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ORIGINAL ARTICLE

EVALUATION OF SELECTED PHYSICAL AND CHEMICAL CHARACTERISTICS OF SOME CRUDE OIL EXPOSED SOILS AT OGBOINBIRI BAYELSA STATE, NIGERIA

Akaaza S. E.[1*], Anjembe, B. C.[1], Ibrahim, F.[1] and Tsaku, N. A.[2]

[1]Department of Soil Science, Joseph Sarwuan Tarka University, Makurdi, Benue State, Nigeria
[2]Department of Agronomy, Nasarawa State University, Keffi, Nasarawa State, Nigeria
*****Corresponding Author Email: elijahakaaza@gmail.com

ABSTRACT
Soil samples were collected from surface (0-15cm) depth at each location during the wet and dry seasons a total of twenty-eight (28) soil samples were collected per season and were taken to the laboratory for analysis. Soil colour ranged from light brown, dark brown to brown in both surface and subsurface soil for both seasons. The soils were sandy, loam and clay. Mean permeability values were 0.71mm/. Porosity of the soil varied with season. The soil pH ranges from strongly acidic to moderate acidic. Mean temperature of the soil during the wet season was 26.43℃ while dry season has a mean value of 26.47. The Carbonates and sulphates recorded higher than other anions in both seasons. Oxidation reduction potential (ORP) 189.4mV at wet season and 255.9mV at dry season, total petroleum hydrocarbon (TPH) values were 0.20mg/kg in both seasons, total hydrocarbon (THC) values were 1.34mg/kg at wet season and 1.54mg/kg at dry season. BTEX concentration were below 0.001 mg/kg in all seasons. Cation exchange capacity was very low with a mean value of 0.39 Cmo1/kg during the wet season while during the dry season the mean value was 59.48 Cmo1/kg. Heavy metals were <0.001 mg/kg exception of (Fe) and Zn which (Fe) has a mean value of 314.40 mg/kg in the wet season while in the dry season it has a mean value of 1294 mg/kg and (Zn) has a mean value of 0.31 mg/kg in wet season while in the dry season it has a mean value of 0.10 mg/kg s. The increase in acidity accelerated reaching ability and metal mobilization with a loss in cation exchange capacity of the soil, permeability and consequently lead to plant absorptive increase in phytotoxic element and death. All these are notable indices of ecosystem toxicity as a result of crude oil spill. Periodic monitoring of soils of the flow stations should be carried out to prevent build-up of contaminants beyond limits of maximum tolerance.
***Keywords**: Heavy metals, soils, contamination, crude oil*

INTRODUCTION

Nigeria is Africa's second largest crude oil producing nation after Angola and ranks fifteen in the world (World Population Review, 2022). Currently, Nigeria operates over 600 oil fields and in the process of granting more prospecting licenses. The southern part of the country is well-known for her wealth of oil deposits; however, because of the great demand for oil globally, the region is so influenced by crude oil spills both illegal and accidental thus impacting on the lives of the terrestrial and aquatic communities (Ite *et al.*, 2013; Anani *et al.*, 2021). Report shows that from January to March 2022, 1,545 barrels of crude oil, an equivalent of 246,000 litters was estimated to have been spilled into the oil rich Niger-Delta (Ripple Nigeria, 2022), causing significant negative impact on the ecosystem and eventually reducing the quality of life of the people living around this area. So, the likely impacts on water and terrestrial soil communities are worrisome because of the health and ecological threats they foretell. Khan *et al.* (2013) and Nwaichi *et al.* (2015) reported high levels of petroleum hydrocarbon as pollutants in sediment and water at different locations of the Niger-Delta environment, thus, posing a very serious environmental challenge in the oil rich area. Part of the impacts of crude oil spillage on soil properties is indicated by increased levels of petroleum hydrocarbon (PHC), acidic pH values, and increased concentration of heavy metals such as lead (Pb), zinc (Zn), cadmium (Cd), chromium (Madukosiri and Dressman, 2010; Wegwu *et. al*., 2011; Ogbeibu, 2011; UNEP, 2011; Ekeocha *et al.*, 2015). Non conformity of these indicators in soil from their provisional or guideline values can result to adverse environmental and health problems and can also limit the use of the affected soils. Furthermore, continuous contamination without immediate or prompt remediation, can result to bioaccumulation in groundwater and other water bodies causing more damage. Hence this study was carried to evaluate some crude oil exposed soils at Ogboinbiri, Bayelsa state, Nigeria

MATERIALS AND METHODS

Study Location

Ogboinbiri is located in Southern Ijaw Local Government area of Bayelsa State, Nigeria. The location lies between Latitude 4º 49 35 N 4.8292° N and longitude 5º 57’ 57 E 5.9497° E with an elevation of 60m above sea level. The soils are poorly drained and rich in acidic sulphates hence termed acid sulphate soils. Ogboinbiri has scattered cloud with mean temperature of 29ºC, relative humidity of 69% and wind speed of 2.43 m/S. Average daily pressure of 1009hpa. The location has a dynamic population of freshwater snails, periwinkles, earthworms, fish etc.

Sample Collection

A simple random sampling method was used in soil sample collection from the fields, where each sample was collected randomly and independent of the previous sampling point. Fourteen (14) soil samples were collected from fourteen different points for each season (wet and dry) at a depth of 0 – 15cm using a stainless-steel auger summing up to a total of twenty-eight (28) soil samples altogether from the study area. Part of the 14 samples collected for each season included two samples which were collected at a distance away from the flow station to serve as controls. A hand-held Geographic Positioning System (GPS) was used to locate the sampling points (Table 1).

Laboratory Analysis

Sub samples of the Soils were air dried and sieved to pass through a 2mm sieve for laboratory analysis. The samples were analysed for the following parameters using standard procedures.

Routine Analyses

The pH was determined using a glass electrode in a 1:2 soil water suspension. Total organic carbon: was determined using dichromate wet oxidation method (Carter, 1993) Total Nitrogen (TN) was determined by Micro-Kjeldahl digestion method (AOAC, 1999). Exchangeable cations (Ca, mg, Na and K) were extracted with 1N ammonium acetate solution buffered at PH7. Sodium (Na) and potassium (K) in the extracts were determined using flame photometer while Ca and Mg were determined using Atomic Absorption spectrophotometer (AAS) model. Exchangeable acidity was determined by the titration method (Page *et al*., 1982). Particle size analysis was determined by the hydrometer method using the procedure of Gee, and Or (2002) and the USDA textural triangle was adopted for the textural class determination. Temperature was determined using glass thermometer (World Meteorological Organization, 2008). Colour was determined by comparison of soil samples with the colour chart in the Munsel soil colour chart. Data generated was compared with that obtained at the controls as well as the accepted safety limit of environmental guideline to determine the quality of the soil studied.

Heavy metals

1g of soil was weighed in to a 125ml beaker and digested with a mixture of 4ml, 25ml and 2ml each of concentrated $HClO_4$, $4NO_3$ and H_2SO_4 respectively, on a hot plate in a fume cupboard. On completion of digestion, the samples were cooled and 50ml of deionized water was added and then the samples were filtered. The samples were made up to 100ml with deionized water and concentrations of Cd, Ba, Cr, Fe, Hg, Ni, Pb, V, Zn, were analysed using Atomic Absorption spectrophotometer.

Total petroleum hydrocarbons

Total petroleum hydrocarbon was determined using America society for testing material method (ASTMD3821, 2003).

Total Hydrocarbon

Total hydrocarbon was determined using Gas chromatography. Soil samples were dried at 100^0c, lightly crushed and sieved through a 200 mesh Tyler screen. A weighed portion of the minus 200 mesh fraction was placed in a reaction flask and the system was evacuated.

***Benzene, toulene, ethelyn and* xylene**

Benzene, Toulene, Exthlyne and Xylene was determined using Gas chromatography. Stock solutions were prepared in LC-MS grade analytical methanol (Baker, Philipsburg,) from a 2000 mg^{-1} BTEX calibration standard (Phenomenex. Inc., Torrance, CA) and fluorobenzene (≥99.7%) (Sigma – Aldrich; St. Louis, Mo) was used as an internal standard (is). Dilutions in methanol with 50 of IS were used for calibration. To reduce losses by evaporation, the BTEX solutions were stored at 4^oC in sealed vials without free headspace. RTILS 1- ethyl-3-methylimidazolium samples were heated at 100^0C for 10min and seven-point calibration curves were obtained.

Oxidation reduction potential and Anions

Oxidation Reduction Potential was determined using Erlenmeyer flask with Pt-ring electrode (competence centre titration). Anions were determined using U-V spectrophotometer (Arnold, 1941). Forty (40) gram soil sample were design for the DI water extraction procedure followed by analysis for all anions. They include nitrate, nitrite, sulphate and carbonate.

RESULTS AND DISCUSSION

Table 1: Sampling points for Ogboinbiri Flow station

S/No	Sample Point	Longitude	Latitude
1	EES/SS1	$5^0$58’115.1820E	$4^0$49’111.2820N
2	EES/SS2	$5^0$57’144.1000E	$4^0$48’147.9000N
3	EES/SS3	$5^0$57’131.4000E	$4^0$48’151.9000N
4	EES/SS4	$5^0$58’118.1850E	$4^0$49’144.2040N
5	EES/SS5	$5^0$57’128.3000E	$4^0$48’151.9000N
6	EES/SS6	$5^0$58’115.1820E	$4^0$49’121.9000N
7	EES/SS7	$5^0$58’125.4300E	$4^0$49’141.5300N
8	EES/SS8	$5^0$57’146.0000E	$4^0$48’158.5000N
9	EES/SS9	$5^0$57’129.5000E	$4^0$48’147.7000N
10	EES/SS10	$5^0$58’128.9780E	$4^0$49’137.8370N
11	EES/SS11	$5^0$58’140.9000E	$4^0$49’110.9000N
12	EES/SS12	$5^0$57’135.1000E	$4^0$48’157.8000N
13	EES/SS13 (Ctrl 1)	$5^0$59’121.0000E	$4^0$50’117.2000N
14	EES/SS14 (Ctrl 2)	$5^0$57’127.4000E	$4^0$49’123.3000N

Table 2: Selected Physical Properties of Surface Soils (0-15cm) at Ogboinbiri, Flow Station for 2022 wet and dry Seasons.

	Temp (ºc)		Colour		Texture		Porosity%		Perm mm/h	
Point/station	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wed**	**Dry**
1	26.46	27.33	light brown	Light brown	Clay	Clay	51.74	58.49	0.09	0.07
2	26.43	24.41	Light brown	Light brown	Clay	Clay	56.98	57.72	0.06	0.06
3	26.14	27.36	Light brown	Light brown	Clay	Clay	56.98	57.72	0.05	0.06
4	26.82	27.50	Light brown	Light brown	Clay	Clay	57.74	58.49	0.06	0.07
5	26.44	26.33	Light brown	Light brown	Clay	Clay	58.49	59.25	0.05	0.06
6	26.49	25.67	Light brown	Light brown	Clay	Clay	55.47	56.19	0.06	0.06
7	26.37	26.73	Light brown	Light Brown	Clay	Clay	56.23	56.96	0.08	0.07
8	26.43	25.32	Light brown	Light Brown	Sand	Sand	54.72	55.43	0.80	0.08
9	26.58	26.97	Dark Brown	Dark Brown	Sand	Sand	35.09	35.55	2.50	2.20
10	26.39	27.03	Dark Brown	Dark Brown	Loam	Loam	41.51	42.04	2.00	2.60
11	26.18	26.34	Brown	Brown	Sand	Sand	40.38	40.90	2.50	2.50
12	26.42	27.33	light brown	light Brown	Loam	Loam	57.74	58.49	1.80	1.91
Upper Region 13	26.41	27.06	Light brown	Light Brown	Clay	Clay	39.62	40.14	0.05	0.07
Lower Region 14	26.43	25.41	Light brown	Light Brown	Clay	Clay	58.41	39.25	0.05	0.07
Mean	26.43	26.47					52.02	52.70	0.71	0.71

Table 3: Selected Chemical Properties of Surface Soil (0-15cm) at Agip Flow Station Ogboinbiri, Bayelsa State

	pH		ORP		THC		TPH		BTEX		TOC		TN		CEC	
Point	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
1	3.33	4.04	197.2	263.4	0.71	0.82	0.098	0.107	<0.001	<.001	3.2	3.2	1.516	1.604	0.291	63.360
2	3.44	3.85	168.3	301.7	1.32	1.52	0.182	0.199	<0.001	<0.001	2.9	2.9	1.549	1.532	0.337	63.360
3	3.46	5.07	164.1	257.8	0.43	0.49	0.059	0.065	<.001	<0.001	4.8	4.8	1.534	1.549	0.364	64.131
4	3.66	5.01	199.1	283.3	0.55	0.63	0.076	0.083	<0.001	<0.001	6.2	6.2	1.493	1.537	0.274	66.294
5	3.43	5.33	190.7	263.7	1.47	1.69	0.203	0.222	<0.001	<0.001	7.1	7.1	1.628	1.619	0.319	68.030
6	3.78	6.88	17.88	215.6	1.66	1.91	0.229	0.251	<0.001	<0.001	4.1	4.1	1.569	1.503	0.428	61.856
7	4.33	5.07	181.7	236.3	1.26	1.43	0.174	0.190	<0.001	<0.001	4.9	4.9	1.503	1.537	0.508	63.465
8	3.58	3.61	197.3	219.9	1.82	2.09	0.251	0.275	<0.001	<0.001	1.6	1.6	1.543	1.602	0.231	58.710
9	4.46	3.81	191.2	306.4	2.25	2.59	0.311	0.340	<0.001	<0.001	6.2	6.2	1.599	1.577	0.378	45.528
10	5.37	3.52	151.2	199.8	3.19	3.67	0.440	0.482	<0.001	<0.001	4.6	4.6	1.604	1.536	0.532	50.785
11	4.05	4.44	193.2	30.35	1.93	2.22	0.266	0.292	<0.001	<0.001	3.2	3.2	1.610	1.570	0.557	48.173
12	4.05	3.03	167.2	271.6	1.16	1.33	0.160	0.175	<0.001	<0.001	2.8	2.8	1.550	1.510	0.473	64.706
13	4.38	4.404	284.2	231.8	0.42	0.48	0.058	0.063	<0.001	<0.001	6.2	6.2	1.534	1.519	0.329	47.917
14	4.56	4.11	187.3	228.1	0.56	0.64	0.007	0.085	<0.001	<0.001	5.4	5.4	1.614	1.650	0.388	66.401
Mean	4.00	4.30	189.4	255.9	1.34	1.54	0.20	0.20			4.51	4.51	2.00	1.60	0.39	59.48

ORP = oxidation reduction potential; THC = Total hydrocarbon; TPH = Total petroleum hydrocarbon; BTEX = benzene, toluene, ethylbenzene and xylem; TOC = Total organic carbon; TN = Total Nitrogen; CEC = Cation exchange capacity.

Table 4: Exchangeable Cation Status of the Experimental Location

	Ca^{2+} (mg/kg)		Mg^{2+} (mg/kg)		K^{+} (mg/kg)		Na^{+} (mg/kg)	
Sampling point	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
1	0.068	0.156	2.716	2.720	2.975	5.196	3.196	1.094
2	0.356	0.252	3.499	3.622	3.443	3.035	3.674	1.969
3	0.100	0.093	3.006	3.264	3.141	3.407	3.365	0.085
4	0.189	<0.001	1.994	1.8433	2.579	3.069	2.792	0.153
5	<0.001	<0.001	3.808	1.8382	1.420	3.357	1.609	0.028
6	0.043	0.066	3.655	1.7946	3.602	2.831	3.836	3.637
7	1.073	<0.001	3.808	1.0816	5.196	0.196	5.463	0.485
8	<0.001	<0.001	3.629	2.720	3.035	3.443	3.258	0.491
9	<0.001	0.043	2.720	1.0816	3.407	3.141	3.637	0.165
10	0.419	0.0654	3.474	0.7573	3.069	2.579	3.292	0.06
11	0.242	0.139	4.533	0.7493	3.357	1.420	3.585	0.059
12	0.336	0.863	3.206	1.9525	2831	3.602	3.049	1.128
Upper Region 13	0.151	1.838	2.538	19503	0.196	0.196	0.361	0.948
Lower Region 14	0.924	1.125	2.892	1.9667	1.237	1.237	1.423	0.03
Mean			3.21	2.00	2.82	2.62	3.04	1.00

Table 5: Anions Properties of Surface Soils (0-15cm) at Ogboinbiri, during the 2022 wet and dry Seasons.

	NO_2^- (mg/kg)		SO_4^{2-} (mg/kg)		NO_3^- (mg/kg)		PO_4^{3-} (mg/kg)		CO_3^{2-} (mg/kg)	
Sampling Point	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
1	0.1565	0.1652	8.986	3.418	0.818	0.828	0.0665	0.0628	190	60
2	0.1626	0.1661	8.994	3.284	0.833	0.863	0.0669	0.0629	170	250
3	0.1631	0.1666	9.031	3.357	0.823	0.864	0.0671	0.0630	280	140
4	0.1643	0.1664	9.016	1.445	0.795	0.818	0.0672	0.627	360	90
5	0.1643	0.1646	9.044	1.432	0.882	0.831	0.0627	0.0623	420	120
6	0.1645	1.1626	9.006	8.994	0.844	0.833	0.628	0.669	240	170
7	0.1644	0.1631	9.021	9.031	0.802	0.823	0.2628	0.0671	290	280
8	0.1645	0.1626	3.432	8.994	0.827	0.833	0.0629	0.669	90	170
9	0.1657	0.1631	3.396	9.031	0.862	0.823	0.0628	0.0671	370	280
10	0.1667	0.1626	3.366	8.994	0.864	0.823	0.0630	0.0669	270	170
11	0.1668	0.1631	1.442	9.031	0.868	0.823	0.0630	0.0671	190	280
12	0.1654	0.1643	1.426	9.044	0.831	0.882	0.0626	0.0627	160	420
Upper Region 13	0.1641	0.1645	0.290	9.006	0.822	0.844	0.0623	0.0628	370	240
Lower Region 14	0.1652	0.1641	0.301	9.021	0.872	0.802	0.0627	0.0628	320	290
Mean	0.16	0.20	5.50	6.72	0.84	0.84	0.10	0.10	266.0	211.4

Table 6: Selected Heavy Metals Properties of Surface soils (0-15cm) of the Experimental location during the 2022 wet and dry season

	Cd (mg/kg)		Ba (mg/kg)		Cr (mg/kg)		Fe (mg/kg)		Hg (mg/kg)		Ni (mg/kg)		Pb (mg/kg)		V (mg/kg)		Zn (mg/kg)	
Sampling Point	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**
1	<0.001	<0.001	<0.001	<0.001	-	0.008	488.652	1218.1	<0.001	<0.001	0.046	<0.001	<0.001	<0.001	-	-	0.2656	0.054
2	-	-	-	-	-	0.014	356.896	1435.4	-	-	0.092	0.043	-	0.02	-	-	0.2656	0.054
3	-	-	-	-	-	0.004	277.915	1440	-	-	0.118	0.04	-	0.02	-	-	0.3650	0.0855
4	-	-	-	-	-	<0.001	328.711	1352.1	-	-	0.026	0.072	-	<0.001	-	-	0.0733	0.078
5	-	-	-	-	-	<0.001	254.801	1345.8	-	-	0.127	0.066	-	0.01	-	-	0.3268	0.064
6	-	-	-	-	-	0.01	359.133	1351.5	-	-	0.72	0.065	-	0.04	-	-	0.2759	0.096
7	-	-	-	-	-	0.005	312.203	1420.3	-	-	0.143	0.071	-	<0.001	-	-	0.3874	0.065
8	-	-	-	-	-	<0.001	252.740	1412.9	-	-	0.064	-	-	<0.001	-	-	0.2611	0.065
9	-	-	-	-	-	<0.001	288.736	1333.4	-	-	0.093	<0.001	-	0.04	-	-	0.1775	0.066
10	-	-	-	-	-	-	302.156	14357.5	-	-	0.091	<0.001	-	0.04	-	-	1.2814	0.064
11	-	-	-	-	-	-	363.212	1430.6	-	-	0.105	0.075	-	0.15	-	-	0.2216	0.327
12	-	-	-	-	-	-	328.139	1362.8	-	-	0.081	0.045	-	0.01	-	-	0.1654	0.043
Upper Region 13	-	-	-	-	-	-	286.252	1362.8	-	-	0.029	0.081	-	0.01	-	-	0.1568	0.043
Lower Region 14	-	-	-	-	-	-	202.431	221.84	-	-	0.165	0.081	-	0.02	-	-	0.3662	0.088
Mean	-	-	-	-	-	-	314.40	1294	-	-	0.10	0.098	-	-	-	-	0.31	0.10

Cd – Cadmium; Ba – Barium; Cr – Chromium; Fe – Iron; Hg – Mercury; Ni – Nickel; Pb – Lead; V – Vanadium; Zn – zinc

The physical characteristics of the soils provide a basis for understanding contaminant behaviour (Table 2). The predominant clay texture at most sampling points (1-7, 13, 14) is a defining feature, directly responsible for the very low permeability rates observed (0.05–0.09 mm/hr). This low hydraulic conductivity suggests a high potential for surface runoff during precipitation events, posing a risk of contaminant transport to adjacent water bodies. Conversely, it also indicates limited vertical leaching, potentially confining contamination to the surface layers but simultaneously restricting aeration and the infiltration of nutrients and remedial agents.

The soil colour offers a visual indicator of soil organic matter (SOM) content. The dark brown coloration observed at points 9 and 10 correlates well with elevated Total Organic Carbon (TOC) levels of 6.2% and 4.6%, respectively (Table 3), which are likely a mixture of natural SOM and recalcitrant petroleum hydrocarbons. The predominantly light brown colour elsewhere suggests a lower SOM content, which may have been further compromised by the toxic effects of oil on soil biota responsible for organic matter decomposition.

The most striking chemical property of the soils is the soil acidity, with pH values ranging from 3.33 to 4.56 in the wet season (Table 3). Such acidic conditions (pH < 5.5) are strongly indicative of the generation of organic acids and the oxidation of sulphur compounds during the weathering of crude oil (Agbenin, 2020). This acidification has a cascading effect on soil fertility. The data on exchangeable cations (Table 4) show critically low levels of essential base cations—Calcium (Ca^{2+}), Magnesium (Mg^{2+}), and Potassium (K^{+})—with many values near or below the detection limit (<0.001 mg/kg). In acidic environments, these cations are readily leached from the soil profile, depleting the nutrient pool available for plant uptake.

This leaching is exacerbated by the soil's cation exchange capacity (CEC). The wet-season CEC values (0.231 – 0.557 cmol/kg) are characteristic of highly weathered, acidic soils with low-activity clay minerals, confirming a poor capacity to retain nutrient cations. The reported dry-season CEC values (45–68 cmol/kg) are physiochemically implausible for these soils and are likely an artefact of a methodological or unit error; thus, they are excluded from this discussion. The combination of low pH and low effective CEC creates a nutrient poor environment that is fundamentally infertile.

Heavy metal status of surface soils (0-15cm) at the experimental locations during the 2022 wet and dry seasons are presented on Table 5. Cadmium, barium and chromium values were less than <0.001 mg/kg for both seasons and. Iron (Fe) status of the soils ranged from 202.431 to 488.652 mg/kg during the wet season. During the dry season however, the values for this parameter ranged from 221.84 mg/kg at sampling point 14 (control 2) to 1440 mg/kg. Mercury status of the soils was less than <0.001 mm/kg for both seasons. Nickel (Ni) ranged from 0.026mg/kg to 0.165mg/kg during the wet season, however during the dry season values ranges from <0.001mg/kg to 0.098mg/kg. Lead (Pb) had a mean value of less than <0.001 at wet season and in dry season it ranged from <0.001 to 0.15 mg/kg. Zinc status of the soils ranged from 0.0733 mg/kg to 1.2814 mg/kg during the wet seasons while in the dry season, it ranged from 0.043 to 0.327 mg/kg with a mean value of 0.10 mg/kg. Petroleum hydrocarbon also affects soil fertility, it sterilizes the soil and prevent crop growth and yield for a long period of time (Ohwrah, 1999). This may also ascertain why the soils were brownish and dead grasses in an oil spilled soils as observed during the cause of this research work in most of the sampling points.

Petroleum toxicity has been identified as a contributing factor to the stressed conditions of soil polluted by crude oil even in small amount crude oil can delay germination of seed while in large quantity, it will prevent germination of the seed altogether (Ionescu *et al.*, 2020) similarly, Marinescu *et al.*, 2010 confirmed that oil spills on soil caused variations in chemical properties and at high pollution levels, inhibited the growth of crops. Benzene, Toulene, Ethylene and xylene (BTEX) of the sampling points in the experimental location indicate that the concentration of these chemical was low and generally below

0.001 mg/kg in both seasons depths. The contamination is directly confirmed by the quantifiable levels of Total Petroleum Hydrocarbons (TPH), ranging from 0.058 to 0.440 mg/kg (Table 3). The absence of detectable Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX; <0.001 mg/kg) across all samples is a significant finding. It suggests that the contamination event is not recent, as these volatile and biodegradable compounds have likely weathered or been degraded, leaving behind heavier, more persistent hydrocarbon fractions.

The Oxidation-Reduction Potential (ORP) values, ranging from 151.2 to 284.2 mV, place these surface soils within the oxic regime (Patrick *et al.,* 1996). This is consistent with the well-drained physical setting and indicates the presence of oxygen as the primary electron acceptor. This oxic condition is a positive indicator for the potential of natural attenuation, as it favours the aerobic microbial degradation of hydrocarbons. However, the process of aerobic degradation itself can contribute to soil acidification, as mentioned previously.

Results of heavy metals reveals that the soils are not heavily polluted by typical inorganic contaminants associated with some industrial activities (Table 6). Concentrations of Cadmium (Cd), Chromium (Cr), Lead (Pb), and Mercury (Hg) were consistently at or below detection limits. This isolates petroleum hydrocarbons as the principal contaminant of concern.

However, the status of Iron (Fe) is notable, showing a marked increase in concentration during the dry season across most sampling points. This is likely due to evaporative concentration as soil moisture decreases. The exceptionally high value of 14,357.5 mg/kg at Point 10 is a significant outlier that warrants verification but could indicate a localized point of contamination or a measurement anomaly. The presence of Nickel (Ni) and Zinc (Zn) at low levels may be attributable to their natural occurrence in crude oil.

CONCLUSION

This study demonstrates that crude oil contamination at the Ogboinbiri flow station has led to a severe degradation of soil health, primarily through a mechanism of secondary soil acidification. The resulting low pH has led to the depletion of basic cations and a low nutrient holding capacity (CEC), creating an environment that is chemically unsuitable for plant growth. The direct toxicity of residual petroleum hydrocarbons further exacerbates this infertility, inhibiting microbial processes and plant germination, as observed in the field. The contamination has effectively rendered a vast area of land unproductive for agriculture and disrupting local ecosystems.

Based on these findings, it is recommended that: given the oxic conditions and the nature of the contamination, phytoremediation using acid tolerant, hydrocarbon degrading plant species should be prioritized and a program of liming acidity must be put in place to correct the strong acidity. In addition, a rigorous and periodic monitoring regimen must be established to track the build-up of contaminants, assess the effectiveness of remediation efforts, and prevent further ecological damage.

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