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Evaluating the Impact of Artisanal Crude Oil Refining on Soil Properties at a Mangrove Wetland , Eastern Bonny River , Rivers State

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ABSTRACT
The effects of artisanal crude oil refining on soil properties in the parts of the creeks of the Niger Delta were determined and the distortions due to the exposure of the soils to extreme temperatures of the refining process evaluated. The study was aimed at determining the impact of the local crude oil refining on the soils and it's implication on the environment. Ten (10) abandoned local crude oil refining sites and a control point were selected at a mangrove wetland East of Bonny River, near Bodo town. Field investigation was achieved by augering 8.0-10m deep drill holes both at the impacted and the control sites. Soil samples were collected at 0.5m, 1.0m and every 1m intervals up to depth of 10m. Insitu tests were performed for Moisture content and pH while Laboratory tests performed include Grain size, specific gravity, Atterberg limits, Organic Carbon content soil porosity and coefficient of permeability for the various horizons estimated using Hazen's formula. Variations were observed in moisture content of impacted soil (14.5-22.9), Organic Carbon content (1.15-4.65), Liquid limits (29.98-34.27) and plastic limits (18.52 -21.77) , Soil porosity (26%-43%) and permeability coefficient of $4.24x10^{-4}$ to $2.35x10^{-3}$ cm/sec when compared with values of the control site Moisture content (6.84-13.98). Organic Content of (0.55 to 2.45), LL (31.15),PL(14.35-18.25), Porosity 40% to 46%, permeability coefficient of $4.24x10^{-4}$ to $1.35x10^{-3}$cm/sec . These variation trends suggests a weakened soil structure that may allow percolation of residual hydrocarbon contaminants into the subsurface. Clean up of such sites will therefore require site specific considerations for wholesome restoration of the impacted environment.

Keywords*: Contamination, Artisanal Refining, migration, mobility,crude oil, Hydrocarbon.*

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I. Introduction

Oil exploration and production has precipitated a wide range of environmental problems associated with its activities. Crude oil releases into the environment is necessitated through a variety of means such as leaks from storage, production, processing and pipeline facilities, accidental releases, by-products of industrial activity, crude oil theft and wilful damage to oil installations. Contamination of the environment has significant impact on human and environmental health worldwide [8]. The chemicals and products commonly released into the environment have associated toxic properties from acute and/or chronic exposure to humans,other organisms and the environment [3]. Crude oil released into the environment is known to denature the impacted media , the extent of which depends on the type and nature of the environmental media e.g geology, composition and quantity of the spilled product [4]. Spill incidents accompanied by fire outbreak usually leads to further destruction of the soil fabric, mineralogical alterations, mass loss, alterations of soil permeability [15] thereby weakening the protective cover and enhancing contaminant migration into the subsurface. At artisanal refining sites the heat from the distilleries distort the soil permeability, mass loss, particle size distribution and mineralogy. This enhances contaminant infiltration into the groundwater aquifer systems [1]. Groundwater pollution in many cases is a near impossible situations to manage due to uncertainties of early detection and management skills [8] the volume of spills and magnitude of the impact.

The rate of movement and storage of fluids in earth materials is influenced by inherent characteristics of the geologic materials and fluid properties. Soil-contaminant interactions affects hydraulic conductivity, shrinkage limits , effective grain size, compaction characteristics, strength and consolidation properties of soil. The permeability characteristic of earth materials is influenced by the nature of the pore fluid, cations and absorbed anions. The distortions can lead to easy migration and spread of contaminants.

Changes in soil temperature conditions can lead to distortion in the soil grain size distribution, mineralogical alterations, mass loss and soil permeability. The soil grain size decreases in sandy soil with increasing temperature due to a mobilisation of fines, because the bonds between the sand grains is destroyed by the temperature rise. Increasing temperature cause increase in overall particle size in clay soils due to aggregation and cementation of the clay fraction. Soil mineral composition is also altered by high temperatures. Elevated temperatures or heat in sandy and silty soils decreases organic matter and nitrogen, mobilizes clay and silt-sized particles, reduces cation exchange capacity and elevate soil pH. [15].

[14][15] noted that crude oil contamination in deltas and wetlands potentially damage the structure, function and ecosystem service values . They also observed that the impacts also increases soil pH significantly, decrease in strength, permeability, maximum dry density, optimum water content , Atterberg consistency limits and deplete phosphorus concentrations in the soil and hence it could potentially alkalinize marsh soils, adversely affect soil fertility and physical properties, and cause deterioration of the marshes.

Two principal factors are known to be responsible for its behaviour; these are environmental and physicochemical factors. Physicochemical factors include physical state of the crude oil and concentration of the oil spilled while the environmental factors are climatic (e.g rainfall, temperature, availability of oxygen) geological and physiographic factors (e.g slopes, drainage, terrain conditions) etc. Several critical parameters enhance or retard the rate of migration, these parameters include migration properties such as soil Organic carbon(OC), Cation exchange capacity(CEC), pH, Clay content, which influence the retardation of contaminant migration by controlling the adsorption of contaminants to migrating constituents. Other soil properties (e.g porosity, permeability, soil water content) influence the rate of water migration and therefore are also critical parameters [2][5].The durability of petroleum contaminants in the soil is determined by soil graining, climate as well as by their composition and concentration. In the soil porous space different phases coexist: Soil water phase , air phase and organic phase which seeps into the subsurface.

1.1 Location and Description of the Study Area

The Creek in Bodo community, is located in Ogoniland 56 km South East of Port Harcourt, Rivers State. Nigeria. It is located in Gokana LGA between Latitude 4°40´5´´N -4°43´19.5´´N and Longitude 7°22′53.7´´ E-7°27′9.8´´ E of the equator (Figure 1.1). The area is accessible by road through Sakpenwa –Bori road, off Port Harcourt –Eket section of the East West expressway and by Water, through the major Bodo River which serves as a transport route to other neighboring communities, Andoni, Ogu Bolo, Okrika and Bonny Island. 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. The Bodo creek is a coastal plain estuary with several channels. [11] and is dominated by intertidal sediments composed of silts and clay and the tidal channels separating the sediment, the area is accessible mostly by boat.

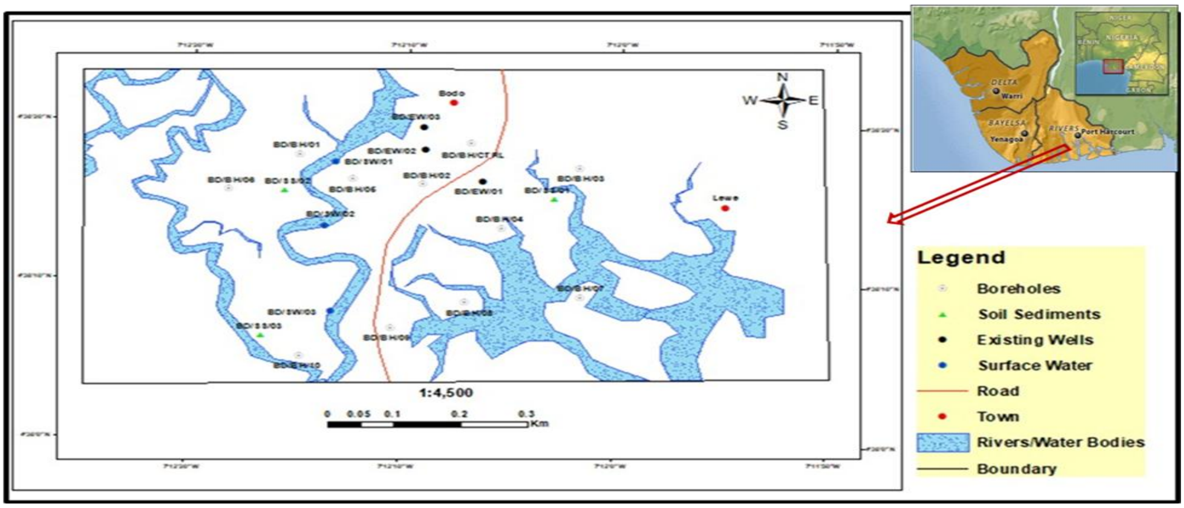


Figure 1.1 Location Map of The Study Area

II. MATERIALS AND METHODS

2.1 Study Site: The study was carried out at 10 artisanal refining sites 1-10 in addition to a site CTRL (control in surround of a settlement) around the eastern part of the Bonny River near Bodo in Gokana LGA, Rivers State, Nigeria (Fig. 1).

2.2 Sample collection and analysis: The geographical position of the sample point is established and read off using a GPS device and recorded. At each artisanal polluted site (BD-BH-01 to BD-BH-10 and BD-BH-

Control) the sample collection point is identified and the auger handle is pushed and turned 3600 to advance through the ground until it is filled with soil. The auger is then pulled up and the content discharged. Soil samples were collected at depths of 0.5m, 1.0m , 2.0m, and at intervals of 1m up to 10.0m.. The process is repeated until the required calibration is achieved. The soil obtained is then collected in aluminium foil plates for analysis. The sample containers are then labelled stored temporarily in samples box. In order to avoid cross contamination, the auger is cleaned by scrubbing it with a brush and washing in a bucket filled with soapy water. The process is repeated after each flight until required depth is achieved.

2.3 In-situ Tests: These were carried out onsite using hand held device (Soil pH and Moisture meters). *The Soil pH Meter* uses an exclusive two-probe measuring system which allows both probes to be inserted into the same depth in the soil and allows the metals to be exposed to the same amount of soil providing the most effective way to consistently and properly measure soil pH. The pH was then read on the calibration and recorded. The pH and moisture meters are made of sensitive tips.

The Moisture Meter is a Brass soil moisture probe with an eight inch metal stem and Meter with 0 -10 calibration mounted on top. The probe has a sensor at the tip and penetrates to root level. The moisture reading is then indicated is read off at the tip of the pointer needle and recorded. These devices devices were washed with sterilized water after each use.

2.4 Laboratory Analysis: The soil samples were subjected to oven drying and sieved with 2mm sieves before analysis of various parameters according to procedures in BS 1377 of 1990 . A series of tests were performed to evaluate the thermo-chemical effect of the refining process on soil properties. Laboratory test performed include: Grain size, specific gravity, Soil porosity, Soil Organic Content (Loss on Ignition), Atterberg consistency limit tests etc. Graphs of percentage passing versus sieve diameter was plotted (particle size distribution curves). The following deductions were made from the curve - % gravel, % sand, % fine, mass of clay and % clay, coefficient of uniformity and permeability co-efficient were also determined. The particle size were also used in grading and USC classification of the soil which utilized the Coefficient of uniformity, CU expressed as

i) CU = D60/D10

ii) CU of less than 5, and 5 and above rates the soils as poorly and well graded soils respectively. By the USC scheme these soils are denoted as SP in the case of sand.

iii) Also the D10 of the soils were used to estimate the permeability of the soils using the Hazen (1911) relationship between coefficient of permeability (K) and D10 where

iv) K = Cd102 (cm/sec)

Where C is a constant

The K obtained was used to infer the degree of permeability, and hence mobility of fluids/contaminants in the soils.

III. Results /Interpretation

3.1 Moisture Content

The moisture content of the impacted soil ranges from 6.76% - 13.98 % with an average of 6.967% compared to that of the control site where soils moisture ranges from 14.5% - 22.8% with an average of 14.6 %. This shows a difference of 7.63% in the moisture content of the oil impacted soils exposed to high temperatures of the distilleries when compared with that of unpolluted soils (Fig. 1). The variation between the impacted and the control sites can be said to be significant and correlates closely the atterberg consistency limits. The variability trends imply that soils at the upper horizon which probably suffered the highest impact of the heat acquired higher water resistant (hydrophobic) tendency and unable to absorb much water. Extreme temperature have the capability of altering the nature of soils completely as demonstrated by charred surfaces at most of the artisanal refining sites in the area. Plate 1.

Plate 1: Completely Burnt carbonized material at artisanal refining site.

Table 1: Soil Properties at the Artisanal refineries and control sites across the various soil horizons

	0.5	1	2	3	4	6	8	10	Total	Av.
Moisture Content-Control	17.24	14.9	14.7	17.44	14.5	21.6	22.8	22.9	146.08	14.6
Moisture Content-Impacted site	13.98	6.76	6.84	8.12	8.43	8.5	8.54	8.5	69.67	6.967
pH- Control	5.6	4.6	4.8	5.8	6.8	6.4	6.55	6.7	47.25	4.7
pH- Impacted Site	7	6.3	6.8	6.7	6.5	6.8	6.9	6.9	53.9	5.39
Specific Gravity-Control	2.32	2.25	2.4	1.7	2.58	2.56	2.6	2.6	19.01	1.9
Specific Gravity-Impacted Site	2.42	2.25	2.4	1.74	2.45	2.46	2.5	2.6	18.82	1.88

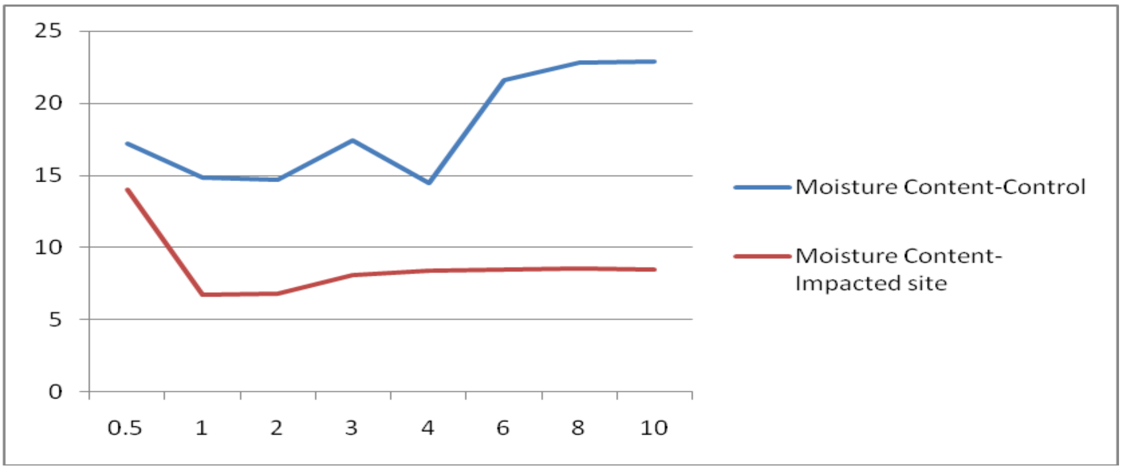


Figure 1: Plots of Moisture Content at Artisanal Crude oil Refining & Control Site across various depths.

3.2 Particle Size distribution

Generally, the soil particle sizes at this area consists 92.2% sand, 5.26% fines(silts and clays) and 2.36% gravel and were classified according to the Unified Soil Classification System (USCS) as poorly graded. From the grain size analysis , the coefficient of permeability shows soils of low permeability. [15] put it that high temperatures affect the particle size distribution, mass loss, mineralogy and permeability of the soil. In clayey soils, the overall particle size increases with increasing temperature due to aggregation and cementation of the clay fraction.

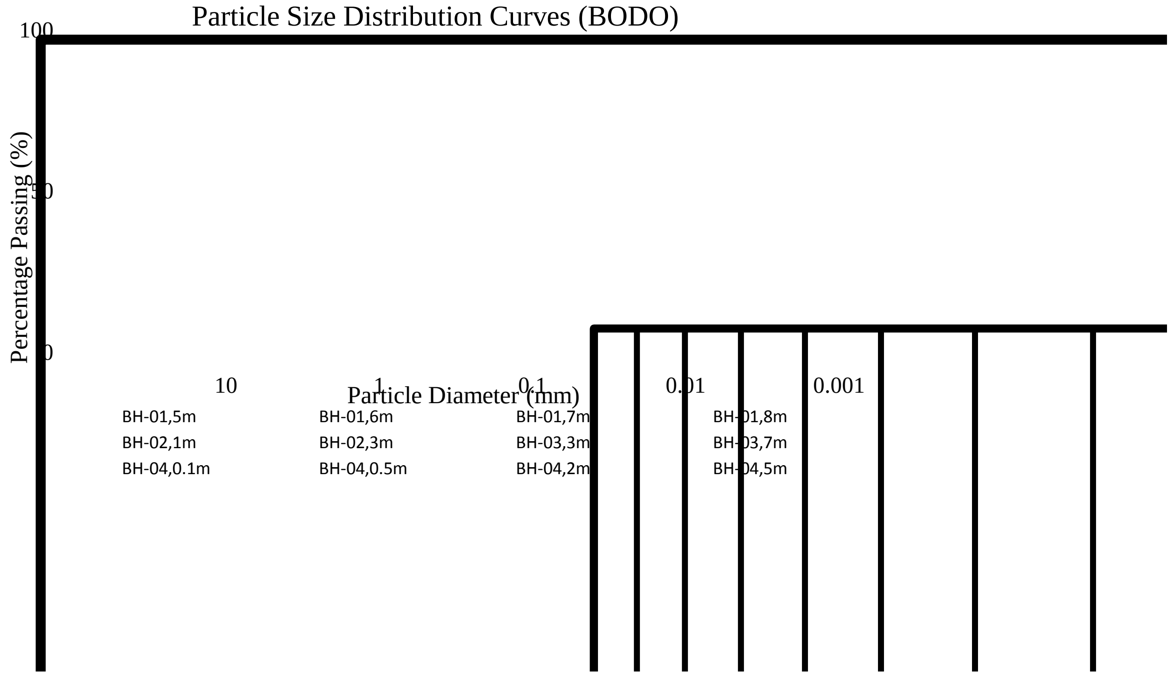
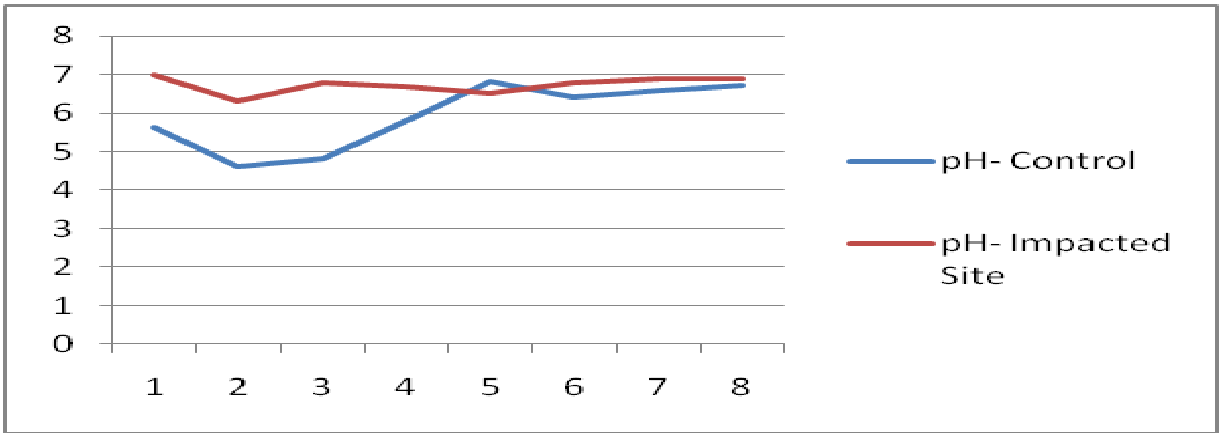


Figure 2: Particle size distribution curves for the site

3.3 Soil pH and Specific Gravity

Marginal variations were observed for pH and specific gravity for the sites with the impacted sites having average value of 4.7 is an indication of higher acidity levels at the impacted sites while the control site pH value of 5.39 indicates moderate acidity levels. Implying degraded soil conditions at the impacted sites when compared to the control sites. The variation in the specific gravity of 18.82 for the impacted sites against 19.01 (i.e difference of 0.69 for soil pH and 0.19 for specific gravity) for the control sites shown in Table 1 and Figs. 3 and 4, illustrates slight alteration of the soil density due to the heat effects. The rate of alteration of the specific gravity of the impacted sites across the depths at this sites varied slightly at the shallow depth up to 1.0m and was almost at same levels with the control at the depths of 1.0m to 3.5m and then reduced afterwards to depths of 9.8m depth. This variation depicts amount of change in temperature levels, level of exposure of the soil materials to the heat, viscocity of fluids and hence their mobility in the subsurface. Viscosity of hydrocarbon products is greatly reduced at higher temperatures, making them very mobile in the subsurface.



Figures 3: Graph of pH for impacted and Control site

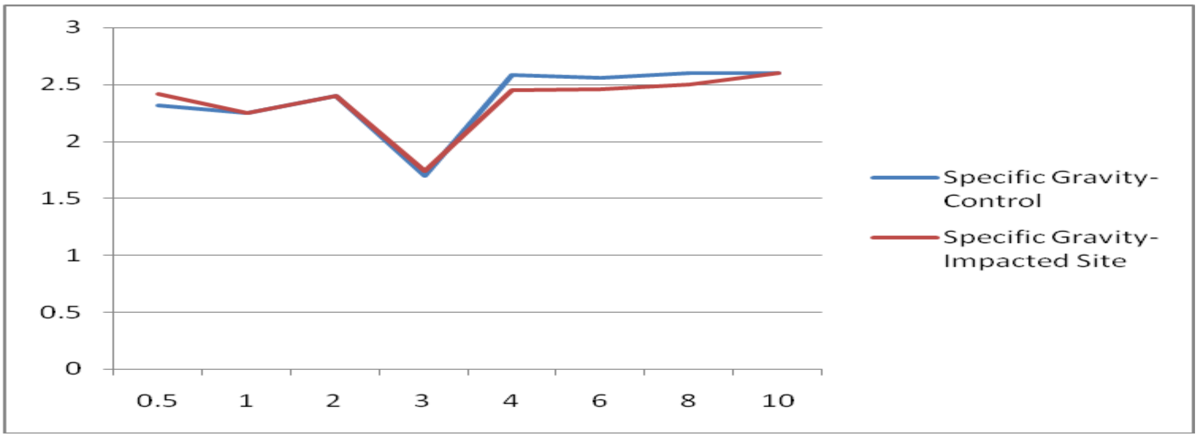


Figure 4: Graph of variation in specific gravity across the depths for the area

3.4 Atterberg Limits

The liquid limit of the unpolluted soils is same (31.15%) , while plastic limit decreased from 18.25% to 14.35% and plasticity index increased from 11.15 % - 13.1 % at the control site up to 2.0m when compared with that of the impacted soils which Liquid limit values increased from 29.98 % to 34.27 % and plastic limit from 18.52 % to 21.77 % with decreased plasticity index 21.63 % to 18.93% respectively. This clearly indicates that the thermo-chemical effects of artisanal refining does alters the soil consistency, significantly reducing its liquid limits and plasticity index. (Table 2; Fig. 3). [12] put it that the interaction between water and clay particles is hindered or completely removed when oil comes in contact with clay particles., this situation is made worse with the introduction of heat to the soils.

Table 2: Soil Consistency Limits (Atterberg)

		0.5	1	2	Total	Av.
Control Site	Liquid Limit	31.15	31.15	31.15	93.45	31.15
	Plastic Limit	18.25	16.45	14.35	49.05	16.35
	Plastic Index	11.15	12.54	13.1	36.79	12.23
Impacted site	Liquid Limit	29.98	32.14	34.27	96.39	32.13
	Plastic Limit	18.52	20.16	21.77	60.45	20.15
	Plastic Index	21.63	18.93	20.33	60.89	20.88

3.5: Soil Organic Carbon Content

The variability of Organic carbon content in samples at the impacted sites and control site presented in Table 4 and Figure 5.0 is a clear demonstration of the depletion of organic matter from the impacted soils due the contamination which is worsened and the heat effects. The shallow depth 0.5m to 1.0m which suffers the most exposure heat has shown significant differences in their organic carbon contents. Organically rich soil are known to retain hydrocarbon products for prolonged periods especially the persistent organic pollutants (PoPs), which gradually released into the environment. The burning effects of the refining process at the refineries, burns off the organic matter in the soil and reduces or completely deplete the hydrocarbon retention capabilities of the soil and hence increases the mobility of the contaminants in those soil layers.

Table 4: Soil Organic Content for Impacted Vs Control Site

	0.5	1	2	3	4	6	8	10	Total	Av.
Control Site	2.2	2.3	2.45	1.3	0.55	1.09	1.55	ND	11.44	1.69
Impacted Site	4.65	3.4	2.53	2.5	2.58	2.07	1.15	ND	18.88	2.73

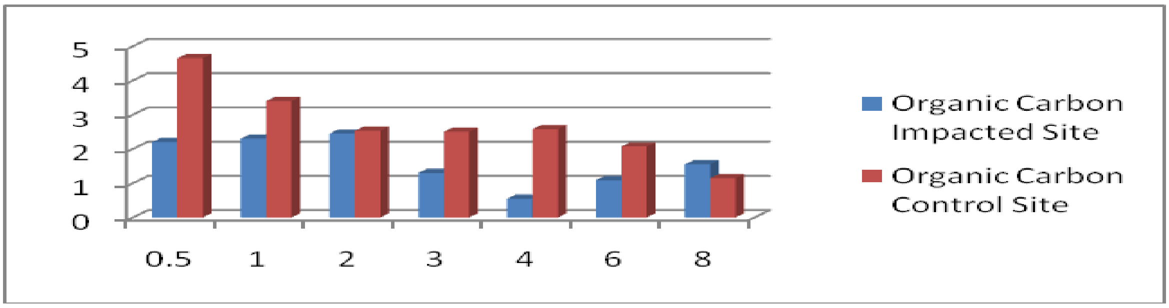


Figure 5.0: Soil Organic Carbon Content

3.6 Soil porosity and Permeability Coefficient

The variation in the soil porosity in impacted samples points to the impacts of the activities at the refining sites when compared with the control site. [15] noted that the particle sizes and permeability of soil decreases with increasing temperature due to a mobilisation of fines, which is likely due to the bond of fines to the sand grains being affected by temperature. The average soil porosity of 33% at the impacted sites and 42% at the control site agrees with the above position, however, it is significant to allow significant movement of fluids and contaminants in the soil horizons. The average coefficient of permeability properties 7.7 x 10^{-4} at the control and 4.4 x10^{-3} at the impacted sites which increased with depth (Table 5 and Figs. 6 and 7) points to the fluid transmission properties of the soil in the area. These implies that infiltration of contaminants will be relatively easier at the artisanal refineries which may be enhanced in the lower soil horizons due to the nature of the soil in those layers.

Table 5: Coefficient of Permability (k) and Porosity (p) of Impacted site Vs Control Site .

	0.5	1	2	3	4	6	8	10	Av.
porosity- Control	0.45	0.44	0.42	0.4	0.38	0.4	0.46	0.43	0.42
porosity-Impacted Sites	0.26	0.43	0.31	0.42	0.34	0.32	0.28	0.32	0.33
permeabilty- Control	0.00726	0.006	0.00486	0.00456	0.00424	0.0135	0.0135	0	0.0077
permeability- Impacted Sites	0.047985	0.03361	0.03176	0.052215	0.0385	0.037715	0.05068	0.02783	0.04004

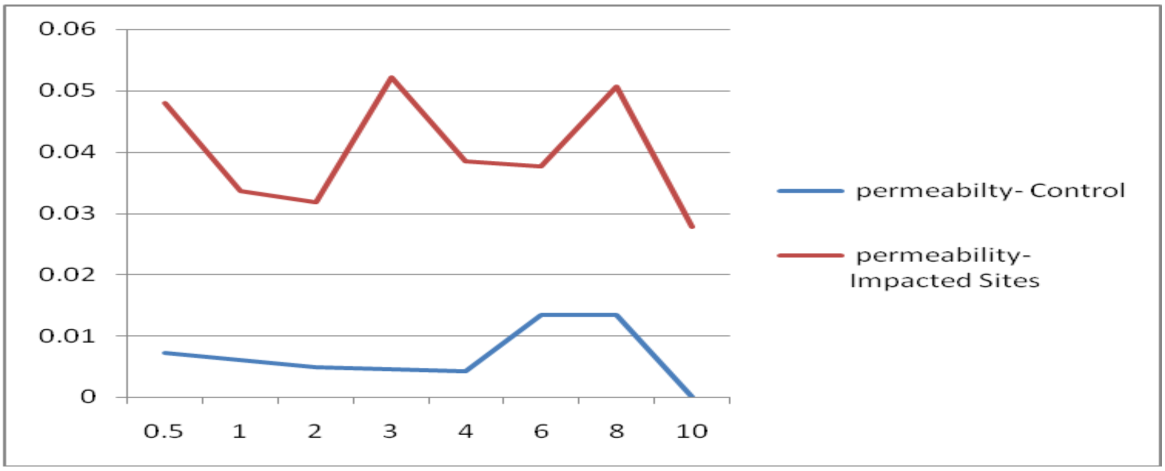


Figure 6: Variation of coefficient of permeability across various depths at impacted and control sites

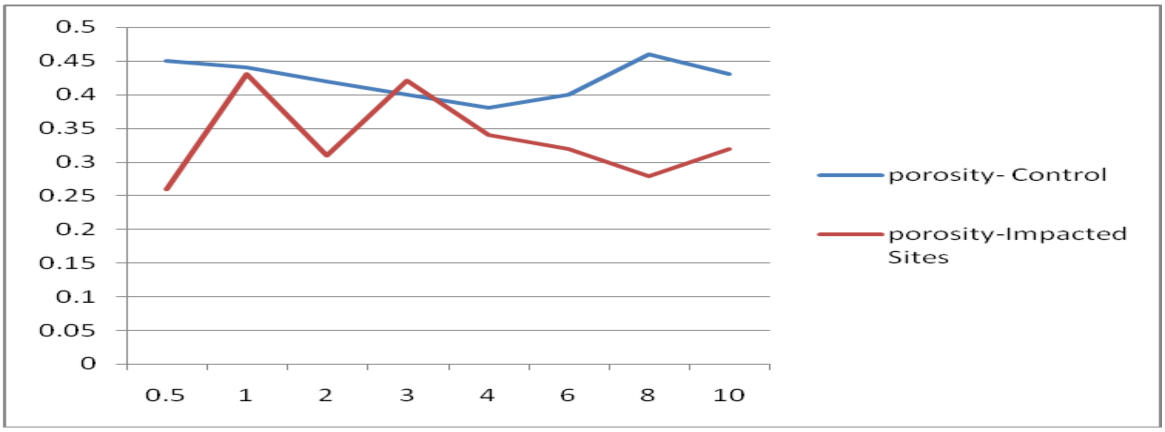


Figure 7: Variation of Soil Porosity Across Soil horizons for impacted and control sites

IV. DISCUSSION

The magnitude of modification of the soil properties can be inferred from the changes observed in the various soil parameters. The changes noted in moisture content, atterberg limits, soil porosity and coefficient of permeability imply high significance. These changes in the behavior of soils can be related to the changes of its fabric as a result of the hydrocarbon contamination and worsened by the exposure to extreme heat from the distillation processes at the refining sites [12]. Soils are usually a 3 phase system- Solid, Void, fluid, the presence of hydrocarbon on soil introduces a fourth phase and hydrocarbon molecules adsorb onto the soil grains. The result of this interaction is the changes in soil characteristics. Heat treatment on hydrocarbon impacted soil causes the fusion of resins with the soil grains thereby precipitating chemical reactions. Soil contamination set in motion forces which increases the chances of interparticle slippage hence reducing shear strength parameters of the soil. These forces which are dominant in the impacted and less in the control soil samples [12]. This reduction in soil characteristics is worsened by the introduction of a fourth phase into the natural three phase system and escalated by the exposures to extreme temperatures of the particulate earth materials. soil samples

V. CONCLUSION

From the above results, it can be deduced that hydrocarbon contamination has several negative impacts on soil properties. The introduction of abnormally high temperatures to the already contaminated soils comes with a whole lot of transformations in soil consistency, strength, alterations in soil grain sizes, porosity and permeability, specific gravity, moisture content etc. The adsorption effectively reduces soil engineering properties, e.g. permeability is reduced by repelling water from the surface of the soil grains. The results have clearly shown that oil contamination on the soils have significantly worsened their geotechnical properties. These changes which are dependent on the intensity of the heat, soil structure and the dominant mineral composition, increases the vulnerability of the soil to hydrocarbon contaminant migration and also makes the soil unfit for construction and even plant growth which is very devastating to the ecological systems. Local crude oil refining activities have significant impacts on the environment and heightens the vulnerability of the groundwater system in the area. Appropriate actions must be taken to abate the spate of these activities for environmental sustainability.

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