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Alterations in Physicochemical Properties of Soils Impacted by Ahoada Oil Spill in Rivers State, Nigeria

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Abstract **Original Research Article**

Oil spills remain a critical environmental threat in the Niger Delta region of Nigeria, particularly in Edeoha, Ahoada East, Rivers State. This study evaluated the physicochemical alterations in oil-contaminated soils. Ten composite soil samples were collected from depths of 0–15 cm and 15–30 cm across affected sites. Key parameters measured included pH, electrical conductivity (EC), total organic carbon (TOC), total organic matter (TOM), total nitrogen (TON), phosphorus, potassium, chloride, nitrate, carbonate, sulfate and phosphate. Results showed pH values ranged from 5.67 to 6.10, falling below the EGASPIN-recommended 6–9 range. EC levels (75–106 µS/cm) indicated altered ion content. TOC values (1.53%–3.99%) exceeded the 3% USEPA threshold for non-agricultural soils. TON (0.088%–0.166%) was within natural soil ranges, while phosphorus (0.19–0.36 mg/kg) and potassium (16.45–34.30 mg/kg) were below agronomic thresholds. Chloride levels (14.2–19.2 mg/kg) approached the USEPA advisory limit of 20 mg/kg. Nitrate (2.25–2.67 mg/kg) slightly exceeded typical background values, whereas carbonate (2.30–3.40 mg/kg) and sulfate (1.23–2.31 mg/kg) remained within acceptable ranges. These findings highlight extensive alterations in soil chemistry and pollutant concentrations that exceed national and international safety standards, indicating an urgent need for targeted soil remediation and long-term environmental monitoring in the region.

Keywords: Oil Spills, Niger Delta, Soil Contamination, Physicochemical Properties, Remediation, Environmental Monitoring, Nigeria.

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1. INTRODUCTION

The environmental effects of crude oil exploration in the Niger Delta area have been both extensive and catastrophic. The area has, for many years, suffered serial oil spill incidents due to pipeline sabotage, equipment failure, and illegal bunkering operations. The spills have caused widespread devastation to the ecology, with soils being among the most severely affected environmental constituents (Ayuba, 2012; Olukaejire et al. 2024). Pollution by crude oil is a sophisticated combination of hydrocarbons and heavy metals added to the soil, which changes its physical and chemical properties and deteriorates its potential to support vegetation.

Petroleum contamination introduces a complex array of hydrocarbons and heavy metals into the soil that alters its physical and chemical composition and annihilates its potential to sustain vegetation. Soils with once exuberant agricultural productivity, now frequently exhibit symptoms of degeneration like poor fertility, unfavorable structure, and disrupted microbial populations. Ayuba (2012) mentions that Nigeria witnessed the spillage of an estimated 9 to 13 million barrels of crude oil between the last five decades which is equivalent to 50 Exxon Valdez catastrophes.

The physicochemical alterations resulting from oil spills are quite significant. It has been proven through research that there are significantly reduced soil pH levels associated with polluted soils that move towards the range of 3.6 to 5.5, as opposed to a level between 6.0 to 7.0 for unpolluted soils (Ngah et al., 2023; Olukaejire et al. 2024). High electrical conductivity (EC), sometimes greater than 1124.7 µS/cm, is a sign of high ionic content due to hydrocarbon degradation and related salts (Hassan et al., 2018). These alterations are not theoretical concerns; they have real implications in terms of decreased availability of nutrients in the form of nitrogen and phosphorus that leads to plant suppression and declining crop yields (Vincent et al., 2011).

Furthermore, its impact on microbial populations is very important. Crude oil alters soil microbiota diversity and composition, promoting oil degrading species at the cost of nutrient cycling beneficial microbes (Mafiana et al., 2021). Despite this interference, microbial communities with the capacity for natural remediation through biodegradation processes are found to attain up to 81.69% efficiencies under optimum conditions (Vincent et al., 2011). But this potential exists to be cautious in perpetuity by the creation of toxic heavy metals like lead and cadmium, which further hinder microbial life and increase toxicity in the soil (Hassan et al., 2018; Olukaejire et al. 2024).

In Niger delta, the case is more desperate. Records have reported soil pH ranging from 4.14 to 5.60, with the total petroleum hydrocarbons (TPH) concentration up to 1935 mg/kg far beyond acceptable levels (Olabode, 2023; Ejairu & Okiotor, 2022; Gighi et al., 2012). Concurrently, nitrate content in these polluted soils dropped significantly, compromising the agricultural value (Gighi et al., 2012). Even though remediation strategies such as NPK fertilizer applications have been effective to some degree in reclaiming the levels of TOC and TOM (Osuji et al., 2006),

This study, therefore, seeks to conduct a critical assessment of the physicochemical alteration of crude oil impacted soils of Ahoada. With the determination of critical parameters such as pH, EC, TOC, TOM and nutrient content we will acquire empirical evidence that will be utilized for effective remediation. Recognition of the full extent of hydrocarbon-induced soil contamination is important not just for environmental rehabilitation but also for safeguarding public health, food security, and socio-economic well-being of local communities.

2. MATERIALS AND METHODS

2.1 Location of the Study Area

This study was conducted in Edeoha, a community located in Ahoada East Local Government Area (LGA) of Rivers State, Nigeria, to the northwest of Port Harcourt. Situated within the oil-rich Niger Delta region, Ahoada lies between latitudes 5°05'N and 5°10'N and longitudes 6°40'E and 6°50'E, encompassing both Ahoada East and Ahoada West LGAs. The map of the study area, including Edeoha and its surroundings, is shown in Figure 1.

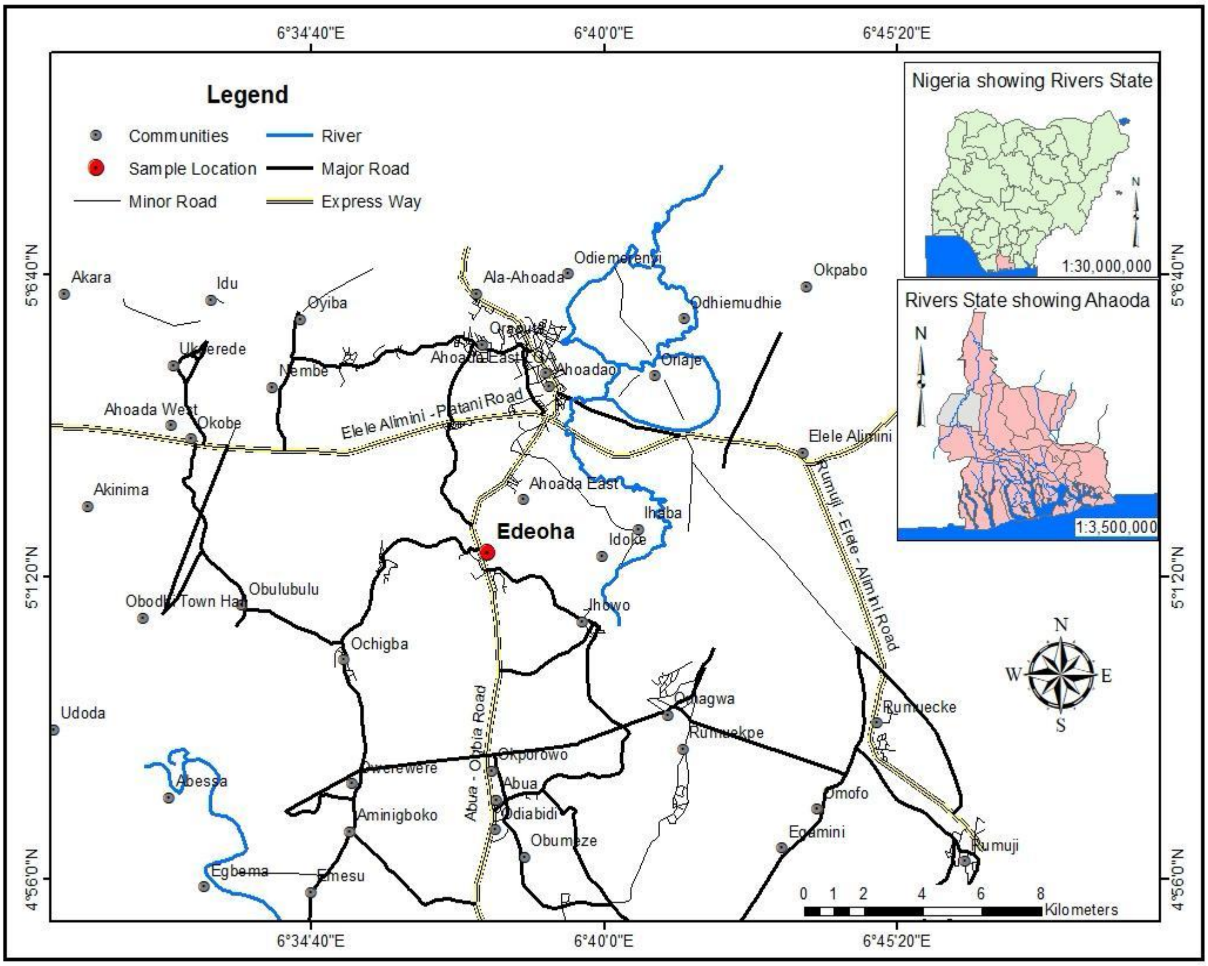

Figure 1 Map of the study area showing Edeoha oil spill impacted site.

2.2 Sampling Method

Soil sampling was conducted at an oil spill-impacted site in Edeoha, where a significant contamination event had occurred. A total of ten composite soil samples were collected from ten distinct points (Points 1–10) within the impacted zone.

At each location, soil cores were extracted from two depths: 0–15 cm (surface) and 15–30 cm (subsurface) using a clean metal soil auger. These two samples were thoroughly homogenized to produce a composite sample for each point, ensuring an accurate representation of the soil profile and contaminant distribution. This random sampling procedure followed the method outlined by Onyeike et al. (2002), where multiple cores within a 1-meter radius were aggregated to minimize spatial variability.

To prevent cross-contamination between sampling events, the soil auger was meticulously cleaned with distilled water after each use. The composite samples were placed in pre-labeled amber bottles, sealed immediately to preserve volatile components, and transported to the laboratory under cooled conditions for subsequent analysis.

2.3 Laboratory Analysis

2.3.1 Determination of Soil pH and Electrical Conductivity (EC)

Air-dried soil samples were sieved using a 2 mm mesh. A 10 g portion was weighed into a clean container, and 10 ml of deionized water was added (1:1 w/v ratio). The mixture was agitated for 30 minutes using a mechanical shaker and allowed to stand undisturbed for 1 hour.

The resulting supernatant was filtered through Whatman No. 42 paper, and the filtrate was used to measure pH and EC. Calibrated meters were immersed in the solution, and readings were recorded at room temperature (25°C), following EPA Method 9045D for pH and ASTM D1125 for EC.

3.3.2 Determination of Total Organic Carbon (TOC) and Total Organic Matter (TOM)

TOC was analyzed using the Walkley-Black wet oxidation method. A 0.2 g soil sample was treated with 10 ml of 0.2 M potassium dichromate and 20 ml of concentrated sulfuric acid. After oxidation, diphenylamine indicator was added, and the excess dichromate was titrated with 0.5 M ferrous sulfate until a maroon endpoint.

TOC (%) was calculated as:

$$\text{TOC \%} = \frac{\text{mEq } K_2Cr_2O_7 - \text{mEq } FeSO_4}{0.03 \times \text{Weight of sample (g)}}$$

To convert to mg/kg, TOC % was multiplied by 10,000. TOM was calculated as:

TOM (%) = TOC (%) × 1.724

2.3.3 Determination of Total Nitrogen (mg/kg)

Nitrogen content was determined using the modified Kjeldahl method. A 1.0 g soil sample was digested with a sulfuric-nitric-perchloric acid mix (2:2:1) until a clear solution formed. After cooling and filtration, the digest was alkalized with 10% KOH and reacted with Nessler's reagent.

Absorbance was measured at 460 nm, and nitrogen concentration was calculated using a calibration curve based on standard ammonium sulfate solutions.

2.3.4 Determination of Phosphorus (mg/kg)

Using the vanadomolybdate colorimetric method, phosphorus was extracted from digested soil using a 2:2:1 mix of H_2SO_4, HNO_3, and $HClO_4$. The filtrate was reacted with ammonium molybdate–ammonium vanadate reagent and measured at 400 nm. Concentration was determined using a phosphate standard curve.

2.3.5 Determination of Chloride (mg/kg)

Chloride concentration was analyzed using Mohr's titrimetric method. A 0.5 g portion of the air-dried sample was extracted with nitric acid, filtered, and titrated with 0.1 M $AgNO_3$ using potassium chromate as the indicator. The reddish-brown endpoint signified chloride presence. A blank titration was included, and calculations were based on the $AgNO_3$ titre values.

2.3.6 Determination of Nitrate (mg/kg)

The sodium salicylate colorimetric method was used for nitrate analysis. A 0.5 g soil sample was extracted with sodium salicylate solution. After filtration and color development, absorbance was measured at 415 nm. Calibration was done with potassium nitrate standards.

2.3.7 Determination of Sulfate (mg/kg)

The sulfate content was determined using the turbidimetric method. A 0.5 g air-dried soil sample was extracted in nitric acid, filtered, and reacted with $BaCl_2$ to form barium sulfate. After 1.5 hours, turbidity was read at 425 nm. Sulfate concentration was calculated using a sodium sulfate calibration curve.

2.3.8 Determination of Phosphate (mg/kg)

Phosphate levels were assessed using the molybdenum blue method. After digestion and filtration, the filtrate was treated with ammonium molybdate reagent and the resulting yellow color was measured at 420 nm. Calibration was done using KH_2PO_4 solutions.

3. RESULTS AND DISCUSSION

3.1 Soil Acidity and Salinity (pH and Electrical Conductivity)

Soil acidity and salinity are crucial indicators of soil health, especially in hydrocarbon-impacted regions like the Niger Delta. The pH of soil samples ranged from 5.67 to 6.10, indicating slightly acidic conditions across all sampled points (Table 4.1). The lowest pH was observed at Point 5 (5.67), consistent with hydrocarbon degradation by-products that contribute to soil acidification and subsequently suppress microbial functionality (Omemu et al., 2022). The pH value of 5.93 falls below the EGASPIN-recommended range of 6.0–9.0, indicating the potential for nutrient uptake interference and reduced microbial diversity.

Electrical conductivity (EC) values varied from 75 to 106 µS/cm, maximum at Point 7. These elevated EC values reflect increased ionic concentration, most likely as a result of hydrocarbon breakdown and deposition of soluble salts. Elevated EC can induce osmotic stress in plants, limiting water uptake and potentially triggering physiological drought (Lund, 2015). These findings are in line with earlier studies in the region, where high EC was linked with adverse plant growth and structural breakdown of soil (Edwin-Wosu and Nkang, 2019).

Table 1. Soil pH and Electrical Conductivity (EC) Across Sampling Points in Oil-Impacted Soils of Edeoha, Ahoada, Rivers State

Parameter	Point	Point	Point	Point	Point	Point	Point	Point	Point	Point
	1	2	3	4	5	6	7	8	9	10
pH	6.06	6.08	6.07	6.00	5.67	5.90	5.99	6.02	6.05	6.10
EC (µS/cm)	75	102	88	98	82	100	106	97	102	92

Table 2. Organic and Macronutrient Concentrations in Oil-Impacted Soils across Sampling Points in Edeoha, Ahoada, Rivers State

Parameter	Point	Point	Point	Point	Point	Point	Point	Point	Point	Point
	1	2	3	4	5	6	7	8	9	10
TOC (%)	2.66	1.98	3.87	3.99	2.55	1.53	1.86	2.03	2.06	2.15
TON (%)	0.154	0.161	0.134	0.088	0.099	0.166	0.119	0.144	0.162	0.142
P (mg/kg)	0.27	0.20	0.23	0.24	0.36	0.34	0.33	0.22	0.21	0.19
K (mg/kg)	34.30	24.91	30.63	25.52	29.68	27.50	27.97	21.96	21.47	16.45

3.2 Organic Matter and Nutrient Levels (TOC, TON, P, K)

Total Organic Carbon (TOC) levels ranged from 1.53% to 3.99%, with the highest concentration observed at Point 4. These values indicate elevated hydrocarbon pollution, exceeding the United States Environmental Protection Agency (USEPA) recommended upper limit of 3% for non-agricultural soils. Such high TOC levels can impair soil structure by hindering aggregation and limiting oxygen diffusion, thereby suppressing microbial and plant activity (Osuji et al., 2005). Similar contamination patterns have been observed in Umuahia and across the Niger Delta, highlighting an urgent need for remediation efforts (Eze et al., 2014).

Total Organic Nitrogen (TON) ranged between 0.088% and 0.166%. TON at point 4 was the lowest, suggesting hydrocarbon pollution may have immobilized nitrogen through microbes or quenched nitrogen-fixing activities (Ou et al., 2024). The content of phosphorus (P) and potassium (K) in samples were likewise sub-optimally low below agronomic standards, and this may delay soil fertility and crop growth (Reimer et al., 2020). Deficiency in nutrients can be prevented by low-dose phosphorus supplements and organic waste amendments, which have proven to contribute to the enhancement of microbial degradation (Griffiths, 2022).

3.3 Ionic Composition and Buffering Capacity (Cl^-, PO_4^{3-}, NO_3^-, CO_3^{2-})

Chloride (Cl^-) concentrations ranged from 14.2 to 19.2 mg/kg, which is close to the USEPA advisory concentration of 20 mg/kg. Excessive chloride at Points 3 and 9 suggest potential salinity stress that triggers ionic toxicity, chlorosis, and plant growth retardation (Geilfus, 2018). Salinity also hinders nutrient uptake, aggravating nutrient imbalance and reducing crop yield (Jabeen, 2018).

Phosphate levels were consistently low (0.21–0.61 mg/kg), suboptimal for microbial and plant demand. Phosphate deficiency has the potential to suppress microbial degradation of hydrocarbons, thus slowing natural remediation processes (Carillo et al., 2011). Nitrate concentrations ranged from 2.25 to 2.67 mg/kg, indicating active microbial nitrogen cycling, likely facilitated by hydrocarbon-degrading microorganisms such as Pseudomonas and Bacillus (Abdel-Shafy & Mansour, 2018).

Carbonate (CO_3^{2-}) content ranged in optimal levels (2.3–3.4 mg/kg), showing appropriate buffering capacity. Good buffering promotes microbial stability by inhibiting pH fluctuations resulting from hydrocarbon degradation (Chikere et al., 2011). The presence of active microbial communities and stable carbonates indicates the potential for bioremediation in soils, although heavily contaminated areas may still require supplementary measures (Udume et al., 2019).

Table 3. Concentration of Major Anions in Oil-Impacted Soils at Different Sampling Points in Edeoha, Ahoada, Rivers State

Parameter	Point 1	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Point 9	Point 10
Cl^- (mg/kg)	15.00	18.00	19.00	17.00	17.23	16.00	16.50	17.00	19.20	14.20
PO_4^{3-} (mg/kg)	0.45	0.55	0.27	0.61	0.33	0.45	0.60	0.43	0.49	0.21
NO_3^- (mg/kg)	2.34	2.65	2.25	2.34	2.45	2.44	2.67	2.55	2.59	2.49
CO_3^{2-} (mg/kg)	2.30	3.00	2.70	2.88	2.65	2.67	3.40	3.23	3.30	3.11

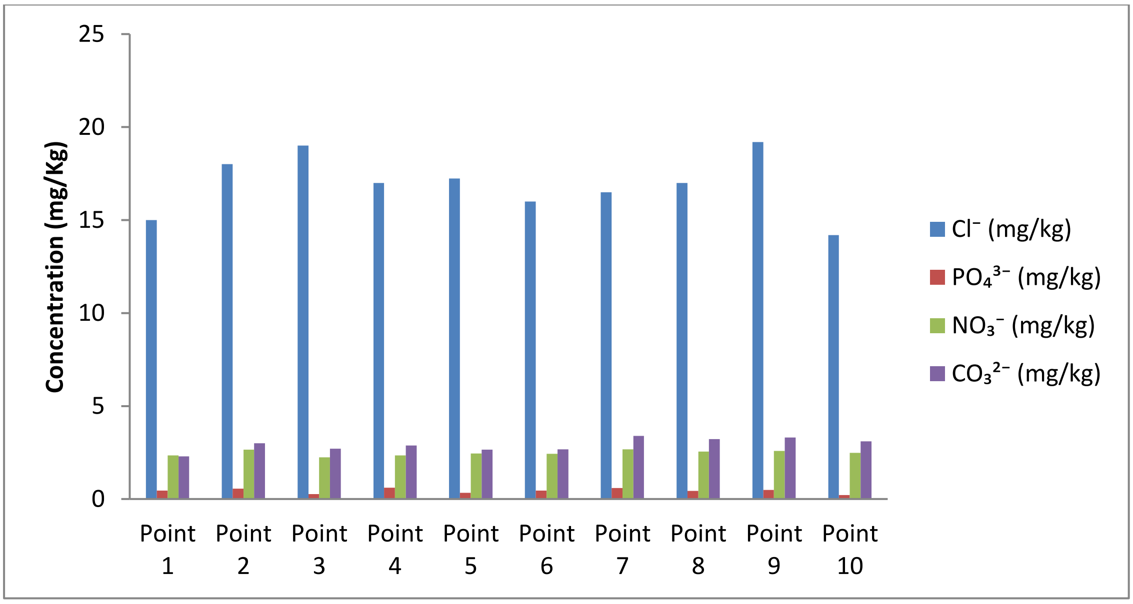

Figure 3. Concentrations of Major across Soil Sampling Points in Oil-Impacted Soils of Edeoha, Ahoada, Rivers State

4. CONCLUSION

The findings in general highlight that oil-contaminated soils in the study area have severe degradation with slightly acidic pH, high EC, high TOC, and nutritional imbalances (low TON, P, and K). The high nitrate concentration suggests active microbial activity, which could possibly be harnessed for bioremediation. However, the general state of the soils suggests decreased agricultural capability and ecological risks.

Restoration strategies such as the application of organic amendments, low-level nutrient inputs, and engineered bioremediation show promise in restoring soil health. In addition, long-term environmental monitoring is required to assess recovery and guide adaptive management practices according to local conditions.

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