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Research Article

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Characterization of Artisanal Refining Sites in Mangrove Wetlands in Parts of Eastern Niger Delta

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Abstract This study aims to characterize the subsurface in the mangrove wetland where artisanal refining and disposal of waste by-products are rife and to delineate the lateral and vertical extent of contamination in the area. Soil boring with hand augers was used to obtain soil samples to depth 10.0m maximum depth to determine the subsurface stratification and hydrocarbon concentrations and river sediment samples from the mangrove areas were also obtained by grab sampling. The particle size distribution of soil recovered from the boreholes comprised of 92.2% sand 5.26% fines (silts/clays) and 2.36% gravel with coefficient of permeability was estimated from Hazen's formula with values ranging between $7.26x10^{-4}$ cm/sec and 1.35 $x10^{-3}$ cm/sec. Laboratory analysis of two hundred and forty (240) soil samples for Total Petroleum Hydrocarbon (TPH), Polycyclic Aromatic Hydrocarbon (PAH) and Benzene Toluene Ethylene Xylene (BTEX) fractions was achieved with Gas Chromatography-Mass Spectrometry (GC-MS) and Gas Chromatography-Flame Ionization Detector (GC-FID). The contaminant concentration in soil and sediment ranged between 128mg/kg to 59,235.00mg/kg across the four strata of the area. Ninety six (96) of the soil samples analysed showed values above the regulatory thresholds for TPH, PAH and BTEX of 5,000mg/kg, 40mg/kg and 1mg/kg for soil respectively. This data will be very useful the design and proactively effect mitigation measures in the environmental remediation management and other recovery actions for the impacted environment.

Keywords Artisanal crude oil refining, Hydrocarbons, Persistent Organic Pollutants, Gas Chromatography-Mass Spectrometry, Gas Chromatography-Flame Ionization Detector

Introduction

This paper analyses the major cause and extent of soil contamination resulting artisanal refining along the eastern side of the Bonny River, Rivers State, Nigeria. The information is critical for proper undertaking of remedial and restoration methods [27] and the implementation of remediation by Hydrocarbon Pollution Remediation Project (HYPREP) under the Nigerian Ministry of Environment. Oil Bunkering is an oil industry term for supplying oil to a ship for its own use. In the wider Niger Delta this term refers to the illegal tapping of oil industry infrastructure with a view to procuring oil illegally. The oil collected was either transferred to larger boats for onward shipment or used locally for illegal artisanal refining. There are frequent reports of these pipelines being tapped illegally, in some cases leading to spills and fires.

Artisanal refining is a process that involves crude oil refining using primitive methods in which crude oil is boiled often times in metal pipes and drums welded together. The resultant fumes are collected, cooled and condensed in tanks and used locally for energy or transport. The distilleries are heated on open fires fed by crude oil that is tipped into pits in the ground [4] . As part of the oil burns away, the soil burns alongside with the physical, chemical and biological properties of the soil permanently altered. These fire effects incinerates the organic matter and consequently distort the natural soil profile altering its particle size distribution , porosity and permeability thereby enhancing seepages of fluids into the ground (Plate 1.0). Several sizes of artisanal refinery ranging from 100 m^2 to 1000m^2 or more are visible across the Niger Delta landscape and are mostly located at the water's edge, primarily to facilitate the transportation of both the crude oil and refined products [15] [20]. These practices represents a huge environmental, health and safety problem. Aside the longer-term health effects of ingestion, absorption and inhalation of hydrocarbons, the storage of the crude oil products in open containers or open pits increases the risk of fire and the contamination of the environment and possibly impacting the underground aquifer.

Researchers have documented 217 illegal refinery sites are found which destroyed 116 ha of high ground habitat adjacent to mangroves (Figure 2.0) along the Eastern Bonny river which became very obvious between 2010 - 2011 [15] [27]. Large mangrove losses are in the area were observed due to oil-related activities, that 4415 ha of mangroves has been lost due directly to oil spill from both operational and illegal activities. Mangrove Habitats with high hydrocarbon concentration may require interventions to aid natural recovery due to changes in the soil which my inhibit settlement and growth [4] [15].

High concentration of hydrocarbon contamination in the low-lying mangrove mudflats areas, especially in the topmost surficial cover (0-0.5.0cm). These areas have similar characteristics with the mangrove areas in the present study. [15] [7] [17] [21] [26]. The high contamination levels imply that degradation processes may be resisted and, remain persistent in sediments. Some of the contaminants especially Polycyclic Aromatic Hydrocarbon (PAH), may transferred up the trophic chain. Spilled oil remains in the environment for prolonged periods with very slow degradation rates and the situation becomes worse when groundwater is affected due to challenges of early detection, skills needed to predict its fate, rate of movement, degree and spread of impact[14] [20] [25]. This study was necessitated by the concern of escalating environmental contamination and is aimed at assessing the vulnerability of the shallow groundwater aquifers to artisanal refining activities, the character and behaviors of the contaminating substances and the contaminated media. The study will help in decisions on remediation and restoration of affected area.

Materials and Methods

The Study Area

The study area, Bodo, is a town located in the eastern Niger Delta (Figure 1.0). It is made up of intertidal sediments dominated by silts and clays (commonly called "Chikoko") and bisected by tidal channels mostly accessible only by boat. Several crude oil spill incidents related to illegal activities related to oil theft, artisanal refining and the transport of stolen oil in open boats have been reported in the area. [15]. The. Bodo community has a population of 228,828 (2006 census) and they depend largely on the creek for their livelihood, food and marine products and services. The Bodo creek area is underlain by quaternary deposits of the sombreiro deltaic plain directly overlying the Benin Formation, with a typical lithology of this area is sand, silts clay and gravels of varying thicknesses. The area slopes North- South towards the Atlantic ocean , with spots heights ranging from 11.0m in the north to 0.9m above sea level in the south (Figure 3.0). The Bodo creek is a coastal plain estuary with several channels. [23] [24] and small island or platforms. It contains dead and living mangroves which are intersected by two major channels and a network of smaller mud-dominated channels with intertidal sediments composed of silts and clay and the tidal channels separating the sediment, the area is accessible mostly by boat. The major occupation of the locals includes fishing and farming with other activities like trading and transportation. The hydrogeology of Bodo which is similar to other areas in the Niger Delta is dominated by three types of flow; a unidirectional flow in the upper delta, bilateral tidal flow in the coastal areas and estuaries, and a mixed flow which is a combination of unidirectional and bilateral attributes in transitional zones [1]. Estuaries in Niger Delta are controlled by current and wave actions due to closeness to the Atlantic Ocean [2] [10]. During the rainy season, the rivers flood the estuary with fresh water while at dry seasons there is an outflow of saline water from the estuaries. The major aquifer materials deposited in the intertidal flats and tidal channel of Bodo creek are sand, silt, gravel [2][3]. The depth of 100m is most exploited, about 300m depth has been exploited for water [19] [26] [27].

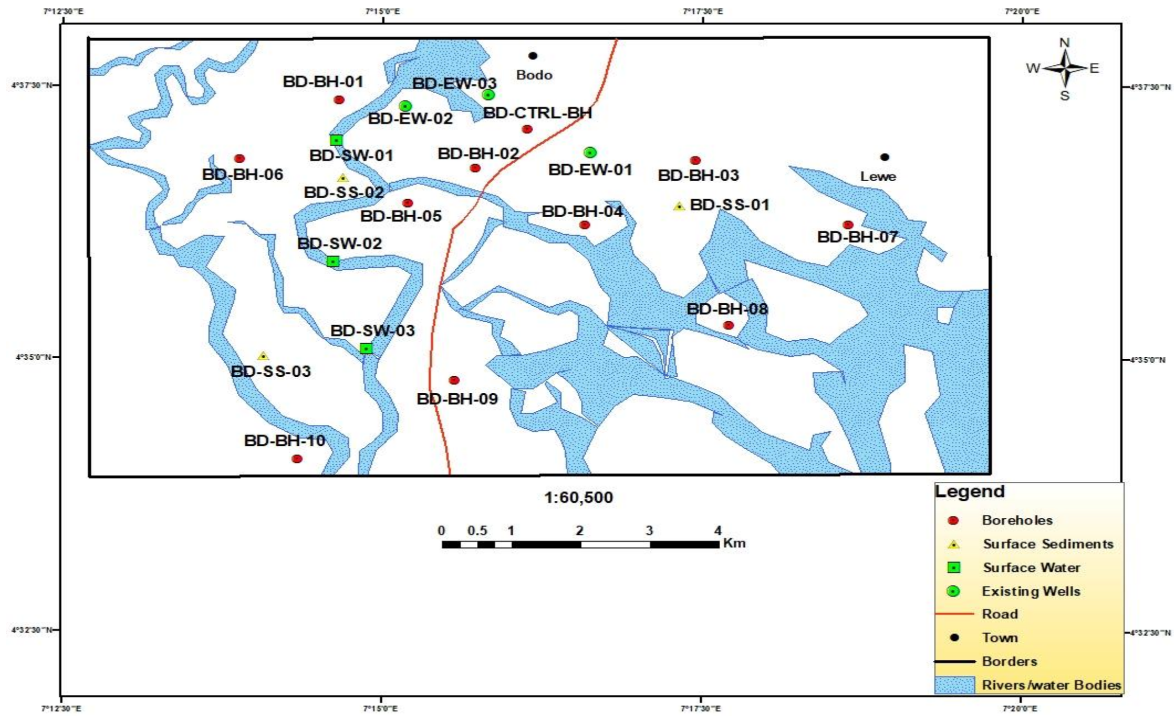

Figure 1.0: Map Showing Positioning of Boring Points

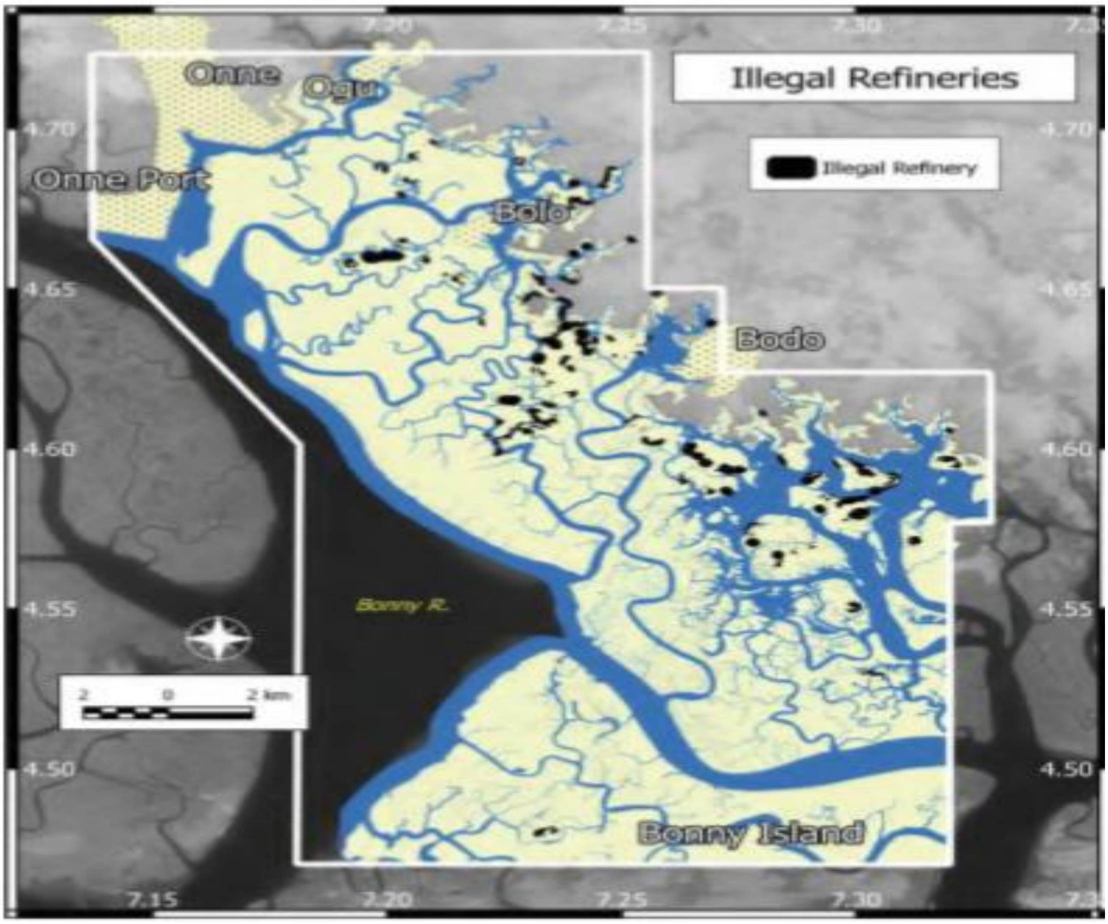

Figure 2.0: 217 Illegal Refineries across sections of Ogu, Bolo and Bodo [15]

The uppermost section of the Benin Formation is the Quaternary deposits of about 40- 150m thick and comprises of rapidly alternating sequences of sand and silt / clay with the later becoming increasingly more prominent seawards [13]. The clayey intercalations have given rise to multi aquifer systems and are mainly through direct precipitation where annual rainfall is as high as 2000-2400 mm. The water infiltrates through the highly permeable sands of the Benin Formation, The surficial aquifer is recharged by percolation, the zones of saturation expands to the extent that the water table rises [5] [26] [27]. The aquifer usually drains into surface water bodies and streams, this interaction makes the shallow unconfined aquifers vulnerable to hydrocarbon contamination. The Coastal Plain Sands of the Benin formation, the aquifers from which the local population get water supply, are is highly permeable, prolific, productive and is the most extensively tapped aquifer in the Niger Delta [12] [13]. They are also of very good transmissivity, with the value range of $1.05\ x10^{-2}\ m^{-2}$/sec, their co-efficient of storage varies from $1.07x10^{-4}$ and $3.53x10^{-4}$ while the specific capacity value lies between 19.01 and $139.8m^{-3}$/h/m drawdown [3] [5] [19].

Plate 1.0: Typical abandoned artisanal crude oil refining fire pit at the site

Scope of Study

This study was carried out between December 2019 and July, 2020. The site was divided into three transects, Transect 1,2 and 3 based on their unique characteristics and similarities. Bored holes were drilled in accordance with standard field practice. Hand augers were used to recover soils samples to predetermined depths of 10.0m from ten (10) abandoned artisanal refining sites and a control location due to the loose and soft nature of the soils. Disturbed samples were collected in each borehole at intervals of 0.1m, 0.5m first, then at 1.0m intervals until the total borehole depths of 10.0m was achieved. A total of ten (10) holes were bored on the anaboned refining sites and one (1) control hole. To preserve and protect samples from cross contamination along the borehole profile while monitoring changes in the subsurface strata, augers were washed clean with detergent and distilled water at the end of each flight. Samples of river sediment were obtained from the creek at relative distances to the borehole locations at intervals of 0.1m and 0.5m. Bottom river channel and top surface sediments samples were obtained using grabs and shovels to recover sediments at 0.5m by digging of trial pit and recovering of cuttings at the desired depths into the appropriate sample containers and stored in ice boxes on site. Results were processed into view graphs using computer softwares including starter 5, grapher 4, surfer 16, rockworks 16 & 17.

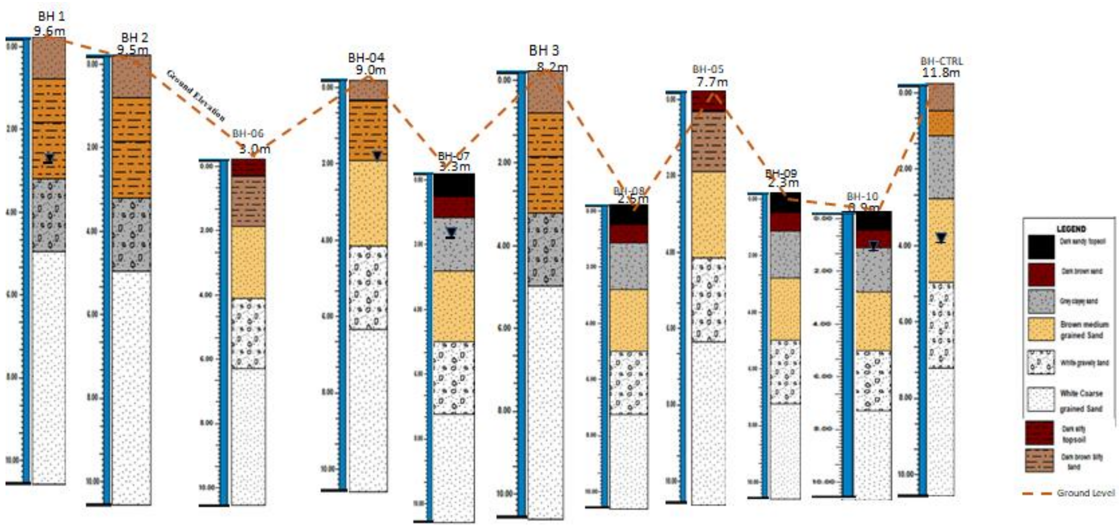

Figure 3.0: Lithological Logs of Study Area

Results and discussion

Four major soil types were identified across the study area (Figure 4.0.) as silts/topsoil, clay, coarse, gravelly sand layers.

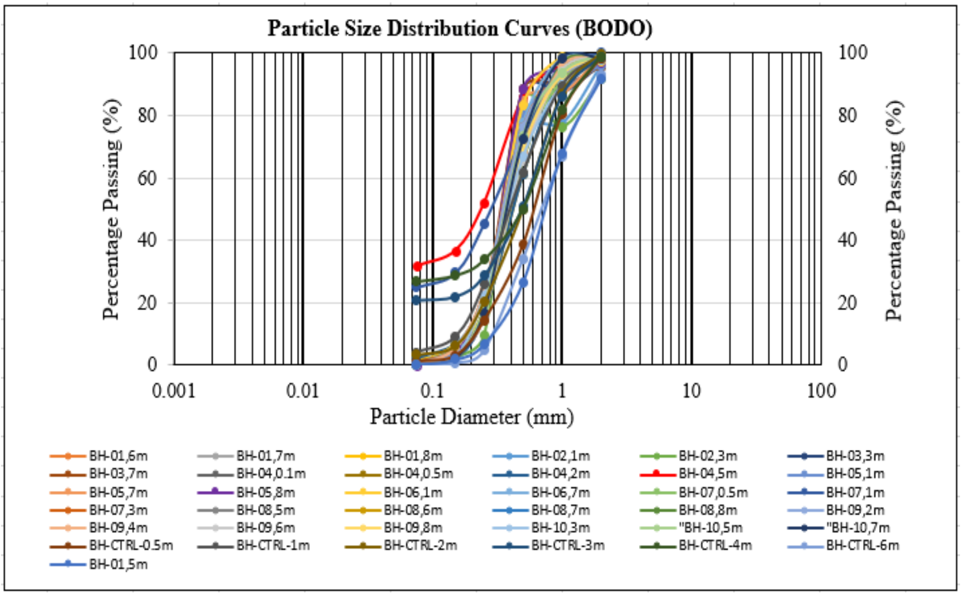

Figure 4.0: Particle Size Distribution Envelope of study Area

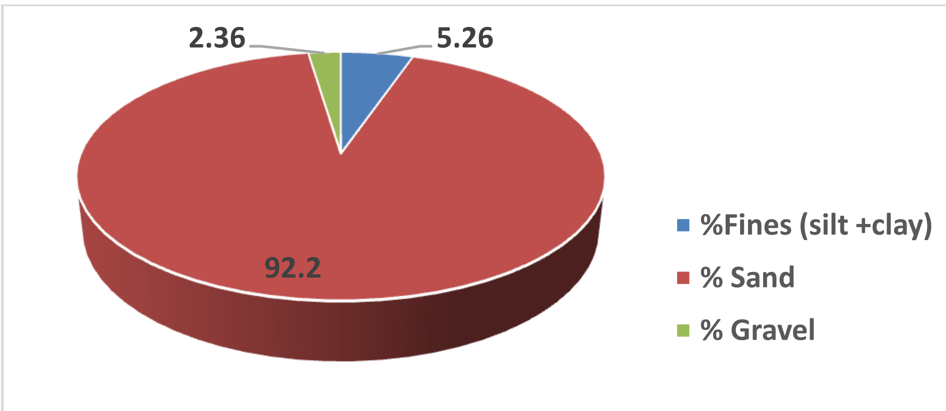

Figure 5.0: Particle Size Distribution Chart of Study site

Generally, the soil particle sizes consists 92.2% sand, 5.26% fines (silts and clays) and 2.36% gravel (Figure 5.0) with medium coefficient of permeability in the range of 7.26x10^{-4} cm/sec to 1.35 x10^{-3} cm/sec and classified as poorly graded [8] [9].

Soil Chemistry

Results of 80 soil samples were analysed for TPH indicate concentration between 128.00mg/kg –59,235.00 mg/kg and concentrations above the regulatory intervention threshold of 5,000mg/kg in 30 samples and 41 samples with concentration exceeding the Target limit of 50mg/kg for soil/sediment [11]. TPH concentrations were higher in the North Eastern and South Western flanks of the area while the lowest values were observed in the northern and southern axis. Regular cases of re-pollution have been reported at the site from fresh spills due to oil theft activities ,transportation of hydrocarbon products, refined products loading and offloading amongst others, Organic soil which dominate the top soil layers of the area are known to retain crude oil products for longer periods of time and hence persistence of these chemicals in this soil horizon can be explained in terms of soil type, nature of contaminants as the crude oil is composed of persistent Organic pollutants (PoPs). The variability of the contaminant contamination expressed in the upper strata may most likely be the result of the burning effects of the high temperature distillation process by the local crude oil refiners at the locations (Figure 6.0 and 7.0)., while intermittent changes in concentrations noticeable in the third and fourth layers may be the result of natural attenuation and other degradation processes in those horizons. The low permeability coefficients especially in the top soil layer may be the results of distortions in the soil properties as a results of prolonged exposure to extreme temperatures from the refining process. The contaminants in the higher permeability sand and gravel layers depicts their mobility along with fluids and the most likely cause of the enrichment in the western and eastern flanks in the different soil layers.

The concentration of the PAH fractions in soil generally increased with depth with values of <0.01mg/kg – 235.73mg/kg (Table 1 and 2.) Twenty 27 of the 80 samples analyzed for PAH recorded concentrations above the EGASPIN Intervention limit of 40mg/kg while 21 had concentrations above the target limit of 40mg/kg and 38 were below the target limits for PAH in soil/sediment. Significant Concentration of PAH compounds was recorded in the lower soil layers (Figure 8.0- 9.0) and probably due to the fire effects, destroying the upper soil fabric and allowing the percolation of contaminants into the subsurface. Farther away from the points of higher concentration are visible reduction in colour intensity which depicts attenuation of the contaminant plumes in the subsurface which limits the distance of travel of the contaminants.

The concentrations of the BTEX obtained from 80 samples are within the range <0.01mg/kg to 180.00mg/kg with exceedances of the regulatory limits recorded in 39 samples, 6 are above target limits and 35 samples recorded values lower than their respective DPR intervention limits (1mg/kg for benzene, 130mg/kg for toluene, 50mg/kg for Ethylbenzene and 25mg/kg for Xylene).

BTEX concentration in the northern flank of the site is observed to be higher (Figure 10.0 and 11.0). This may not be unconnected with the assemblage, sales, loading and offloading of refined oil products at the locations which border the communities at the northern axis of the site. Higher values of BTEX in this axis may be the contributions by discharges mainly from the refining processes where residues are thrown carelessly into the environment, spills resulting from handling of these products.(loading and offloading) of most of the refined products, resident time of recent spill product brought in by tidal waters and deposited on the shoreline areas amongst others.

BTEX are known as Volatile Organic Compounds, they are lighter than other hydrocarbon components, very unstable and degrade faster than the other hydrocarbon constituents when released into the environment. The concentrations of BTEX across the profiles show decreasing trends with depth, this may be due to their relatively higher solubility potential , volatility and natural attenuation in course of their transportation across the depths and soil profiles. The concentrations recorded in the deeper horizons may be residual concentrations trapped with the fine clay fractions.

Table 1.0: Average Hydrocarbon Concentration and Standard Deviation in Soil and Sediment

	Parameters	MIN	MAX	AV	SD
Downhole Soil Samples (mg/kg)	**TPH**	128.00	59235.00	4649.61	8488.78
	PAH	0.01	225.73	41.53	63.37
	BTEX	0.01	180.44	13.58	39.33
Surface Sediment Samples (mg/kg)	**TPH**	7003.00	35232.12	18155.89	11194.90
	PAH	12.51	231.00	100.86	89.89
	BTEX	5.60	30.11	19.51	7.28

Table 2.0: Chemistry of Soil /Sediment across the Sites

		Transect 1		**Transect 2**		**Transect 3**		**Control**	
Specific depth horizon (m) Depth	**Soil Layer**	**Min TPH (mg/kg)**	Max TPH (mg/kg)	**Min TPH (mg/kg)**	Max TPH (mg/kg)	**Min TPH (mg/kg)**	Max TPH (mg/kg)	**Min TPH (mg/kg)**	Max TPH (mg/kg)
0.1 0.5	**Layer 1**	**128**	16,312.58	275.54	15,118.59	98.43	35,232.12	89.43	118.58
1 2	**Layer 2**	**321.43**	59,235.00	1,523.34	7,086.45	433.23	5454.28	<0.01	20.23
3 4	**Layer3+**	**4,780.65**	29,459.66	876.45	5280.74	786.23	3,243.22	<0.01	<0.01
5 6				988.34	9,061.06	765.22	2,987.12	<0.01	<0.01
7 8 9 10	**Layer 4+**	**4,698.76**	7,832.34	3,542.12	4,688.52	22.43	2,243.56	<0.01	<0.01

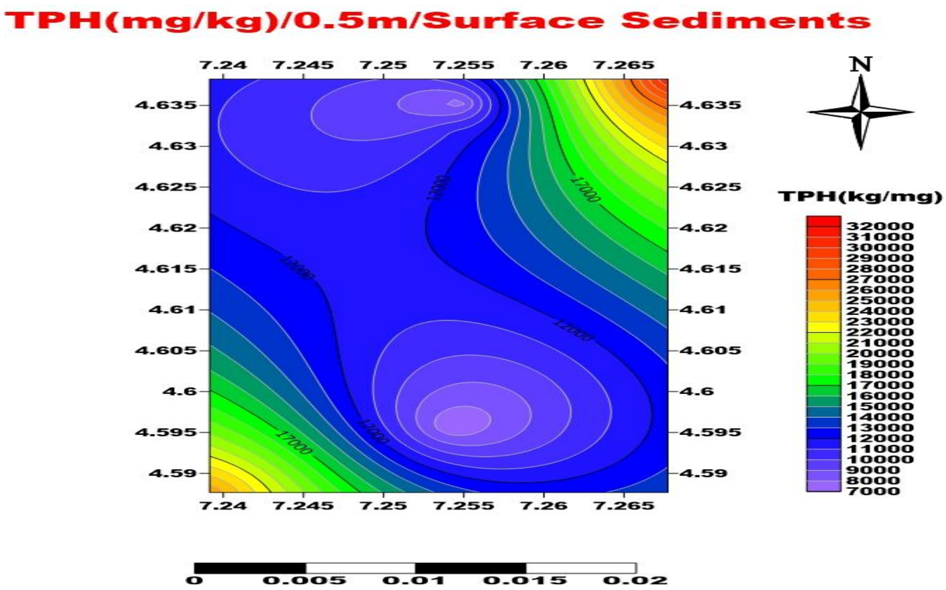

Figure 6.0: TPH concentration Map of 0.5m depth

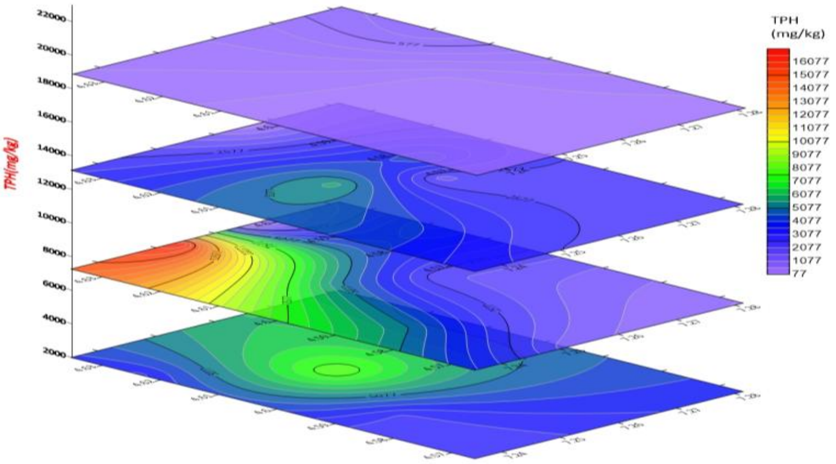

Figure 7.0: TPH concentration Profile across the Soil Horizons

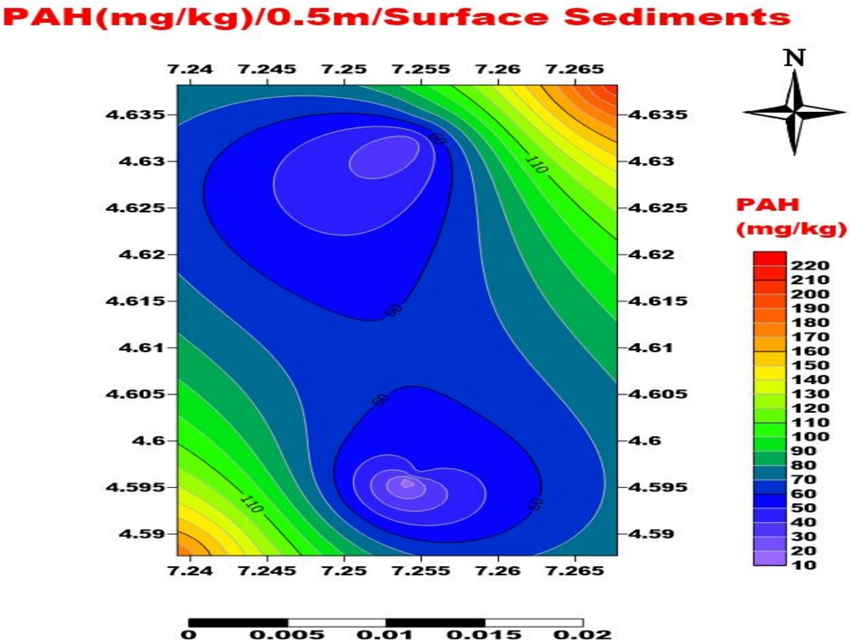

Figure 8.0: PAH concentration Map of shallow sediments 0.5m depth

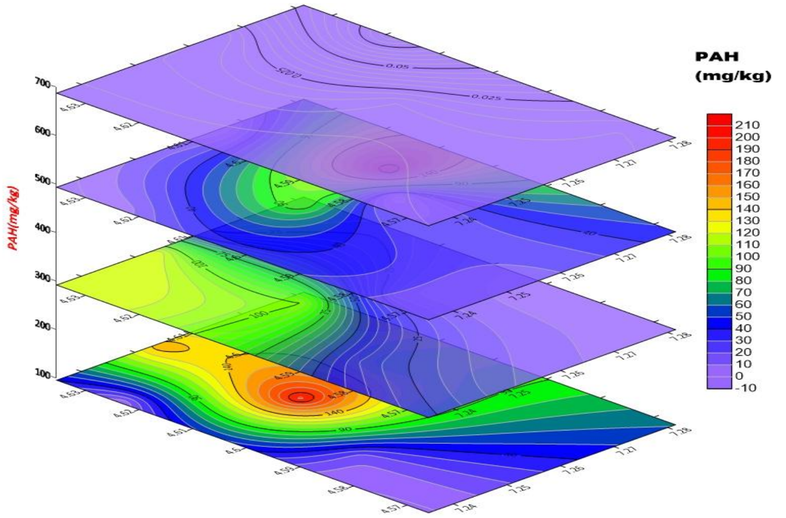

Figure 9.0: PAH Concentration Profile across the Soil Horizons

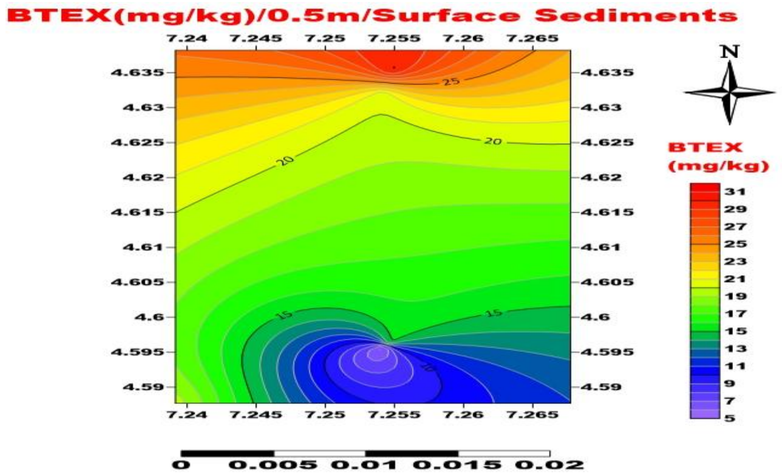

Figure 10.0: BTEX concentration Map of 0.5m depth

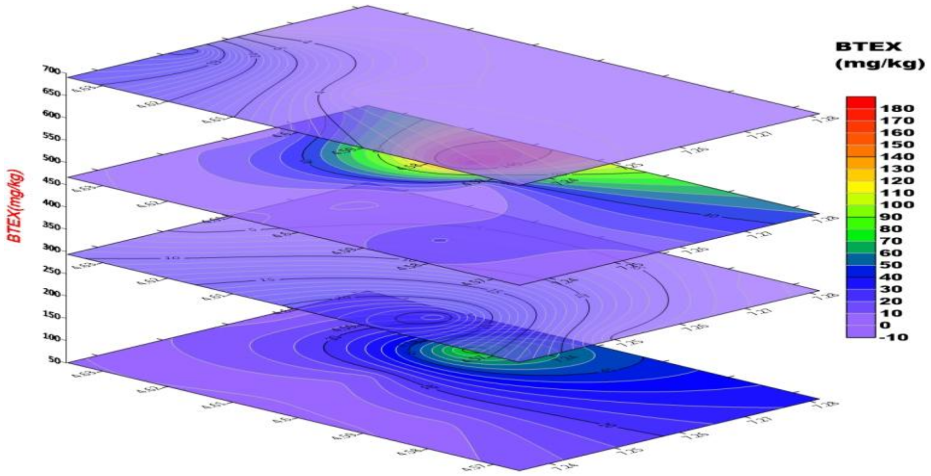

Figure 11.0: BTEX Concentration Profile across the Soil Horizons

Statistical analysis of data generated during the study show strong correlation between contaminant concentrations and the depths or soil layers across the site (Figures 12.0-13.0). While the minimum and Maximum TPH concentrations show uphill (Positive) and downhill (Negative) linear correlations with depth across the different horizons of the study area. Minimum PAH and maximum BTEX concentration show indicates strong positive correlation while maximum PAH show slightly negative correlation with the various depths. The relationships expressed are indication that these results can be depended on for prediction of future contamination trends.

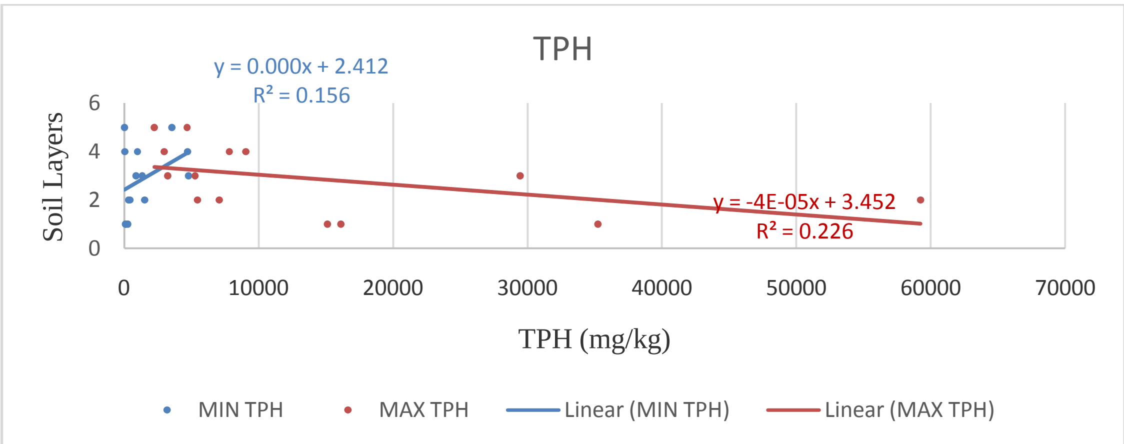

Figure 12.0: Regression Plots of TPH Soil Concentration Vs Soil Horizons

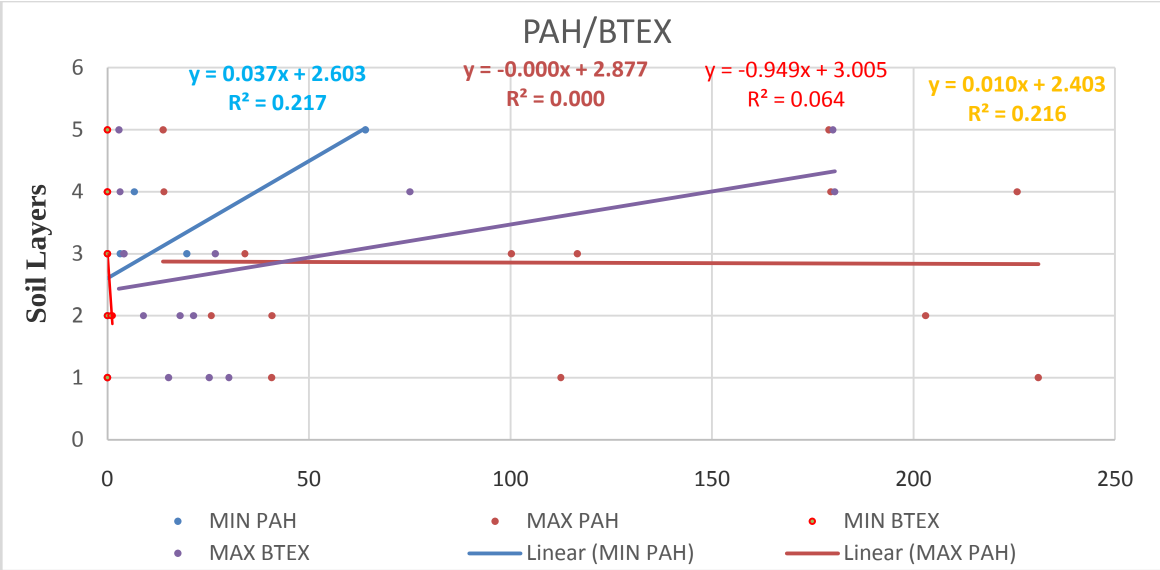

Figure 13.0: Correlation of Contaminant Concentration Soil Horizons

From the results, it can be implied that fluid movement and by implication, dispersion and contaminant migration in the shallow subsurface may be enhanced due to the dominance of loose sandy soils in the subsurface, however, natural degradation processes may limit the spread via Biological, chemical, physical etc factors that act on the contaminants thereby reducing the concentration and hence the toxicity in the impacted media. (Figures 14.0-15.0).

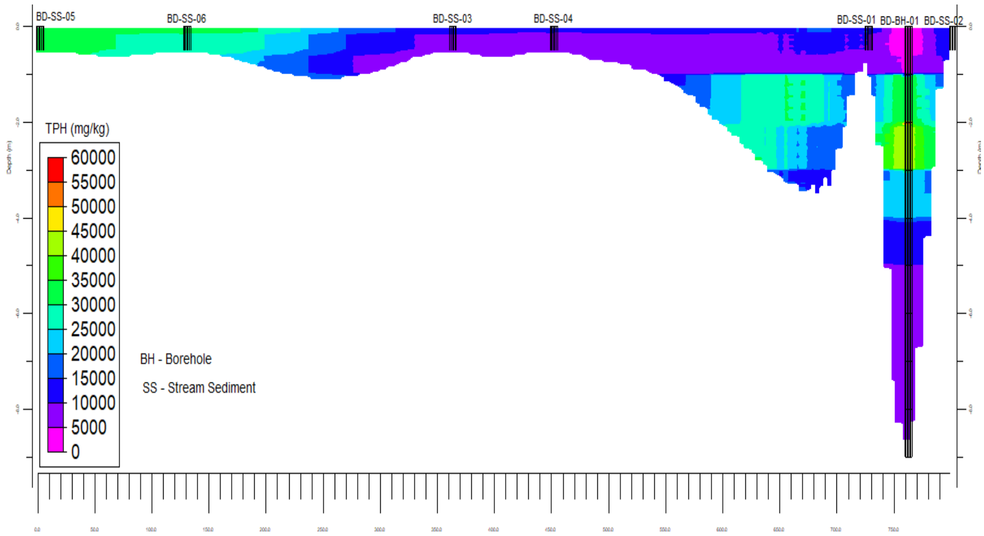

Figure 14.0: Contamination Profile of Sediments and BH 01

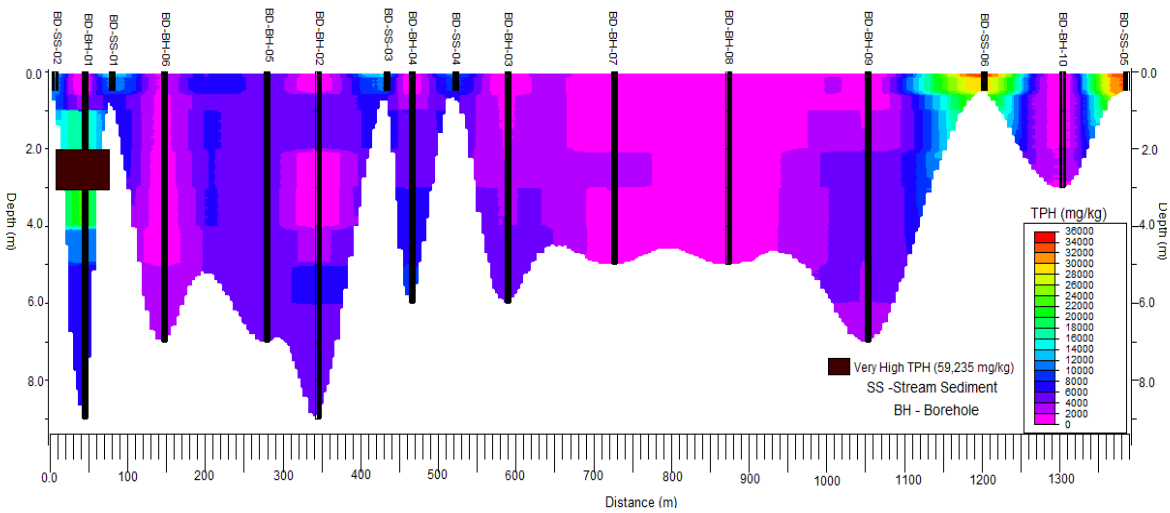

Figure 14.0: Contamination profile Across the Site

Conclusion and Recommendations

This research has shown that the illegal crude oil refining activities has increased the quantities of crude oil, petroleum products and residue (waste) into the soil environment, with the accompanying heat, used for the distillation process greatly affecting both microbial load and diversity in the soil environment. The refining activities could exert a negative impact on the population, diversity as well as the activities of soil microorganisms. Since, the microbial diversity is important for soil health, community structure and functions. Thus, the continuous exposure of the soil to the indiscriminate illegal refinery activities, will not only hamper the texture or structure of the soil but, would also lead to a decline in microbial populations which could pose a serious threat to the food chain, decomposition, nutrient recycling, bioremediation and the ecological balance.

The government, industry and community stakeholders need to dialogue and put a stop to activities of artisanal refining as there will be no meaningful development with these activities continuing unabated.

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