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Profiling of Hydrocarbon-Impacted Soil from Selected Ogoni Communities, Rivers State, Nigeria

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ABSTRACT
The contamination of soil by hydrocarbons is a threat to environmental and human health around the world. This study was conducted to profile total petroleum hydrocarbons (TPH) in soils of Gokona Local Government Area of Rivers State, Nigeria. Soil samples were collected from depths ranging from 0 cm to 6 m. The concentrations of TPH in the samples were determined using Gas Chromatography-Flame Ionisation Detection (ASTM D3921-96). All analysis and presentation of data were done using Microsoft Excel 2016 and sigma plot. Total petroleum hydrocarbon (TPH) concentrations in soil showed wide variability with depth. At 0–15 cm, values ranged from 62.03–12,031.62 mg/kg, while 15–30 cm recorded 121.64–31,854.25 mg/kg. Concentrations at 30–45 cm were 7.24–38,558.40 mg/kg, and 45–60 cm ranged from 12.74–151,950.00 mg/kg. Higher levels were observed at 60–75 cm (1.21–204,119.80 mg/kg) and 75–90 cm (0.07–300,745.00 mg/kg). Beyond 1 m, concentrations generally declined, with 0.00–55 mg/kg,194.90 mg/kg at 1 m, 0.00–80,250.00 mg/kg at 2 m, and 0.00–6,426.25 mg/kg at 6 m. The values for most sampling points exceeded the regulatory Environmental Guidelines and Standards for Petroleum Industry's recommended Total Value of 50 mg/kg and the Intervention Value of 5000 mg/Kg, indicating potential environmental and human health risks. Remediation actions are recommended.

Keywords:
Crude Oil Spill, TPH, Soil, Pollution

INTRODUCTION

The deleterious impact of hydrocarbon pollution on ecosystems and human well-being has made it a major worldwide issue, especially in soil contamination. Some areas have a lot of activity related to oil exploration and production, making this problem more severe (Ezugwu *et al.*, 2022). Due to several oil spills and other circumstances that have caused the build-up of petroleum hydrocarbons in the soil, Ogoniland has been a focus point for environmental deterioration caused by oil for many years (Okoye *et al.*, 2024). Total Petroleum Hydrocarbons (TPH) is a critical matrix for assessing petroleum contamination in the environment. Petroleum-derived hydrocarbons or TPHs, are a large class of chemical substances that represents the total measurable amount of petroleum-based hydrocarbons in an environmental sample like soil, water, or air. It's a broad term used to assess the overall level of petroleum contamination (Kuppusamy *et al.*, 2020). These chemicals can vary in weight from heavier materials like polycyclic aromatic hydrocarbons to lighter hydrocarbons like methane, ethane, and propane (PAHs). To gauge the level of hydrocarbon pollution in the environment, TPH is frequently utilised (Abena *et al.*, 2019). The environment is exposed to TPH due to a variety of sources, such as unintentional oil spills, storage tank leaks, incorrect oil product disposal, and industrial discharges related to the distribution and refining of oil (Almutairi, 2022). The case study here is the extensive oil extraction operations in Ogoniland that have elevated TPH contamination to a level of serious environmental threat (Jaja & Obuah, 2019).

Hydrocarbon pollution has a serious and complex negative influence on the ecosystem, when it comes in contact with soil, it changes the structure of the soil, lowering the availability of nutrients, and suppressing microbial activity. TPH pollution in the soil can lower the fertility of agricultural land (Zuzolo *et al.*, 2021).

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Through leaching, this contamination also impacts groundwater, lowering water quality, it also endangers the aquatic habitat. Water contaminated with TPH has the potential to be hazardous to aquatic life, upsetting the food chain and creating long-term ecological imbalances (Waluyo *et al.,* 2020). Hydrocarbons not only contaminate water and soil, but they also significantly affect air quality. Hydrocarbons have the ability to volatilize and produce smog and other air pollutants that have an adverse effect on the environment and human health (Ihunwo *et al.,* 2021).

There are major health hazards associated with hydrocarbon pollution for humans. Depending on the amount and kind of hydrocarbon involved, extended exposure to TPH and other petroleum compounds can cause a number of health problems (Adipah, 2019). Skin contact with volatile hydrocarbons can result in dermatological diseases, while inhaling them might induce respiratory issues (Kuppusamy *et al.,* 2020). Prolonged exposure to specific hydrocarbons, especially polycyclic aromatic hydrocarbons, has been associated with carcinogenic effects on the liver, kidneys, and lungs (Hu *et al.,* 2022). These health hazards are made worse in places where locals are constantly exposed to contaminated soil, water, and air as a result of oil spills and related pollutants (Okoye *et al.,* 2024). The aim of this study is to profile the hydrocarbon-impacted soil in selected Ogoni communities of Rivers State, Nigeria.

MATERIALS AND METHODS

Study Area

Gokana, a significant Local Government Area in Ogoniland, Rivers State, Nigeria, was the location of the study. Gokana, which is in the Niger Delta, is distinguished by a system of rivers and creeks as well as vegetation typical of a tropical rainforest. Widespread environmental deterioration has resulted from frequent oil spills and substantial oil prospecting in the region. The main economic activities include small-scale trading, fishing, and agriculture; nevertheless, these livelihoods have been negatively impaired by oil contamination. Gokana is a choice location for evaluating the effects of hydrocarbon contamination on the environment and human health due to its close proximity to significant oil production sites. Within the study area, soil samples were collected from a total of sixteen (16) sampling sites. Using a soil auger, samples were taken from depths ranging from 0 cm to 6 m (0-15 cm; 15-30 cm; 30-45 cm; 45-60 cm; 60-75 cm; 75-90 cm; 1 m; 2 m; 3 m; 4 m; 5 m and 6 m). In order to produce a uniform sample, the samples were homogenised after being allowed to air dry for five days. The samples were then ground and sieved using a 2 mm mesh screen and stored in amber bottles for extraction and analyses of TPH.

Table 1. Coordinates of sampling points

CODE	Sampling points	LONGITUDE	LATITUDE
SS1	CA POINT 1	7°15'0.93"	4°41'47.02"
SS2	CA POINT 11	7°14'58.69"	4°41'46.69"
SS3	CA POINT 14	7°14'58.10"	4°41'49.29"
SS4	CAT2	7°14'55.19"	4°41'48.37"
SS5	CAT3	7°14'56.10"	4°41'46.75"
SS6	CAT4	7°14'58.18"	4°41'44.37"
SS7	CAT5	7°15'0.16"	4°41'44.61"
SS8	CAT6	7°15'3.15"	4°41'43.90"
SS9	EPH1	7°15'4.24"	4°41'47.29"
SS10	EPH2	7°15'3.36"	4°41'48.85"
SS11	EPH3	7°15'1.09"	4°41'49.72"
SS12	HES2	7°14'59.46"	4°41'51.57"
SS13	HES3	7°15'3.45"	4°41'51.74"
SS14	HES4	7°15'5.47"	4°41'49.05"
SS15	HES5	7°15'4.34"	4°41'45.72"
SS16 Control	SS16 Control	7°15'10.80"	4°41'43.56"

Figure 1 shows the map of the study area with the sampling locations indicated.

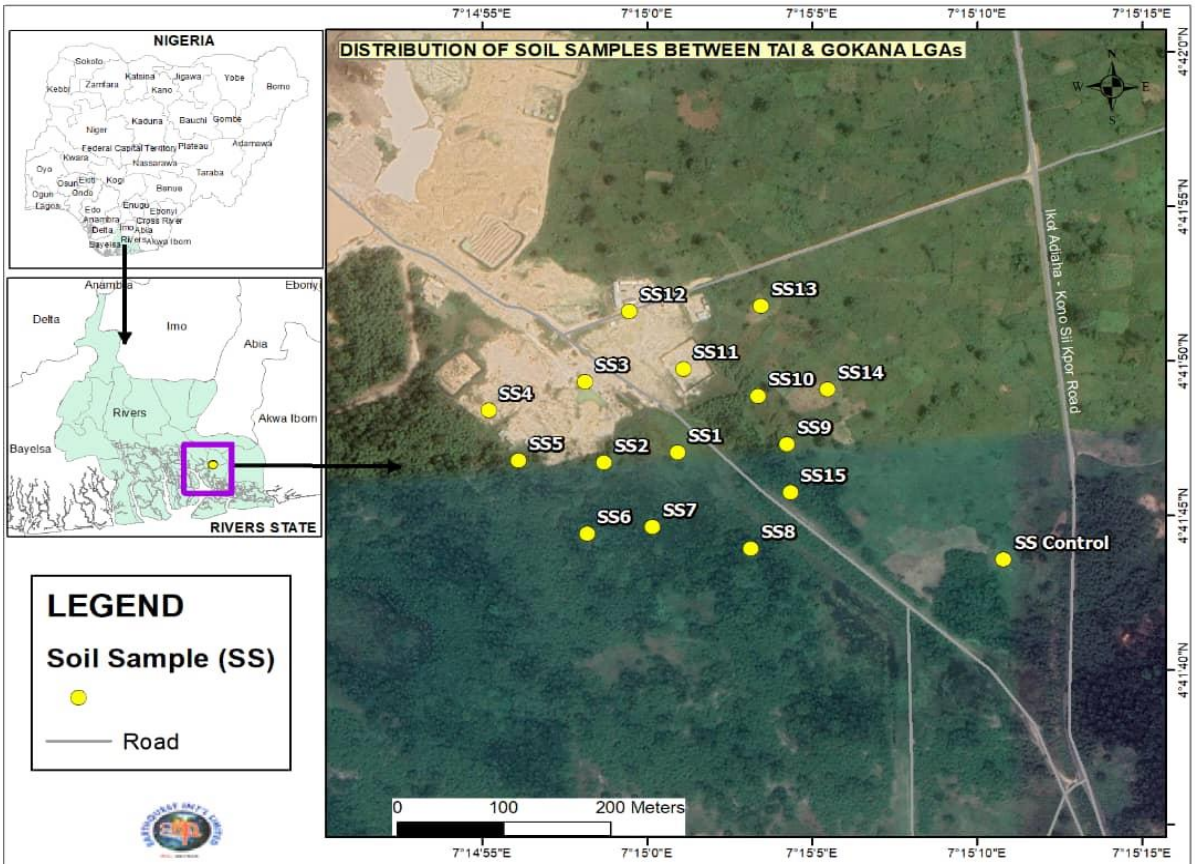

Figure 1: Map of the study area with sampling locations

Analytical Procedures

Total petroleum hydrocarbon (TPH) was analysed as described by Alinnor and Nwachukwu (2013). Anhydrous sodium sulphate (4 g) was added to an amber glass container after ten grammes (10g) of the prepared soil sample had been weighed in. Next, the mixture was given a stir. After adding a standard of 300µg/ml of surrogate (1-chlorooctadecane), 30ml of dichloromethane was added. After being corked, the bottle was left to sit at room temperature for 6 h in a mechanical shaker. The sample was then allowed to sit for 1 h and filtered into a beaker. A fume cupboard was used to concentrate the filtrate to 1ml overnight by evaporation. Sample clean-up was done with a glass column constructed by inserting glass cotton, silica gel slurry with dichloromethane, anhydrous sodium sulphate and pentane in the column. The sample extract was put to the column along with cyclohexane. Pentane was used to elute the sample into a beaker that was positioned beneath the column. After elution, the sample was put in a fume cabinet and left there overnight. Compounds in the eluent were separated and detected using an Agilent 6890N Gas Chromatograph - Flame Ionization Detector. Using the micro-syringe, using nitrogen as carrier gas, 1µl of the eluted sample was injected into the injector of the GC. The gas chromatography was operated under conditions according to US EPA method 8015B.

RESULTS AND DISCUSSION

The concentrations of TPH in the samples are presented in Table 2. The concentrations of TPH at the various depths ranged as follows: The concentration of TPH in soil varied considerably with depth. At 0–15 cm, values ranged from 62.03 to 12,031.62 mg/kg, while at 15–30 cm, the range increased to 121.64 to 31,854.25 mg/kg. At 30–45 cm, concentrations ranged from 7.24 to 38,558.40 mg/kg**,** and at 45–60 cm, from 12.74 to 151,950.00 mg/kg**.** At greater depths, very high variations were observed, with 60–75 cm ranging from 1.21 to 204,119.80 mg/kg**,** and 75–90 cm from 0.07 to 300,745.00 mg/kg. Beyond 1 m, TPH concentrations generally declined, with ranges of 0.00–55 mg/kg,194.90 mg/kg (1 m)**,** 0.00–80,250.00 mg/kg (2 m)**,** 0.00–7,462.56 mg/kg (3 m)**,** 0.00–23,280.00 mg/kg (4 m)**,** 0.00–6,433.26 mg/kg (5 m)**,** and 0.00–6,426.25 mg/kg (6 m)**.**The Department of Petroleum Resources recommends a target limit of 50 mg/kg for TPH in soil (Ibeto & Nwuga, 2018).

Table 2: Concentrations of TPH in the soil samples

Sampling Point	mg/kg											
	0-15	15-30	30-45	45-60	60-75	75-90	1M	2M	3M	4M	5M	6M
CA POINT 1	308.84	6099.17	16686.46	14980.60	15240.00	300745.00	8.52	0.81	0.00	0.00	0.00	0.00
CA POINT 11	523.75	121.64	6775.15	429.71	31372.20	141999.70	6425.42	194.20	99.61	5.14	0.00	0.00
CA POINT 14	6457.83	6723.76	38558.40	151950.00	204119.80	69.19	73.42	309.68	124.92	977.31	32.62	9.05
CAT2	6883.07	6428.53	7.24	19.01	3.37	0.07	0.03	0.09	0.01	0.01	0.00	0.00
CAT3	3522.50	7070.30	756.59	81.36	4.13	0.96	0.00	0.00	0.00	0.00	0.00	0.00
CAT4	6457.02	14998.70	2203.29	8061.81	872.49	12.42	0.85	0.00	0.00	0.00	0.00	0.00
CAT5	7197.43	5646.46	414.66	58.82	1.21	0.72	0.00	0.00	0.00	0.00	0.00	0.00
CAT6	12031.62	31854.25	2448.55	18.64	3.57	1.86	0.64	0.00	0.00	0.00	0.00	0.00
EPH1	62.03	238.42	737.37	30.08	417.09	747.07	722.56	1151.28	7462.56	4285.14	6433.26	6426.25
EPH2	964.22	1393.71	732.12	44724.14	1590.35	2373.62	47891.58	17945.30	508.62	23280.04	5.21	0.00
EPH3	463.99	963.42	5043.05	42530.90	6542.58	65199.30	11.25	1.44	0.00	0.00	0.00	0.00
HES2	765.94	1857.94	6422.48	12.74	1.58	0.35	0.00	0.00	0.00	0.00	0.00	0.00
HES3	1056.84	1214.51	248.73	644.84	947.89	314.08	55194.90	80250.00	6784.04	12.06	0.84	0.00
HES4	7097.46	778.14	59.33	42.75	6.09	0.55	0.00	0.00	0.00	0.00	0.00	0.00
HES5	912.69	991.96	624.32	9758.52	5184.74	20529.03	33046.60	1.32	0.00	0.00	0.00	0.00

Figure 1: Map of the study area with sampling locations

Contamination at Various Depths

Significant hydrocarbon contamination was found in both surface and subsurface strata at different depths, according to the findings. The upper soil layers (0–15 cm) at several sampling sites have the highest levels of contamination, which suggests recent oil spills or continuous surface pollution. CAT6 has a high degree of contamination (12,031.62 mg/kg), while CAT5 and CAT4 have comparable amounts of surface contamination (7,197.43 mg/kg and 6,457.02 mg/kg, respectively). Previous studies in the study area have recorded similar TPH concentrations (Azuka *et al.*, 2023; Okoye *et al.*, 2024). This pattern indicates that production-related leaks and oil spills are recent since hydrocarbons tend to build up in the topsoil when they are newly deposited. The adsorption characteristics of the soil and the sluggish downward transport of hydrocarbons because of natural soil barriers or restricted rainfall infiltration could be responsible for the concentration of hydrocarbons in these top soil layers (Abena *et al.*, 2019). Numerous sample sites exhibit contamination peaks between 15 and 90 cm in depth. CA POINT 14 displays 151,950 µg/kg at 45–60 cm, while CA POINT 1 reaches its maximum level of 300,745.00 µg/kg at 75–90 cm. These values far exceed those which have been recorded in previous investigations (Chikere *et al.*, 2019; Gbarakoro & Bello, 2022). These higher concentrations at deeper depths point to possible hydrocarbon leaching over time as a result of groundwater movement, rainfall, and soil permeability. The hydrocarbons seem to have accumulated in particular soil strata, maybe as a result of soil composition changes (the presence of clay or organic matter, for example, might trap toxins) (Almutairi, 2022). This also suggests past pollution episodes in which hydrocarbons have descended but have been prevented from doing so by less permeable layers, allowing them to build up over time (Wu *et al.*, 2022).

Most places in deeper levels (over 1 metre) have a dramatic decline in the hydrocarbon concentration. At CA POINT 1 contamination drops from 8.52 µg/kg at one metre to 0 µg/kg at two metres. These results are similar to those of Jason-Ogugbue *et al.* (2019) The marked decrease indicates that the more profound soil layers have not been significantly impacted by oil spills. This was

probably because impermeable barriers like clay exist in the deeper soil layers, which limit the downward movement of hydrocarbons (Hoang *et al.,* 2021). Hydrocarbons can be found at deeper levels in some regions, including HES3 and EPH1, where HES3 shows 55,194.90 µg/kg at 1 metre and 80,250 µg/kg at 2 metres, which are similar to the results of Azuka *et al.* (2023). This pattern may point to the possibility of soil fractures or cracks that have allowed hydrocarbons to infiltrate deeper, as well as the possibility of past pollution that has gradually seeped downward (Zuzolo *et al.*, 2021).

Variability Across Sampling Points

There is a noticeable variation in the amount of hydrocarbon contamination at different sampling sites, and there are clear patterns that indicate to different pollution sources, soil types, and environmental factors. One of the most notable trends, for example, can be seen in CA POINT 1, where the concentration peaks at 75–90 cm (300,745.00 mg/kg) and then drops down dramatically at 1m and upwards. This pattern implies that hydrocarbons have accumulated below the surface, maybe as a result of particular characteristics of the soil that prevent further transport (Nwankwoala *et al.,* 2020). On the other hand, CA POINT 14 exhibits consistently high contamination levels at a number of depths, with a peak of 151,950 mg/kg at 45–60 cm. This pattern suggests that the pollution in this location might be more widespread, with hydrocarbons eventually seeping into deeper levels through soil fissures or porous layers (Kim *et al.,* 2022). This may further affect other physicochemical properties and heavy metals of the aquifer within this area (Agbogidi et al., 2024).

Relatively lower levels of contamination are seen in CAT2 and CAT3, with CAT2 having a maximum concentration of 6,883.07 µg/kg at 0–15 cm and minor contamination at other depths. This points to limited surface pollution, most likely caused by recent spills, and raises the possibility that the soil in this location is less porous, which would hinder hydrocarbons from migrating deeper (Nwankwoala et al., 2020). However, CAT6 shows substantial levels of contamination at both intermediate and surface depths (12,031.62 µg/kg at 0–15 cm), indicating recent and continuing pollution episodes that have enabled hydrocarbons to penetrate into the subsurface layers.

Conversely, several point, such as EPH1 and EPH2, display peculiar patterns with higher contamination at lower depths. In contrast, EPH2 exhibits considerable contamination at 45–60 cm (44,724.14 µg/kg) as well as at deeper levels (23,280.04 µg/kg at 4 metres). For instance, EPH1 exhibits continuously rising contamination from 1 to 6 metres (e.g., 7,462.56 µg/kg at 3 metres and 6,433.26 µg/kg at 5 metres). These patterns imply that hydrocarbons might have been carried lower by groundwater or have seeped deeper through fractures. The greater levels in these deeper depths may be the result of earlier pollution that has moved over time due to soil fractures or water movement (Kokah *et al.,* 2019).

The complicated nature of soil contamination in Gokana is highlighted by the variation in hydrocarbon concentration among sampling stations. Hydrocarbon distribution is greatly influenced by localised characteristics such as the frequency of oil spills, the nature of the soil, permeability, and the existence of fractures (Chen and Tien, 2020). Higher pollution is seen at sampling points CA POINT 1 and CA POINT 14, which are closer to pipelines or facilities used for oil production. This indicates the direct effect of oil exploration activities. On the other hand, lower contaminated sites (CAT2, CAT3) probably represent less impacted places from oil spills, where the protective qualities of the soil have prevented hydrocarbons from migrating as far (Resen *et al.,* 2024).

CONCLUSION

The hydrocarbon-impacted soil investigation conducted in Gokana, Ogoni, reveals considerable contamination at different depths and locations, as well as a noticeable range in hydrocarbon contents. The findings show significant contamination in both surface and subsurface layers, especially in the vicinity of oil production activities. These pollutants are probably the consequence of both recent and past oil spills. Lower levels of contamination are often found in deeper soil layers, unless there are fractures or permeable soil that allow hydrocarbons to move even lower. This implies both long-term leaching and recent contamination incidents. The pollution puts the health of the local community at risk and creates serious environmental dangers to the quality of the land, water, and air. In order to reduce the continuous pollution in Gokana, the study made clear how urgently remediation work and stronger environmental regulations are needed.

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