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Migration Patterns of Petroleum Hydrocarbons across Soil Horizons in an Oil Spill-Affected Area of Mkpanak, Akwa Ibom State

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Abstract

This study investigated the vertical migration and contamination levels of total petroleum hydrocarbons (TPH) across the soil profile in Mkpanak Community, located in Ibeno Local Government Area of Akwa Ibom State, Nigeria. The objective was to assess the potential risk of groundwater contamination from surface petroleum pollutants, in alignment with baseline Environmental Impact Assessment (EIA) practices. Four sampling boreholes designated SP1, SP2, SP3, and SP4 were randomly established within the area affected by a documented oil spill. Soil samples were collected at 0.5-meter intervals down to a depth of 6.0 meters at each location. The samples were transported to the laboratory in labeled polythene bags, air-dried, ground, and sieved through a 2 mm mesh. Total hydrocarbon concentration was determined by extracting 10g of fresh soil with 20ml of toluene, followed by spectrophotometric analysis of the extract at 420 nm using a Supertonic 21-D spectrophotometer. TPH concentrations were calculated with reference to a standard calibration curve and adjusted for moisture content and dilution. Results revealed significantly high TPH concentrations at SP1, peaking at 40,645.00 mg/kg at 0.5 m depth, with a general trend of decreasing concentration with increasing depth. TPH values at 0.5 m for SP2, SP3, and SP4 were 3.38 mg/kg, 20.00 mg/kg, and 3.38 mg/kg, respectively. Spatial variation in TPH concentrations was notable: SP1 ranged from 3.38 to 40,645.00 mg/kg (mean 3710.65 ± 3083.36), SP2 from 3.38 to 80.00 mg/kg (mean 10.75 ± 5.87), SP3 from 3.38 to 190.00 mg/kg (mean 36.58 ± 16.21), and SP4 from negligible levels up to 105.00 mg/kg (mean 11.64 ± 7.90). The findings confirm that the soils in Mkpanak Community are significantly contaminated with petroleum hydrocarbons. This contamination, primarily a result of crude oil exploration and pipeline vandalism, poses considerable environmental, health, and socio-economic risks. The study highlights the urgent need for public awareness campaigns on the adverse impacts of oil pollution and calls for the implementation of robust mitigation and remediation strategies

Keywords: Hydrocarbons, oil spill, bore holes, soil contamination, Mkpanak.

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INTRODUCTION

The environmental impact of petroleum hydrocarbon contamination has become a growing concern, particularly in oil-producing regions of Nigeria such as the Niger Delta (Ukhurebor *et al*., 2021). Intensive oil exploration and production activities, coupled with frequent pipeline failures and illegal bunkering, have resulted in widespread and persistent pollution of terrestrial and aquatic ecosystems (Chukwuka *et al*., 2018). One of the most affected communities is Mkpanak in Ibeno Local Government Area of Akwa Ibom State an area heavily exposed to oil spills and related industrial discharges.

Total petroleum hydrocarbons (TPHs), which encompass a wide range of aliphatic and aromatic compounds, are among the primary pollutants released during oil exploration and transportation (Sah *et al*., 2022). Once introduced into the environment, these compounds can penetrate the soil surface and migrate vertically through the soil profile, potentially reaching and contaminating groundwater aquifers (Sun *et al*., 2019). This vertical transport poses serious environmental and public health risks, including soil infertility (Chiu *et al*., 2017), disruption of microbial communities (Du *et al*., 2025), and increased incidence of waterborne diseases (Cai *et al*., 2019) due to the deterioration of groundwater quality (Copetti *et al*., 2016).

The movement and retention of TPHs in soil are influenced by various factors such as soil texture, porosity, organic matter content, and the physicochemical properties of the hydrocarbons themselves (Wang *et al*., 2021). Monitoring their migration through the soil column is therefore essential for assessing the extent of subsurface contamination, predicting potential groundwater pollution, and guiding environmental remediation and policy interventions (Jiang *et al*., 2024).

This study investigates the vertical distribution and concentration of petroleum hydrocarbon contaminants in the soil profile of Mkpanak Community. The objectives are to assess the depth-wise migration of TPHs, evaluate the risk of groundwater contamination, and contribute to the broader environmental impact assessment framework for oil-producing communities. By providing empirical data on hydrocarbon distribution across soil layers, the study offers valuable insights for environmental scientists, policymakers, and stakeholders in sustainable oilfield management.

MATERIALS AND METHODS

Study Area

The study area encompasses the Mkpanak community situated in the Ibeno Local Government Area of Akwa Ibom State, Nigeria lies along the southern coast of Nigeria, bordered by the Atlantic Ocean to the south. It is geographically positioned at approximately 4.7272° N latitude and 7.8396° E longitude.

Geography

The geography of Mkpanak community is characterized by low-lying coastal terrain, with mangrove swamps and estuaries prevalent along the coastline. The soil composition is predominantly sandy, facilitating the movement of contaminants through the soil profile into

the groundwater. The proximity to the Atlantic Ocean also influences the climate and environmental dynamics of the region.

Climatic Conditions

Mkpanak community experiences a tropical maritime climate, characterized by high temperatures, humidity, and rainfall throughout the year. The wet season typically spans from April to October, with heavy rainfall contributing to soil erosion and surface runoff, potentially exacerbating the spread of contaminants. The dry season, from November to March, is marked by lower precipitation but higher evaporation rates, influencing groundwater recharge dynamics.

Economic History and Population

The economy of Mkpanak community has been historically reliant on fishing, agriculture, and more recently, hydrocarbon extraction activities facilitated by Exxon Mobil. The presence of the oil company has attracted migrant workers seeking employment opportunities, leading to fluctuations in the local population. However, socioeconomic disparities persist, with many residents facing challenges related to poverty, unemployment, and limited access to basic services.

Economic trees such as oil palm (*Elaeis guineensis*) and rubber (*Hevea brasiliensis*) dominate the area. Annual crops, chiefly cassavas are grown fairly extensively in the area. Pineapples, okra, maize and vegetables are also grown in farm plots.

Environmental Health and Sanitary Systems

The environmental health conditions in Mkpanak community are greatly influenced by the industrial activities of Exxon Mobil. While the company adheres to environmental regulations, concerns persist regarding contamination from hydrocarbon spills and leakage into the soil and groundwater. Sanitary systems are relatively basic, with limited access to clean water and sanitation facilities, exacerbating health risks for residents.

Determinants of Health

Several health determinants affect the health of individuals in Mkpanak community, including exposure to hydrocarbon contaminants, inadequate sanitation infrastructure, limited access to healthcare services, and socioeconomic factors. These determinants interact to shape the overall health outcomes of the population, with vulnerable groups such as children and the elderly being particularly at risk.

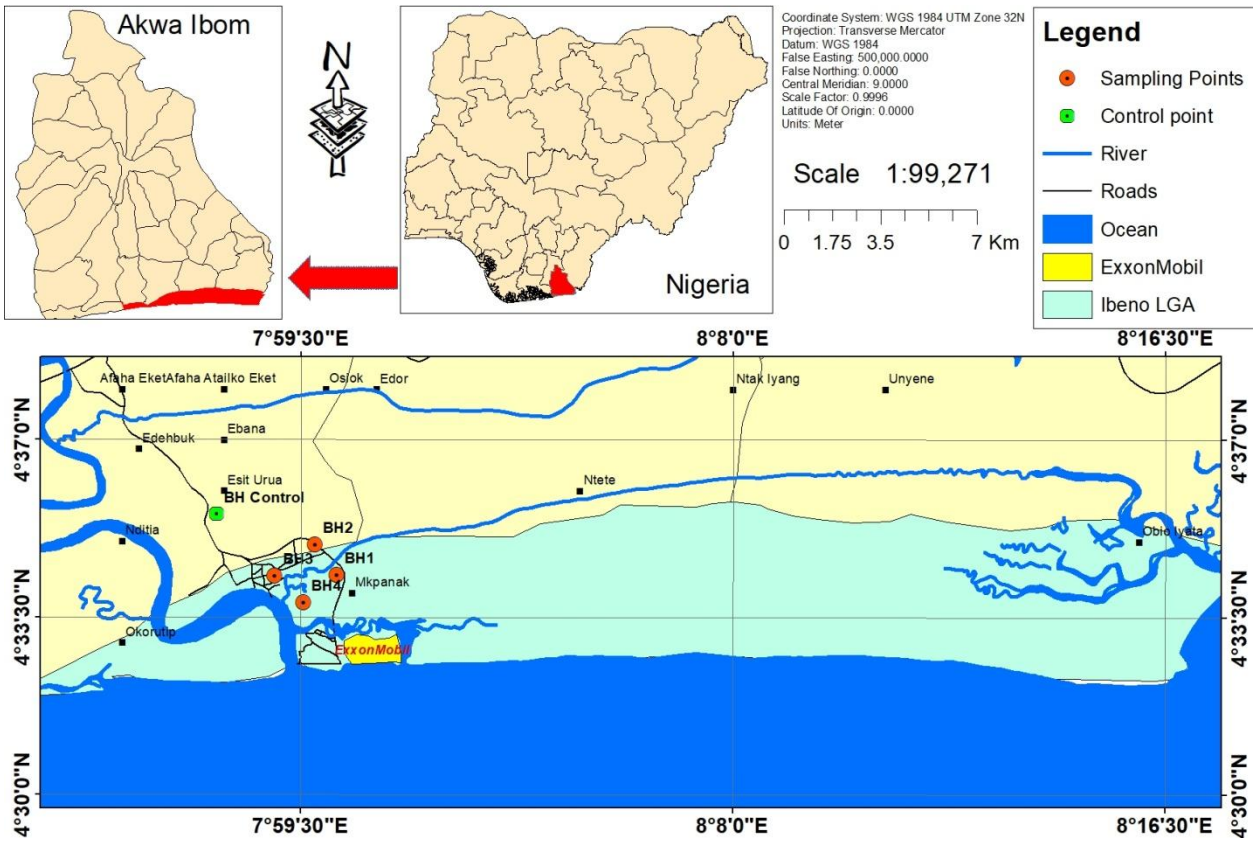


Figure 1: Study Area
Source: Geosat Consult 2024

Methodology (APHA, 1998; 2000)

Soil profile sampling

Soil samples were collected at 0.5m depth intervals during drilling of the site monitoring boreholes from 5 points; with borehole 5 (BH 5) as control borehole located outside the oil-impacted areas.

Collection of Groundwater samples

Groundwater samples were collected from the 5 boreholes (BH 1, BH 2, BH 3, BH 4) within the spill area and another borehole (BH 5 control) outside the spill area (which was used as control). Samples for THC content were collected in pre-rinsed 1-litre glass containers and sealed with aluminum foil for onward transfer to the laboratory for analysis.

In situ measurements in water samples

In situ measurements for water pH, dissolved oxygen (DO), turbidity, and electrical conductivity were made with the HORIBA U-10 Water Quality Checker that had been standardized with phthalate auto-calibration solution. Total dissolved solids (TDS) were also determined *in situ* electrometrically with HACH conductivity meter (Model CO 150) with an inbuilt automatic TDS measuring device. In each case, the probe of the instrument was immersed in water and the parameter values read off directly in mg/L from the LCD display screen.

Laboratory Analyses

Determination of Total Petroleum Hydrocarbon (THC) contents

TPH content was obtained by shaking 10g of a representative fresh soil sample with 20mL toluene and oil extracted was determined by absorbance at 420nm wavelength in a Spectronic 21-D spectrophotometer. Concentration was then calculated with reference made to the standard curve that was prepared using a known concentration of hydrocarbons in the extractant. Multiplication was made by the appropriate dilution factor (Concawe, 1972).

The oil in water samples was determined after pre-extracting 100mL sample with 10mL carbon tetrachloride, using HORIBA oil content analyzer (OCMA-200).

Five-Day Biological Oxygen Demand (BOD_5)

Biological oxygen demand was determined after 5 days incubation period at 20 ± 1 °C by measuring the DO of the water samples in the 250 ml brown bottles with pre-auto-calibrated (with standard phthalate solution) HORIBA U-10 Water Quality Checker.

Calculation

$$BOD_5 \text{ (mg/l)} = \frac{D_1 - D_2}{P}$$

Where
D_1 is initial dissolved oxygen
D_2 is dissolved oxygen after incubation period of 5 days, and
P is decimal fraction of sample used.

Nitrate ion (NO_3^-) concentrations

The cadmium reduction method was employed in the determination of nitrate levels in the water samples. A cadmium-based reagent pillow was added into 25mL of the water sample in a cuvette and shaken for 1 minute and allowed to stand for another 5 minutes for complete reaction to occur. The absorbance and concentration in mg/L was read at 500nm wavelength using HACH DR 2010 UV-visible spectrophotometer.

Sulphate ions (SO_4^{2-}) concentration

The barium chloride (Turbidometric) method was adopted. The barium chloride based powdered reagent pillow was added into 25mL of water sample. The mixture was properly mixed and allowed to stand for 5 minutes for reaction to occur. The absorbance and concentration in mg/L was read at 450nm wavelength using HACH DR 2010 UV-visible spectrophotometer.

Phosphate ions (PO_4^{3-}) (as total phosphorous) concentration

Total phosphorous was determined by the ascorbic acid method, which is a reaction between ammonium molybdate and potassium antimonyl tartrate with orthophosphate in an acid medium to form a heteropoly acid- phosphomolybdic acid. This was then reduced to intensely coloured molybdenum blue by ascorbic acid. The intensity of the colour, which is proportional to the phosphate concentration present as phosphorous, was measured with a spectrophotometer at a wavelength of 690 nm. The actual concentrations as determined from the calibration curve were recorded in mg/L.

Chloride ions (Cl^-) concentration

In the determination of the chloride content of water samples, the Argentometric method was employed

Reagents

a. **Potassium chromate (K_2CrO_4) indicator solution:** Five grams of K_2CrO_4 was added to 10ml-distilled water in a 50ml beaker. Drops of 0.014N $AgNO_3$ solution were added until a definite red precipitation was formed. The precipitate was allowed to stand for 12 hours, after which it was filtered and diluted to 10ml with distilled water.

b. **0.0141N standard silver nitrate:** This was prepared by dissolving 0.2395g $AgNO_3$ in 100ml-distilled water.

c. **0.0141N standard sodium chloride:** This was prepared by dissolving 82.4mg NaCl (dried at 140°C) in 100ml-distilled water.

Procedure

The pH of 60ml of the sample was first determined to be less than 7 and then adjusted to about 10 by adding drops of 1N NaOH solution. One millilitre of K_2CrO_4 indicator solution was added to 25ml of sample. This was followed with titration with $AgNO_3$ solution to a pinkish-yellow end point. For the standardization of the $AgNO_3$ solution, 25ml of distilled water containing the reagent (reagent blank) was also titrated with the $AgNO_3$ solution.

Calculation

Mg Cl/L= (A-B) x N x 35,450/Ml sample

Where A is ml titration for sample,
B is ml titration for blank,
N is normality of $AgNO_3$
Mg NaCl/l = (mg Cl^-/L) x 1.65

Total Hardness (Calcium and Magnesium Hardness)

The ASTM D807-52 (Titrimetric) method was used.

-Mg hardness:

Exactly 25mL of the sample was dilute to about 50mL in a conical flask and 2mL of buffer solution was added. Two drops of indicator solution (Eriochrome Black T) was added, and the standard EDTA titrant in the burette was titrated against the mixture from red to blue as end point and the volume recorded.

-Ca hardness:

Exactly 25mL of the sample was diluted to 50mL in a conical flask, and 2mL of 0.1N NaOH was added. One milliliter of mureoxide indicator was also added and the mixture stirred properly. The standard EDTA titrant in the burette was titrated against the mixture and volume used was recorded.

Calculations:

$$\textbf{Hardness } MgCaCO_3/L = \frac{\textbf{Titre value X 0.4 X 2.5 X 100}}{\textbf{Volume of sample}}$$

$$\textbf{Ca, Mg } CaCO_3/L = \frac{\textbf{Titre value X Normality of EDTA X } \frac{1}{2} \textbf{ Molar mass of Ca X 1000}}{\textbf{Volume of sample}}$$

And Mg, $MgCaCO_3/L$ =

$$\frac{\text{Titre value X Normality of EDTA X } \frac{1}{2} \text{ Molar mass of Mg X 1000}}{\text{Volume of sample}}$$

Exchangeable cations (Ca^{2+}, Mg^{2+}) and Fe

The atomic absorption spectrophotometric (AAS) method was used. The concentrations of acid and matrix modifiers were ensured to be same in both samples and standards. About 100 mL samples were diluted and mixed with 10 mL lanthanum solution before aspirating. At least 3 concentrations of each standard sample solution were selected. Blank was aspirated and the instrument (spectrophotometer) zeroed. Each standard was then aspirated in turn into flame and absorbance recorded. Calibration curves were then prepared by plotting on linear graph paper absorbance of standards versus their concentrations. The nebulizer was rinsed by aspirating water containing 1.5 mL conc. HNO_3/L. Blank was aspirated and instrument zeroed. Samples were then aspirated and their absorbance determined. Concentration of each metal ion in mg/L was calculated by referring to the appropriate calibration curve prepared.

Statistical Analysis

The SPSS© version 17.0 and MS Excel packages were used in the analysis data. Descriptive statistical analysis was used to obtain range, means, standard deviation, standard error as well as in the graphical presentation of the different parameters investigated. The test of homogeneity of variance in means of the variables was carried out using the one way ANOVA. Further structure detection was made with means plots. The interrelationships between the parameters were explored using the Pearson product moment correlation coefficient (r).

RESULTS

Concentrations of Total Petroleum Hydrocarbons (TPH) across Soil Profile

The Concentrations of Total Petroleum Hydrocarbons (TPH) across the soil profile of the study area are shown in Table 1.

At the surface level, total petroleum hydrocarbon (TPH) concentrations ranged from 3.38 mg/kg to 40,645.00 mg/kg. At a depth of 0.5 meters, concentrations varied between 3.38 mg/kg and 1,679.00 mg/kg, while at 1.0 meter, values ranged from 3.38 mg/kg to 1,514.00 mg/kg. At 1.5 meters, concentrations were slightly higher, ranging between 17.00 mg/kg and 1,778.00 mg/kg. At 2.0 meters, TPH levels ranged from 3.38 mg/kg to 1,193.00 mg/kg, while at 2.5 meters, concentrations declined to a range of 3.38 mg/kg to 252.00 mg/kg. Similarly, at 3.0 meters, TPH values ranged from 3.38 mg/kg to 313.00 mg/kg, and at 3.5 meters, they increased slightly, spanning 3.38 mg/kg to 419.00 mg/kg. At 4.0 meters, concentrations ranged between 3.38 mg/kg and 158.00 mg/kg, and at 4.5 meters, they declined further, ranging from negligible to 75.00 mg/kg. At 5.0 meters, TPH levels ranged from negligible to 140.00 mg/kg, while at 5.5 meters, values fell within the negligible to 69.00 mg/kg range. By 6.0 meters, TPH concentrations were minimal, ranging from negligible to 11.70 mg/kg.

Table 1: Concentrations of Total Petroleum Hydrocarbons (TPH) (mg/kg) in boreholes around a spill site

	Sampling points			
Depth(m) Soil Profile	BH1	BH2	BH3	BH4
0.0	40,645.00	3.38	20.00	3.38
0.5	1,679.00	80.00	3.38	4.00
1.0	1,514.00	3.38	8.00	3.38
1.5	1,778.00	17.00	74.00	22.00
2.0	1,193.00	3.38	124.00	105.00
2.5	252.00	3.38	190.00	3.38
3.0	313.00	3.38	3.38	3.38
3.5	419.00	3.38	3.38	3.38
4.0	158.00	3.38	3.38	3.38
4.5	75.00	4.11	3.38	Negligible
5.0	140.00	8.20	27.60	Negligible
5.5	69.00	3.38	3.38	Negligible
6.0	3.38	3.38	11.70	Negligible

BH =borehole

Table 1 shows Concentrations of Total Petroleum Hydrocarbons (TPH) (mg/kg) in boreholes around a spill site. There are four boreholes labeled BH1, BH2, BH3 and BH4.

Spatial variation in Concentrations of Total Petroleum Hydrocarbons

The concentrations of TPH across the sampling boreholes are shown in Figure 2. In Borehole1 (BH1), TPH concentrations varied from 3.38-40, 645.00 (3710.65 + 3083.36) mg/kg. In BH2, it ranged from 3.38-80.00 (10.75 + 5.87) mg/kg and in BH3 it ranged from 3.38-190.00 (36.58 + 16.21) mg/kg. However, in BH4 it ranged from negligible -105(11.64 + 7.9) mg/kg.

A pair wise comparison in concentrations of TPH across the sampling boreholes revealed that there was no significant difference between BH1 and BH2 (Sig.t=0.253), BH1 and BH3 (Sig.t=0.257), BH1 and BH4 (Sig.t=0.253), BH2 and BH3 (Sig.t=0.932) and BH3 and BH4 (Sig.t=0.102) at the 95% confidence interval.

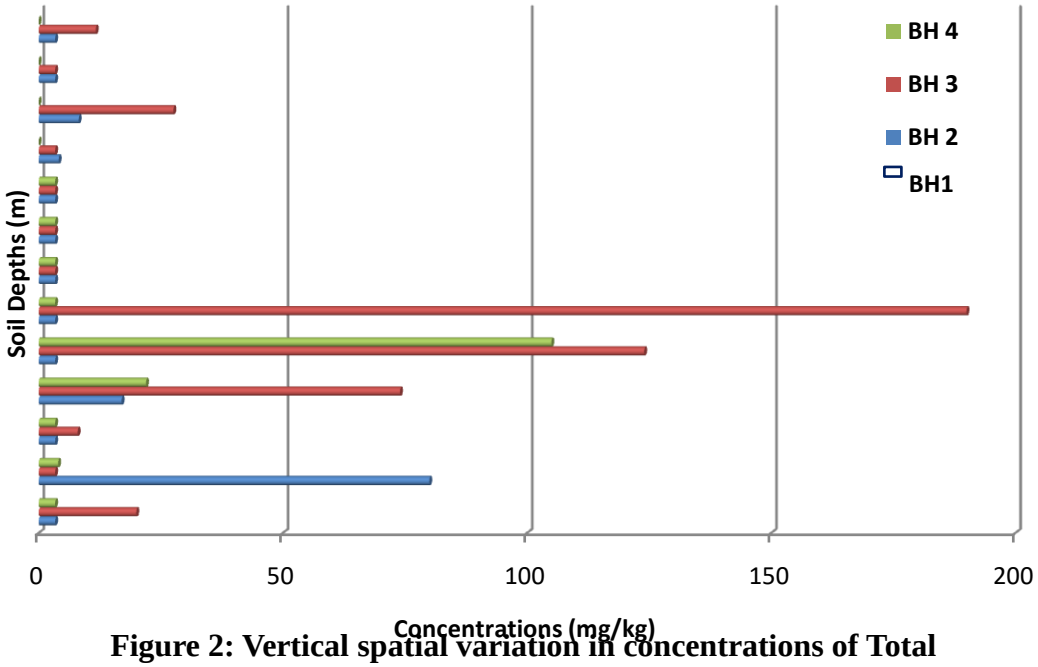


Figure 2: Vertical spatial variation in concentrations of Total Petroleum Hydrocarbons (TPH) in three boreholes proximal to a spill site

Table 2: Distribution of Total Petroleum Hydrocarbons (TPHs) across Soil Profile impacted by Oil spill

Sample (Borehole) ID	Depth (m)	THC concentration (mg/kg)
BH 1	0.0	40,645
	0.5	1,679
	1.0	1,514
	1.5	1,778
	2.0	1,193
	2.5	252
	3.0	313
	3.5	419
	4.0	158
	4.5	75
	5.0	140
	5.5	69
	6.0	55
	6.5	50
	7.0	42
	7.5	22
	8.0	13
	8.5	11
	9.0	8.0
BH 2	0.0	60
	0.5	55
	1.0	30
	1.5	33
	2.0	17
	2.5	5

	3.0	**3.38**
	3.5	**3.0**
	4.0	**3.0**
	4.5	**3.2**
	5.0	**4.11**
	5.5	**8.2**
	6.0	**3.3**
	6.5	**3.0**
	7.0	**3.0**
	7.5	**3.38**
	8.0	**3.3**
	8.5	**3.1**
	9.0	**2.7**
BH 3	**0.0**	**30**
	0.5	**3.32**
	1.0	**8**
	1.5	**74**
	2.0	**124**
	2.5	**190**
	3.0	**3.3**
	3.5	**3.0**
	4.0	**3.13**
	4.5	**3.2**
	5.0	**27.6**
	5.5	**3.5**
	6.0	**11.7**
	6.5	**4.0**
	7.0	**2.8**
	7.5	**3.0**
	8.0	**2.6**
	8.5	**2.1**
	9.0	**3.38**
BH 4	**0.0**	**44.0**
	0.5	**32.0**
	1.0	**28.0**
	1.5	**24.0**
	2.0	**26.0**
	2.5	**19.0**
	3.0	**13.0**
	3.5	**8.0**
	4.0	**7.0**
	4.5	**3.0**
	5.0	**6.0**
	5.5	**5.0**
	6.0	**7.0**
	6.5	**4.0**
	7.0	**2.0**
	7.5	**3.0**
	8.0	**2.0**
	8.5	**2.1**

	9.0	**1.3**
BH Control	**0.0**	**3.3**
	0.5	**4**
	1.0	**3.2**
	1.5	**2.2**
	2.0	**10.5**
	2.5	**3.38**
	3.0	**3.3**
	3.5	**3.12**
	4.0	**3.1**
	4.5	**1.5**
	5.0	**1.2**
	5.5	**1.2**
	6.0	**0.5**
	6.5	**0.5**
	7.0	**0.2**
	7.5	**ND**
	8.0	**ND**
	8.5	**ND**
	9.0	**ND**

Table 3: Physicochemical Characteristics of groundwater samples impacted by Oil spill in Nkpanak Community, Ibeno LGA, Akwa Ibom State

Sample ID	Depth (m)	pH	EC (µS/cm)	Turb (NTU)	THC (mg/L)	DO	BOD	TDS	mg/L PO_4^{3-}	NO_3^-	SO_4^{2-}	Cl^-	mg/LCaCaCO$_3$ ∑Hard	Ca^{2+}	Mg^{2+}	mg/L ∑Fe
BH 1	**9.0**	**6.3**	**180**	**109**	**42.28**	**0.00**	**12.6**	**130**	**0.16**	**1.12**	**2.74**	**0.08**	**49.05**	**17.32**	**1.40**	**1.75**
BH 2	**9.0**	**6.0**	**77**	**80**	**12.86**	**1.66**	**2.53**	**54**	**0.24**	**2.08**	**7.02**	**0.07**	**34.10**	**12.88**	**0.46**	**0.11**
BH 3	**6.5**	**6.1**	**177**	**107**	**4.96**	**1.93**	**1.38**	**124**	**0.05**	**0.35**	**2.98**	**1.96**	**81.62**	**31.12**	**0.94**	**0.15**
BH 4	**9.0**	**6.1**	**80**	**84**	**11.60**	**1.70**	**2.55**	**56**	**0.22**	**2.05**	**7.00**	**0.05**	**33.40**	**12.50**	**0.45**	**0.10**
BHControl	**4.0**	**6.1**	**29**	**8**	**2.54**	**2.12**	**1.13**	**25**	**0.74**	**0.05**	**0.05**	**1.00**	**14.94**	**3.22**	**1.68**	**1.69**

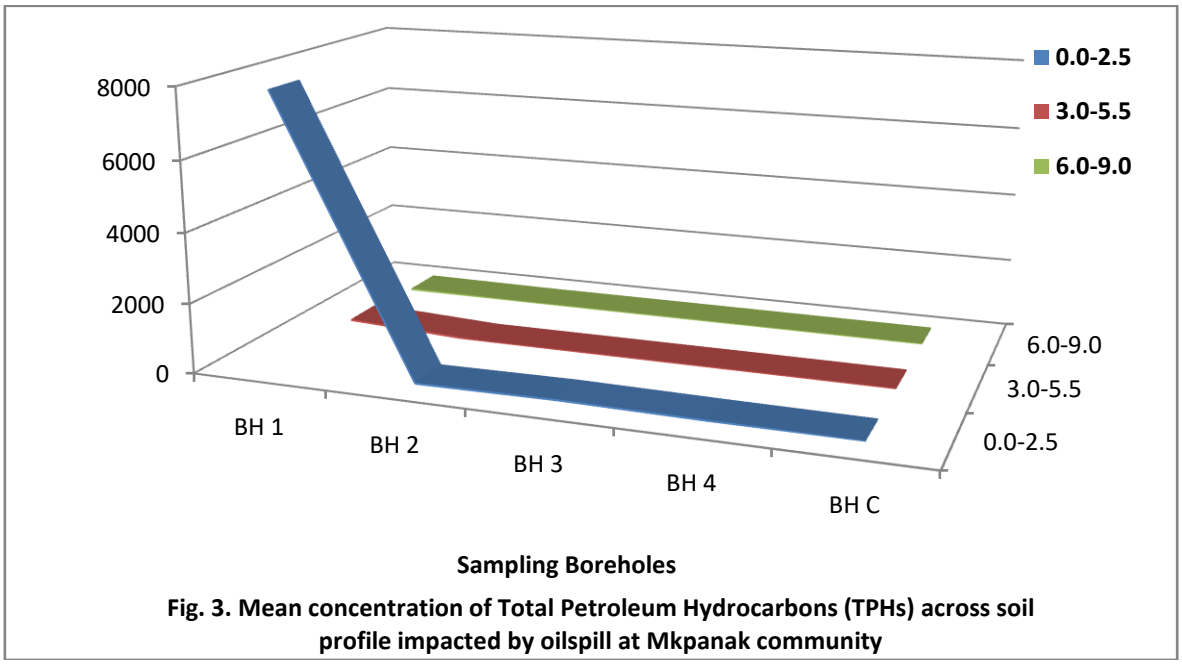


Fig. 3. Mean concentration of Total Petroleum Hydrocarbons (TPHs) across soil profile impacted by oilspill at Mkpanak community

Figure 3: Shows the mean concentration of Total Petroleum Hydrocarbons (TPHs) across soil profile impacted by oil spill at Mkpanak community

Table 4: Relationships between the physicochemical parameters in groundwater

Correlations

		pH	EC	Turb	THC	DO	BOD	TDS	PO_4	NO_3	SO4	Chloride	T.Hard	Ca	Mg	Fe
pH	Pearson Correlation	1	.594	.336	.814	-.845	.880*	.628	-.173	-.236	-.416	-.146	.175	.143	.560	.685
	Sig. (2-tailed)		.290	.581	.094	.072	.049	.257	.781	.703	.486	.814	.778	.819	.327	.202
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
EC	Pearson Correlation	.594	1	.867	.566	-.606	.581	.999**	-.812	-.097	-.033	.250	.872	.861	.021	-.024
	Sig. (2-tailed)	.290		.057	.320	.279	.305	.000	.095	.876	.958	.685	.054	.061	.973	.969
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Turb	Pearson Correlation	.336	.867	1	.536	-.545	.479	.846	-.983**	.390	.468	-.065	.790	.806	-.456	-.398
	Sig. (2-tailed)	.581	.057		.352	.342	.414	.071	.003	.516	.426	.918	.112	.100	.440	.507
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
THC	Pearson Correlation	.814	.566	.536	1	-.998**	.990**	.587	-.377	.265	.044	-.553	.106	.095	.172	.450
	Sig. (2-tailed)	.094	.320	.352		.000	.001	.298	.532	.667	.944	.334	.866	.879	.782	.447
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
DO	Pearson Correlation	-.845	-.606	-.545	-.998**	1	-.995**	-.628	.385	-.205	.008	.495	-.148	-.135	-.214	-.472
	Sig. (2-tailed)	.072	.279	.342	.000		.000	.257	.523	.741	.990	.397	.812	.829	.729	.422
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
BOD	Pearson Correlation	.880*	.581	.479	.990**	-.995**	1	.606	-.312	.128	-.096	-.466	.110	.093	.304	.552
	Sig. (2-tailed)	.049	.305	.414	.001	.000		.278	.610	.837	.878	.429	.860	.882	.619	.334
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
TDS	Pearson Correlation	.628	.999**	.846	.587	-.628	.606	1	-.783	-.127	-.074	.249	.854	.840	.068	.026
	Sig. (2-tailed)	.257	.000	.071	.298	.257	.278		.117	.839	.906	.687	.066	.075	.913	.967
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
PO4	Pearson Correlation	-.173	-.812	-.983**	-.377	.385	-.312	-.783	1	-.409	-.539	-.014	-.825	-.846	.566	.551
	Sig. (2-tailed)	.781	.095	.003	.532	.523	.610	.117		.494	.349	.982	.085	.071	.319	.336
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
NO3	Pearson Correlation	-.236	-.097	.390	.265	-.205	.128	-.127	-.409	1	.946*	-.787	-.156	-.110	-.825	-.536
	Sig. (2-tailed)	.703	.876	.516	.667	.741	.837	.839	.494		.015	.114	.802	.861	.085	.352
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
SO4	Pearson Correlation	-.416	-.033	.468	.044	.008	-.096	-.074	-.539	.946*	1	-.545	.057	.109	-.963**	-.780
	Sig. (2-tailed)	.486	.958	.426	.944	.990	.878	.906	.349	.015		.342	.927	.862	.008	.120
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Chloride	Pearson Correlation	-.146	.250	-.065	-.553	.495	-.466	.249	-.014	-.787	-.545	1	.559	.536	.307	-.089
	Sig. (2-tailed)	.814	.685	.918	.334	.397	.429	.687	.982	.114	.342		.327	.352	.615	.886

	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
T.Hard	Pearson Correlation	.175	.872	.790	.106	-.148	.110	.854	-.825	-.156	.057	.559	1	.999**	-.193	-.388
	Sig. (2-tailed)	.778	.054	.112	.866	.812	.860	.066	.085	.802	.927	.327		.000	.756	.518
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Ca	Pearson Correlation	.143	.861	.806	.095	-.135	.093	.840	-.846	-.110	.109	.536	.999**	1	-.245	-.433
	Sig. (2-tailed)	.819	.061	.100	.879	.829	.882	.075	.071	.861	.862	.352	.000		.691	.466
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Mg	Pearson Correlation	.560	.021	-.456	.172	-.214	.304	.068	.566	-.825	-.963***	.307	-.193	-.245	1	.919*
	Sig. (2-tailed)	.327	.973	.440	.782	.729	.619	.913	.319	.085	.008	.615	.756	.691		.027
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Fe	Pearson Correlation	.685	-.024	-.398	.450	-.472	.552	.026	.551	-.536	-.780	-.089	-.388	-.433	.919*	1
	Sig. (2-tailed)	.202	.969	.507	.447	.422	.334	.967	.336	.352	.120	.886	.518	.466	.027	
	N	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

* Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Discussion

The results indicate that TPH concentrations were highest in the topsoil across the borehole stations. This elevated surface concentration is attributed to the fact that the oil spill occurred at ground level, where the presence of impermeable materials and fine clay particles hindered the downward migration of crude oil. Due to their low porosity and small pore sizes, these soil components tend to retain hydrocarbons at the surface, limiting deeper infiltration. At Borehole 1 (BH1), the total petroleum hydrocarbon (TPH) concentration at the surface (0.0 m depth) was 40,645.00 mg/kg. At 0.5 m, the TPH level dropped to 1,679.00 mg/kg, followed by 1,514.00 mg/kg at 1.0 m, and a slight increase to 1,778.00 mg/kg at 1.5 m. At 2.0 m, the concentration decreased to 1,193.00 mg/kg, and further dropped to 252.00 mg/kg at 2.5 m. At 3.0 m, TPH concentration was 313.00 mg/kg, and increased slightly to 419.00 mg/kg at 3.5 m. By 4.0 m, the level reduced to 158.00 mg/kg, followed by 75.00 mg/kg at 4.5 m, and 140.00 mg/kg at 5.0 m. At 5.5 m, the concentration was 69.00 mg/kg, and finally dropped to 3.38 mg/kg at 6.0 m depth At Borehole 2 (BH2), the total petroleum hydrocarbon (TPH) concentration at the surface (0.0 m depth) was 3.38 mg/kg. At 0.5 m, the TPH level increased to 80.00 mg/kg, and then dropped to 3.38 mg/kg at 1.0 m. At 1.5 m, a slight rise was observed with 17.00 mg/kg, followed by a consistent value of 3.38 mg/kg recorded at 2.0 m, 2.5 m, 3.0 m, 3.5 m, and 4.0 m depths. At the deepest measured level, 6.0 m, the TPH concentration remained at 3.38 mg/kg, indicating minimal vertical migration of petroleum hydrocarbons at this borehole location. At Borehole 3 (BH3), the total petroleum hydrocarbon (TPH) concentration at the surface (0.0 m depth) was 20.00 mg/kg. At 0.5 m, the TPH level dropped to 3.38 mg/kg, and then increased to 8.00 mg/kg at 1.0 m. A more significant rise was observed at 1.5 m with 74.00 mg/kg, followed by 124.00 mg/kg at 2.0 m, and a peak concentration of 190.00 mg/kg at 2.5 m. beyond this depth, the TPH concentration declined, with 3.38 mg/kg recorded consistently at 3.0 m, 3.5 m, 4.0 m, and 4.5 m. At 5.0 m, there was a slight increase to 27.60 mg/kg, followed by a drop to 3.38 mg/kg at 5.5 m, and 11.70 mg/kg at 6.0 m. This pattern suggests localized hydrocarbon accumulation in the mid-depth layers with limited vertical migration. At Borehole 4 (BH4), the total petroleum hydrocarbon (TPH) concentration at the surface (0.0 m depth) was 3.38 mg/kg, and slightly increased to 4.00 mg/kg at 0.5 m. At 1.0 m, the concentration returned to 3.38 mg/kg, then rose to 22.00 mg/kg at 1.5 m. A significant increase was observed at 2.0 m, with a TPH concentration of 105.00 mg/kg. Beyond this point, the levels dropped back to 3.38 mg/kg at 2.5 m, 3.0 m, 3.5 m, and 4.0 m depths. From 4.5 m downward to 6.0 m, TPH concentrations were negligible, indicating minimal contamination at greater depths in this borehole. BH1 and BH3 recorded higher concentrations of TPH because the soil samples were collected closer to the exact location of the spill. In contrast, BH2 and BH4, which showed significantly lower TPH levels, were situated farther away from the spill site, leading to reduced hydrocarbon contamination. As depth increases, TPH concentrations decrease due to the presence of impermeable materials within the soil layers. These include natural clay barriers and paved surfaces that slow down the downward migration of contaminants, effectively limiting further penetration and protecting the underlying groundwater, this is in agreement with the research conducted by Shi *et al*., (2024).

Crude oil affect soil characteristics like soil pH, soil moisture, soil texture and reduction on nutrient that will be available for plant growth, phosphorus is one of the major plant nutrient alongside with nitrogen (N) and potassium (K) (Devatha *et al*., 2019). As oil infiltrate the soil, it has a considerable effect on the structure and welting ability of soil (Sutormin *et al*., 2024). This

study has observed a complete disintegration of soil structure and dispersion of soil particles. The rate of contaminant movement into and through the soil will largely depend on the type of oil, organic matter content, moisture content of the soil and depth to water table (Hu *et al*., 2025). As oil infiltrates the soils, it physically displaces soil air and water. This has been considered of significant effect in promoting anaerobic conditions in soil (Daâssi and Qabil Almaghribi, 2022; Li *et al*., 2022; Adeniran *et al*., 2023; Elshafei and Mansour, 2024).

The findings indicated notably high concentrations of total petroleum hydrocarbons (TPH), especially in the topsoil layers closest to the spill origin at Borehole 1 (BH1) this is in agreement with other studies (Yuan *et al*., 2022; Bai *et al*., 2022; Chen *et al*., 2022; Fakunle *et al*., 2021; Tang *et al*., 2021; Elie *et al*., 2019; Okop and Persaud, 2019).

CONCLUSION

This study assessed the vertical and spatial migration of petroleum hydrocarbons across soil horizons in an oil spill-affected area of Mkpanak, Akwa Ibom State. Findings revealed significantly elevated levels of total petroleum hydrocarbons (TPH), particularly in topsoil layers near the spill epicenter (BH1), with concentrations decreasing progressively with depth and distance from the spill site. The results indicate that impermeable soil layers, such as clay and compacted materials, play a crucial role in limiting the vertical movement of hydrocarbons, thereby offering partial protection to underlying groundwater resources. The study further highlights the degradation of soil structure and increased dispersion of soil particles in contaminated zones, which may impair soil productivity and ecosystem function. The presence of residual hydrocarbons at varying depths also emphasizes the persistence and mobility of petroleum contaminants in the environment.

Recommendations

Based on the findings from the study on the migration of petroleum hydrocarbons in the Mkpanak community, the following recommendations are proposed:

1. Appropriate soil remediation techniques such as bioremediation, phytoremediation, or excavation and safe disposal should be implemented in areas with high TPH concentrations, especially around the spill site.

2. Regular monitoring of groundwater quality should be conducted to detect potential contamination early, particularly in areas with shallow aquifers.

3. In future drilling operations, impermeable liners or clay barriers should be installed around drilling sites to prevent vertical migration of oil contaminants.

4. Comprehensive EIAs should be mandatory before any drilling activity to assess potential risks and ensure appropriate safeguards are in place.

5. Enforcement of stricter regulations on the disposal of drilling waste is essential to prevent indiscriminate dumping and spills.

6. Local communities should be sensitized to the environmental and health hazards of oil spills, and trained on how to respond to contamination incidents.

7. Oil companies responsible for spills should be held accountable for the environmental damage caused, including full funding of cleanup efforts and compensation for affected communities.

8. A long-term monitoring framework should be established to track the recovery of the ecosystem and effectiveness of remediation strategies.

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