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Soil Quality Assessment of Crude Oil-Exposed Environments in Obama, Bayelsa State, Nigeria

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ABSTRACT

Soil is a living natural system whose healthy condition is essential for both economic and environmental sustainability. Therefore, this study evaluated soil quality parameters of some crude oil exposed soils in Obama oil flow stations in Bayelsa State, Nigeria, between 2022 and 2023. Thirteen (13) soil samples were collected each at two depths (0 – 15 cm and 15 – 30 cm) across wet and dry seasons, alongside control samples away from the stations. Physical observations indicated no marked differences in colour, texture, or permeability between exposed and control soils. Porosity declined with depth in both seasons. Soil pH remained strongly acidic during the wet season, but ranged from strongly acidic to moderately acidic in the dry season. Oxidation-reduction potential (ORP), total petroleum hydrocarbons (TPH), and total organic carbon in top-soils varied across sites and seasons. Concentration of benzene, toluene, ethyl benzene and xylene (BTEX) were consistently low, generally < 0.001 mg kg^{-1}. Cation exchange capacity was very low in surface soils with slightly higher values in the dry season. Among anions, carbonate predominated across depths and seasons. Overall, results suggest that soils in the study area are not currently contaminated; however, periodic environmental monitoring remains essential to prevent the accumulation of hydrocarbons or other pollutants.

Keywords: Soil, Environmental sustainability, Crude oil, Pollutants, Contaminants, Physical and chemical properties of soil samples

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INTRODUCTION

Soil is a dynamic, living natural system whose healthy condition is vital for both economic and environmental sustainability (Brady & Weil, 2022). Soil quality can be seen as the capacity of a soil to function within some ecosystem's boundaries (natural or managed systems), as well as to sustain plant, animal and human health (Larson & Pierce, 1994; Soil Science Society of America [SSSA], 1996). Soil quality affects not only the productivity but also the quality of agricultural produce and economic sustainability of the land which has great consequences on plant, animal and human health (Parikh & James, 2012). This integrates soils biological, chemical and physical attributes which aggregate assessments of a soil's capacity to function.

The function of soil includes the supply of nutrients and physical structural support for plant growth, and provision of buffer against pollutants (Scalenghe & Marsan, 2009). Soil has both inherent (example; soil texture, soil depth, clay type, CEC, drainage class) and dynamic properties (example; pH, bulk density, and organic matter content) and processes. These properties are used to assess the capacity of a soil to function within some ecosystems boundary, and interact positively with the environment external to that ecosystem. Collectively these properties are referred to as the soil quality parameters. Soil quality assessment based on inherent soil factors and focusing on dynamic aspects of soil system is an effective method for evaluating the environmental sustainability of land use and management activities (Zhu et al., 2009).

In many parts of Nigeria, crude oil exploration and production have led to increasing concerns about environmental degradation, soil contamination, and declining agricultural productivity (Akeju & Oguntimein, 2023). Bayelsa State, located in the core of the Niger Delta region, hosts several oil flow stations that support the nation's petroleum industry. However, communities around these installations depend heavily on the surrounding land for subsistence farming and other livelihood activities. Crude oil spills and leakages can alter soil physicochemical properties, disrupt microbial activity, and reduce soil fertility, posing significant ecological and socioeconomic challenges (Owordi et al., 2025; Ekundayo & Obuekwe, 2000). In the Niger Delta region of Nigeria, oil exploration and production have raised concerns about soil degradation, pollution, and loss of agricultural productivity (Arausi et al., 2025). Communities in Bayelsa State, particularly around oil flow stations, rely heavily on soil resources for farming and livelihood.

Understanding how crude oil exposure affects soil quality parameters is therefore crucial for assessing potential ecological risks and guiding sustainable land management. Against this background, the present study evaluated the soil quality parameters of crude-oil-exposed soils around selected oil flow stations in Obama, Bayelsa State, Nigeria.

MATERIALS AND METHODS

Study Area

Laboratory and field studies were carried out at Obama flow stations, located in Bayelsa state, Nigeria. The facilities are owned by Nigeria, Agip Oil Company (NAOC) (Figure 1).

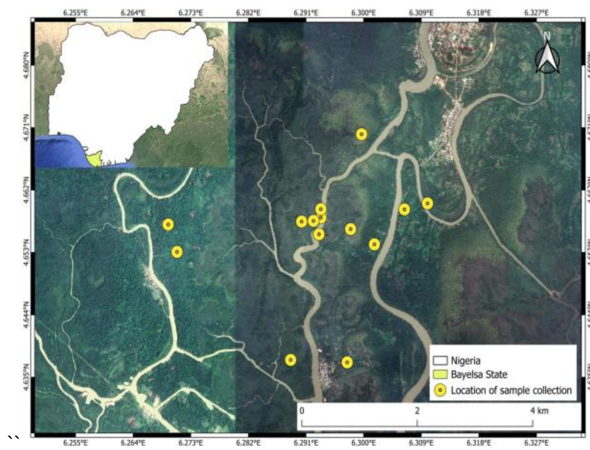

Figure 1. Soil Collection Sites in Obama Oil Flow Stations in Bayelsa State, Nigeria (Generated using QGIS version 3.38.3)

Soil Samples Collection

This study was conducted in the wet and dry season of 2022. Fourteen (14) sampling points were used for the study. Thirteen (13) were oil-exposed soils within the Obama flow station, while one (1), which served as the control (non-oil exposed soil) was a point away from the Obama flow station and served as the control. From each sampling point, two soil samples were taken from two separate depths i.e. surface (0 - 15 cm) and sub-surface (15 - 30 cm), bringing the total number of collected samples for the two seasons to fifty-six (56). These depths were selected because hydrocarbon contaminants are usually concentrated within the top 30 cm of soil due to limited vertical infiltration, as reported in previous studies (Ijah et al., 2003).

Determination of Physical and Chemical Properties of Soil Samples

The collected soil samples were air dried and passed through a 2 mm sieved prior to laboratory analysis. Standard procedures were employed to determine both physical and chemical properties. Soil pH was measured in a 1:2 soil-to-water suspension using a glass electrode. Particle size distribution was analysed using the hydrometer method as describes by Gee and Or (2002) and the USDA textural triangle was applied to classify soil texture. Total Organic Carbon/matter was determined by

Table 1: Physical Properties of Soils at Obama Flow Station in Wet Season 2022.

Point	P^{H}- $H_2$0		Temperature (^{O}C)		Colour		Texture		Porosity (%)		Permeability (m/day)	
DEPTH (cm)	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
SS_1	3.36	3.41	26.17	26.34	Light brown	Light brown	Sandy	Sandy	40.75	39.62	4.1	4.0
SS_2	4.17	3.66	26.48	26.81	Dark brown	Dark brown	Sandy	Clay	39.62	39.62	4.0	4.0
SS_3	3.81	3.76	26.17	26.11	Light brown	Light brown	Loam sandy	Sandy loam	41.89	43.02	4.2	4.3
SS_4	3.48	4.06	26.11	26.03	Brown	Brown		Sandy loam	42.64	43.02	4.3	4.3
SS_5	3.63	3.79	26.45	26.33	Dark brown	Dark brown	Sandy loam	Sandy loam	44.15	43.77	4.4	4.4
SS_6	4.13	4.01	26.41	26.35	Light brown	Light brown	Sandy	Loam sandy	43.02	43.02	4.3	4.3
SS_7	3.03	3.72	26.62	26.42	Light brown	Light brown	Sandy	Sandy	42.64	43.02	4.3	4.3
SS_8	3.56	3.45	26.28	26.11	Light brown	Light brown	Sandy sandy	Sandy	40.75	43.04	4.1	4.4
SS_9	4.05	3.68	26.50	26.18	Brown	Brown	Loam sandy	Sandy loam	43.02	43.02	4.3	4.3
SS_{10}	3.44	4.09	26.19	26.11	Light brown	Light brown	Sandy loam	Sandy loam	42.64	43.40	4.3	4.4
SS_{11}	3.99	4.00	26.91	26.73	Light brown	Light brown	Clay sandy	Clay	58.49	58.49	5.9	5.9
SS_{12}	3.79	4.06	26.030	26.25	Light brown	Light brown	Loam sandy	Sandy loam	39.62	41.13	4.0	4.1
SS CTL_1	3.39	3.58	26.41	26.37	Light brown	Light brown	Loamy sandy	Sandy loam	40.38	40.75	4.1	4.1
SS CTL_2	3.71	4.15	26.41	26.35	Light brown	Light brown	Loam	Sandy loam	43.02	41.51	4.3	4.2
Mean	3.70	3.82	26.38	26.32	-	-	-	-	43.04	43.34	4.23	4.40
Std. Values	0.33	0.25	0.23	0.23					4.66	4.58	0.47	0.47

the dichromate wet oxidation method (Carter, 1993; Walkley & Black, 1934), while total nitrogen (TN) was analysed using the micro-kjeldhal digestion technique (AOAC, 1999). Available phosphorus was extracted using the Bray-1 process with P concentration determined by the Murphy and Riley (1962) procedure.

Exchangeable acidity was assessed through titration following Page et al. (1982). Exchangeable cations (Ca, Mg, Na and K) were extracted with 1 M ammonium acetate solution buffered at PH 7. Sodium (Na) and Potassium (K) were quantified using a flame photometer, whereas calcium and magnesium concentration were determined using the Atomic Absorption Spectrophotometer (AAS, UNICAM 936 Model). Additionally, Energy Depressive X-ray florescence spectrophotometer (EDXRF) was employed for further elemental analysis (AOAC, 2005).

RESULTS

Analyzed Physical Properties of the Experimental Locations during the Wet Season of 2022

The analyzed physical properties of the soil samples around the Obama flow stations during the wet season of 2022 are presented on (Table 1). The colour of the soil samples varied from light brown to dark brown both at the surface and subsurface horizons. pH ranged from 3.03 to 4.17 (mean=3.70) with higher values (mean value of 3.82) recorded in the subsoil. Soil temperature was slightly higher in the surface soils (26.38°C compared to the subsurface soils (26.32°C).

Most of the sites had a sandy to sandy loam texture, exception being SS_{11} which was clay. In the subsurface soil, soil texture ranged from sandy to sandy loam. However, SS_2 and SS_{11} were clay. Mean permeability values were 4.24 and 4.40 (m/day) for the surface and subsurface soils respectively.

Porosity decreased with depth with mean values of 43.04 and 43.34% in the surface and subsurface soils, respectively.

Analyzed Physical Properties of the Experimental Locations during the Dry Season of 2022

The analyzed physical properties of the soil samples around the Obama flow stations during the dry season of 2022 are presented on (Table 2). The colour of the soil samples varied from light brown to dark brown both at the surface and subsurface horizon. However, sampling point 8 was brownish-white in colour at the subsurface. Soil pH ranged from a mean value of 4.40 at the surface soil to a mean value of 4.70 at the subsoil. While the mean soil temperature was 26.33°C at the surface and 27.18°C at the subsurface. In most of the sample sites, soil texture of the surface soil was sandy to sandy loam with the exception of SS_{11} which was clay. In the subsurface soil, the texture ranged from sandy to sandy loam. However, SS_2 and SS_{11} were clay. Permeability values were 4.52 m/day for the surface soil and 4.54 m/day for the subsurface soil. Porosity decreased with depth with Mean value of 44.43% and 44.73% for the surface and subsurface soils respectively.

Chemical Properties of the Experimental Location during the Wet Season of 2022

The analyzed chemical properties of the experimental locations are presented on (Table 3). Results indicated that oxidation reduction potential of the upper soils was high (mean value of 174.1 mg/kg) compared to the sub-surface soils (with a mean of 173.10 mg/kg). TPH in the surface soils was variable with mean values of 1.34. At the subsurface level, mean TPH was 1.34mg/kg. The concentration of benzene, toluene, ethyl benzene and xylene (BTEX) in the experimental soils was low and generally below 0.001 mg kg^{-1} in both surface and subsurface soils while total organic carbon in the surface soil was variable with a mean of 3.44%. At the subsurface soil, the mean TOC level was 2.20% in the wet season. Total Nitrogen values in the surface soil was variable and ranged from 1.14 to 1.62 % with a mean value of 1.34%. While at the subsurface level, the mean N level was 1.40

Table 2: Physical Properties of Surface (0 – 15 cm) and subsurface (15 - 30cm) soils at Obama during dry season.

Point	P^{H}- H_20		Temperature (^OC)		Colour		Texture		Porosity (%)		Permeability (m/day)	
Depth (CM)	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-3
SS_1	3.8	4.41	27.24	27.32	Light Brown	Light Brown	Sandy	Sandy	42.06	40.89	4.3	4.2
SS_2	4.36	5.08	27.66	27.22	Dark brown	Light brown	Sandy	Clayey	40.89	40.89	4.2	4.2
SS_3	4.33	4.66	26.66	25.38	Light Brown	Brown	Sandy Loam	Sandy Loam	43.23	44.40	4.4	4.5
SS_4	3.73	3.9	27.26	27.33	Brown	Brown	Sandy Loam	Sandy Loam	44.01	44.40	4.5	4.5
SS_5	4.03	4.66	27.63	27.41	Dark Brown	Brown	Sandy Loam	Sandy Loam	45.56	45.17	4.6	4.6
SS_6	5.66	5.41	27.63	27.36	Light Brown	Light Brown	Sandy	Sandy	44.40	44.40	4.5	4.5
SS_7	3.83	4.93	26.33	27.14	Light Brown	Light Brown	Sandy	Sandy	44.01	44.40	4.5	4.5
SS_8	4.06	4.88	26.38	26.36	Light Brown	Whitish Brown	Sandy	Sandy	42.06	44.78	4.3	4.5
SS_9	5.03	5.36	27.18	27.29	Brown	Light Brown	Sandy Loam	Sandy Loam	44.40	44.40	4.5	4.5
SS_{10}	4.09	4.36	26.33	26.46	Light Brown	`Light Brown	Sandy Loam	Sandy Loam	44.01	44.78	4.5	4.5
SS_{11}	5.36	3.66	27.63	27.68	Light Brown	Light Brown	Clayey	Clayey	60.36	60.36	6.1	6.1
SS_{12}	4.08	3.49	27.19	27.33	Light Brown	Brown	Sandy Loam	Sandy Loam	40.89	42.45	4.2	4.3
$SSCTL_1$	3.53	5.64	26.93	27.41	Light Brown	Light Brown	Sandy Loam	Sandy Loam	41.67	42.06	4.2	4.3
$SSCTL_2$	5.41	4.64	26.33	27.18	Light Brown	Brown	Sandy Loam	Sandy Loam	44.40	42.84	4.5	4.4
MEAN	4.40	4.70	27.03	27.06					44.43	44.73	4.52	4.54
STD VALUE	0.70	0.67	0.55	0.62					4.96	4.78	0.49	0.47

Table 3: Selected Chemical Properties of Soils at Obama Flow Station in Wet Season 2022.

Point	ORP (mg/kg)		THC (mg/kg)		TPH (mg/kg)		BTEX (mg/kg)		TOC (%)		Total N (%)		CEC (mg/Kg)	
Depth (cm)	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**
SS_1	118.3	176.4	8.46	4.11	0.977	0.475	<0.001	<0.001	2.9	1.8	1.204	1.207	0.07	0.05
SS_2	191.7	186.1	3.93	2.84	0.454	0.328	<0.001	<0.001	3.2	2.8	1.204	1.207	0.07	0.11
SS_3	166.7	159.6	6.08	4.70	0.702	0.543	<0.001	<0.001	3.2	3.0	1.144	1.146	0.17	0.13
SS_4	187.4	203.3	17.98	15.71	2.076	1.814	<0.001	<0.001	4.2	3.0	1.588	1.425	0.12	0.10
SS_5	199.6	153.5	24.93	17.26	2.879	1.993	<0.001	<0.001	2.6	2.0	1.210	1.143	0.12	0.09
SS_6	198.7	141.9	18.76	15.89	2.166	1.835	<0.001	<0.001	4.6	3.1	1.137	1.594	0.12	0.07
SS_7	211.5	168.4	17.79	16.08	2.0584	1.857	<0.001	<0.001	4.1	3.2	1.597	1.210	0.080	0.08
SS_8	166.8	152.3	7.61	5.32	0.879	0.614	<0.001	<0.001	4.0	2.8	1.210	1.209	0.12	0.08
SS_9	167.9	177.9	6.08	3.61	0.702	0.417	<0.001	<0.001	3.2	1.9	1.207	1.209	0.40	0.14
SS_{10}	159.1	220.4	13.79	11.38	1.592	1.314	<0.001	<0.001	2.0	0.6	1.210	1.210	0.12	0.09
SS_{11}	147.8	162.3	17.14	4.81	2.010	1.637	<0.001	<0.001	3.9	2.2	1.217	1.614	0.14	0.09
SS_{12}	176.7	165.5	4.18	3.04	0.483	0.351	<0.001	<0.001	2.2	1.6	1.614	1.614	0.07	0.09
SS CTL_1	181.6	191.1	9.12	3.61	1.053	0.417	<0.001	<0.001	4.8	1.9	1.616	1.614	0.08	0.08
SS CTL_2	163.8	164.9	6.07	1.71	0.701	0.197	<0.001	<0.001	3.2	0.9	1.620	1.620	0.10	0.12
Mean	174.1	173.1	11.58	8.53	1.34	1.00	-	-	3.44	2.20	1.34	1.40	0.12	0.09
Std. Values	23.13	20.55	6.44	5.71	0.75	0.68			0.83	0.79	0.20	0.20	0.08	0.02

Key: ORP = Oxidation Reduction Potential; THC = Total Hydrocarbon; TPH = Total Petroleum Hydrocarbon; BTEX = Benzene, Toluene, Ethyl Benzene and Xylene; TOC = Total Organic Carbon; Total N = Total Nitrogen; CEC = Cation Exchange Capacity.

%. Higher N contents were obtained at the control sites than the impacted soils. Cation exchange capacity was very low in the top soil in both seasons with the values for the dry season been slightly higher. Mean CEC values were 0.12 cmol kg $^{-1}$ and 0.09 cmol kg^{-1} in surface and subsurface soils respectively.

Selected Chemical Properties of the Experimental Location during the Dry Season of 2022

Some selected chemical properties of the Obama flow station during the dry season are presented on (Table 4). ORP in the surface soil ranged from 199.3 to 339.1 mg/kg with a mean of 246.6 mg/kg. Mean value of the subsurface soil was 235.1 mg/kg. TPH in the surface soil was variable with mean values of 1.33 mg/kg at the dry season. At the subsurface level, mean TPH was 0.98. The concentration of benzene, toluene, ethyl benzene and xylene (BTEX) in the soil was low and generally below 0.001 mg kg^{-1} in both surface and subsurface soils in the dry season. While the total organic carbon in the surface soil was variable with a mean value of 2.61%. At the subsurface soil level average TOC was 3.00% while Total Nitrogen values ranged from 1.14 to 1.63. Similarly, mean N was 1.40 % in the dry season. Higher N contents were obtained at the control sites than the impacted soils. Cation exchange capacity

Table 4: Selected Chemical Properties of Surface (0 – 15 cm) and Subsurface (15 - 30cm) at Obama during the dry Season 2022.

Point	**ORP (mg/kg)**		**THC (mg/kg)**		**TPH (mg/kg)**		**BTEX (mg/kg)**		**TOC (%)**		**Total N (%)**		**CEC (mg/Kg)**	
Depth (cm)	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	15-30
SS_1	339.1	208.3	8.10	3.93	0.973	0.473	<0.001	<0.001	4.2	3.0	1.597	1.210	2.387	1.291
SS_2	236.1	198.7	3.78	2.72	0.454	0.327	<0.001	-	2.6	2.0	1.210	1.209	2.387	1.143
SS_3	264.8	360.8	58.82	4.50	0.699	0.540	<0.001	-	4.6	3.1	1.207	1.209	2.188	3.316
SS_4	306.1	217.3	17.21	15.03	2.067	1.806	<0.001	-	3.2	4.0	1.210	1.425	2.611	2.639
SS_5	221.5	251.6	23.86	16.52	2.866	1.984	<0.001	-	2.8	3.2	1.210	1.143	2.759	5.638
SS_6	234.4	234.4	17.95	15.21	2..157	1.827	<0.001	-	1.9	2.0	1.137	1.594	5.434	1.738
SS_7	290.3	224.1	17.03	15.39	2.045	1.894	<0.001	-	0.6	3.9	1.210	1.143	0.973	1.020
SS_8	256.1	276.2	7.28	5.09	0.875	0.612	<0.001	-	2.2	2.2	1.130	1.594	1.658	4.758
SS_9	208.7	218.5	5.82	3.45	0.699	0.415	<0.001	-	1.6	4.8	1.207	1.209	1.047	1.605
SS_{10}	199.3	`186.9	13.20	10.89	1.585	1.308	<0.001	-	1.9	3.2	1.616	1.614	2.280	1.956
SS_{11}	216.7	281.3	16.66	`13.52	2.002	1.630	<0.001	-	0.9	2.2	1.620	1.620	1.593	2.097
SS_{12}	324.1	204.6	4.00	2.91	0.481	0.349	<0.001	-	2.2`	1.6	1.634	1.336	1.110	1.091
$SSCTL_1$	215.3	219.7	8.73	3.45	1.048	0.415	<0.001	-	4.8	1.9	1.619	1.434	1.461	1.561
$SSCTL_2$	220.5	209.4	5.81	1.64	0.698	0.197	<0.001	-	3.0	2.9	1.625	1.628	1.572	1.650
Mean	246.60	235.10	11.09	8.16	1.33	0.98		`	2.61	3.00	1.40	1.40	2.10	2.30
Std. Values	44.01	43.25	13.62	5.61	0.73	0.68			1.27	0.90	0.21	0.19	1.09	1.35

Key: ORP = Oxidation Reduction Potential; THC = Total Hydrocarbon; TPH = Total Petroleum Hydrocarbon; BTEX = Benzene, Toluene, Ethyl Benzene and Xylene; TOC = Total Organic Carbon; Total N = Total Nitrogen; CEC = Cation Exchange Capacity

Table 5: Exchangeable Cations Status of the Surface and Subsurface at Obama during the Wet Season 2022

Point	**Exchangeable base (mg/kg soil)**									
Depth (cm)	**Na^+**		**K^+**		**Ca^{+2}**		**Mg^{+2}**		**Total bases**	
	0-15	15-30	0-15	0-30	0-15	15-30	0-15	15-30	0-15	15-30
SS_1	0.2118	0.1454	0.163	0.163	0.177	0.172	0.597	0.470	1.1488	0.9504
SS_2	0.1570	0.1360	0.154	0.155	0.159	0.156	0.712	1.140	1.182	1.587
SS_3	0.1484	0.1401	0.214	0.192	1.311	0.995	1.188	0.957	2.8614	2.2811
SS_4	0.4798	0.4789	0.163	0.154	0.189	0.222	1.058	0.819	1.8898	1.6739
SS_5	0.1490	0.1376	0.153	0.215	0.189	0.733	0.864	0.578	1.995	1.6636
SS_6	0.3037	0.0009	0.216	0.163	0.406	0.196	0.994	0.725	1.9197	1.0849
SS_7	0.2108	0.2105	0.163	0.163	0.225	0.241	0.698	0.748	1.2968	1.3625
SS_8	0.2103	0.2105	0.163	0.163	0.377	0.234	1.168	0.725	1.9183	1.3325
SS_9	0.4953	0.7171	`0.163	0.163	5.498	0.546	1.237	0.963	7.3933	2.3891
SS_{10}	0.2119	0.2812	0.164	0.218	0.342	0.235	1.098	0.755	1.8159	1.4892
SS_{11}	0.2812	0.2812	0.218	0.218	0.402	0.247	1.292	0.793	2.1932	1.5392
SS_{12}	0.3294	0.3157	0.218	0.218	0.238	0.212	0.521	10.737	1.3064	1.4827
$SS\ CTL_1$	0.3872	0.3610	0.219	0.219	0.117	0.113	0.696	0.720	1.4192	1.413
$SS\ CTL_2$	0.2583	0.2561	0.157	0.157	0.669	0.587	0.625	0.998	1.7093	1.9981
Mean	0.27	0.26	0.81	0.18	0.78	0.40	0.91	0.80	2.77	1.64
Std. values	0.11	0.18	0.03	0.03	1.40	0.26	0.27	2.66	1.58	0.41

was very low in the surface soil in both seasons with the values for the dry season been slightly higher. Mean CEC values were 2.10 cmol kg $^{-1}$ and 2.30cmol kg $^{-1}$ in surface and subsurface soils in dry seasons respectively

Cation Status at the Obama Flow Stations during the Wet Season of 2022

The exchangeable cations status at the Obama flow stations during the wet season are presented on (Table 5). Mean Calcium (Ca) level at the surface and subsurface soils were 0.78 and 0.40 cmolkg^{-1}. Mean Magnesium (Mg) value at the surface and subsurface soils were 0.91 and 0.80 cmol kg^{-1}respectively. Potassium (K) had a mean value of 0.81 and 0.18 cmol kg^{-1}at the surface and subsurface level. Mean Sodium (Na) values were 0.27 and 0. 26 cmol kg^{-1} respectively for the surface and subsurface soils. While Ammonium (NH_4^+) had a mean value of 0.21 cmol kg^{-1} in both depths.

Cation Status at the Obama Flow Stations during the Dry Season of 2022

Exchangeable cations Status at the Obama flow station during the dry season are presented on (Table 6). Mean Calcium (Ca) level at the surface and subsurface soils were 1.00 and 0.90 cmol kg^{-1} respectively. Mean Magnesium (Mg) value at the surface and subsurface soils were 0.18 and 0.18 cmol kg^{-1} respectively. Potassium (K) had a mean value of 0.33 and 0.32 cmol kg^{-1}at the surface and subsurface level respectively. Mean Sodium (Na) values were 0.21 and 0. 21 cmol kg^{-1} at the surface and subsurface level respectively. While Ammonium (NH_4^+) had a mean value of 0.21 cmol kg^{-1} in both depths.

Selected Anions Properties of the Obama Flow Stations during the Wet Season of 2022

Selected anion properties of the Obama flow station during

Table 6: Exchangeable Cations Status in Surface (0-15cm) and Subsurface (15-30cm) at Obama during the Dry Season 2022.

	Cations (Mg/Kg Soil)									
Point	**Na^+**		**K^+**		**Ca^{+2}**		**Mg^{+2}**		**Total Bases**	
Depth (cm)	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**
SS1	0.451	0.459	0.163	0.163	0.118	0.122	1.4701	0.3613	2.2021	1.1053
SS2	0.454	0.461	0.154	0.155	0.003	<0.001	0.3548	1.3967	0.9658	2.0137
SS3	1.746	0.569	0.214	0.192	0.221	0.224	0.89	1.4067	3.071	2.3917
SS4	0.142	0.2105	0.163	0.154	0.359	0.363	1.7887	1.8556	2.4527	2.5831
SS5	0.074	0.419	0.153	0.215	3.583	3.497	1.6534	1.058	5.4634	5.189
SS6	0.152	0.164	0.216	0.163	0.758	0.094	0.3666	0.3661	1.4926	0.7871
SS7	0.009	0.219	0.163	0.163	0.092	0.096	0.578	0.994	0.8420	1.472
SS8	0.171	0.162	0.163	0.163	3.573	0.173	0.6657	0.3624	4.5727	0.8604
SS9	0.195	0.298	0.163	0.163	0.135	0.135	0.9256	1.498	1.4186	2.094
SS10	0.304	0.293	0.164	0.218	0.133	0.108	1.168	0.725	1.769	1.344
SS11	0.278	0.177	0.218	0.218	0.115	0.112	1.237	0.355	1.848	0.862
SS12	0.16	0.475	0.218	0.218	0.11	0.069	0.354	0.4505	0.842	1.2125
SS CTRL 1	0.189	0.178	0.219	0.219	<0.001	0.038	0.9043	0.8887	1.3133	1.3237
SS CTRL 2	0.355	0.357	0.157	0.157	0.061	0.061	0.8981	0.9	1.4711	1.475
Mean	0.33	0.32	0.18	0.18	-	-	1.00	0.90	1.510	1.400
STD VALULE	0.43	0.14	0.03	0.03			0.47	0.50	1.39	1.14

Table 7: Exchangeable Anions of the Surface and Sub-surface of Obama during the Wet Season.

	Anions (Mg/kg soils)									
Point	**$N0_3$** mg/kg soil		**SO_4^2** mg/kg soil		**NO_2** mg/kg soil		**$P0_4^{2-}$** mg/kg soil		**CO_3^{2-}**	
Depth (cm)	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**	**0-15**	**15-30**
SS_1	0.578	0.578	3.274	3.288	0.206	0.208	08082	0.094	60	120
SS_2	0.537	0.539	3.281	3.253	0.208	0.207	0.091	0.094	120	120
SS_3	0.827	0.719	3.264	3.244	0.207	0.209	0.094	0.095	120	180
SS_4	0.580	0.538	3.245	3.253	0.208	0.206	0.095	0.095	60	120
SS_5	0.534	0.832	3.236	3.233	0.206	0.206	0.096	0.096	60	180
SS_6	0.833	0.580	3.238	3.24	0.207	0.208	0.095	0.095	120	60
SS_7	0.580	0.581	3.206	3.202	0.208	0.206	0.095	0.095	180	120
SS_8	0.581	0.581	3.199	3.206	0.205	0.206	0.095	0.095	120	180
SS_9	0.581	0.580	3.225	3.222	0.207	0.208	0.095	0.095	60	180
SS_{10}	0.583	0.0842	3.206	3.208	0.209	0.209	0.095	0.095	60	120
SS_{11}	0.842	0.842	3.217	3.249	0.209	0.209	0.015	0.095	120	60
SS_{12}	0.842	0.842	3.192	3.193	0.210	0.209	0.095	0.095	60	120
SS CTL_1	0.845	0.845	3.148	3.163	0.210	0.210	0.95	0.95	180	120
SS CTL_2	0.547	0.546	3.209	3.104	0.210	0.210	0.095	0.095	60	60
Mean	1.00	0.70	3.22	3.22	0.21	0.21	0.10	0.10	99.00	124.30
Std. Values	0.14	0.20	0.04	0.05	0.00	0.00	2159.96	0.23	44.70	43.80

the wet season are presented on (Table 7). Mean Nitrites (NO_2) values were 0.21 and 0.21 mg kg^{-1}at the surface soil and subsurface soils. Sulphates (SO_4^{2-}) had a mean value of 3.22 and 3.22 mg kg^{-1}at the surface and subsurface level. Mean Nitrates (NO^{3-}) values were1.00 and 0.70 mg kg^{-1}at the surface and subsurface level, mean Phosphate (PO_4^{2-}) value was 0.10mg kg^{-1}in both surface and subsurface soils. While Carbonate (CO_3^-) had a mean value of 99.00 mg kg^{-1}at surface soil and 124.30 mg kg^{-1}at the subsurface soil, respectively.

Selected Anions Properties of the Obama Flow Stations during the Dry Season of 2022

Selected anion properties of the Obama flow station during the dry season are presented on (Table 8). Nitrites (NO_2) mean values were 0.22 and 0.22 mg kg^{-1} were at the surface and subsurface soils. The mean Sulphates (SO_4^{2-}) value were 3.20 and 3.20 mg kg^{-1} for both surface and subsurface soils respectively. Nitrates (NO^{3-}) had a mean value of 1.00 and 0.70 mg kg^{-1} at the surface and subsurface soils respectively. In both surface and subsurface soil, mean Phosphate (PO_4^{2-}) value was 0.10mg kg^{-1}. While, Carbonate (CO_3^-) had a mean value of 107.10 mg kg^{-1} at the surface and 116.00 mg kg^{-1} at the subsurface soil respectively.

DISCUSSION

This study evaluated the soil quality parameters of oil-exposed soils around the Obama flow stations in Bayelsa State, Nigeria, during the 2022 wet and dry seasons. Both surface and subsurface soils were analysed for their physical and chemical properties to assess their fertility

Table 8: Exchangeable anions in surface (0-15) and sub-suface (15-30) at Obama during the dry season 2022.

Point	????		????		NO_2 mg/kg soil		$P0_4^{2-}$ mg/kg soil		CO_3^{2-}	
Depth (cm)	0-15				0-15	15-30	0-15	15-30	0-15	15-30
SS1	0.580				0.208	0.206	0.095	0.095	180	120
SS2	0.581	0.581	3.199	3.206	0.225	0.206	0.095	0.095	120	180
SS3	0.581	0.580	3.225	3.222	0.227	0.208	0.095	0.095	60	180
SS4	0.583	0.538	02.06	3.253	0.209	0.206	0.095	0.095	60	120
SS5	0.534	0.832	3.236	3.233	0.206	0.216	0.096	0.096	60	180
SS6	0.833	0.580	3.238	3.24	0.207	0.208	0.095	0.095	120	60
SS7	0.842	0.842	3.217	3.249	0.222	0.209	0.015	0.095	120	60
SS8	0.842	0.842	3.192	3.193	0.210	0.209	0.095	0.095	60	120
SS9	0.845	0.845	3.148	3.163	0.210	0.210	0.095	0.095	180	120
SS10	0.583	0.842	3.206	3.208	0.209	0.209	0.095	0.095	60	120
SS11	0.845	0.845	3.148	3.163	0.210	0.234	0.095	0.095	180	120
SS12	0.547	0.546	3.209	3.104	0.11	0.210	0.095	0.095	60	60
SS CTRL 1	0.845	0.845	3.148	3.163	0.220	0.270	0.095	0.095	180	120
SS CTRL 2	0.547	0.546	3.209	3.04	0.284	0.299	0.095	0.095	60	60
Mean	1.00	0.70	3.20	3.20	0.22	0.22	0.10	0.10	107.10	116.00
	0.14	0.14	0.31	0.06	0.04	0.03	0.02	0.00	53.55	43.80

status and contamination levels. The soil samples were found to be strongly to slightly acidic (pH 3.03 - 5.64) a condition that supports only acid-tolerant microorganisms and adversely affects crop performance. This result is consistent with that of Gondal et al. (2021), who reported similar pH values in crude oil–impacted soils. The observed acidic he observed acidity may be linked to intense rainfall, erosion, and leaching typical of humid environments, where the removal of basic cations leaves behind hydrogen and aluminium ions (Weil & Brady, 2017). Soil pH is a key determinant of soil health as it affects crop yields, crop suitability, plant nutrient availability, and the activity of soil microorganisms, which influences key soil processes (National Research Council (NRC), 2000). It specifically affects plant nutrient availability by controlling the chemical forms of the nutrients in the soil.

Mean soil temperature recorded in the study was 26.38°C in wet seasons and 27.03°C in dry seasons which were within WHO limits of 25°C - 30°C. Generally, extremely low or high temperature affects the growth and yield of crops adversely. Hence, the temperature ranges obtained in this study are ideal for both crops and microbial activities. The colour of the soil samples in this study varied from light brown to dark brown both at the surface and subsurface horizons except for sampling point 8 which was brownish white in colour at the subsurface soil. The soil textural class in this study range from clay to loamy and sandy to sandy loam at both seasons and locations indicating that the area retains more water. This could be as a result of metabolic processes occurring in the soil as noted by Onwouka et al. (2021). The Oxidation Reduction Potential (ORP) of the soil samples were observed to vary with a mean value of 174.1 in surface soil and 173.10 mg/kg-1 in subsurface soil. This is an indication of higher volume of oxygen in the soil and this favors the growth and function of micro-organism involved in the breaking down and decomposition of organic residues as reported previously by Mattila (2024). Total hydrocarbon (THC) content ranged between 38.90 mg/kg and 17.64 mg/kg in the wet and dry season, indicating that these are only present in trace level likely from organic compounds. Total Petroleum Hydrocarbon (TPH) is a large family of 100 chemical compound originating from crude oil, Higher TPH in soil could pose dangerous health effect/challenges if exposed to them over a long time through consumption of crops grown on such soil. High concentration of TPH at values of 1.34mg/kg in wet season and 1.00 mg/kg in dry season in surface and subsurface soil were recorded across sampling points. This could be due to the decomposition of organic matter, gas, volatile transmission, semi combustion of fossil fuels by automobile and the combination of tree leaves, hydrocarbon and combustion of fuels. An accumulation of these causes' harmful effects to humans apart from the direct contamination of water and soil as well as air (Jonson et al., 2019).

In this study, the concentration of BTEX is below 0.001 mg kg^{-1} in both surface and subsurface soils. Volatile organic compounds especially BTEX including benzene, toluene, xylene and ethyl-benzene are dangerous organic air pollutants, particularly in indoor environments, when their concentration level exceed 0.001mg/kg. Total organic carbon in wet season was quite higher than that of the dry season in surface soil, while that of the dry season was higher than that of the wet season in subsurface soil. This result is in line with the observation made by Dosbergenov (2010) that oil contaminant has some impact on the total organic carbon content of the soil as non-gaseous phase liquids could change the composition and structure of soil organic matter and the C/N ratio in the soil. High organic carbon in soil is favorable for crop production and environmental sustainability.

A reduction in total soil nitrogen results in decreased soil fertility, soil nutrient supply and penetrability as well as productivity. In this study, the soils samples were found with high total nitrogen which could be as a result of exposure to oil. This is in line with the previous observation by John et al. (2016). Variation in nitrogen content of a soil is caused by multiple factors including parent materials and land used. The exchangeable cations in the study showed variable amount of cations but they were generally low as it has been established by several researchers that low calcium status of oil affected soils will cause poor stem growth and discoloration of crops and thus low crop yield. Low potassium has been associated with retard plant growth, causing poor stem development and wilting (Brady, 1999; Nwilo & Badoj, 2005; Inoni et al., 2006). on further investigation, the findings from the study revealed that the soil samples around the flow station were depleted of some important nutrients that are necessary for plant growth and cannot favor high crop yield. The concentration of nitrate obtained in the study were low (0.70 and 1.00 mg/kg) than the standard range values (10-15 mk/kg) reported in the environmental evaluation guideline. The concentration of the Sulphate obtained in surface and subsurface soil were high (3.22 mg/kg) and above the environmental standard guidelines (<2 mg/kg). While phosphate concentration recorded in surface and sub-surface soils were low (0.10 mg/kg) than the mean values (20 mg/kg) reported in the environmental standard guideline. Furthermore, the concentration of carbonate obtained in surface and sub-surface soils were high (90.00 mg/kg and 124.30 mg/kg) and above the standard values (30-50 mg/kg) reported as environmental standard guideline. These would impact negatively on the health and productivity of the soil around the flow station.

Conclusion

The results of this study indicate that the soil samples collected around the Agip Flow Stations in Bayelsa State exhibited good soil health, with minimal variation in physicochemical properties between the surface and subsurface layers. No significant evidence of hydrocarbon contamination was detected in the analyzed samples. Nonetheless, regular environmental monitoring is recommended to ensure early detection and prevention of potential future contamination.

REFERENCES

Akeju, F. B., & Oguntimein, G. B. (2023). Environmental impact of oil exploration in Nigeria: A case study of Nembe Local Government. *International Journal of Research and Innovation in Applied Science,* 8(9), 75–89.

AOAC (2005). Official Methods of Analysis. 18th Edition, Association of Official Analytical Chemists, Washington, DC.

Arausi, R. E., Clark, E. V., & Ikenga, F. A. (2025). Oil production and climate change in the Niger-Delta region: Synergic implication and adaptation. *Journal of Public Administration, Finance and Law,* 33(2024), 78–93.

Association of Official Analytical Chemists (AOAC) (1999). Official Methods of Analysis. 16th Edition, Association of Official Analytical Chemists, Washington, DC.

Brady, N. C., & Weil, R. R. (1999). *The Nature and Properties of Soils*. 12th Edition. Prentice Hall, New Jersey.

Carter, M. R. (1993). Soil Sampling and Methods of Analysis. *Canadian Society of Soil Science*. Lewis Publishers, Boca Raton, FL.

Disbergenou, S. (2010). Effect of crude oil pollution on organic carbon and humus content in grey-brown soils in Mangyshlak, Pre-Caspian Sea Region: Effect of crude oil pollution on organic carbon and humus content in grey-brown soils in Mangyshlak, Pre-Caspian Sea Region. *Journal of Arid Land*, *2*(2), 133-136

Ekundayo, E. O., & Obuekwe, O. (2000). Effects of an oil spill on soil physico-chemical properties of a spill site in a typic Udipsamment of the Niger Delta Basin of Nigeria. *Environmental Monitoring and Assessment,* 60(2), 235–249.

Gee, G. W. & Or, D. (2002) Particle Size Analysis. In: Dane, J.H. and Topp, G.C., Eds., Methods of Soil Analysis, Part 4, Physical Methods, Soils Science Society of America, Book Series No. 5, Madison, 255-293.

Gondal, A.H., Hussain, I., Ijaz, A.B., Zafar, A., Imran, B., Zafar, H., Sohail, M.D., Niazi, H., Touseef, M., Khan, A.A., Tariq, M., Yousuf, H., & Usama, M. (2021). Influence of Soil Ph and Microbes on Mineral Solubility and Plant Nutrition: A Review. *International Journal of Agriculture and Biological Sciences,* 71-81.

Ijah, U. J. J., & Antai, S. P. (2003). Removal of Nigerian light crude oil in soil over a 12-month period. *International Biodeterioration & Biodegradation,* 51(2), 93–99.

Inoni, O.E., Omotor, D.G., & Adun, F.N. (2006). “The Effect of Oil Spillage on Crop Yield and Farm Income in Delta State, Nigeria. *Journal of Central European Agriculture*, 7(1), 41-49

John, R., Ntino, E., & Itah, A. (2016). Impact of Crude Oil on Soil Nitrogen Dynamics and Uptake by Legumes Grown in Wetland Ultisol of the Niger Delta, Nigeria. *Journal of Environmental Protection,* 7, 507-515.

Larson, W. E., & Pierce, F. J. (1994). The Dynamics of Soil Quality as a Measure of Sustainable Management, In Defining Soil Quality for a Sustainable Environment. SSSA Special Publication 35, *Soil Science Society of America and American Society of Agronomy*, 37-51.

Mattila, T. J. (2024). Redox potential as a soil health indicator – how does it compare to microbial activity and soil structure?. *Plant Soil*, *494*, 617–625.

Murphy, J., & Riley, J. P. (1962) A Modified Single Solution Methods for the Determination of Available Phosphate in Natural Water. *Analytica Chimica Acta,* 27, 31-36.

National Research Council (NRC) (2000). US Committee on Copper in Drinking Water. Copper in Drinking Water. Washington (DC): National Academies Press (US). Available from: https://www.ncbi.nlm.nih.gov/books/NBK225397/ doi: 10.17226/9782

Nwilo, P. C., & Badejo, O. T. (2005) Oil Spill Problems and Management in the Niger Delta. *International Oil Spill Conference Proceedings, 1,* 567-570.

Owordi, J. C., Osuji, L. C., & Onojake, M. C. (2025). Soil fertility after an oil pipeline spill in Niger Delta, Nigeria. *Asian Journal of Current Research,* 10(2), 153–165.

Page, A. L., Miller, R. H., & Keeney, D. R. (1982). Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties. American Society of Agronomy. In Soil Science Society of America, Vol. 1159.

Parikh, S. J. & James, B. R. (2012) Soil: The Foundation of Agriculture. *Nature Education Knowledge, 3*(10), 2.

Scalenghe, R., & Marsan, F. A. (2009). The anthropogenic sealing of soils in urban areas. *Landscape and Urban Planning, 90*(1-2), 1-10.

Soil Science Society of America (SSSA) (1996). Glossary of Soil Science Terms. Soil Science Society of America, Madison, W.I.

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, 37(1), 29–38.

Weil, R. R., & Brady, N. C. (2017). The Nature and Properties of Soils. 15th Edition, Pearson, New York.

Zhu, X., Chen, Y., & Li, D. (2009). Soil environmental quality assessment in sustainable rehabilitation of mine waste area: establishing an integrated indicator-based system. *Wseas Transactions on Information Science and Applications, 3*(6), 457-466.