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PHYSICOCHEMICAL AND HEAVY METAL VARIATIONS IN OIL-POLLUTED SOILS OF BAYELSA STATE: IMPLICATIONS FOR PLANT SURVIVAL

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ABSTRACT
This study provides a comprehensive environmental assessment of three oil-affected sites in Bayelsa State, Nigeria, Oloibiri, Ikarama, and Agudama, by analysing total petroleum hydrocarbons (TPH), nutrient levels, heavy metals, and key physicochemical parameters. Field surveys were conducted using the quadrat sampling method. A distinct pollution gradient was observed, with Ikarama being the most contaminated site (TPH ≈ 5,150 mg/kg; Fe = 5.01 mg/L; PO_4^{3-} = 20.01 mg/L), followed by Oloibiri, while Agudama showed the least impact. Several parameters, including Fe, NH_4^+, NO_3^-, total dissolved solids (TDS), and electrical conductivity, exceeded the environmental safety thresholds set by the World Health Organisation (WHO) and Nigerian Industrial Standards (NIS). Statistical analysis confirmed significant differences among the three sites ($p < 0.05$), underscoring the substantial impact of oil contamination on water and soil quality. The findings indicate that contamination levels are closely tied to human activities and provide valuable insights into the resilience and adaptive capacity of native plant species in these environments. To foster ecosystem recovery, it is recommended to engage in small-scale planting of tolerant species, alongside community training programs to enhance awareness of the ecological significance of these plants in soil restoration. Priority interventions are essential in Ikarama and Oloibiri, where elevated levels of Fe, NH_4^+, and TPH pose the greatest environmental risks. Suggested remediation strategies include bioremediation, phytoremediation, and soil washing. Ultimately, this research establishes a crucial baseline for assessing plant community structures and pollutant-tolerant species, offering scientific guidance for ecosystem recovery efforts. restoration and phytoremediation strategies in the Niger Delta.

KEYWORDS: *Oil contamination, Total petroleum hydrocarbons (TPH), Heavy metals, Phytoremediation, Environmental assessment, Niger Delta*

1.0 INTRODUCTION

The exploration and extraction of oil have significantly influenced the social and ecological environment of the Niger Delta in Nigeria. Years of oil spills, pipeline breaks, and small-scale refining have harmed soils, surface waters, and plant life.[1]. These disruptions affect soil quality by introducing hydrocarbons and harmful trace elements, resulting in decreased aeration, interruption of microbial processes, and lasting contamination that endures for many years [2, 3].

Soils contaminated with oil generally show alterations in their physicochemical characteristics, including pH, electrical conductivity, total dissolved solids, and nutrient composition, along with the build-up of heavy metals like Fe, Cu, Pb, and Cd.[4, 5]. Chemical stressors, such as heavy metals and industrial pollutants, significantly hinder nutrient cycling, leading to a marked reduction in soil fertility. These disruptions adversely affect the intricate relationship between soil microorganisms and plant systems, ultimately impairing vegetation growth. Recent studies have uncovered compelling evidence that hydrocarbon contamination not only alters soil chemistry but also disrupts the delicate balance of microbial communities crucial for organic matter decomposition and nutrient availability. This disruption diminishes the essential services these microbes provide, such as nitrogen fixation and nutrient mineralization, further exacerbating the stress on plant survival in affected environments. Consequently, the health of entire ecosystems may be compromised, leading to decreased biodiversity and reduced resilience against environmental changes.[6].

The ecological risks associated with heavy metal bioavailability are significant, particularly regarding their impact on plant uptake and, subsequently, food chain contamination. Research conducted in Ihwrekreka and various other communities throughout the Niger Delta has revealed alarmingly high concentrations of iron (Fe) and copper (Cu) in contaminated soils, often surpassing the thresholds established by the World Health Organisation (WHO). These elevated levels raise serious concerns not only for the physiological health of local plant species, which may experience inhibited growth and altered metabolic processes, but also for human health, as the consumption of contaminated plants can introduce toxic metals into the food chain, posing long-term health risks to the population. The persistence of these heavy metals in the environment further exacerbates the situation, highlighting the urgent need for comprehensive environmental monitoring and remediation efforts in affected regions.[7]. While

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remediation techniques like phytoremediation, chemical stabilisation, and nano-based amendments are gaining attention, their success is highly influenced by the unique soil chemistry of the site and the adaptability of indigenous plant species.[8].

Despite the extensive documentation of oil pollution in the Niger Delta, relatively few studies have systematically linked variations in soil physicochemical and heavy metal parameters with plant survival in contaminated environments. Most available studies emphasise pollutant concentrations or remediation techniques, often overlooking how native vegetation responds under different contamination intensities[9-11]. This gap is critical because understanding soil–plant interactions under pollution stress provides essential insights for natural recovery and for designing targeted ecological restoration programs.

This study addresses the gap by investigating the physicochemical properties and variations in heavy metals of oil-polluted soils in the Oloibiri, Ikarama, and Agudama communities of Bayelsa State, Nigeria. Specifically, it evaluates how pollution alters soil conditions relative to established standards and assesses the implications for plant survival and distribution. The findings aim to provide baseline data for prioritizing remediation strategies and identifying tolerant plant species with potential for natural colonisation or phytoremediation in oil-impacted environments.

2.0 MATERIALS AND METHODS

2.1 Study Area

The study was carried out in three oil-impacted communities of Bayelsa State, Nigeria, Oloibiri, Ikarama, and Agudama, selected for their long history of exposure to oil exploration and environmental degradation.

2.2 Survey Method

2.2.1 Vegetation Sampling

Vegetation surveys were conducted in the 2024 wet season using 50 × 50 m quadrats, with at least seven quadrats established in each community. Plant species occurring within and at the edge of quadrats were identified using field guides and herbarium consultation, while voucher specimens were collected for further verification. Soil samples (about 5 kg each) were collected near representative plants, sealed in polythene bags, and transported to the laboratory for physicochemical and hydrocarbon analysis.

2.2.2 Soil Sampling

Soil samples were prepared through solvent extraction with dichloromethane (DCM), cleaned using silica gel and sodium sulfate columns, and analysed with an Agilent 6890N Gas Chromatograph equipped with a Flame Ionisation Detector (GC-FID) for total petroleum hydrocarbons (TPHs).

2.3 Statistical Analysis

Means and standard deviations were calculated for the different parameters. Analysis of Variance (ANOVA) was employed to measure the degree of variability or similarities in the observed mean parameters. Mean separation was determined using Duncan's New Multiple Range test (DMRT) post-hoc test at a 5% significance or confidence level. This methodology enabled the integration of soil chemistry and vegetation structure, providing insights into plant survival and community resilience under oil-polluted conditions.

Figure 1:(a) Megathysus maximus (b) Praxelis clematidea, (c) Fuirena umbellata Rottb (d) Aspilia Africana.

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3.0 RESULTS AND DISCUSSION

Parameters. pH values ranged from slightly acidic to moderately acidic, while electrical conductivity (EC) indicated elevated salinity in some locations. Organic matter and total hydrocarbon content (THC/TPH) were notably higher in polluted quadrats compared to reference points. Soil texture analysis showed that the sites were predominantly sandy-loam, but oil contamination altered water retention and nutrient availability

Table 1: Physicochemical Parameters for three different Sample groups (A, B & C)

SAMPLE	PH	COND	TDS	NH4+ mg/kg	PO43mg /kg	NO3- mg/kg	S042- mg/kg	Cu mg/kg	Fe mg/kg
A	5.45 ± 0.025	1090 ± 10	545 ± 5	6.065 ± 0.028	13.213 ± 0.004	28.093± 0.015	22.056 ± 0.0031	0.406 ±0.003	3.684 ± 0.0036
B	4.21 ± 0/025	1305 ± 5.05	652.3 ± 2.52	7.282 ± 0.004	20.011 ±0.002	17.010 ± 0.0007	30.984± 0.0031	0.525 ±0.0051	5.013 ± 0.0031
C	7.83 ± 0.03	194.3 ± 4.04	97.2 ± 2.02	0.324 ± 0.002	5.325 ± 0.003	6.545 ± 0.004	11.357 ±0.0031	0.324 ± 0.002	2.312 ± 0.0025

The Total Petroleum Hydrocarbons (TPH) results across the three sites reveal a clear gradient of contamination, with Site A showing the highest pollution level (average 5,150.65 mg/kg), followed by Site B (2,657.77 mg/kg), and Site C with the lowest (991.01 mg/kg). Both Sites A and B significantly exceed the DPR Nigeria intervention limit of 1,000 mg/kg, indicating severe to moderate hydrocarbon pollution likely due to oil spills or industrial activity, which can hinder soil quality and plant growth. Site C, though below the critical threshold, still shows signs of residual contamination. This pattern supports the inference that only species with high tolerance or phytoremediation potential are likely to thrive in Sites A and B, while Site C may support a more diverse range of native vegetation, as shown in **Table 1**

Table 2: Comparison Table: Test Results vs WHO/NIS Standards

Parameter	Unit	WHO Limit	NIS Limit	Sample A (Avg.)	Sample B (Avg.)	Sample C (Avg.)	Remark
Ph	-	6.5–8.5	6.5–8.5	5.45	4.21	7.83	A & B below the limit
Conductivity	µS/cm	-	≤1000	1090	1305	194	A & B exceed NIS
TDS	mg/L	≤1000	≤500	545	652.3	97.2	A & B above NIS
Ammonium (NH_4^+)	mg/L	≤0.5	≤0.5	6.065	7.283	0.475	A & B high
Phosphate (PO_4^{3-})	mg/L	Not specified	Not specified	13.213	20.011	5.325	No regulatory limits
Nitrate (NO_3^-)	mg/L	≤10	≤50	28.093	17.010	6.545	A exceeds WHO
Sulfate (SO_4^{2-})	mg/L	≤250	≤100	22.056	30.984	11.357	All within limits
Copper (Cu)	mg/L	≤2.0	≤1.0	0.406	0.525	0.324	All within limits
Iron (Fe)	mg/L	≤0.3	≤0.3	3.684	5.013	2.312	All exceed limits

The laboratory findings indicate significant deviations from established WHO and Nigerian Industrial Standards (NIS) thresholds for oil-contaminated soil. Sample B showed extreme pollution with pH = 4.21 (below the WHO/NIS acceptable range of 6.5–8.5), TDS = 652.3 mg/L (exceeding the NIS limit of 500 mg/L), and iron concentration = 5.01 mg/L (far above the 0.3 mg/L limit). Similarly, Sample A had nitrate levels = 28.09 mg/L, surpassing the WHO threshold of 10 mg/L, and ammonium = 6.07 mg/L, exceeding the standard 0.5 mg/L limit. Both samples also had elevated electrical conductivity values (>1000 µS/cm) and acidic pH, indicative of oil-related contamination. In contrast, Sample C had near-neutral pH (7.83), low TDS (97.2 mg/L), and acceptable levels for most parameters except iron = 2.31 mg/L, which still exceeded the allowable limit. These deviations confirm that Samples A and B were collected from oil-contaminated zones, where elevated pollutant levels create harsh ecological conditions. Such chemical stressors influence the survival and distribution of native plant species, and the data serve as a foundation for identifying tolerant species capable of natural colonisation or phytoremediation in oil-impacted environments, as shown in **Table 2.**

Table 3 shows the one-way ANOVA results, which clearly demonstrate that all oil-contaminated soil parameters differ significantly among the three sampling sites (A, B, and C). Each parameter has a p-value well below 0.05, indicating strong statistical significance in variation due to site differences, likely influenced by varying levels of oil contamination.

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Table 3: ANOVA Results for All Parameters

Parameter	F-Statistic	p-Value	Interpretation
pH	13,845.27	$1.017e^{-11}$	Highly significant difference in acidity/alkalinity across sites.
Conductivity	22,035.61	$2.522e^{-12}$	Significant variation in dissolved ion content.
TDS	22,035.61	$2.522e^{-12}$	Correlated with conductivity; confirms difference in mineral loads.
NH_4^+	2,325,896.71	$2.146e^{-18}$	Major differences in ammonium concentrations are a strong contamination indicator.
PO_4^{3-}	6,313,311.03	$1.073e^{-19}$	Phosphate levels are significantly different, possibly from fertiliser or sewage intrusion.
NO_3^-	4,378,615.32	$3.216e^{-19}$	Significant nitrate differences confirm the impact of oil.
SO_4^{2-}	31,036,954.25	$9.031e^{-22}$	Highest F-value; large variability in sulfate across sites.
Cu	3,535.73	$6.093e^{-10}$	Copper levels also vary significantly, possibly due to corrosion or metal pollutants.
Fe	572,651.03	$1.438e^{-16}$	Significant iron contamination, especially in sample B.

The extremely low p-values and high F-statistics confirm that site location (likely to be related to varying oil contamination levels) has a statistically significant effect on all tested soil parameters. This justifies further ecological and remediation studies, especially in highly impacted zones (like Sample B), which supports the research hypothesis that oil-contaminated sites in Bayelsa State alter environmental quality and potentially plant species composition.

Figure 2 illustrates spatial variations in physicochemical parameters across the three oil-impacted sites in Bayelsa State, Oloibiri, Ikarama, and Agudama. Notably, Ikarama exhibited the highest levels of electrical conductivity (COND), total dissolved solids (TDS), and key pollutants such as ammonium (NH_4^+), phosphate (PO_4^{3-}), nitrate (NO_3^-), and sulphate (SO_4^{2-}), indicating severe hydrocarbon contamination likely from active or historic oil spills. Oloibiri also showed elevated values, though less intense than Ikarama, while Agudama consistently recorded the lowest parameter concentrations, suggesting relatively lesser impact. These trends reflect a pollution gradient across the sites and support the conclusion that anthropogenic oil activities significantly alter water chemistry, with implications for soil health and vegetation structure in this environment

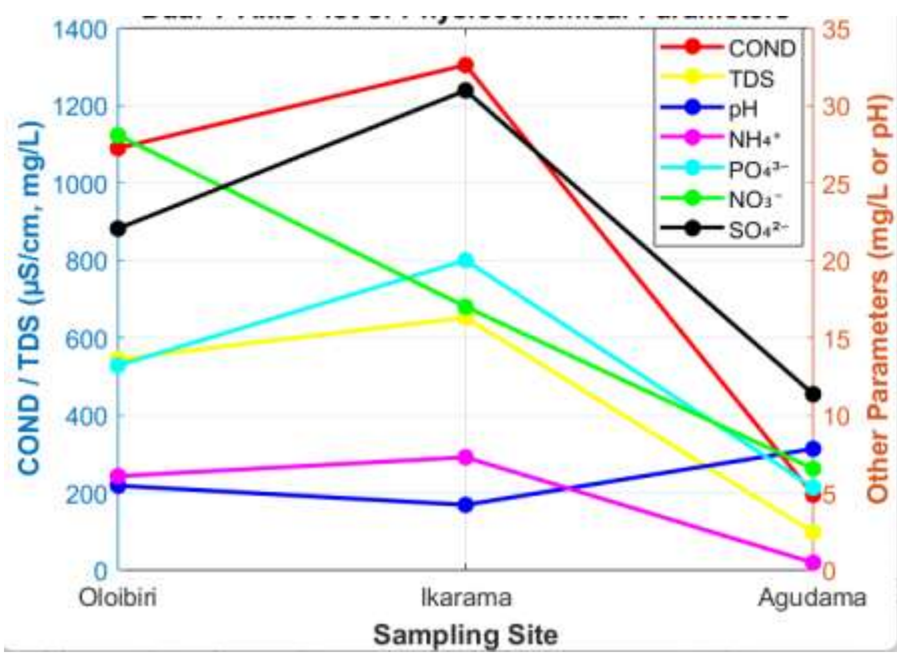

Figure 2:: Physicochemical Parameters Across Oloibiri, Ikarama, and Agudama.

Figure 3 displays the nutrient profile across the three sampling sites, showing distinct spatial variation, highlighting the impact of oil-related disturbances. Oloibiri exhibited the highest concentration of nitrate (NO_3^-) at nearly 29 mg/L, likely resulting from hydrocarbon degradation and nutrient-rich runoff. Ikarama, on the other hand, recorded the highest levels of phosphate (PO_4^{3-}) and ammonium (NH_4^+), indicating active microbial decomposition and possible secondary contamination from agricultural or domestic sources. In contrast, Agudama presented the lowest concentrations for all three nutrients, suggesting

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minimal anthropogenic influence or more advanced natural recovery. The declining nutrient gradient from Oloibiri and Ikarama to Agudama further supports the classification of these sites into heavily, moderately, and slightly impacted zones, information critical for prioritising remediation and monitoring efforts.

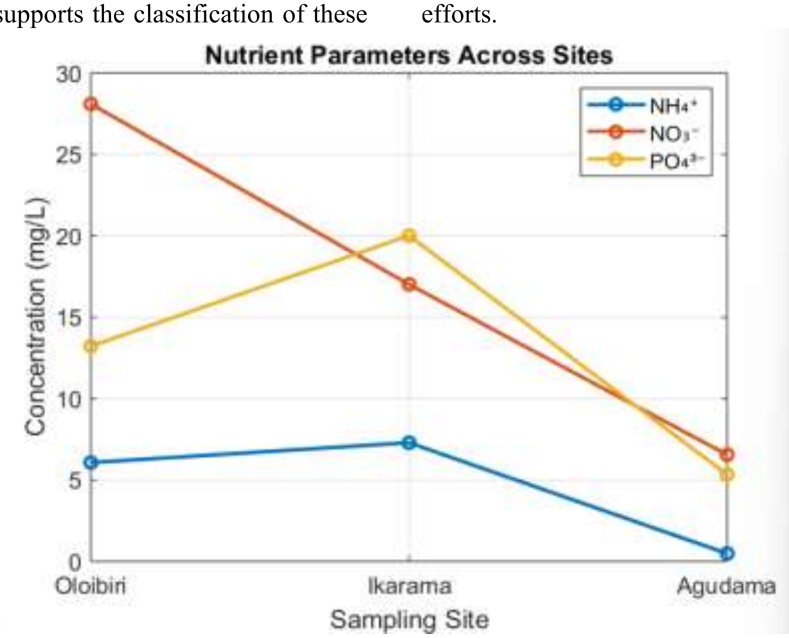

Figure 3: showing variations in nutrient concentrations (NH_4^+, NO_3^-, and PO_4^{3-}) across three oil-impacted sites in Bayelsa State, Oloibiri, Ikarama, and Agudama.

Figure 4 illustrates the results of metal concentration analyses in various locations, highlighting that Ikarama recorded the highest levels of both iron (Fe) and copper (Cu). Specifically, Fe levels in Ikarama reached an alarming 5.01 mg/L, a figure that significantly surpasses the World Health Organisation/Nigeria Institute of Soil (WHO/NIS) threshold of 0.3 mg/L, which is considered safe for contaminated soils. In contrast, Agudama exhibited the lowest concentrations of these metals, suggesting a comparatively lesser degree of contamination in that area. The notably elevated levels of Fe and Cu found in Oloibiri and Ikarama can be attributed primarily to the extensive oil-related activities prevalent in the region. This includes not only the direct impacts of oil extraction but also the potential environmental consequences stemming from leaching processes associated with corroded infrastructure and the improper disposal of drilling waste. Such findings underscore the urgent need for remediation efforts and further investigation into the lasting effects of industrial activities on soil quality and public health.

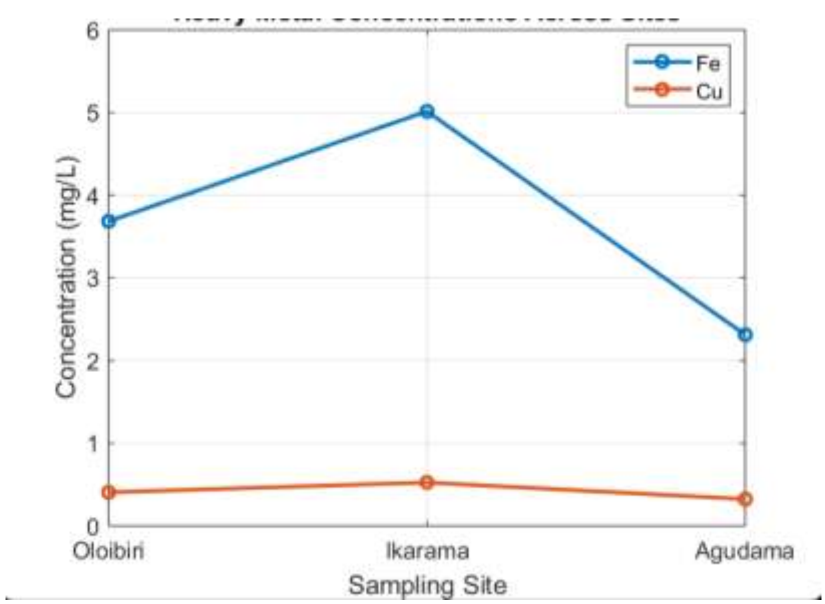

Figure 4: Concentrations of heavy metals, Iron (Fe) and Copper (Cu), across (Oloibiri, Ikarama, and Agudama).

4.0 CONCLUSION AND RECOMMENDATIONS

This research provided an in-depth environmental assessment of three oil-impacted sites in Bayelsa State, Oloibiri, Ikarama, and Agudama, by analysing total petroleum hydrocarbons (TPH), nutrient concentrations, heavy metals, and key physicochemical parameters. Results showed a clear pollution gradient, with Ikarama being the most contaminated (TPH ≈ 5,150 mg/kg; Fe = 5.01 mg/L; PO_4^{3-} = 20.01 mg/L), followed by Oloibiri, and Agudama as the least impacted site. Several parameters, including Fe, NH_4^+, NO_3^-, TDS, and COND, exceeded WHO and NIS environmental safety thresholds.

Statistical analysis confirmed that site differences were highly significant ($p < 0.05$), underscoring the influence of oil contamination on water and soil quality. These variations are directly linked to the degree of anthropogenic disturbance and provide a scientific basis for understanding the resilience and adaptive capacity of plant species naturally occurring in these environments.

Communities in oil-impacted areas should be engaged in small-scale planting of tolerant plants to speed up natural recovery and reduce soil erosion. Training programs can help local farmers and youth understand the value of these plants in soil care and recovery.

Priority should be given to Ikarama and Oloibiri, where contamination levels (especially Fe, NH_4^+, and TPH) exceed environmental safety limits. Techniques such as bioremediation, phytoremediation, and soil washing should be considered.

The environmental data from this study should serve as a baseline for evaluating plant community structure, guiding further research on species that tolerate or accumulate pollutants for ecosystem restoration. These findings are vital for guiding future restoration and phytoremediation efforts in the Niger Delta.

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