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Preliminary Studies of Elele and Isiokpo Oilfields in the Niger Delta: Macro-Nutrient Status of Spill-Impacted Soils

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ABSTRACT

The preponderance of oil spill in the petroliferous Niger Delta region of Nigeria calls for regular checks on the status of the soil ecosystem, which is the most affected by onshore spills. Soils originally useful for agricultural purposes, are now prostrate to petroleum hydrocarbons owing to incessant spills. Elele (E) and Isiokpo (I) are two onshore oilfields in the region predisposed to oil pollution. Soil samples collected according to standard methods using a stainless-steel hand-auger, were subdivided into five, E1 to E5 for the Elele and I1 to I5 for Isiokpo soils. E1 and I1 acted as control with no contamination while E2 to E5 and I2 to I5 were contaminated with 10 ml, 20 ml, 50 ml and 100 ml of crude oil respectively. Soil samples were evaluated for nutrient stability after estimating the residual oil in the soils by subjecting samples to hydrocarbon (THC, TPH) analyses. Soils were subsequently analysed for the presence of macronutrients (total N, P, Ca, K and Na) and micronutrients (Ni, Cu and Fe) as well as physicochemical properties such as pH, electrical conductivity (EC), total organic carbon (TOC) and total organic matter (TOM). Results showed that oil contamination increased the value of total N and P, as well as Ca, K and Na and Ni, Cu and Fe. TOC and TOM in both soil locations as compared to their uncontaminated control. Further, there was a linear reduction in pH and EC for the Elele oilfield soils, while soils from Isiokpo oilfield showed no dependence on volume of crude oil contamination. Generally, our findings showed that oiling substantially altered the soil nutrient status and physico-chemical properties of the soils.

Keywords: Petroleum hydrocarbons; Oil spill; Soil nutrients; Physicochemical properties

Introduction

Crude oil is a complex mixture of different organic compounds that are generated over a long period of time by the chemical conversion under various geological conditions. The main constituents of crude oils are carbon and hydrogen, which together make up a large variety of hydrocarbons from light vapours to heavy residues. Sulphur, oxygen and nitrogen are also present in lower amounts, along with metals like iron, nickel and vanadium. When oil and gas are explored, produced, transported and stored, liquid petroleum hydrocarbon products can leak into the environment, including the terrestrial and aquatic environments.

Since the discovery of crude oil in Nigeria in 1956 at Oloibiri, the Niger Delta region has continued to suffer from the negative environmental impacts of crude activities[1]. The region has known no respites in oil spillage and other form of pollutions resulting from oil activities[2]. Crude oil spillage from underground pipeline and storage tanks is a frequent occurrence within communities of intense oil exploration activities. Both natural and human factors such as pipe burst due to high pressure, corrosion of pipes, malfunctioning of equipment, sabotage and vandalism have been identified as some of the causes of oil spillage[3].

Soil degradation by hydrocarbon pollution is a major environmental challenge facing oil producing communities[4,5]. Soil, a vital resource of microorganism activities and plant nutrients, is a major recipient of crude oil spillage. One of the major impacts of crude oil pollution on soil is its inability to support plant growth and microecological activities due to dynamical changes in the physical, chemical and biological properties. Oil pollution results to inputs of hydrocarbon chemicals that may have substantial impacts on the physicochemical functions and nutrients supply of the soil[6]. The resultant impacts of unavailability of essential nutrients such as nitrogen, phosphorus and calcium and the elevation of some toxic metals such as arsenic, lead and cadmium to plants are major obstacle to food availability and sufficiency[5]. Several studies have shown the inhibiting impacts of oil pollution on soil microbial activities[6] and retardation of plant growth and yields[7,8].

The imbalance in soil nutrient and physicochemical properties of farm soil due to oil activities in the Niger delta region is a serious concern of soil fertility and food insecurity that needs the inputs of all stakeholders. Therefore, this study is one of such efforts to investigate the impacts of crude oil on soil nutrients and physicochemical properties in an off-field laboratory simulated contamination. The main objective of the study is to assess the extent of crude oil contamination on the availability of macronutrients (N, P, K, Ca and Na) and micronutrients (Ni, Cu and Fe). The study will help in the understanding of scope of growth of plants in contaminated environment and in planning of proper bioremediation strategies.

Materials and Methods

Soil samples collection area

Soil samples for crude oil contamination were collected from Isiokpo and Elele, both in Ikwerre Local Government Area (LGA) of Rivers State **(Figure 1)**. Ikwerre LGA lies roughly within the coordinates of 6°50’0’E and 7°0’0’E latitude and 0‘0°°N and 5°100N longitude.

Samples collection

Surface soil samples were collected from Elele (E) and Isiokpo (I) in an area with no history of crude oil pollution. Samples were collected within depth of 0-30 cm randomly at different points using a hand augur to form a representative and homogeneous sample of the two study locations. The samples were collected in sampling bags, labelled accordingly and thereafter taken to the laboratory for preparation and analysis. The collected composite sample of each location was divided into five subsamples with that from Elele labelled E1 to E5 and that from Isiokpo labelled I1 to I5. Plant debris and pebbles were removed from the soil samples. The subsamples were housed in polyethene bags, dried in normal laboratory conditions for 10 days.

Figure 1: Showing sampling locations.

Crude oil contamination

Samples of crude oil were obtained from Forcados terminal in the Niger Delta region. Two kilogram of each soil samples were weighed out and used for the crude oil contamination. The soil samples were manually spiked with different volume of crude oil and thoroughly mixed for homogenous contamination. **(Table 1)** shows the crude oil experimental contamination design.

Table 1: Crude oil experimental contamination of soil.

Elele (E) soil code	Isiokpo (I) soil code	Crude oil contamination
E1	I1	control (no contamination)
E2	I2	10 ml of crude oil contamination
E3	I3	20 ml of crude oil contamination
E4	I4	50 ml of crude oil contamination
E5	I5	100 ml of crude oil contamination

Each prepared soil sample was analysed for macronutrients such as total nitrogen (N), available phosphorus (P), calcium (Ca), potassium (K) and sodium (Na) and micronutrients such as nickel (Ni), copper (Cu) and iron (Fe). Physicochemical properties such as soil pH, electrical conductivity (EC), total organic carbon (TOC) and total organic matter (TOM) were also analysed.

Determination of total hydrocarbon content and total petroleum hydrocarbon

A two-gram soil sample was weighed into a clean extraction container, 20 ml of hexane was added, mixed thoroughly and then allowed to settle. The mixture was carefully filtered into clean extraction bottle by means of filter paper in a Buchner funnel. The extract was then concentrated to 2 ml and thereafter transferred for separation. Separation was done using slurry of 2 g activated silica in 10 ml dichloromethane placed into the chromatographic column. 8 ml of the extracted eluant was collected into labelled glass vials for GC analysis. The concentration of THC and TPH in sample was measured at a particular chromatogram in units of mg/kg.

Determination of soil physicochemical properties and micro and macro nutrients

The soil physicochemical properties were determined following outlined standard procedures[9,10]. Soil pH and EC were by 1:1 soil/distilled water solution using calibrated pH and conductivity meter. TOC and TOM were determined by titrimetric procedures of Walkley-Black method[11,12]. Soil total nitrogen was determined by regular micro-kjeldahl digestion method[13,1]. Available phosposrous was determined by Brays No. I extraction method[14]. Potassium and sodium were obtained by flame photometer[14,12]. Iron, nickel, copper, calcium and magnesium were determined by flame atomic absorption spectrophotometer (FAAS) after acid digestion of the samples. All measurement were conducted in triplicate.

Results

The results of measured soil pH, EC, TOC and TOM are given in Table 2. As observed, control soil of Elele registered a pH and EC value 6.84 and 88.0 µS/cm respectively, while that of Isiokpo had value of 6.09 and 68.0 µS/cm respectively. The Elele soil pH decreased from 6.34 to 5.84 in response to the quantity of crude oil contamination. This trend was not the case of the Isiokpo soil as the pH decreased from 7.02 to 4.61 for I2 to I4 and then had an increased value of 5.45 for soil I5. The EC of the control soil of Elele was higher than those of the contaminated soil, soil E3 had the highest EC of 78.0 µS/cm among the contaminated soil. Except soil I3, all other contaminated soil of Isiokpo had EC higher than the control soil with highest value of 185.0 µS/cm for soil I°. TOC and TOM value of 2.767 % and 4.788 % respectively was measured in Elele control soil while that of Isiokpo had value of 0.975 % and 1.686 %. In the contaminated soil, the TOC and TOM values in Elele soil increased steeply with volume of crude oil contamination from 4.524 % to 5.226 % for TOC and 7.822 % to 9.036 % for TOM. In Isiokpo soil, the values also increased steeply with volume oil contamination from 3.588 % to 5.226 % for TOC and 6.204 % to 9.036 % for TOM **(Table 2)**.

Table 2: Physicochemical properties of soil.

Physicochemical properties	Elele soil						Isiokpo soil				
	E1	E2	E3	E4	E5		**I1**	**I2**	**I3**	**I4**	**I5**
pH	6.84	6.34	5.57	5.95	5.84		6.09	7.02	6.28	4.61	5.45
EC (µS/cm)	88.0	53.0	78.0	34.0	29.0		68.0	82.0	41.0	123.0	185.0
TOC (%)	2.767	4.524	4.758	5.148	5.226		0.975	3.588	4.797	5.187	5.226
TOM (%)	4.788	7.822	8.226	8.901	9.036		1.686	6.204	8.294	8.968	9.036

(Figures 2 and 3) show the levels of macronutrients in Elele and Isiokpo soils respectively. The levels of the micronutrients in both soil locations are shown in Figures 4 and 5 respectively. For the Elele soil, the total N, available P, Ca, K and Na registered a value of 0.239 %, 0.20 mg/kg, 1453.16 mg/kg, 57.32 mg/kg and 352.51 mg/kg respectively in the control soil. In the contaminated soil, the measured concentration of macronutrients were in the range of 0.391 % (E2) – 0 .451 % (E5) with mean of 0.425 % for total N, 0.29 mg/kg (E2) – 0.52 mg/kg (E5) with mean of 0.39 mg/kg for available P, 13.82 mg/kg (E5) – 581.33 mg/kg (E2) with mean of 232.03 mg/kg for Ca, 40.91 mg/kg (E3) – 140.66 mg/kg (E2) with mean of 67.67 mg/kg for available K and 413.86 mg/kg (E2) – 526.86 mg/kg (E3) with mean of 453.92 mg/kg for Na. Similarly, the control uncontaminated Isiokpo soil had value of 0.084 %, 0.32 mg/kg, 399.64 mg/kg, 49.12 mg/kg and 351.90 mg/kg for total N, available P, Ca, K and Na respectively. The contaminated soils had values of the macronutrients in the range of 0.310 % (I2) – 0 .451 % (I5) with mean of 0.406 % for total N, 0.25 mg/kg (I3) – 0.56 mg/kg (I5) with mean of 0.41 mg/kg for available P, 121.57 mg/kg (I4) – 2192.44 mg/kg (I2) with mean of 922.78 mg/kg for Ca, 34.35 mg/kg (I4) – 90.16 mg/kg (I2) with mean of 67.10 mg/kg for available K and 298.34 mg/kg (I3) – 442.49 mg/kg (I5) with mean of 351.65 mg/kg for Na.

The micronutrient contents measured in the Elele soil had value of 3.21 mg/kg in the control soil and values of 4.62 mg/kg (E4) to 8.68 mg/kg (E2) with mean of 6.63 mg/kg in the contaminated soil for Ni; 6.51 mg/kg in the control soil and values of 4.50 mg/kg (E5) to 14.03 mg/kg (E2) with mean of 9.14 mg/kg in the contaminated soil for Cu; and 6790.0 mg/kg in the control soil and values of 6106.5 mg/kg (E3) to 6656.9 mg/kg (E4) with mean of 6489.83 mg/kg in the contaminated soil for Fe. For the Isiokpo soil, measured value of Ni was 3.40 mg/kg in the control soil and 4.39 mg/kg (I5) to 5.75 mg/kg (I4) with mean of 5.07 mg/kg in the contaminated soil; value of Cu was 3.87 mg/kg in the control soil and 3.34 mg/kg (I4) to 10.98 mg/kg (I3) with mean of 6.82 mg/kg in the contaminated soil; and for Fe, value of 6581.3 mg/kg was measured in the control soil and 5719.3 mg/kg (I4) to 6650.9 mg/kg (I3) with mean of 6092.85 mg/kg for the contaminated soils.

Discussion

The results show a linear reduction in pH and EC of the Elele soil while that of Isiokpo soil show no dependent on volume of crude oil contamination. The contaminated soil from Elele shows a significant decline in the pH and EC in soil comparison with the control soil. This observation differs from that of Isiokpo soil. The result of this study shows that crude oil contamination reduced soil pH level to acidic nature (pH level < 6.0) in a manner that is dependent on the quantity of oil spilled. Earlier studies have also given similar observation[15,9]. Generally, the EC of the soils, except that of I4 and I5, were below 120 µS/cm prescribed by DPR[16], which means that the soil can be described as non-saline. This implies that the crude oil contamination did not result in severe salinity change of the soil unlike crude oil contaminated soil of Ovia North East local government area of Edo State with EC value of 417.50 to 794.45 µS/cm[17]. pH and EC are essential soil properties that safeguard soil fertility and micronutrients availability for optimum crop yield. Although there are mixed debates on effect of crude oil contamination on soil pH and EC values. Some studies have reported increased in pH of crude oil contaminated soil[18,12,19]. TOC and TOM are direct measure of organic richness[2]. Generally, the study results show that both TOC and TOM had a linear dependent on the volume of crude oil spilled on the soil. This further shows that crude oil has a significant influence on organic matter content of soil. The obtained result of the TOC and TOM show that the soils contain significant amount of organic matter. The TOC and TOM of all contaminated soil of both locations had higher values than the control soils. This increase in the TOC and TOM values in response to crude oil contamination indicates that crude oil can cause a change in soil chemical properties[18]. Soil TOC and TOM are generally due to biota degradation[12], however, crude oil contamination may also contribute to the organic content of due to the hydrocarbon content. The results of present study aligned with the findings of[12,18] that oil contamination significantly increased soil organic contents which might be as a result of slow decomposition rate owing to poor soil aeration occasioned by the crude oil content.

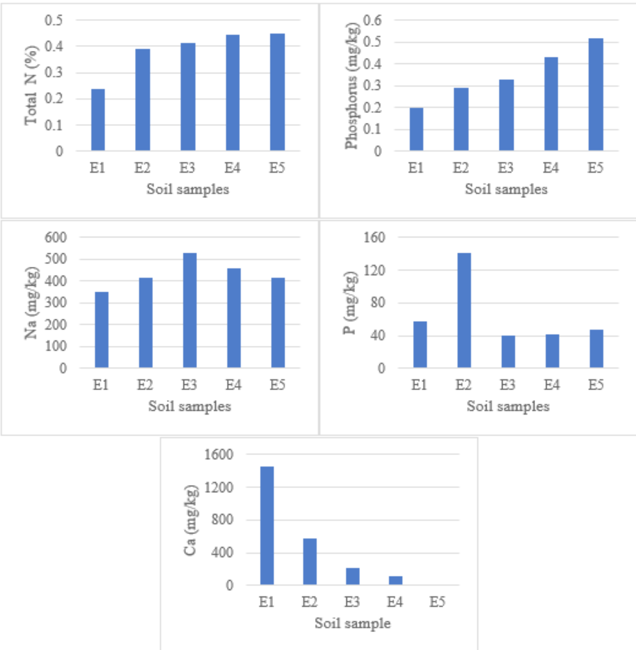

Figure 2: Levels of macronutrients in soil from Elele**.**

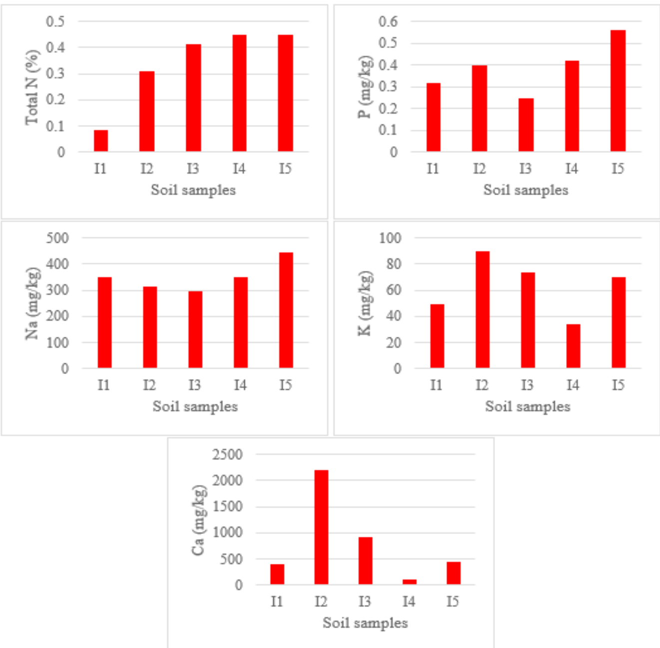

Figure 3: Levels of macronutrients in soil from Isiokpo.

As shown in **(Figures 2 to 5)**, the present study showed that crude oil contamination resulted in both increase and decrease of some of the macro and micro nutrients. Crude oil contamination increased the value of total nitrogen and available phosphorus in both soil locations as compared to their uncontaminated control. Also, the sodium content in Elele soil increased in respond to increasing volume of crude oil contamination. As evident from the results, the total nitrogen contents and phosphorus in the contaminated soil of both locations were elevated as a result of the crude oil contamination. The linear response of the total N and P shows that higher volume of crude oil may result to their elevation in soil above recommended range for a fertile soil. This is also true for Ca in soil from Elele. Soil nitrogen and phosphorus are essential part of plant protein and chlorophyll and cell nucleus respectively[20,14]. The current result aligned with that of Saikia et al[12]. who had reported increase in nitrogen and phosphorus contents of oil impacted soils. On the contrary to the response of total N, P and Ca to crude oil contamination of present study[18] reported a decline of the macronutrients in contaminated soil of Momoge Wetland, China in comparison to a control site. Obasi et al. (2013) and Onuh et al. (2008) also reported a decrease. The increase in total N and available P in the crude oil contaminated soil can be attributed to the impact of crude oil which promotes the organic matter and carbon contents of the soil[12]. Similar, Agbogidi et al. (2007) opined that increase in available phosphorous content of the oil impacted soils may be due amendment in the soil pH resulting from the crude oil. Nitrogen and phosphorus are key macronutrients for plant growth and helps in the transfer of energy. Correlation analysis between TOC and total N, TOC and P shows value of $R^2 = 1$ in both soil locations. According to Saikia et al. (2023) soils with high organic matter content have better supplies of organic nitrogen and phosphate for plant uptake. Positive relationship between soil organic carbon, nitrogen and phosphorus have also been reported by other researchers[21,22,12].

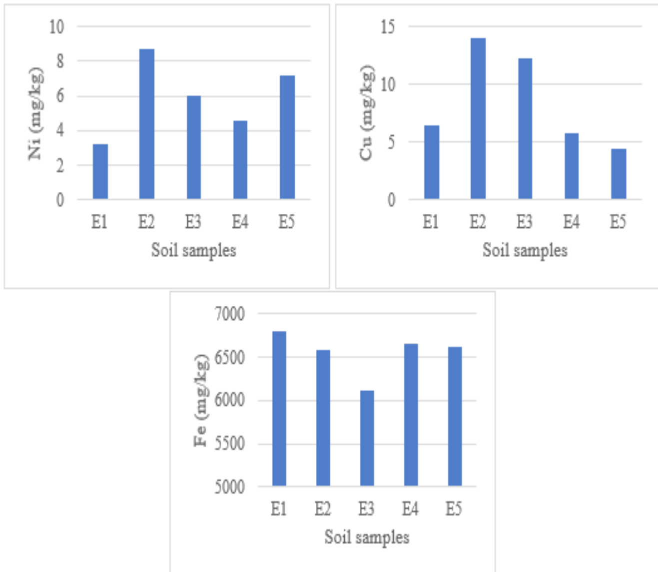

Figure 4: Levels of micronutrients in soil from Elele.

Potassium content in Elele contaminated soil decreased accordingly in comparison with the uncontaminated soil E1 with value of 57.32 mg/kg, except for contaminated soil E2 with value of 140.66 mg/kg. This is contrary to that of Isiokpo soil where the contaminated soils measured higher concentration than the control soil except for soil E4 with value of 34.35 mg/kg lower than that of the control of value 49.12 mg/kg. Similarly, Na recorded higher value in the Elele contaminated soils than in the control while in Isiokpo soil the control soil had a higher level of 351.90 mg/kg than the contaminated soil except for soil I5 having value of 442.49 mg/kg. This inconsistency in K and Na level in the contaminated soils may be due to immobilization that arose from the formation of complexes in the soil after the contamination Agbogidi et al. (2007). K is a vital soil nutrient required by plants for some physiological processes and growth. Na is not too considered an essential macronutrient due to salt stress buildup associated with high concentration in soil. In situation of low K, Na acts as a counter-ion in soil[12].

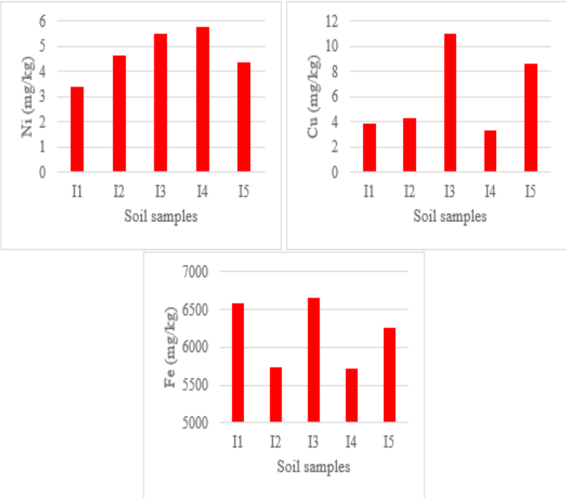

Figure 5: Levels of micronutrients in soil from Isiokpo.

Crude oil contamination raised the concentrations of the micronutrients, Ni and Cu, in the contaminated soils of both locations as compared to that respective control. Though, the increase did not follow the order of increasing volume of the crude oil contamination. The Fe content in the contaminated soils show both increase and decrease in both soils. These elements, within a certain recommended limit, are required as essential macronutrients to fulfil certain biochemical and metabolic functions[23], values above the recommended limits can result to them being toxic to plants and as well as human. The level of hydrocarbon contamination of soil influenced the noticeable decrease/increase of these elements in the contaminated soil, which also impacted on the nutrient status of the soil[17].

A preview to the level of contamination by the fugitive oil was first evaluated to know the concentrations of TPC (total hydrocarbon content) and TPH (total petroleum hydrocarbon) and the results showed measurable levels of the crude oil in the contaminated soils from both locations, these results are captured in **(Figures 6 and 7)**.

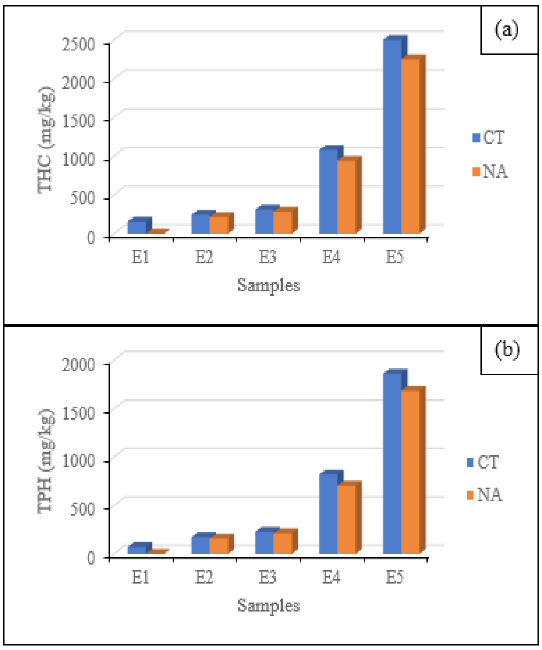

Figure 6: Comparison of THC and TPH of contaminated and natural attenuation of Elele soil.

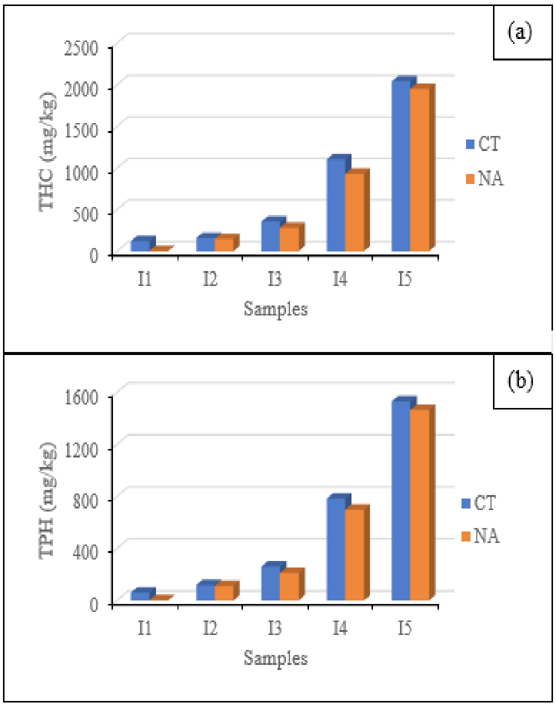

Figure 7: Comparison of THC and TPH of contaminated and natural attenuation of Isiokpo soil.

It is widely reported that oiling sffects the biogeochemical cycle of the ecosydtem by altering the micro- and macro-nutrients available in the soil. The presence of oil encourages the metabolic activities of microorganisms which increase in their numbers in the soil following the incursion of hydrocarbons, which provide carbon for the growth and expansion[24,25,26].

Conclusion

Crude oil exploration and production have been associated with degradation of the environment effecting soil physicochemical characteristics and nutrients status of both cultivated and arid land. This study was designed to investigate the impact of crude oil contamination on soil nutrients properties. The study has shown that crude oil contamination results in both increase and decrease of some macro and micro nutrients of contaminated soil. Physicochemical properties such as pH, electrical conductivity, total organic carbon and total organic matter were also impacted by the crude oil contamination

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