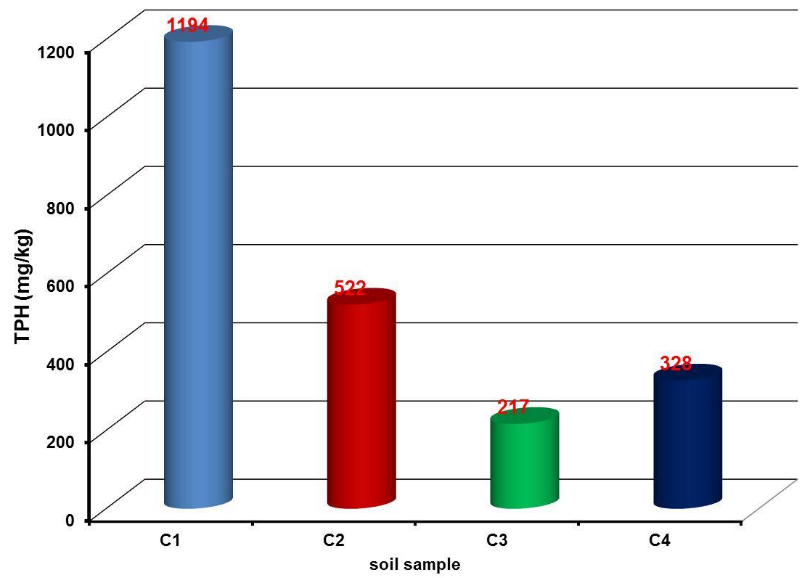

Figure 5. The TPH values of the remediated soils.

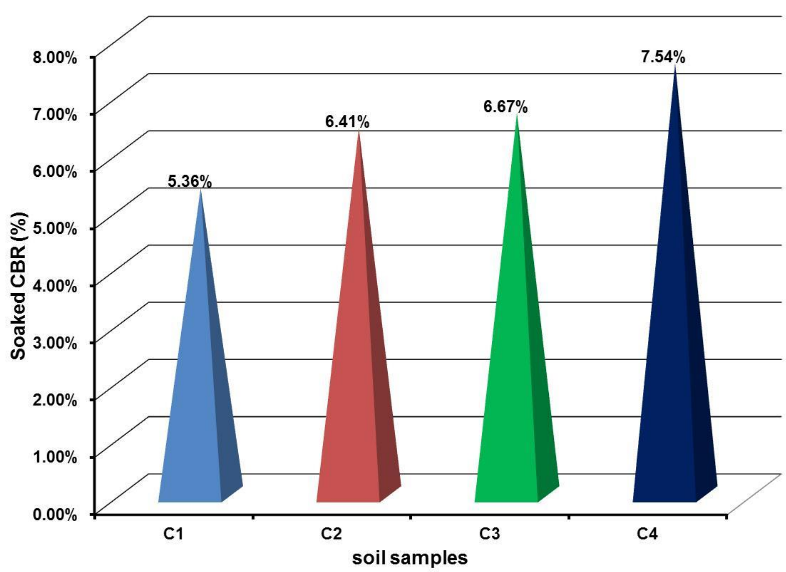

Figure 6. The soil soaked CBR after the remediation period.

samples could be attributed to the high nutrient content level of the seaweed extract, which will facilitate phytoremediation and soil-beneficial microorganisms' activities (Uguru *et al*., 2022). Also, it was noted that the contaminated soil amended with charcoal block (C2) showed a remarkable decline (56.72%) in the soil TPH value, which can be linked to the high sorption capacity of charcoal products (Edokpayi *et al.,* 2018; Uguru *et al*., 2022).

Geotechnical parameters

California bearing ratio: The result of the soil's soaked CBR after the remediation is presented in Figure 6. It can be observed from the results that the CBR of the C1, C2, C3 and C4 soil samples increased respectively by 8.69%, 29.49%, 34.75% and 50.30% at the end of the experimental period. This is an indication that the remediating agents have a significant effect on the soil

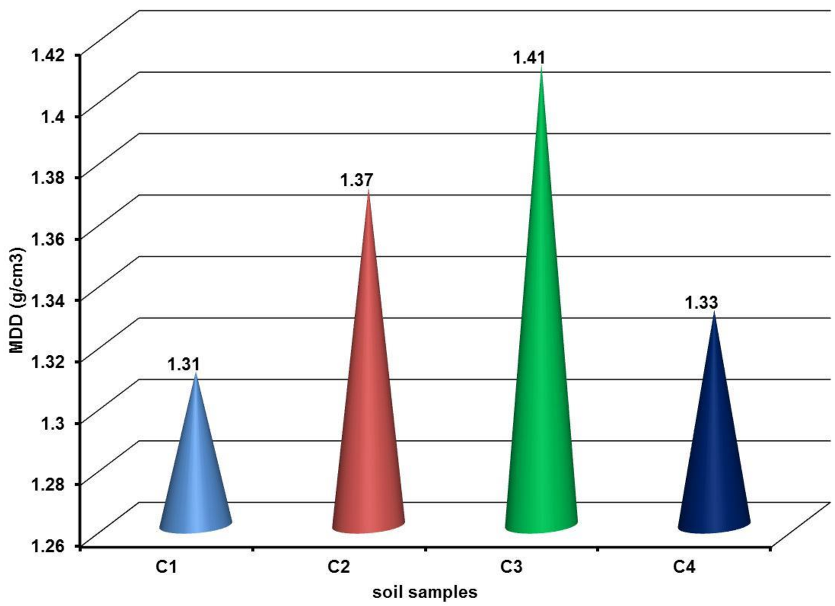

Figure 7. The soil's MDD values after the remediation period.

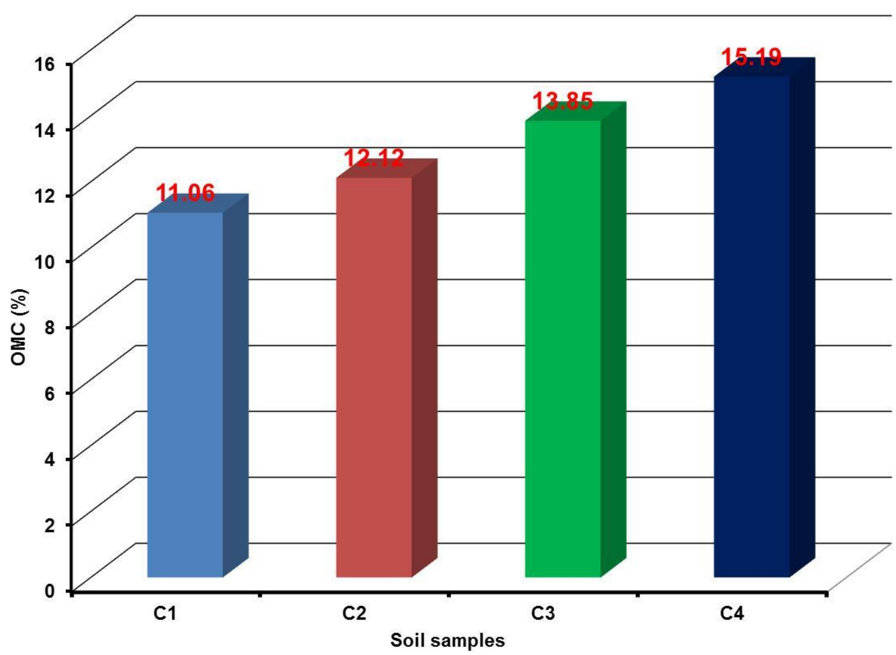

Figure 8. The OMC values of the soil samples after remediation.

CBR. The high CBR value recorded C4 compared to C2 and C3, could be attributed to the stabilizing effect of the wood ash. According to Abdulwahab *et al.* (2018), wood ash has the potential of increasing the CBR of weak soils; as it increased the CBR value of poorly graded soil by approximately 47%.

Maximum dry density and optimal moisture content: The soil samples compaction test results after the remediation period are presented in Figures 7 and 8. It was observed in Figure 7 that after the experimental period, the MDD values of the C1, C2, C3 and C4 samples were 1.31, 1.37, 1.41 and 1.33 g/cm^3, respectively. Remarkably,

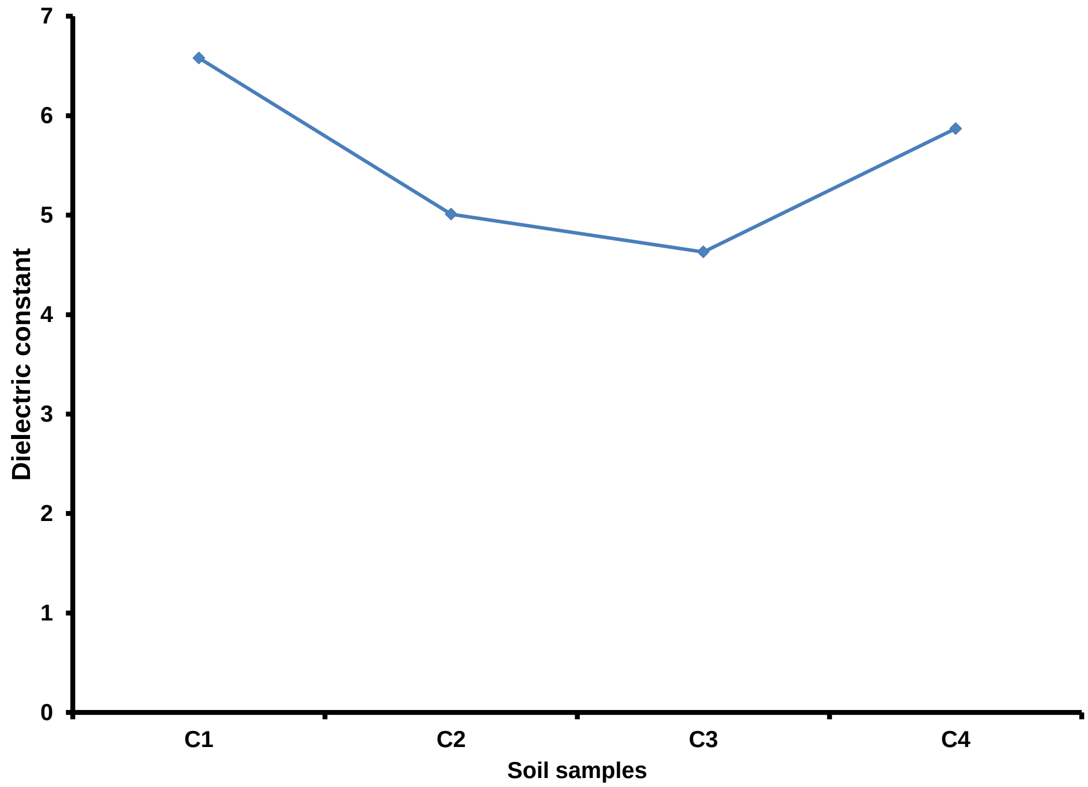

Figure 9. The dielectric constant of the remediated and un-remediated soils.

Figure 8 shows that these OMC values - 11.06%, 12.12%, 13.85% and 15.19% - were recorded in the C1, C2, C3 and C4 soil samples, respectively. The associated increment in the OMC for C2, C3 and C4 samples were approximately 12.02%, 28.01% and 40.38%, respectively. These reflect that the materials used in amending the contaminated soil had a remarkable effect on the soil MDD and OMC, which is in conformity with observations made by Salimnezhad *et al*. (2021) in their study that, bioremediation had a significant effect on the OMC and MDD of oil-polluted soils.

Furthermore, the lowest MDD value recorded in the C1 sample can be attributed to the high percentage of oil still present in the soil, as revealed in Figure 8. Oil viscosity and density values are lower than the values attained by water; thus, when oil occupies soil pores it lowers the soil bulk density and subsequently the soil's MDD values (Mustafa *et al*., 2018). The lowest MDD and highest OMC recorded in the C4 sample could be linked to the activities of the wood ash used in remediating the polluted soil. This is in conformity with previous observations made by Bayshakhi *et al*. (2018) that wood ash caused a significant depreciation of the MDD of several soil samples. Wood ash is a physical soil stabilizing agent that tends to decrease the soil MDD and increases the soil OMC. According to the reports of Abdulwahab *et al*. (2018), wood ash can be used for soil stabilization as it has the potential of reducing the soil OMC and MDD, but increasing the soil CBR level during the process.

Soil's electrical properties

Dielectric constant: The results of the dielectric constant of the soil samples after the experimental period are presented in Figure 9. At the completion of the experimental period, the dielectric constant values of the C1, C2, C3 and C4 soil samples were 6.58, 5.01, 4.63 and 5.87, respectively, signifying 10.23%, 31.65%, 36.85% and 19.92% reduction in the dielectric constant of C1, C2. C3 and C4 soil samples respectively. The findings revealed that the hybridization of charcoal block and seaweed extract (C3) has the highest potential of lowering the dielectric constant of the contaminated soil. Likewise, the findings depicted that hybridization of charcoal and wood ash developed the lowest potential of lowering the soil ε' value.

The high ε' value recorded in the C4 samples could be attributed to the presence of the hydroscopic nature of the wood ash. Organic materials with hygroscopic properties (such as wood ash) have the capacity to increase the soil's water-holding capacity, transition water content and

Table 3. The samples EC and Electrical Resistivity values after remediation.

Sample code	Electrical conductivity	Electrical Resistivity (Ωm)
C1	1.44^{a}±0.41	1162^{a}±21.2
C2	2.36^{b}±0.53	619^{b}±13.81
C3	2.85^{c}±0.69	538^{c}±17.3
C4	2.73^{c}±0.55	563^{c}±23.1

Columns with the same common letter (superscript) indicated that the means are not significantly different (p ≤0.05), values are means ± standard deviation.

electrolyte production (Liu *et al*., 2013; Fusade *et al.*, 2019). According to Palta *et al.* (2022), most organic materials tend to increase the soil water and saline contents, thereby increasing the soil dielectric properties in the process. Similar observations were made by Bircher *et al*. (2016) and Chaudhari (2015) during their investigation into the effect of moisture content and humus on the dielectric properties of different soil samples.

Electrical conductivity and resistivity: The results of the soil's electrical conductivity and resistivity after the remediation program are presented in Table 3. It can be seen in Table 3 that the soil's ability to conduct electrons increased significantly after the remediation. The EC of the contaminated soil increased by 103.45%, 145.68% and 135.34% in the polluted soil amended with charcoal, charcoal + seaweed extract, and charcoal + wood ash. This further affirmed the significance of heterogeneous treatment of contaminated soils, as earlier observed by Ebisine *et al*. (2023). Idama *et al*. (2021) and Paniagua-López *et al.* (2023) reported that heterogeneous/combined treatment significantly affects the soil's physiochemical and biological attributes, and treatment therapies that involve organic matters have several advantages over therapies that contain inorganic matters. Similarly, Hu *et al.* (2022) reported that bioremediation helps to increase the EC of contaminated soil, and is one of the best methods of remediating contaminated soils.

Furthermore, the results depicted that the soil electrical resistivity declined non-linearly after the remediation (Table 3). The resistivity values recorded in the C2, C3 and C4 samples were 619 Ωm, 538 Ωm and 563 Ωm, respectively, signifying 56.32%, 62.03% and 60.27% reduction in the C2, C3 and C4 samples electrical resistivity, respectively. This shows that the remediation procedures exhibited a significant effect on the electrical resistivity of the contaminated soil. The remarkably lower electrical resistivity values recorded in the C3 and C4 samples can be attributed to the higher TPH remediation attributes of these samples and the higher amount of organic matter in these two sets of remediated soil samples. According to the findings of Carmo *et al*. (2016), organic materials have the capacity to increase the soil's EC, thus reducing the soil's electrical resistivity to an appreciable extent. Additionally, Siow *et al.* (2013) stated that organic materials tend to increase the soil moisture content, therefore downgrading the soil's electrical resistivity.

The findings in this study have indicated that biological (organic) materials (charcoal, wood ash and seaweed extract) are ideal for the restoration of geotechnical and electrical properties of petroleum-polluted soils, and better results are obtained through hybridization of the organic materials. Remarkably, it was observed that the TPH, electrical and geotechnical parameters investigated in this study "improved' at the end of the experimental period. This could be attributed to the evaporation and natural degradation of the volatile components of the crude (Akpokodje and Uguru, 2019); hence, reducing the concentration and volume of crude oil in the soil, resulting in the reduced impact of the oil on the soil engineering properties.

The geotechnical properties evaluated in this study are essential for road construction, as the higher a soil's CBR values, the better its suitability for road construction. According to the Federal Ministry of Works and Housing (FMWH) recommendations, soil having a CBR value lower than 5% cannot be used as sub-grade material during road construction (FGN, 1997). Likewise, soils with low MDD values are susceptible to rapid deterioration under loading, thus they are not ideal backfilling and pavement material. Although a high dielectric constant is beneficial during capacitor production, high values of soil dielectric resistivity and dielectric constant are detrimental to the electrical grounding system. Soils with high electrical resistivity require special treatment during electrical earthing, as they can lower the integrity of the earthing system, thereby endangering the lives and properties within the structure and the immediate environment (Obukoeroro and Uguru, 2021).

Conclusion

This research was conducted to evaluate the effectiveness of combined remediation procedures, in remediating the impact of oil spillage on the electrical and geotechnical properties of soil samples. Contaminated soil samples were remediated through physical (by using charcoal and wood ash) and bioremediation (by using groundnut plants and seaweed extract) techniques. Findings obtained from this study revealed that both remediation techniques remediated the negative impacts of crude oil pollution on the geotechnical and electrical properties of the contaminated soil samples. Remarkably, the results depicted that the contaminated soil samples remediated with the combination of charcoal, seaweed extract and groundnut plant yielded the best remediation potential. The information obtained from this study will be helpful in planning remediation programs for contaminated soils, to sustain the integrity of the geotechnical and electrical properties of the soil.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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