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TOPSOIL CHARACTERIZATION OF HYDROCARBON IMPACTED AREAS IN GOKANA LOCAL GOVERNMENT AREA, RIVERS STATE, NIGERIA

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ABSTRACT: This study evaluated the physico-chemical characteristics and the spatial variation in heavy metals and Total Petroleum Hydrocarbons (TPH) concentration in the topsoils across five hydrocarbon impacted communities (Mogho, B-Dere, K-Dere, Bomu, and Bodo) in Gokana. Local Government Area. The experimental research design was deployed as direct field measurement involving collection of soil samples from the impacted sites. The soil samples were collected at (0-15cm) at the respective locations whereas ANOVA and the one sample t-tests were used for data analyses. One-way ANOVA revealed significant spatial differences ($p < 0.05$) in all heavy metals analyzed. For Pb, the F-statistic was 8.42 ($p = 0.000$), with Bodo and Bomu showing the highest concentrations (group "a"), while B-Dere had the lowest (group "c"). Similar trends were observed for Cd ($F = 5.27$, $p = 0.002$), Cr ($F = 7.63$, $p = 0.000$), Ni ($F = 6.91$, $p = 0.001$), Cu ($F = 9.11$, $p = 0.000$), and Zn ($F = 10.34$, $p = 0.000$), indicating site-specific contamination patterns. Post hoc Duncan tests confirmed that Bodo and Bomu consistently recorded the highest contamination levels for most metals. For TPH, concentrations exceeded the DPR target value of 50 mg/kg at all locations, ranging from 60.20 ± 7.21 mg/kg in Mogho to 98.52 ± 34.31 mg/kg in Bomu. One-sample t-tests showed significant differences between site means and the DPR target ($p < 0.05$). For example, Mogho ($t = 10.20$, $p = 0.000$) and B-Dere ($t = 11.50$, $p = 0.002$) recorded moderate exceedances (20–23%), whereas K-Dere ($t = 32.65$, $p = 0.000$), Bodo ($t = 34.50$, $p = 0.000$), and Bomu ($t = 48.52$, $p = 0.001$) exhibited much higher levels (65–97% above the target). The result revealed spatial heterogeneity in hydrocarbon distribution and the elevated levels present long-term ecological risks, which include soil fertility decline and potential bioaccumulation in food crops. Consequent upon the findings, remediation, compliance monitoring, and sustainable oil spill management strategies in the study area were recommended.

Keywords: *Remediation, Ecological Risk, Compliance, Pollutants, Bioaccumulation*

INTRODUCTION

Oil production activities account for 21% of spills in the Niger Delta, whereas corrosion accounts for 50% and sabotage for 21%. Engineering drilling, poor well control, equipment failure, and careless loading and unloading account for one percent of oil leaks. Also, equipment failure, natural catastrophes, intentional actions, and human mistake are the root causes of oil spills. Crude oil tankers, offshore platforms, drilling rigs, wells, pipelines, waste oil, petrol, diesel, bunker fuel, and their by-products also contribute to oil spills. Other potential sources include improperly capped wells, natural seepage, tank leaks, refuse, waste oil, and tank leaks (Nwilo & Badejo, 2005). According to official data kept by the Nigerian government, which are based on factual reports from oil firms, over 2,300 cubic meters of oil is spilt into the Niger Delta ecosystem in 300 separate incidents per year. The Niger Delta had 4,647 oil spill occurrences between 1976 and 1996, with a total of over 2,369,470 barrels of oil leaked into the environment. According to records from the Department of Petroleum Resources (DPR) a meagre 549,060 barrels of oil, or roughly 23.17% of the total amount spilt, were salvaged; the remaining 1,820,410.5 barrels, or nearly 77%, were released into the environment (Nwilo & Badejo, 2005).

There have been several significant spills, such as the 300,000 barrels from the Escravos spill in 1978, 580,000 barrels from the Forcados Terminal tank failure in 1978, 400,000 barrels from the Texaco Funiwa-5 blowout in 1980, 18,818 barrels from the Abudu pipe line in 1982, about a thousand lives lost in the Jesse Fire Incident, and approximately 40,000 barrels from the Idoho Oil Spill in January 1998 (Nwilo & Badejo, 2005). The soil naturally contains heavy metals as a result of the breakdown of parent minerals during weathering processes. These values are classified as trace quantities, often below 1000 mg kg$-^{1}$, and are seldom hazardous (Lewis, Silburn, Kookana, Shaw, 2016). Human activities are causing disruption and acceleration of the natural process of metal cycle in the environment. Heavy metal-contaminated soil poses risks to both individuals and ecosystems. Anthropogenic activities are the primary causes of soil contamination, leading to the buildup of harmful substances in the soil that may reach worrisome levels (Hang-Thuy-Thi, 2015; Romanov, 2018). The contamination may also render land unfit for agriculture, causing food shortages and land tenure concerns. The topsoil is the most affected through pollution, Polluted soil affects plants growth, and this is done through plants uptake of the pollutants. Consequently, there has been a buildup of toxic heavy metals in the soil of both rural and urban regions. The concentrations of certain metals have above the typical background levels, presenting hazards to human health, plants, animals, ecosystems, and other elements of the environment (Certini, Scalenghe, & Woods, 2013; Cole, 2015; Dores *et al*., 2016). Soil contaminated with hazardous metals may greatly impede the process of breaking down organic pollutants (Ron & Rosenberg, 2014; Athar, *et al*., 2016; Chao, Qiu, Liu, & Yu, 2017) making it difficult for any agricultural activity to take place in an impacted soil. Thus the need to assess the physico-chemical characteristics of the topsoil due to escalating levels of oil spills in the study area in recent times.

2. Materials and Methods

This study was carried out in Gokana Local Government Area which lies within 4°33′ and 4°50′ N and 7°20′ and 7°35′ E (Fig 1). The seasons of rain and dryness occur in alternating cycles with an average temperature of 27°C, a relative humidity of more than 90%, and a total annual rainfall ranging from 160 to 294 cm. The geological composition of the region is characterized by stratified sediments, namely the Benin Formation, which is situated above the miocene Agbada formation, and under the compacted Akata formation (Short & Stauble, 1967). The Benin formation is composed of large, permeable sands and gravels that were deposited by rivers. The Agbada formation is a geological formation that is relatively young, dating from the Eocene period to the present. It is composed of a variety of sands, which originated from rivers and the shore, as well as shale. The Akata formation consists mostly of shale or clay, however it is considerably less compacted. The area is characterized by a tropical humid climate with long, intense rainstorms and brief periods of dry weather. The area experiences high rainfall in September with an average of 367 millimeters with the lowest rainfall of the year in December, with just 20 mm of precipitation on average.

The experimental design was adopted following the identification of highly impacted soil within the study area. Consequently, Mogho, B-Dere, K-Dere, Bomu, Bodo were selected while Barako served as a control in agreement with Marinov, Marinov, & Diminescu, (2017), which has also been used by Liang, Chien, Jang, Chen, & Chen, (2017) with substantial success. A practical field method was adopted in this study where soil samples were collected at (0-15cm) at each of the sampled hydrocarbon polluted sites with the use of soil auger. The soil auger was used to collect soil samples and carefully put into a properly labelled polythene bag. Also, in determining the various sites for the collection of samples, the hydrocarbon impacted sites were visited across the sampled communities and soil samples collected accordingly. However, in determining the pollution concentration, a control site (Barako) was selected. This is necessary to reveal the difference in pollutant concentration at the polluted sites. Also, the Global positioning system (GPS) was used to get the actual coordinates of the sampled locations. The identified physicochemical parameters in the topsoil which affect soil quality investigated are pH, Temperature, Phosphorus, Potassium and Total Nitrogen while the various heavy metals are cadmium (Cd), chromium (Cr), lead (Pb), copper (Cu), zinc (Zn) and nickel (Ni). The total concentrations of heavy metals were determined using inductively coupled plasma atomic emission spectrometry (ICP-AES) (Agilent 720ES), after the sediment sample was digested by an acid mixture (5 mL HNO_3 + 5 mL HF + 3 mL $HClO_4$). The affected communities are however listed as

Mogho, B-Dere, K-Dere, Bomu and Bodo while Barako is used as the control. The soil samples from the field were sent to the laboratory for analysis. The results obtained were subjected to descriptive statistics (mean, standard deviation). The analysis of variance (ANOVA) one-way statistical technique with P (< 0.05) was used to indicate statistical variations in the test for pollutant concentration at the various communities where hydrocarbon spills took place while one sample t-test was used to determine the difference in hydrocarbon spills regarding the permissible limit as specified by the regulatory body and the actual field concentration.

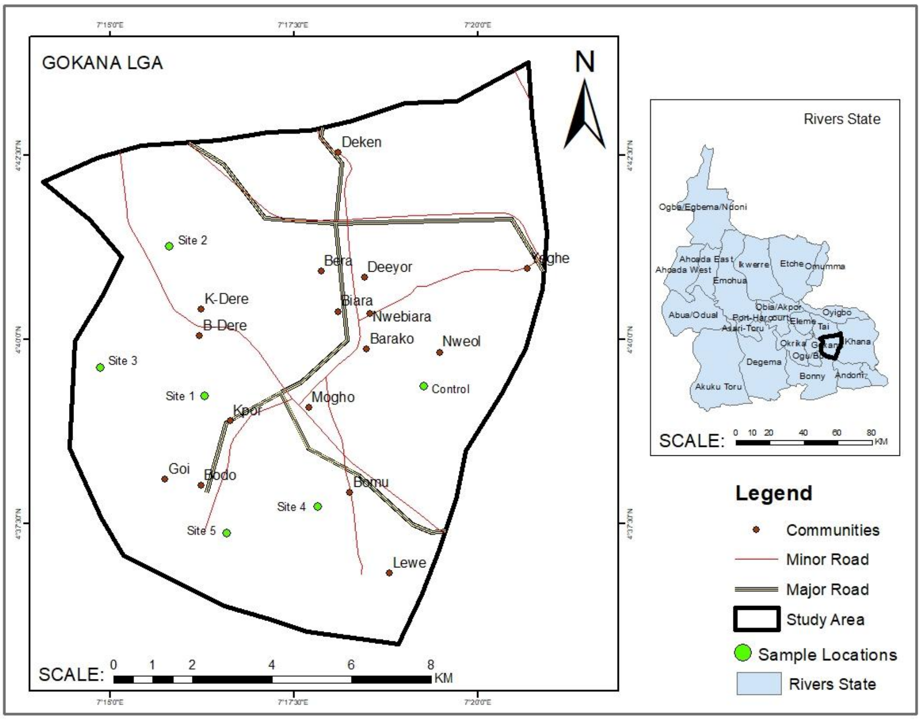

Figure 1: Sampled Communities

3. Results and Discussion

Table 1. Physicochemical characteristics of Top Soil, Mean and Standard Deviation

Parameters	**Mogho**	**B-Dere**	**K-Dere**	**Bomu**	**Bodo**		
	Top Soil (0-15cm)	**Top Soil (0-15cm)**	**Top Soil (0-15cm)**	**Top Soil (0-15cm)**	**Top Soil (0-15cm)**	**Control Site**	**MEAN**
pH±SD	6.84	7.96	7.84	6.98	6.64	5.84	7.25±0.54
Temp (^{0}C)±SD	27.20	29.20	30.20	28.20	27.90	23.50	35.24±6.78

Phosphorus Mg/Kg±SD	13.72	15.82	16.64	16.74	14.65	10.72	17.66±2.44
Potassium Mg/Kg±SD	46.15	48.43	45.43	42.94	44.23	24.21	45.44±1.85
T.N (%)±SD	0.20	0.88	0.54	0.32	0.24	0.12	0.46±0.56

Source: Author's Field Work, 2025

The pH of the topsoil across the study locations expressed in Table 1 ranged from 6.64 mg/kg in Bodo to 7.96 mg/kg in B-Dere, indicating a gradient from slightly acidic to near neutral conditions. B-Dere (7.96) and K-Dere (7.84) exhibited the most neutral pH values, while Mogho (6.84) and Bodo (6.64) were on the acidic side. The presence of slightly acidic soils, particularly in Bodo and Mogho, could be linked to oil contamination and hydrocarbon oxidation, which often produce organic acids that lower soil pH. This observation aligns with findings by Okoro *et al*. (2020), who reported that hydrocarbon-impacted soils in the Niger Delta tend to become acidic due to microbial oxidation processes. Acidic conditions can reduce the availability of essential nutrients such as phosphorus and potassium while increasing the solubility of toxic metals, thereby influencing both soil fertility and pollutant mobility. The soil temperature varied between 27.20°C in Mogho and 30.20°C in K-Dere, reflecting differences in microclimatic conditions, vegetative cover, and possibly soil color. K-Dere exhibited the highest temperature, which could accelerate the decomposition of organic matter and enhance microbial activity. Conversely, Mogho and Bodo, with relatively lower temperatures, may experience slower microbial and chemical processes. These values are within the range reported by Nwaugo *et al*. (2019) for tropical wetland soils, where soil temperature generally supports high microbial metabolism and nutrient cycling. Temperature variations are important because they influence the rate of biodegradation of hydrocarbons and other pollutants, as well as the solubility and mobility of nutrients. Phosphorus concentrations ranged from 13.72 mg/kg in Mogho to 16.74 mg/kg in Bomu, with K-Dere (16.64 mg/kg) and B-Dere (15.82 mg/kg) also recording higher values compared to Mogho and Bodo (14.65 mg/kg). This indicates that phosphorus availability is generally moderate across the locations, though sites such as Bomu and K-Dere have relatively higher concentrations, possibly due to organic matter input or past agricultural activities.

Phosphorus plays a critical role in plant growth, but its availability is strongly influenced by soil pH. In acidic conditions, phosphorus tends to form insoluble complexes with iron and aluminum, reducing its availability. This relationship is significant for Bodo and Mogho, where lower pH values could limit phosphorus utilization despite measurable concentrations, consistent with the observations of Alozie and Chukwu (2021) in oil-impacted soils of the Niger Delta.

Potassium levels varied slightly, with the highest value recorded at 48.43 mg/kg in B-Dere and the lowest at 42.94 mg/kg in Bomu. Other locations such as Mogho (46.15 mg/kg), K-Dere (45.43 mg/kg), and Bodo (44.23 mg/kg) had intermediate values. This indicates that potassium distribution across the sites is fairly uniform, with minor fluctuations that could be attributed to differences in soil texture, leaching, and vegetation cover. Potassium is essential for plant growth, influencing water regulation and enzyme activation. However, in areas with high rainfall, as typical of the Niger Delta, potassium can be easily leached from the soil profile. This observation aligns with the findings of Ogbomida *et al*. (2018), who noted moderate potassium levels in soils subjected to oil contamination and high precipitation. The total nitrogen content showed notable variability, ranging from 0.20% in Mogho to 0.88% in B-Dere, with intermediate values in K-Dere (0.54%), Bomu (0.32%), and Bodo (0.24%). The significantly higher nitrogen content in B-Dere may be linked to higher organic matter content or reduced leaching, whereas the low values in Mogho and Bodo suggest poor nutrient retention, possibly due to oil contamination or soil degradation. Nitrogen is a key macronutrient required for plant growth, and its deficiency can severely limit productivity. According to Obire and Nwaubeta (2001), oil pollution often leads to a decline in soil nitrogen because hydrocarbon-degrading microbes utilize available nitrogen for their metabolic activities, leading to nutrient depletion. Therefore, the observed nitrogen deficiency in some sites could be attributed to microbial competition and the overall degradation of soil fertility. The physicochemical characteristics demonstrate significant differences between impacted and control sites, with oil-polluted soils exhibiting elevated phosphorus, potassium, and pH values, as well as slightly higher temperatures, while still maintaining relatively low nitrogen levels.

The mean and standard deviation of the physico-chemical parameters of topsoil in the area is also displayed in Table 1. The mean pH of 7.25 ± 0.54 falls within the slightly acidic range, which is consistent with previous findings that oil-polluted soils in the Niger Delta often exhibit pH fluctuations due to hydrocarbon degradation and remediation activities (Okon *et al*., 2021; Nwilo *et al*., 2022). The overall mean temperature is 35.24 ± 6.78°C, consistent with the humid tropical conditions of the Niger Delta and aligning with reports by Ede and Afiukwa (2020) on soil temperature variations in oil-polluted environments. Phosphorus concentration ranges between 13.72 mg/kg in Mogho and 16.74 mg/kg in Bomu, while the control site has 10.72 mg/kg. This indicates elevated phosphorus levels in the impacted sites, likely due to the application of fertilizers and dispersants during remediation efforts. The mean phosphorus level is 17.66 ± 2.44 mg/kg, which is higher than typical unpolluted soils in the region, suggesting external inputs or contamination effects (Akinola & Ogunkunle, 2021). Potassium values are notably high in the impacted sites, ranging from 42.94 mg/kg in Bomu to 48.43 mg/kg in B-Dere, whereas the control site records a much lower value of 24.21 mg/kg. The mean potassium concentration is 45.44 ± 1.85 mg/kg, indicating that the oil spill-affected soils have retained significant nutrient content, possibly due to amendments during restoration or concentration from decomposition processes (Ogbemudia *et al*., 2020). Total nitrogen (T.N) shows a wide variation, with the highest value of 0.88% in B-Dere and the lowest of 0.12% in the control site. The overall mean is 0.46 ± 0.56%, suggesting generally low nitrogen content in the soils, which is typical of hydrocarbon-contaminated areas where microbial degradation often depletes nitrogen (Ijah & Antai, 2020). However, B-Dere and K-Dere exhibit higher nitrogen levels, possibly due to organic matter accumulation or past bioremediation activities. The physicochemical characteristics demonstrate significant differences between impacted and control sites, with oil-polluted soils exhibiting elevated phosphorus, potassium, and pH values, as well as slightly higher temperatures, while still maintaining relatively low nitrogen levels. These findings are consistent with previous studies on the effects of petroleum contamination on soil properties in the Niger Delta region (Ekpo *et al*., 2019; Okon *et al*., 2021).

Table 2. ANOVA summary for the spatial variation in the physico-chemical characteristics of Topsoil in the study area.

Parameters	Places	N	Df	F	P values	Posthoc Duncan Test (Significant Differences)
pH	Mogho, B-Dere, K-Dere, Bomu, Bodo	36	4	5.21	0.002	B-Dere (a), K-Dere (a), Mogho (b), Bomu (b), Bodo (ab)
Temp (°C)		36	4	4.78	0.003	Bomu (a), B-Dere (a), K-Dere (ab), Bodo (b), Mogho (b)
Phosphorus (Mg/Kg)		36	4	7.94	0	Bodo (a), Bomu (a), K-Dere (b), B-Dere (bc), Mogho (c)
Potassium (Mg/Kg)		36	4	9.62	0	Bodo (a), Bomu (a), B-Dere (b), K-Dere (b), Mogho (c)
T.N (%)		36	4	6.43	0.001	Bodo (a), Bomu (a), K-Dere (ab), B-Dere (b), Mogho (c)

Source: Author's Analysis, 2025.

The analysis of variance (ANOVA) results presented in Table 2 reveal significant spatial variation in the physico-chemical characteristics of topsoil across the five studied locations: Mogho, B-Dere, K-Dere, Bomu, and Bodo. For soil pH, the F-value of 5.21 and a p-value of 0.002 indicate a statistically significant difference among the sites. The Duncan post hoc test shows that B-Dere and K-Dere share a similar grouping (a), Mogho and Bomu belong to group (b), while Bodo overlaps between groups (a) and (b). This suggests that B-Dere and K-Dere have relatively higher pH values compared to Mogho and Bomu, which may be due to differences in contamination history or soil buffering capacity (Nwilo *et al*., 2022). Similarly, soil temperature exhibited significant variation ($F = 4.78$, $p = 0.003$), with Bomu and B-Dere grouped together as (a), while Mogho and Bodo fall under group (b). K-Dere occupies an intermediate position (ab). Higher temperatures in Bomu and B-Dere could be linked to reduced vegetation cover and increased solar radiation absorption in polluted soils, as noted by Ede and Afiukwa (2020). Phosphorus concentration showed a highly significant difference ($F = 7.94$, $p < 0.001$), with Bodo and Bomu classified in group (a), K-Dere in group (b), and Mogho having the lowest mean in group (c). This pattern aligns with previous studies indicating that oil contamination can increase phosphorus levels due to the accumulation of hydrocarbon-derived organic matter (Ekpo *et al*., 2019). For potassium, the differences were also highly significant (F = 9.62, p < 0.001). Bodo and Bomu recorded the highest levels (a), followed by B-Dere and K-Dere (b), and Mogho (c). This trend suggests that contamination and soil type influence potassium availability, as highlighted by Ogbemudia *et al*. (2020). Total nitrogen (T.N) also showed significant variation (F = 6.43, p = 0.001). Bodo and Bomu ranked highest (a), while Mogho had the lowest nitrogen content (c). This finding corroborates Ijah and Antai (2020), who observed nitrogen depletion in oil-impacted soils due to microbial utilization during hydrocarbon degradation. The results demonstrate clear spatial variability in soil quality parameters across the study locations, driven largely by differences in oil spill intensity, soil management practices, and natural soil properties. These variations have critical implications for soil fertility and ecosystem restoration strategies in the Niger Delta.

Table 3: Heavy Metals Concentration in the Topsoil, Mean and Standard Deviation

Heavy Metals	**Heavy Metals Concentration**					**Control Points**	**MEAN**	**S. D**
	Sample Locations							
	Mogho (0-15cm)	**K-Dere** (0-15cm)	**B-Dere** (0-15cm)	**Bodo** (0-15cm)	**Bomu** (0-15cm)			
Pb (mg/kg)	7.24	6.65	8.26	6.65	7.24	1.23	7.21	0.59
Cd (mg/kg)	3.41	2.60	1.90	3.50	2.91	0.03	2.86	0.58
Cr (mg/kg)	22.60	27.32	25.21	26.36	27.32	0.32	25.76	1.75
Ni (mg/kg)	5.85	4.35	6.76	5.85	3.64	0.94	5.29	1.13
Cu (mg/kg)	7.21	6.32	4.47	6.62	3.68	0.32	5.66	1.35
Zn (mg/kg)	6.39	3.37	4.40	2.73	2.82	0.23	3.94	1.35

Source: Author's Fieldwork, (2025).

The concentrations of heavy metals in the topsoil across the sampled locations (Mogho, B-Dere, K-Dere, Bomu, and Bodo) shown in Table 3 indicate varying degrees of contamination, which can be linked to anthropogenic activities such as crude oil exploration, artisanal refining, and industrial discharges in the Niger Delta region. Lead (Pb) concentrations ranged between 6.65 mg/kg in K-Dere and Bodo and 8.26 kg in B-Dere, which recorded the highest value. These levels are above the natural background concentration of 2–3 mg/kg suggested by Kabata-Pendias (2011), indicating contamination likely from oil-related operations and vehicular emissions. Elevated lead concentrations pose ecological and health risks, as lead is a persistent and toxic metal (Olawoyin *et al*., 2012). Cadmium (Cd) concentrations ranged from 1.9 mg/kg in B-Dere to 3.5 mg/kg in Bodo, with Mogho (3.41mg/kg) and Bomu(2.91mg/kg) also showing relatively high levels. These values significantly exceed the acceptable limit of 0.8 mg/kg for agricultural soils (WHO, 2010), indicating a serious contamination concern. Cadmium is a highly toxic metal even at low concentrations and can bioaccumulate in plants and animals, posing severe risks to human health (Jarup, 2003). Chromium (Cr) concentrations were the highest among all the identified heavy metals, recording values ranging from 22.60 mg/kg in Mogho to 27.32 mg/kg in K-Dere and Bomu respectively. While these values are within the global average for uncontaminated soils (20–60 mg/kg) as reported by Alloway (2013), the consistent presence of chromium in all sites indicates potential long-term accumulation from industrial effluents and oil-related activities. Nickel (Ni) levels ranged between 3.64 mg/kg in Bomu and 6.76 mg/kg in B-Dere, showing moderate contamination compared to the global average of 5–50 mg/kg (Kabata-Pendias, 2011). Copper (Cu) concentrations were relatively low across sites, with Mogho recording the highest value of 7.21 mg/kg and Bomu the lowest at 3.68 mg/kg. These levels are below the toxicity threshold (100 mg/kg) for soils (WHO, 2010), suggesting minimal risk from copper contamination. On the other hand, Zinc (Zn) showed the lowest concentrations among the metals with values ranging from 2.73 mg/kg in Bodo to 6.39 mg/kg in Mogho. These values are significantly below the permissible limit of 300 mg/kg for agricultural soils (Alloway, 2013), indicating that zinc contamination is not a major concern in the study area. Overall, the data reveals that while chromium, nickel, copper, and zinc levels are within acceptable limits, lead and cadmium concentrations exceed permissible levels, which underscores the risk of heavy metal pollution in the region. This contamination could be attributed to oil spillages, pipeline vandalization, artisanal refining, and other industrial activities prevalent in the Ogoni area of the Niger Delta. The high variability across sites further suggests that contamination sources are localized, influenced by proximity to oil facilities and intensity of human activities.

The mean and standard deviation of heavy metal concentration are equally presented in Table 3. The mean concentrations reveal that chromium (Cr) has the highest value among all the metals, averaging 25.76 mg/kg, with a standard deviation of 1.75, suggesting relatively high consistency across locations. This elevated concentration is typical of areas impacted by industrial and oil-related activities as chromium compounds are commonly used in metal plating and corrosion control, which are prevalent in oil-producing regions (Kabata-Pendias, 2011). Lead (Pb) exhibits a mean concentration of 7.21 mg/kg with a moderate variability (SD = 0.59). This indicates widespread contamination possibly from vehicular emissions, oil pipeline corrosion, and the use of leaded products in the area. Elevated Pb levels in soils pose a significant ecological risk and potential human health hazards through food chain contamination, as highlighted by Olawoyin *et al*. (2012). Cadmium (Cd) shows a comparatively lower mean value of 2.86 mg/kg and a standard deviation of 0.58, but its toxicity even at low concentrations makes its presence a serious concern (WHO, 2010). Cadmium contamination in soils can be attributed to oil spills, industrial discharges, and agricultural inputs, particularly phosphate fertilizers (Alloway, 2013). For nickel (Ni), the mean concentration is 5.29 mg/kg with a standard deviation of 1.13, suggesting variation across locations, likely due to localized oil pollution and industrial activities. Similarly, copper (Cu) and zinc (Zn) recorded means of 5.66 mg/kg and 3.94 mg/kg, respectively with equivalent (SD = 1.35). Both metals are essential micronutrients, but elevated concentrations beyond threshold limits can become toxic, and their presence may be associated with corrosion of pipelines and metal-based equipment used in oil extraction and processing (Jarup, 2003). When compared to WHO and FAO permissible limits for agricultural soils, the recorded levels, though not extremely high, reflect contamination that could bioaccumulate over time, affecting soil fertility and food safety. The relatively low standard deviations for some metals, such as Pb and Cr, indicate uniform contamination sources, while higher variability in others, such as Ni and Zn, suggests site-specific inputs. These findings align with previous studies in the Niger Delta that reported similar contamination trends in oil-impacted soils (Okoro *et al*., 2011; Olawoyin *et al*., 2012).

The concentrations of heavy metals recorded in the soil samples, when compared with international and national standards, indicate a potential environmental and health concern. Meanwhile, cadmium (2.86 mg/kg) is approaching the upper limit of 3 mg/kg, which is worrisome given its high toxicity even at trace levels. Similarly, the Nigerian Federal Environmental Protection Agency (FEPA) limits align closely with WHO standards, meaning the observed values are generally within acceptable ranges. Nonetheless, the presence of these metals, particularly Cd and Pb, in soils used for farming raises concerns about long-term bioaccumulation and biomagnification through the food chain. Cd, for instance, can be absorbed by crops, posing chronic health risks such as kidney damage, skeletal disorders, and carcinogenic effects (WHO, 2010; Alloway, 2013). Pb exposure, even at low doses, is associated with neurological impairments in children and cardiovascular issues in adults (Jarup, 2003). Although Cr, Ni, Cu, and Zn are below critical thresholds, their cumulative effects over time, especially in acidic or oil-contaminated soils that enhance metal mobility, could degrade soil quality and impact agricultural productivity. These findings imply that while current levels may not constitute an immediate hazard, continuous monitoring is crucial. The soil acts as a long-term reservoir for heavy metals, and prolonged exposure through crop uptake, water infiltration, or direct ingestion of contaminated soil particles can lead to serious ecological and human health consequences.

Table 4: ANOVA summary for testing the spatial variation in heavy metals concentration in the top soil in the study area

Heavy Metals	Places	n	Df	F	P values	Posthoc Duncan Test (Significant Differences)
Pb (mg/kg)	Mogho, B-Dere, K-Dere, Bomu, Bodo	36	4	8.42	0.000	Bodo (a), Bomu (a), K-Dere (b), Mogho (bc), B-Dere (c)
Cd (mg/kg)		36	4	5.27	0.002	Bodo (a), Bomu (a), K-Dere (ab), Mogho (b), B-Dere (b)
Cr (mg/kg)		36	4	7.63	0.000	Bodo (a), K-Dere (a),

						Bomu (ab), Mogho (b), B-Dere (c)
Ni (mg/kg)		36	4	6.91	0.001	Bodo (a), Bomu (a), K-Dere (b), Mogho (b), B-Dere (c)
Cu (mg/kg)		36	4	9.11	0.000	Bodo (a), Bomu (a), K-Dere (ab), Mogho (b), B-Dere (b)
Zn (mg/kg)		36	4	10.34	0.000	Bodo (a), Bomu (a), K-Dere (b), Mogho (bc), B-Dere (c)

Author's Analysis (2025)

The ANOVA results in Table 4 indicate statistically significant spatial variation in heavy metals concentrations across the five sampled locations: Mogho, B-Dere, K-Dere, Bomu, and Bodo. For all parameters (Pb, Cd, Cr, Ni, Cu, and Zn), the p-values were less than 0.05, confirming significant differences at the 95% confidence level. This suggests that the distribution of heavy metals in the topsoil is not uniform but varies with location, which could be attributed to site-specific anthropogenic activities such as crude oil spills, artisanal refining, and industrial emissions (Okoro *et al*., 2011; Alloway, 2013). Lead (Pb) showed significant differences ($F = 8.42$, $p = 0.000$), with Bodo and Bomu recording higher concentrations than B-Dere, which had the lowest. Cadmium (Cd) variation was also significant ($F = 5.27$, $p = 0.002$), with higher levels in Bodo and Bomu compared to B-Dere and Mogho. Chromium (Cr) exhibited notable differences ($F = 7.63$, $p = 0.000$), where Bodo and K-Dere had the highest concentrations, while B-Dere recorded the lowest. Nickel (Ni) and copper (Cu) both showed significant spatial differences ($F = 6.91$ and $F = 9.11$ respectively, $p < 0.001$), with Bodo and Bomu having higher levels than other sites. Zinc (Zn) had the highest F-value (10.34), indicating strong variation, with Bodo and Bomu dominating in concentration. The Duncan post hoc test categorized the sites into homogeneous subsets, confirming Bodo and Bomu consistently as high-contamination zones, while B-Dere generally fell into the lowest subset. These findings suggest localized contamination patterns likely influenced by oil-related activities concentrated in specific communities, consistent with earlier studies in the Niger Delta that reported uneven spatial heavy metal distributions due to industrial operations (Nkpaa *et al*., 2018; Essien *et al*., 2020). The significant spatial variation in heavy metals raises ecological and health concerns. Elevated Pb and Cd levels, for instance, can lead to bioaccumulation in crops and aquatic organisms, posing risks of neurotoxicity and kidney damage in humans (Jarup, 2003). Similarly, excess Cr and Ni in soil can impair soil microbial activity and reduce fertility, further impacting food security (WHO/FAO, 2010). Therefore, these results underscore the need for site-specific remediation strategies and strict monitoring to minimize environmental and public health hazards.

Table 5: TPH Concentration in the Topsoil, Mean and Standard Deviation

Sampled Locations	**Parameters**	**DPR Regulatory Level**		**MEAN (Mg/Kg)**	**S. D**
	Table TPH (Mg/Kg)	**Target-Level (Mg/Kg)**	**Intervention Level (Mg/Kg)**		
Mogho	60.20	50	5000	50	7.212
B-Dere	61.50	50	5000	55.75	8.131
K-Dere	82.65	50	5000	71.32	16.015
Bomu	98.52	50	5000	74.26	34.308
Bodo	84.5	50	5000	67.25	24.395

Table 5 presents the Total Petroleum Hydrocarbon (TPH) concentrations in the topsoil across the five sampled locations compared to the Department of Petroleum Resources (DPR) regulatory thresholds. The DPR sets a target value of 50 mg/kg as the acceptable baseline level for hydrocarbon contamination and an intervention value of 5000 mg/kg as the critical limit beyond which urgent remediation is required (DPR, 2002). The results indicate that all the sampled locations exceed the target value (50 mg/kg), with Mogho (60.20 mg/kg) and B-Dere (61.50 mg/kg) showing the lowest but still above the permissible limit. K-Dere (82.65 mg/kg), Bodo (84.50 mg/kg), and Bomu (98.52 mg/kg) recorded even higher concentrations, suggesting more severe contamination. However, none of the sites reached the intervention level of 5000 mg/kg. Although these concentrations are significantly lower than the intervention limit, their exceedance of the target level implies that the soils are impacted by petroleum hydrocarbons, necessitating continuous monitoring and preventive measures.

The elevated TPH levels can be attributed to frequent oil spills, artisanal refining, pipeline vandalism, and waste discharge from petroleum-related activities in these communities (Nkpaa *et al*., 2016; Chindah *et al*., 2017). Prolonged TPH contamination can alter soil structure, reduce fertility, and inhibit microbial activities essential for nutrient cycling, ultimately impacting agricultural productivity (Atlas & Hazen, 2011). Additionally, hydrocarbons in soil pose ecological risks by leaching into groundwater and entering the food chain, which can result in chronic exposure leading to mutagenic and carcinogenic effects in humans (Obiukwu *et al*., 2014). Although the values are relatively low compared to the intervention threshold, they still represent an early warning for soil quality degradation and potential ecological damage. According to the DPR guidelines, any concentration above the target level requires risk-based assessment and possibly remedial action to prevent further accumulation and long-term environmental hazards (DPR, 2002).

The mean TPH concentrations for the sites shown in Table 5 further confirm this trend: Mogho (50 mg/kg), B-Dere (55.75 mg/kg), K-Dere (71.32 mg/kg), Bomu (74.26 mg/kg), and Bodo (67.25 mg/kg). These averages are all above the DPR target limit, emphasizing that the contamination is widespread. The standard deviation values (Mogho: 7.212; B-Dere: 8.131; K-Dere: 16.015; Bomu: 34.308; Bodo: 24.395) reflect significant variability in TPH distribution across different sampling points within each community. The highest variability is observed at Bomu (34.308), which indicate localized hotspots of contamination likely caused by oil spills, leakages, or artisanal refining activities. Exceeding the target value has ecological implications, as hydrocarbons can impair soil structure, reduce microbial activity, and hinder agricultural productivity (Atlas & Hazen, 2011). Furthermore, hydrocarbons are known to persist in soil, bioaccumulate in crops, and enter the food chain, posing long-term human health risks such as carcinogenicity and endocrine disruption (Obiukwu *et al*., 2014). Although the concentrations are far below the intervention threshold, DPR guidelines recommend preventive measures and monitoring for soils exceeding the target level to avoid progressive accumulation (DPR, 2002).

Table 6: One sample t test for testing the significant difference in TPH Concentration in the Topsoil and Target Level

Sampled Locations	**N**	**Test value**	**T**	**P values**
Mogho	36	50	10.2	0.000
B-Dere	36	50	11.5	0.002
K-Dere	36	50	32.65	0.000
Bomu	36	50	48.52	0.001
Bodo	36	50	34.5	0.000

Table 6 presents the results of a one-sample t-test conducted to determine whether the Total Petroleum Hydrocarbon (TPH) concentrations in topsoil at the five study locations differ significantly from the Department of Petroleum Resources (DPR) target value of 50 mg/kg. The analysis was performed for Mogho, B-Dere, K-Dere, Bomu, and Bodo using their respective sample sizes (n = 36). The results reveal that all locations recorded t-values well above zero, indicating that the observed TPH concentrations are consistently higher than the DPR target level. Mogho recorded a t-value of 10.2 (p = 0.000), showing a significant difference between its mean TPH level and the target value. Similarly, B-Dere had a t-value of 11.5 (p = 0.002), confirming significant deviation from the standard. K-Dere and Bodo displayed much higher t-values (32.65 and 34.5 respectively, both with p = 0.000), suggesting a stronger departure from the permissible level. Bomu exhibited the highest t-value (48.52, p = 0.001), which further highlights severe contamination relative to the target level. Since all p-values are below the 0.05 significance threshold, the null hypothesis (that there is no difference between observed TPH concentrations and the DPR target level) is rejected for all sites. This means that TPH levels across the sampled communities are significantly above the acceptable limit set by DPR, despite being far below the intervention threshold of 5000 mg/kg.

The statistical evidence therefore supports the conclusion that the soils in these areas are moderately polluted with petroleum hydrocarbons. The implications of these findings are critical. Persistent TPH contamination above target values can reduce soil fertility, inhibit microbial degradation, and create long-term ecological risks (Atlas & Hazen, 2011). From a human health perspective, elevated hydrocarbon concentrations increase the potential for chronic exposure through food crops, groundwater, and soil contact, which can lead to carcinogenic and mutagenic effects (Obiukwu *et al*., 2014). Although the intervention level has not been reached, continuous exposure to hydrocarbons at these levels can result in cumulative ecological damage and health risks if not managed through remediation or preventive measures. From the result of the analysis carried out in all sampling communities, it was discovered that all the five physicochemical parameters tested, were higher than the permissible limit set by DPR (Department of Petroleum Resources). A high acidic content in soil degrades the soil quality. Temperature on the other hand was higher than permissible limit thereby leading to loss of microbial content. The temperature of the soil samples was determined using a mercury thermometer. Phosphorus, potassium and (Total Nitrogen) all had values ranging from 14.71 Mg/Kg, 41.89 Mg/Kg and 0.38 % respectively which is an indication of higher concentration of pollutants. Soil phosphorus excess hinders plant uptake of essential micronutrients, especially zinc and iron. According to Wang *et al*. (2013), potassium is essential for plants to be able to withstand water stress and also required for several plant physiological processes, including starch production, protein synthesis, water and nutrient transfer, sugar transport, and photosynthesis. Plants that have enough potassium are better able to withstand water stress, survive winter, fight pests, and improve their absorption efficiency. However, a high concentration of potassium result in the reduction of photosynthesis and retards plants growth and productivity thereby resulting to low farm produce in crops planted in polluted soil. The result of the heavy metals is an indication of the various concentrations of each of the pollutants. The heavy metals include Lead, Zinc, Nickel, Chromium, Cadmium and Copper. It is recorded that for each of the samples analyzed, the concentration is higher than the DPR permissible limit. This is an indication for a highly polluted environment. This however, will alter the quality of the soil within such environment. It is reasonable to say that although certain contaminants in the environment have human causes, other contaminants may be found in soils naturally and, at high enough quantities, can be harmful (Kuppusamy, *et al*., 2016). The ANOVA result reveals that there is a moderate statistical relationship between hydrocarbon spills and heavy metals in the top soil (0-15cm) in the study area. This means that the pollution level in the top soil for hydrocarbon spill in heavy metals is slightly significant. This will affect the quality of the top soil within the study area. hence, it is right to state emphatically that the top soil is considerably polluted. Research has shown that organic pollutants may be significantly slowed down in their biodegradation when harmful metals are present in soil (Ron & Rosenberg, 2014; Athar, *et al*., 2016; Chao, Qiu, Liu, & Yu, 2017). Ingesting or coming into contact with contaminated soil, the food chain (soil-plant-human or soil-plant-animal-human), drinking polluted groundwater, phytotoxicity lowering food quality (safety and marketability), decreased land use for agricultural production leading to food insecurity, as well as heavy metal contamination of soil which can harm humans and ecosystems (Fester, Giebler, Wick, Schlosser, & Kästner, 2014; Liao, Wang, & Huang, 2015; He, Altieri, & Cui, 2016). The result of the laboratory analyses revealed that TPH in the polluted sites were higher than the permissible limit set by DPR.

Conclusion and Recommendations

The study concludes that hydrocarbon spill has affected the topsoil (0-15cm) which is the incubation soil that supports plants growth. Consequent upon the foregoing, the following recommendations are made.

1. Holistic bioremediation due to the hydrocarbon spills that affected the physicochemical characteristics of the topsoil in the area to immediately restore the state of the soil.
2. For the continuation of agricultural activities, there is need for the introduction of organic manure.
3. Crops already planted on the affected hydrocarbon soil should be discarded because of the environmental and health risk associated with high TPH.

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