

INTERNATIONAL JOURNAL OF AGRICULTURE, MANAGEMENT AND TECHNOLOGY



Vol 8(1) 2024

Published by
Federal College of Agriculture,
Ishiagu Ebonyi State

CRUDE OIL CONTAMINATION AND PHYSICO-CHEMICAL PROPERTIES OF SOILS OF OFOROLA, OWERRI WEST, IMO STATE

ENYIOKO, C. O., EZECHIKE, N., IGBOJIONU, J., CHIEMEKA, C. I., IROHA, J. AND OKON, B. A.

Department of Soil Science and Land Resources Management Technology, Federal College of Land Resources Technology, Owerri, Imo State.

Corresponding Author: Enyioko, C. O. Email: chimexa@yahoo.com.

Phone: +234(0)8068611483

ABSTRACT

The aim of this research was to examine the effects of crude oil contamination on the physico-chemical properties of soils in Owerri West, Imo State. Soil samples were collected using a systematic sampling method. For the experiment, 12 pots were arranged in a completely randomized design (CRD) with 4 treatments replicated 3 times. The contaminated soils were treated with four levels of crude oil, 0 ml/10kg, 40 ml/10kg, 80 ml/10kg, and 120 ml/10kg. The 0 ml/10kg treatment served as the control (uncontaminated soil). Soil samples were collected from each pot for composite sampling after three months, and the samples were subsequently analyzed in the laboratory. The resulting soil data were subjected to analysis of variance (ANOVA), and the Duncan New Multiple Range Test (DNMRT) at a 0.05% probability level was used to compare treatment means. The highest pH values were recorded in the 0 ml/10kg soil (6.0%) and the 120 ml/10kg soil (5.7%), with no significant difference between them. Significant interaction effects ($P < 0.05$) were observed for sand, silt, clay, and the silt/clay ratio. At 8 weeks after contamination (8WAC), the uncontaminated plots had a lower base saturation (BS) value (93.96%). The results indicated that crude oil contamination increased the total hydrocarbon content, with values of 35.50 in the 120 ml/10kg soil compared to 10.50 in the 0 ml/10kg soil. Total nitrogen was higher in the 80 ml/10kg soil (5.80) than in the control (5.50). Available phosphorus levels were also higher in the 80 ml/10kg soil (14.99) compared to the control (14.40), while organic carbon was lower in the 40 ml/10kg soil (1.15) than in the control (1.34). No significant differences were observed in soil texture and pH between the contaminated and uncontaminated soils. However, crude oil contamination altered the physico-chemical properties of the soil and could be harmful to the soil ecosystem.

Keywords: crude oil, contamination, inoculation, physicochemical properties, pollution

INTRODUCTION

Human technological and scientific progress has led to environmental changes that are challenging to fully assess and understand. Our capacity to alter the environment has outpaced our ability to predict the consequences of such changes. Pollution arises when environmental alterations negatively impact the quality of life, including effects on animals, microorganisms, and plants. Odewunmi (1987) defines pollution as the presence of significant quantities of foreign substances, whether solid, liquid, or gas, in a specific location. Oil pollution refers to the contamination of the environment, particularly terrestrial and aquatic ecosystems, by crude oil, with an estimated 8% of such pollution resulting from oil spills (Odu, 1977).

Oil spills and industrial effluents can severely damage both aquatic and terrestrial ecosystems, leading to the destruction of forests and farmland through deforestation and burning, as well as altering the characteristics and management of agricultural soils (Dambo, 2000). The introduction of

contaminants into the soil can impair or destroy various soil functions and may also contaminate groundwater. When soil contamination exceeds certain levels, it triggers a range of negative consequences for the food chain, human health, ecosystems, and other natural resources (Nor and Cliff, 2012).

Local contamination is commonly linked to activities such as mining, industrial operations, and waste disposal, both during their operation and after their closure. These activities can threaten both soil and water. Oil exploitation and industrial processes can contribute to localized contamination by total petroleum hydrocarbons (TPH) and heavy metals through accidental spills or leaks from wells, storage tanks, pipelines, and industrial waste sites.

Oil pollution alters the chemical and physical properties of soils, diminishing soil fertility. Crude oil extraction has had harmful environmental effects on the soil, forests, and water bodies in communities within Nigeria's Niger Delta region (Worgu, 2000). It is therefore crucial to assess the impact of these contaminants on soils, particularly in the study area, to understand their behavior outside of the exploitation sites in the Niger Delta.

The specific objectives of this project was to determine the physical and chemical properties of the soil before crude oil contamination, evaluate the effects of crude oil pollution on selected soil properties within the contaminated areas, and assess the impact of varying levels of crude oil contamination on the soils of the study area.

MATERIALS AND METHODS

Description of the Study Area

The study was carried out in the greenhouse of Federal College of Land Resources Technology, Oforola, Owerri West Local Government Area, Imo State. The area lies between latitude 5° 41' and 31° North and longitude 6° 151' East (Uwakwe 2012). The annual rainfall in Oforola ranges from 1,500-2000 mm and annual minimum temperature of 20°C and maximum temperature of 31°C (Uwakwe and Iwuala (2012).

The soils of Oforola are porous, weakly structured, well drained in such a way that runoff water disappears 30 minute after a typical rain storm (Ufot 2012). They are composed of dark blue, silt clays and silts sands with occasional lentils of sand and gravels. The general land form of the study area ranges from gentle sloppy to nearly level topography of about 0-3%. The original vegetation of the study area has been destroyed through human activities. The greater part of the area is now covered by secondary bush which constitutes trees, shrubs, legends and vegetation re-growth. They are prone to intermittent cuttings, bush clearing and intensified shifting cultivation pressures.

Climate

The climate of Oforola and Imo State is typically humid rain forest. There are two major seasons, the rainy season and dry season which corresponds respectively to the prevalence of the two major seasonal Air Masses. The moisture laden, South Westerlies (Tropical Maritime Air Masses and dry Northern, Easterlies, Tropical Continental Air Masses) that determine the climate of Nigeria in general (Uwakwe and Iwuala (2012). The rainy season usually occurs from the month of March to the month of November. It is usually interrupted by a short dry spell in the month of August. This period is referred to as "August Break". The dry season occurs from the month of December to February.

Field Method

The study site, 200 m x 100 m was divided into 12 blocks. Twelve of these were selected by the systemic sampling method (Carter 1993). Soil

samples were collected from the top soil (0-15cm) and subsoil (15 cm – 30 cm) using a hand-held auger at three points per block and bulked to form composite samples. A total of 12 polythene bags were used for the experiment. Each polythene bag measuring 40 x 35 cm with perforation at the sides and bottom was filled with 10 kg of soil.

Each bag was inoculated with crude oil at different levels as follows: 0, 40, 80, and 120, ml / 10 kg soil.

These treatments were replicated 3 times. The bags were all laid out under covered shed. The design used for the experiment was the Completely Randomized Design (CRD).

Laboratory Analysis

The following physico-chemical parameters were carried out:

Particle size distribution was determined by hydrometer method according to the procedure of Gee and Or (2002). Soil pH was determined using pH meter and read at a soil- water ratio of 1:2.5.

Available phosphorous was determined by Bray 11 extract as described by Udo *et al* (2009). Exchangeable acidity (H^+ and Al^{3+}) was extracted using 1N / KCl and titrated against 0.05 NaOH. Organic carbon was measured by Walkley and Black wet digestion method (Nelson and Sommers, 1982). Exchangeable Bases were extracted with 1 N ammonium acetate (+ pH7); K^+ and Na^+ contents were read with the aid of flame photometer while Ca^{2+} and Mg^{2+} were determined by EDTA compleximetric titration method (Jackson, 1962). Cation exchange capacity (CEC) was determined by summation of exchangeable acidity and exchangeable bases (Soil Survey Staff, 2010). Base saturation was calculated as percentage of CEC occupied by Ca, Mg, Na and K.

Heavy metals and micronutrients (Co, Pb, Cu, Mn, Fe, Zn) were determined using total elementary analysis and read using Atomic Absorption Spectrophotometer (AAS) while total petroleum hydrocarbon (TPH) was extracted with Xylene and measured using AAS as described by Osuji and Nwoye (2007).

Statistical Analysis

The data generated after physical and chemical analysis were subjected to statistical analysis. Analysis of variance for a Completely Randomized Design (CRD) was carried out using SAS statistic package. Treatment means were separated using Duncan's New Multiple Range Test (DNMRT) at 5% probability level.

RESULTS AND DISCUSSION

Initial soil test

Table 1: Initial physico-chemical properties of the study soil.

Soil Properties	Value
Sand (%)	80.6
Silt (%)	7.4
Clay (%)	12.0
Silt/Clay Ratio	0.62
Texture	LS
pH	5.5
Total Nitrogen (g/kg)	7.7
Organic carbon (g/kg)	2.65
Organic Matter (g/kg)	4.6
Avail. P (mg/kg)	6.8
Exchangeable K ⁺ (Cmol/kg)	0.09
Exchangeable Ca ²⁺ (Cmol/kg)	2.4
Exchangeable Mg ²⁺ (Cmol/kg)	1.4
Exchangeable Na ⁺ (Cmol/kg)	0.03
Exchangeable Acidity (Cmol/kg)	1.50
Cation Exchange Capacity (Cmol/kg)	5.42
Base Saturation (%)	72.3
TPH (mg/kg)	ND
Pb (mg/kg)	10.20
Fe (mg/kg)	21.0
Mn (mg/kg)	10.2
Zn (mg/kg)	11.2
Cu (mg/kg)	10.0
Co (mg/kg)	1.2

Ca, Na, Mg, K = Calcium, Sodium, Magnesium, Potassium

EA = Exchangeable acidity, CEC = cation exchange capacity, BS = base saturation,

TPH = Total petroleum hydrocarbon, Pb = lead, Fe = iron; Mn =manganese; Zn = zinc; Cu = copper; Co = cobalt; ND = Not detected

The soil is predominantly sandy (80.6% sand) with low silt (7.4%) and clay (12.0%) content. The texture is classified as LS (Loamy Sand). This soil type is typical in many parts of Nigeria, particularly in the coastal and southern regions. Loamy sand soils are generally well-drained but have low water and nutrient retention capacity. The pH of 5.5 indicates that the soil is moderately acidic. This is common in many Nigerian soils, especially in the southern regions, due to high rainfall and leaching of base cations. The organic carbon content (2.65 g/kg) and organic matter (4.6 g/kg) are relatively low, which is typical for sandy soils. However, the total nitrogen content (7.7 g/kg) is relatively high. This could be due to previous fertilization or natural nitrogen fixation processes. The available P (6.8 mg/kg) is low, which is common in acidic soils where phosphorus can be fixed by aluminum and iron oxides. The soil has low levels of exchangeable cations, particularly K⁺ (0.09 Cmol/kg) and Na⁺ (0.03 Cmol/kg). The Cation Exchange Capacity (CEC) of 5.42 Cmol/kg is relatively low, which is typical for sandy soils with low clay and organic matter content. This suggests that the soil has a limited capacity to retain nutrients. The base saturation of 72.3% is moderately high, indicating

that despite the acidic pH, a significant portion of the exchange sites are occupied by base cations (Ca, Mg, K, Na) rather than acid cations (H, Al). The levels of heavy metals are generally low to moderate. The lead (Pb) content (10.20 mg/kg) is within the normal range for uncontaminated soils. Iron (Fe) content (21.0 mg/kg) is notably lower than typically found in many Nigerian soils, which could affect iron availability for plants. Total Petroleum Hydrocarbon (TPH) was not detected (ND) in the initial soil sample, indicating that the soil was free from petroleum contamination at the start of the study. This is crucial for establishing a baseline in studies investigating the effects of crude oil contamination. These initial soil properties suggest that the study soil is a moderately acidic, sandy soil with low fertility and limited capacity to retain nutrients. These characteristics are important to consider when interpreting the effects of crude oil contamination on this soil. The low clay and organic matter content, combined with the acidic pH, suggests that this soil might be vulnerable to further degradation if contaminated with crude oil. The low CEC indicates that the soil has a limited capacity to buffer against changes in chemical composition, which could lead to more pronounced effects of contamination.

Table 2: Effect of crude oil contamination on soil particle size distribution and flood potential (silt/clay ratio) of Oforola, Owerri West, Imo State, 4 and 8 weeks after contamination.

Four (4) Weeks after Contamination					
Levels of Crude Oil Contamination	Sand (%)	Silt (%)	Clay (%)	Texture	Silt/clay ratio
120ml/10kg Soil	81.0 ^a	13.0 ^a	6.0 ^b	LS	2.17 ^a
80ml/10kg Soil	80.8 ^a	12.7 ^a	6.5 ^b	LS	1.96 ^b
40 ml/10kg Soil	80.6 ^a	7.8 ^b	11.6 ^a	LS	0.68 ^c
0ml/10kg Soil	80.9 ^a	7.1 ^c	12.0 ^a	LS	0.59 ^c
Eight (8) Weeks after crude oil contamination					
120ml/10kg Soil	80.9 ^{ab}	11.8 ^a	7.3 ^c	LS	1.63 ^a
80ml/10kg Soil	80.5 ^b	7.9 ^b	11.6 ^b	LS	0.68 ^b
40 ml/10kg Soil	80.6 ^{ab}	6.4 ^c	13.0 ^a	LS	0.49 ^b
0ml/10kg Soil	81.2 ^a	6.2 ^c	12.6 ^a	LS	0.49 ^b

The effect of crude oil contamination on soil particle size distribution and flood potential (silt/clay ratio) of Oforola, Owerri West, Imo State at 4 and 8 weeks after contamination is presented in Table 2. The Table shows how crude oil pollution affected soil structure, particularly in terms of sand, silt, and clay proportions, and the silt/clay ratio, which is important for determining flood potential.

At four weeks after contamination, sand content remained fairly stable, ranging from 80.6% to 81.0%, with no significant differences between treatments across all levels of crude oil contamination. The 120 ml/10kg treatment had the highest silt content (13.0%), while the lowest silt was recorded in the 0 ml/10kg soil (7.1%). On the other hand, clay content was highest in the 0 ml/10kg (12.0%) and 40 ml/10kg (11.6%) soils, and significantly lower in the 120 ml/10kg treatment (6.0%). The silt/clay ratio, an indicator of flood potential, was significantly higher in the 120 ml/10kg treatment (2.17), showing a greater flood risk in this treatment compared to the 0 ml/10kg control (0.59).

At eight weeks after contamination, sand content remained fairly stable, with a slight variation, ranging from 80.5% to 81.2%. Silt content was highest in the 120 ml/10kg soil (11.8%) and lowest in the 0 ml/10kg soil (6.2%). Clay content was higher in the 40 ml/10kg and 0 ml/10kg treatments (13.0% and 12.6%, respectively) compared to the 120 ml/10kg treatment (7.3%). The silt/clay ratio was highest in the 120 ml/10kg treatment (1.63), indicating a potential for greater flood risk, while the lowest ratio (0.49) was recorded in both the 40 ml/10kg and 0 ml/10kg treatments.

Crude oil contamination appears to have altered the soil's particle size distribution and flood potential in Oforola, Owerri West. Wokocha and Ajiwe (2011) reported that crude oil contamination can significantly reduce clay and silt content in soils, which aligns with the findings in this table, where the highest contamination level (120 ml/10kg) resulted in lower clay content and higher silt/clay ratios.

Additionally, Ogbo and Okhuoya (2011) found that oil spills alter soil texture, leading to reduced soil fertility, which could impact agricultural productivity in affected areas.

The increase in the silt/clay ratio, particularly in soils contaminated with higher levels of crude oil, indicates a higher potential for flooding. This aligns with findings from Amadi *et al.* (2013), who also observed that crude oil contamination increases the vulnerability of soils to erosion and waterlogging due to changes in particle size distribution.

Table 3: Effect of crude oil contamination on selected soil chemical properties of Oforola in Owerri West L.G.A of Imo State at 4 and 8 weeks after contamination.

Four (4) Weeks after Contamination											
Crude oil treatment (ml/10kgs oil)	Soil pH	OC (g/k g)	TN (g/k g)	Ca (cmol/k g)	Mg (cmol/k g)	Na (cmol/k g)	K (cmol/k g)	EA (cmol/kg)	CEC (cmol/k g)	BS (%)	Avail. P (mg/k g)
120ml/10kg soil	5.6 _a	0.83 _d	5.60 _a	11.52 _d	0.88 _c	0.44 _{ab}	0.37 _a	0.25 _c	13.46 _b	98.14 _{ab}	13.99 _d
80ml/10kg Soil	5.7 _a	0.96 _c	5.80 _a	11.84 _b	1.36 _a	0.40 _b	0.31 _{bc}	0.42 _b	14.33 _a	97.07 _b	14.99 _a
40 ml/10kg Soil	5.6 _a	1.15 _b	5.12 _b	11.94 _a	0.64 _d	0.30 _c	0.26 _c	1.17 _c	13.29 _b	98.73 _a	14.15 _c
0ml/10kg Soil	5.8 _a	1.34 _a	5.50 _{ab}	11.68 _c	0.96 _b	0.49 _a	0.32 _{ab}	0.80 _a	14.25 _a	94.39 _c	14.40 _b
Eight (8) weeks after crude oil contamination											
120ml/10kg soil	5.7 _a	1.92 _a	5.80 _a	10.72 _c	1.60 _b	0.30 _a	0.30 _{ab}	0.40 _b	13.32 _b	97.00 _a	10.72 _d
80ml/10kg Soil	5.8 _a	1.86 _b	5.60 _{ab}	10.88 _b	1.36 _c	0.33 _a	0.32 _a	0.40 _b	13.29 _b	97.00 _a	10.88 _c
40 ml/10kg Soil	5.8 _a	1.60 _c	5.50 _{ab}	10.96 _a	1.76 _a	0.37 _a	0.28 _{ab}	0.50 _b	13.87 _a	96.39 _a	12.87 _b
0ml/10kg Soil	6.0 _a	1.54 _d	5.20 _b	10.24 _d	1.60 _b	0.35 _a	0.24 _b	0.80 _a	13.23 _b	93.96 _b	15.14 _a

Means followed by the same letter(s) within each column at specific weeks after contaminations are not significantly difference (DNMRT at $P < 0$)

Table 3 shows the effect of crude oil contamination on selected soil chemical properties of Oforola in Owerri West L.G.A. of Imo State at 4 and 8 Weeks after contamination demonstrates how crude oil contamination influences various soil chemical properties, including pH, organic carbon (OC), total nitrogen (TN), exchangeable bases (Ca, Mg, Na, K), exchangeable acidity (EA), cation exchange capacity (CEC), base saturation (BS), and available phosphorus (P).

Soil pH values remained relatively stable across all treatments and time periods, ranging from 5.6 to 6.0. This slight acidity is typical of soils in southeastern Nigeria, as reported by Onwudike *et al.* (2016). At 4 weeks after contamination (WAC), OC decreased with increasing crude oil contamination. However, at 8 WAC, this trend reversed, with higher OC in contaminated soils. This aligns with findings by Okoro *et al.* (2011) in the Niger Delta, who observed initial decreases in OC followed by increases due to microbial degradation of hydrocarbons. TN showed slight variations but no consistent trend with contamination levels. This is contrary to some studies, such as Osuji and Nwoye (2007), who found decreased nitrogen in oil-polluted soils. The discrepancy might be due to differences in soil type or contamination duration. Ca levels decreased with increasing contamination at 8 WAC, while Mg

showed mixed trends. These results partially support findings by Umeh *et al.* (2017) who reported decreased cations in oil-contaminated soils. Na and K showed minor variations with no clear trends. This differs from findings by Ogboghodo *et al.* (2004) who observed increases in exchangeable bases with crude oil pollution. Exchangeable Acidity (EA) generally decreased with increasing contamination, especially at 8 WAC. This could be related to the buffering effect of hydrocarbons, as suggested by Osuji and Nwoye (2007). CEC showed slight variations but no consistent trend with contamination levels. This contrasts with findings by Okoro *et al.* (2011) who reported decreased CEC in oil-polluted soils. Base Saturation increased slightly with contamination at both 4 and 8 WAC and it aligns with observations of Umeh *et al.* (2017), suggesting that crude oil contamination can increase the proportion of base-forming cations. At 4 WAC, available P showed no clear trend, but at 8 WAC, it decreased significantly with increasing contamination, in line with the findings by Osuji and Nwoye (2007), who reported decreased available P in oil-polluted soils. The variations in results compared to other Nigerian studies underscore the complexity of soil-oil interactions and the influence of factors such as soil type, climate, and specific crude oil composition.

Table 4: Effect of crude oil contamination on selected heavy metals (Pb, Fe, Mn, Zn, Cu, Co) and TPH at 4 and 8 WAC are shown in Table 4 of Oforola in Owerri West L.G.A of Imo State.

Four (4) weeks after contamination							
Crude oil treatment (ml/10 kg) soil	Pb (mg/kg)	Fe (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Co (mg/kg)	TPH (mg/kg)
120ml/10kg Soil	24.00 ^a	2015.0 ^c	185.0 ^a	32.0 ^a	29.0 ^a	5.60 ^a	35.50 ^a
80ml/10kg Soil	25.00 ^a	2145.0 ^b	184.0 ^a	32.0 ^a	28.0 ^a	4.50 ^b	30.80 ^b
40ml/10kg Soil	15.50 ^b	2150.0 ^b	186.0 ^a	30.0 ^{ab}	26.0 ^b	3.60 ^c	28.50 ^c
0ml/10kg Soil	5.0 ^c	3250.0 ^a	180.0 ^b	28.0 ^b	20.0 ^c	1.80 ^d	10.50 ^d
Eight (8) weeks after contamination							
120ml/10kg Soil	26.00 ^a	2205.0 ^a	194.0 ^a	36.0 ^a	32.0 ^a	6.0 ^a	32.00 ^a
80ml/10kg Soil	27.33 ^a	2160.0 ^b	192.0 ^a	35.0 ^a	31.0 ^a	4.5 ^b	31.50 ^{ab}
40ml/10kg Soil	16.50 ^b	2155.0 ^b	190.0 ^a	30.0 ^b	30.0 ^a	4.0 ^b	30.50 ^b
0ml/10kg Soil	4.50 ^c	20.50 ^c	185.0 ^a	2.40 ^c	1.80 ^b	1.6 ^c	9.50 ^c

Mean followed by the same letter(s) within each column at specific weeks after contamination are not significantly different (DNMRT at P<0.05)

Table 4 presents the effects of crude oil contamination on selected heavy metals (Pb, Fe, Mn, Zn, Cu, Co) and Total Petroleum Hydrocarbons (TPH) in soil samples from Oforola in Owerri West L.G.A of Imo State, Nigeria. The measurements were taken at 4 and 8 weeks after contamination (WAC) with varying levels of crude oil (0, 40, 80, and 120 ml per 10 kg of soil).

The results showed that heavy metal concentrations generally increased with higher levels of crude oil contamination. TPH levels showed a strong positive correlation with crude oil contamination.

Lead (Pb) Contamination at both 4 and 8 WAC, Pb levels increased significantly with higher crude oil contamination. This aligns with findings by Ogbonna *et al.* (2020) which showed that crude oil pollution increased soil Pb concentrations. Fe levels were highest in the control soil (0ml/10kg) at 4 WAC but decreased significantly in contaminated soils. This could be due to the formation of iron-organic complexes, as suggested by Nwankwoala and Kwelechi (2019). Mn levels showed little variation across treatments at 4 WAC, but increased slightly in contaminated soils at 8 WAC. This gradual increase could be attributed to the breakdown of organic matter over time, as observed by Ekeke *et al.* (2021). Both Zn and Cu showed increased concentrations in contaminated soils, with higher levels at 8 WAC compared to 4 WAC. This trend is consistent with the works of Nwaichi *et al.* (2018). Cobalt levels increased significantly with crude oil contamination, showing a clear dose-response relationship in line with findings by Osuji and Nwoye (2007).

Total Petroleum Hydrocarbons (TPH) levels showed a strong positive correlation with crude oil contamination. The slight decrease in TPH levels from 4 WAC to 8 WAC in highly contaminated soils could be due to natural attenuation processes (Godleads *et al.*, 2015; Adetoro *et al.*, 2022). The results demonstrated the significant impact of crude oil contamination on soil heavy metal concentrations and TPH levels.

References:

- Adetoro, A. A., Omidiji, O. M. and Olaojo, A. A. (2022). Environmental impacts of oil spillage on soil properties in the Niger Delta region of Nigeria. *African Journal of Environmental Science and Technology*, 16(1), 1-10.
- Agbogidi, O. M., Eruotor, P. G., and Akparobi, S. O. (2007). Effects of crude oil levels on the growth of maize (*Zea mays* L.). *American Journal of Food Technology*, 2(6), 529-535.
- Amadi, A. N., Ogbulu, K. M., and Eze, C. (2013). Environmental impacts of crude oil spillages and the risk of hydrocarbon contamination in the Niger Delta. *Journal of Environmental Science and Engineering*, 5(1), 26-34.
- Amadi, A., Abbey, S. D. and Nma, A. (1996). Chronic effects of oil spill on soil properties and micro-flora of a rainforest ecosystem in Nigeria. *Water, Air, and Soil Pollution*, 86(1-4), 1-11.
- Ekeke, I. C., Okonkwo, U. C. and Nwoke, O. C. (2021). Assessment of heavy metals in crude oil polluted soil of Ogoniland, Nigeria. *International Journal of Scientific & Engineering Research*, 12(5), 1272-1279.
- Godleads, O. A., Prekeyi, T. F., Samson, E. O. and Igelenyah, E. (2015). Bioremediation, biostimulation and bioaugmentation: A review. *International Journal of Environmental Bioremediation & Biodegradation*, 3(1), 28-39.
- Isirimah, N. O. (2004). Soils and environmental pollution management. *Inaugural Lecture Series, No. 53*, Rivers State University of Science and Technology.
- Nwankwoala, H. O. and Kwelechi, O. K. (2019). Assessment of heavy metals in soils from

- crude oil impacted sites in parts of Rivers State, Nigeria. *Journal of Environmental Science and Public Health*, 3(1), 65-76.
- Nwaichi, E. O., Wegwu, M. O. and Nwosu, U. L. (2018). Distribution of selected carcinogenic hydrocarbon and heavy metals in an oil-polluted agriculture zone. *Environmental Monitoring and Assessment*, 190(3), 1-13.
- Odu, C. T. I., Esuruoso, O. F., Nwoboshi, L. C., and Ogunwale, J. A. (1981). Environmental study of the Nigerian Agip Oil Company operation area. *Soils and Fresh Water Vegetation*, 1, 21-25.
- Ogbo, E. M. and Okhuoya, J. A. (2011). Effects of crude oil contamination on the growth and nutrient uptake of maize (*Zea mays* L.). *Nigerian Journal of Botany*, 24(1), 122-127.
- Ogbonna, P. C., Nzegbule, E. C., & Okorie, P. E. (2020). Impact of crude oil spillage on soil chemical properties in the Niger Delta, Nigeria. *Environmental Monitoring and Assessment*, 192(5), 1-12.
- Okoro, D., Oviasogie, P. O. and Oviasogie, F. E. (2011). Soil quality assessment 33 months after crude oil spillage and clean-up. *Chemical Speciation & Bioavailability*, 23(1), 1-6.
- Ogboghodo, I. A., Erebor, E. B., Osemwota, I. O. and Isitekhale, H. H. (2004). The effects of application of poultry manure to crude oil polluted soils on maize (*Zea mays*) growth and soil properties. *Environmental Monitoring and Assessment*, 96(1), 153-161.
- Onwudike, S. U., Uzoho, B. U., Ihem, E. E., Ahukaemere, C. M., Nkwopara, U. N., Irokwe, I. F. and Echeanyanwu, G. I. (2016). Evaluation of the fertility status of selected soils in Mbaitoli, Southeastern Nigeria using nutrient index method. *Agro-Science*, 15(2), 19-25.
- Osuji, L. C. and Nwoye, I. (2007). An appraisal of the impact of petroleum hydrocarbons on soil fertility: the Owaza experience. *African Journal of Agricultural Research*, 2(7), 318-324.
- Udo, E. J., and Fayemi, A. A. A. (1975). The effect of oil pollution of soil on germination, growth and nutrient uptake of corn. *Journal of Environmental Quality*, 4(4), 537-540.
- Umeh, O. J., Nnaji, G. U., Udegbonam, O. N. and Oduma, O. (2017). Physical and chemical properties of soils as affected by oil spillage in Ukwa West Local Government Area of Abia State Nigeria. *Journal of Environmental Science, Toxicology and Food Technology*, 11(8), 41-46.
- Wokocha, C. C., and Ajiwe, V. I. E. (2011). Soil contamination by crude oil: Implications for agricultural soils and crop productivity. *Nigerian Journal of Agriculture*, 42(4), 33-38.