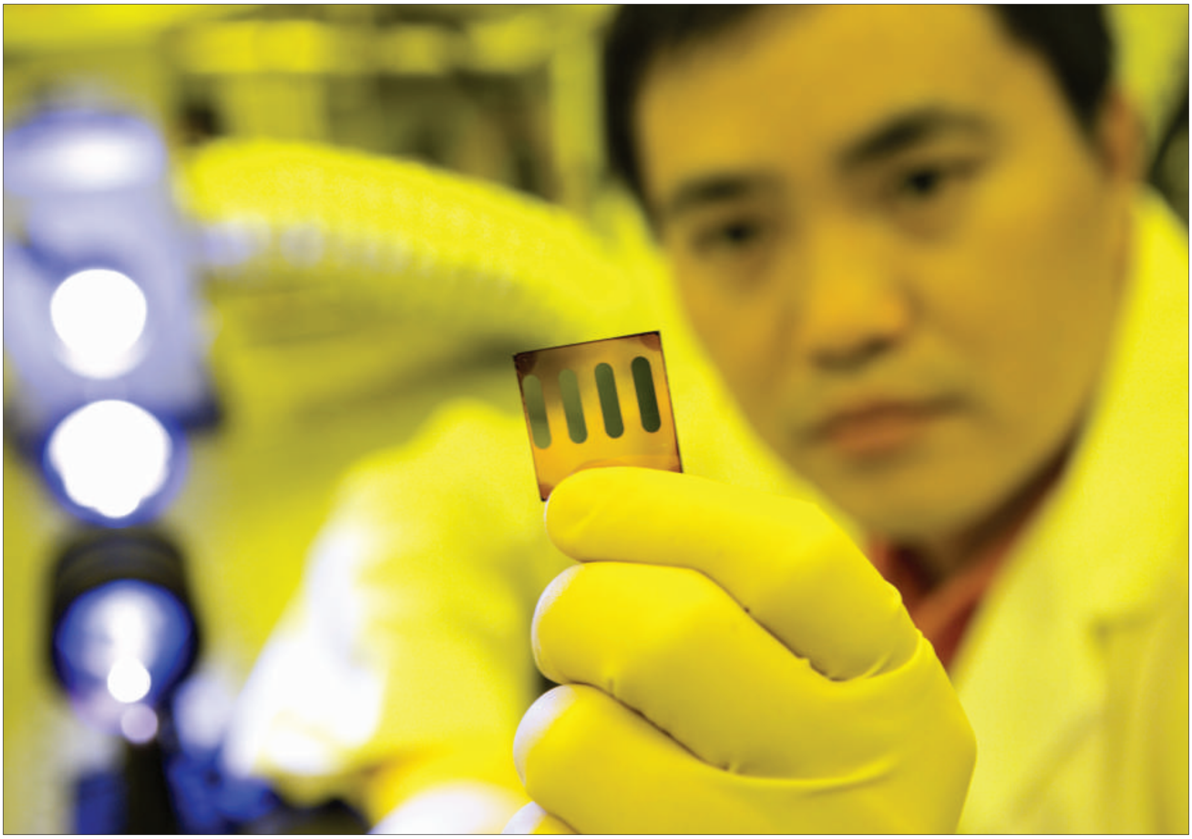

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Research Article
Physicochemical Characteristics of Oil Spill Impacted Agricultural Soils in Three Areas of the Niger Delta

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Abstract

Background and Objective: Oil spillage on agricultural soil in the Niger Delta area of Nigeria is a serious threat to agricultural production and food security. This study was carried out to determine the effects of oil spillage on the physicochemical parameters of agricultural soils at 3 locations (Eleme, Ahoada and Oyigbo) in close proximity to oil production sites. **Materials and Methods:** Five oil spillage sites were selected from each of the locations and three non-spillage sites served as control. A total of 72 triplicate samples were collected from both spillage and control sites at 3 depth (0-15, 15-30 and 35-45 cm). Physicochemical parameters were analyzed using standard methods. **Results:** Results revealed that mean electrical conductivity (EC), chloride, total nitrogen (TN), nitrate, total phosphorus (TP), available phosphorus (AP) and cation exchange capacity (CEC) values were significantly higher ($p<0.05$) in the control samples than in the spillage samples. Sulphate, total organic carbon (TOC) and oil and grease (O and G) concentrations were significantly higher ($p<0.05$) in spillage site samples than in control samples. Mean values for pH, EC, chloride, TN, nitrate, TP, AP and CEC decreased with depth while values for sulphate, TOC and O and G increased with depth. **Conclusion:** Oil and grease levels revealed high hydrocarbon pollution of the spillage sites and agricultural soil of Eleme LGA was impacted more than those of Ahoada and Oyigbo areas.

Key words: Eleme, ahoada, oyigbo, oil spillage, physicochemical

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Oil spills are one of the most widespread forms of pollution on agricultural lands and water bodies in Nigeria propelled by increasing demand for energy. Sustainable use of agricultural soil on which plants depend is absolutely necessary for agricultural productivity. Soil is the most valuable component of the farming ecosystem and environmental sustainability largely depends on proper soil management[1]. Osuocha *et al*.[2] reported that soil represents a dynamic system in which continuous interaction takes place between soil minerals, organic matter and organisms that influence physicochemical and biological properties of terrestrial systems. Crude oil is a complex mixture of various organic compounds including hundreds of aliphatic and aromatic hydrocarbons and trace amounts of heavy metals which are mostly toxic to biota[3]. Oil spill is the accidental or intentional release of liquid petroleum hydrocarbons into the environment as a result of human activity[4]. In the Niger Delta area of Nigeria, the common sources of soil contamination are crude oil spillage, industrial effluents, agricultural wastes and gas flaring. Soil and water contamination by crude oil is a very sensitive issue since the impact is known to be disastrous[5]. Petroleum hydrocarbons negatively impact the germination and growth of plants in soils by creating conditions which make essential nutrients unavailable for plant growth[6,7]. There is a direct need to address soil contamination by oil spillage in order to minimize its harmful effects on the ecosystem, conserve nature and sustain livelihoods. The aim of this study was to determine the effects of oil spillage on physicochemical parameters [pH, electrical conductivity, sulphate, chloride, nitrate, total phosphorus, available phosphorus, total nitrogen, nitrate, exchangeable bases (Ca, Mg, K, Na), organic carbon, cation exchange capacity, oil and grease] of agricultural soil in Eleme, Ahoada and Oyigbo areas of the Niger Delta.

MATERIALS AND METHODS

Study areas: The study was carried out at Chemistry Department Laboratory, Michael Okpara University of Agriculture, Umudike and BGI Laboratories, Port Harcourt between November, 2018 and April, 2019.

Ahoada Local Government Area (LGA) is in the Orashi region of Rivers State, northwest of Port Harcourt City. It consists of two Local Government Areas, Ahoada East and Ahoada West. Ahoada is located on the Latitude 5° 07′01″ and 5°4′26″N and Longitude 6°39′12″ and 6°65′01″E with a population of about 12,848[8]. Their major occupation is farming and fishing. Eleme LGA is located on latitude 4°47' 14.7" N and Longitude 7°8' 37.3" E with an elevation of 21 m. It is part of the greater Port Harcourt metropolitan area with[8] a population of 190,884. The primary occupation of the people is agriculture. Oyigbo LGA (also known as Obigbo) is about 30 km from the Port Harcourt City and is located on Latitude: 4°52' 24.59" N and Longitude: 7°07' 25.20" E. It has a population[8] of 125,331 whose major occupation is agriculture.

Table 1: Sampling points coordinates

L.G.A	Location/Sampling points	East	North
Eleme	Site A	7° 6'30.56" E	4°47'20.62" N
	Site B	7° 6'54.37" E	4°46'3.32" N
	Site C	7°10'54.62" E	4°47'20.49" N
	Site D	7° 9'1.91" E	4°48'47.89" N
	Site E	7°12'24.29" E	4°46'25.23" N
	CTRL 1	7°9'12.77" E	4°48'39.97" N
	CTRL 2	7°10'5.84" E	4°43'39.24" N
	CTRL 3	7°12'24.83" E	4°44'27.26" N
Oyigbo	Site A	7°10'5.65" E	4°51'44.22" N
	Site B	7°15'19.00" E	4°50'51.98" N
	Site C	7°15'19.00" E	4°50'51.98" N
	Site D	7°19'40.28" E	4°49'32.00" N
	Site E	7°8'7.56" E	4°51'13.28" N
	CTRL 1	7°17'53.36" E	4°47'8.99" N
	CTRL 2	7°8'39.92" E	4°54'5.96" N
	CTRL 3	7°14'10.97" E	4°49'17.88" N
Ahoada	Site A	6°33'33.30" E	5°10'16.57" N
	Site B	6°28'25.90" E	5°6'12.80" N
	Site C	6°31'11.65" E	4°58'53.97" N
	Site D	6°27'39.67" E	5°3'14.60" N
	Site E	6°34'57.60" E	5°9'23.93" N
	CTRL1	6°25'27.12" E	5°1'23.15" N
	CTRL2	6°32'21.57" E	5°3'37.09" N
	CTRL 3	6°30'7.63" E	5°8'42.87" N

L.G.A: Local government area

Sampling and sample pre-treatment: The methodology for the sampling was in accordance with DPR Environmental Guidelines and Standards for the Petroleum Industry in Nigeria, EGASPIN[9]. The sampling points were located at 5 oil spilled sites (A, B, C, D and E) and three control sites (1, 2 and 3, located 2 km away from the spilled sites) in each areas at depths of 0-15 (topsoil), 15-30 (subsoil) and 30-45 cm (sub-sub soil). The GPS coordinates of the sampling points are shown in Table 1. Sample collection was done with a hand-held auger and 200 g of each sample was collected at each sampling point. A total of 72 composited samples were collected from the 24 sampling sites (15 stations and 9 controls) in each LGA. Extraneous materials were removed from soil samples and they were air-dried. Samples for hydrocarbon were collected wet and marched with anhydrous sodium hydroxide to absorb water before analysis. The air-dried samples were grounded into fine powder with acid washed plastic mortar and pestle and were further divided into 2 portions and passed separately, through 2 and 0.2 mm sieves. The 2 mm samples were used for the determination of pH, EC, total nitrogen, nitrate, total phosphorus, available phosphorus, sulphate, chloride, cation exchange capacity, exchangeable bases while 0.2 mm samples were used for organic carbon and organic matter analysis.

Quality assurance: Analytical grade reagents and chemicals were used for this study and all digestion and analyses were done in triplicate. Procedural and reagent blanks were used and a clean laboratory environment was ensured during the analyses and preparation of solutions. In addition, glassware, plastic containers, crucibles, pestle and mortar was washed with liquid soap, rinsed with distilled water and then soaked in 10% HNO_3 solution for 24 h and dried in a drying oven at 80°C for 5 h.

Physicochemical analysis of soil samples: Soil pH was determined with a pre-calibrated pH meter[10] while electrical conductivity was determined by shaking 5 g of air dried sample in 50 mL of distilled water, filtering, adding 2 drops of 0.1% $(NaPO_3)_6$, inserting the probe of a conductivity meter and taking the reading[11,12] in μS cm^{-1}. Chloride was determined with the argentometric method, total nitrogen (TN) in the samples was analyzed with the Kjeldahl method while nitrate was analysed with the sulphamic acid method[11,12]. Total phosphorus was determined using HNO_3 digestion and spectrophotometric method[11] and available phosphorus with the Bray-1 method[13]. Organic carbon was analyzed with the wet-acid oxidation method[14] while organic matter (OM) was determined by oxidation of 1 g of oven-dried sample with 50% H_2O_2 solution and ignition in a muffle furnace[12,15]. Sulphate was determined with the Turbidimetric method which involved reading of absorbance at 420 nm with UV-visible spectrophotometer. Oil/grease was determined with the API RP-45 method which included reading oil and grease content with Infracal 2 oil in water/soil Analyzer which was initially blanked with the extracting solvent. Total exchangeable bases (K, Na, Ca and Mg) were determined by the ammonium acetate (NH_4AOC) extraction method[16] and cation exchange capacity CEC in meq/100 g was calculated as:

$$\Sigma C_{Ex}/\text{equiv.wt}\ (C_{Ex} = \text{concentration of the exchangeable bases})$$

Statistical analysis: Statistical analysis was done using the SPSS (version 21.0) for windows software package. Mean concentrations and standard deviations were calculated for each parameter. The results were also subjected to analysis of variance (ANOVA) and means were compared using Duncan multiple range test.

RESULTS

Physicochemical parameters of the samples from Eleme LGA: Ranges and mean values for the physicochemical parameters of the samples from Eleme LGA are shown in Table 2. There was a slight but insignificant variation ($p>0.05$) of mean soil pH across the sites but mean electrical conductivity (EC) and chloride concentration in the soil samples from the spillage sites were significantly lower ($p<0.05$) compared to the control sites samples.

Total nitrogen (TN) concentrations ranged from 0.21-1.25% (mean, 0.52±0.41%), 0.14-0.67% (mean, 0.34±0.19%) and 0.07-0.36% (mean, 0.22±0.10%) at the 0-15, 15-30 and 30-45 cm depths respectively. The control points had ranges of 0.46-0.69% (mean, 0.57±0.10), 0.44-0.56% (mean, 0.48±0.05) and 0.34-0.46% (mean, 0.40±0.04%) at depths of 0-15, 15-30 and 30-45 cm, respectively. For mean nitrate concentrations, values obtained at the control points were significantly higher ($p<0.05$) than those of the spillage sites and mean concentrations decreased as the depth increased.

Mean values obtained for CEC, chloride, total phosphorus (TP) and available phosphorus (AP) followed a similar pattern since concentrations in samples collected at the control sites were significantly higher ($p<0.05$) than in samples from the spillage sites. Mean sulphate concentrations in spillage site soils were 80.70±17.54, 87.89±19.57 and 97.99±14.89 mg kg^{-1} at depths of 0-15, 15-30 and 30-45 cm, respectively. However, the control points recorded significantly lower ($P<0.05$) mean concentrations of 9.22±2.90, 12.08±1.50 and 14.03±1.49 mg kg^{-1} at the same depths, respectively. This same scenario was observed for total organic carbon (TOC) and oil and grease (O and G) where significantly higher ($p<0.05$) concentrations were recorded in spillage samples as against control samples. Mean values for pH, EC, chloride, TN, nitrate, TP, AP and CEC decreased with depth while those of sulphate, TOC and O and G increased with depth.

Physicochemical parameters of the samples from Ahoada LGA: Table 3 shows the ranges and mean values for the physicochemical parameters of the samples from Ahoada LGA. There were no significant differences ($p<0.05$) in pH between

Table 2: Mean±SD physicochemical parameters of soil from Eleme LGA

		Spillage sites		Control sites	
Parameters	Depth (cm)	Range	Mean	Range	Mean
pH	0-15	5.65-6.92	6.13±0.41	6.51-6.99	6.73±0.46
	15-30	5.21-6.41	5.83±0.45	6.37-6.68	6.56±0.16
	30-45	5.10-5.87	5.50±0.21	5.54-6.66	6.22±0.46
EC (µS cm^{-1})	0-15	55.00-97.00	78.61±17.94	110.0-135.3	123.11±11.04
	15-30	45.00-92.00	73.70±17.33	97.00-136.0	117.40±15.95
	30-45	43.0-85.00	61.70±11.72	89.00-125.00	106.22±12.04
Chloride (mg kg^{-1})	0-15	10.98-53.60	28.50±14.58	54.74-68.00	61.94±6.05
	15-30	10.66-46.75	25.24±13.07	45.00-63.00	53.80±7.01
	30-45	7.90-45.36	21.47±12.62	40.00-52.00	47.00±5.15
Total nitrogen (%)	0-15	0.21-1.25	0.52±0.41	0.46-0.69	0.57±0.10
	15-30	0.14-0.67	0.34±0.19	0.44-0.56	0.48±0.05
	30-45	0.07-0.36	0.22±0.10	0.34-0.46	0.40±0.04
Nitrate (mg kg^{-1})	0-15	0.05-0.09	0.07±0.02	0.25-0.40	0.31±0.07
	15-30	0.03-0.06	0.04±0.01	0.16-0.29	0.22±0.06
	30-45	0.02-0.05	0.03±0.01	0.12-0.16	0.14±0.01
Sulphate (mg kg^{-1})	0-15	55.60-99.40	80.70±17.54	5.65-12.28	9.22±2.90
	15-30	62.12-112.32	87.89±19.57	10.00-13.65	12.08±1.50
	30-45	75.56-113.20	97.99±14.89	12.20-15.70	14.03±1.49
Total phosphorus (mg kg^{-1})	0-15	3.56-8.30	6.86±1.75	11.85-16.26	14.47±2.08
	15-30	2.55-6.65	5.49±1.58	9.65-14.65	12.55±2.22
	30-45	1.54-6.32	4.08±1.59	8.65-12.65	10.58±1.65
Available phosphorus (mg kg^{-1})	0-15	0.53-3.54	2.20±1.12	5.14-8.16	7.13±1.49
	15-30	0.33-2.09	1.25±0.62	3.56-6.69	5.28±1.37
	30-45	0.07-1.10	0.67±0.37	3.10-5.15	4.27±0.90
CEC (meq/100 g)	0-15	0.11-0.17	0.14±0.02	0.34-0.39	0.37±0.02
	15-30	0.07-0.13	0.11±0.02	0.27-0.34	0.31±0.03
	30-45	0.04-0.10	0.08±0.02	0.24-0.31	0.27±0.03
TOC (%)	0-15	1.72-3.35	2.39±0.82	0.08-0.16	0.10±0.04
	15-30	1.79-3.51	2.62±0.73	0.16-0.39	0.26±0.10
	30-45	2.18-3.59	2.89±0.61	0.23-0.55	0.42±0.14
Oil and grease (mg kg^{-1})	0-15	10716.75-16011.00	13331.03±2202.49	BDL	BDL
	15-30	11173.50-16900.88	13696.43±2313.16	BDL	BDL
	30-45	11386.13-149988.38	41184.00±56365.84	BDL	BDL

BDL: Below detection limit, TOC: Total organic carbon

spillage and control site samples. Just as was observed for samples from Eleme LGA, mean EC, chloride, TN, nitrate, TP, AP and CEC were significantly higher ($p<0.05$) in the control samples than in the spillage samples. However, sulphate, TOC and O and G concentrations were significantly higher ($p<0.05$) in spillage site samples than in control samples. O and G levels were the below detection limit (BDL) of the instrument in control samples. While mean values for pH, EC, chloride, TN, nitrate, TP, AP and CEC decreased with depth, those of sulphate, TOC and O and G increased with depth.

Physicochemical parameters of the samples from Oyigbo LGA: Ranges and mean values for the physicochemical parameters of the samples from Oyigbo LGA are shown in Table 4. A similar profile for mean values of physicochemical parameters observed in Eleme and Ahoada LGAs were also recorded in Oyigbo spillage site samples in comparison with control site samples. However, mean TN did not decrease with depth in Oyigbo samples as observed in samples from Eleme and Ahoada LGAs.

Oil and grease concentrations: O and G concentrations were below detection limit in all control site samples in the 3 areas but had the following mean values for spillage sites at 0-15, 15-30 and 30-45 cm depths: 13331.03±2202.49, 13696.43±2313.16 and 41184.00±56365.84 (Eleme), 11032.88±4690.12, 12230.78±4682.63 and 12915.45±4673.86 (Ahoada), 4917.83±2864.24, 5260.28±3037.26 and 6517.13±4124.18 (Oyigbo) presented in Table 2 and 3, respectively. Values for Eleme samples were significantly higher ($p<0.05$) than in samples from Ahoada and Oyigbo.

Exchangeable bases: Mean values for calcium concentration in Eleme were 15.26±3.52, 12.44±3.54 and 9.24±3.83 mg kg^{-1} at depths of 0-15 cm, 15-30 cm and 30-45 cm respectively in the spillage sites while at the control points, mean concentrations were 37.81±2.73, 32.70±5.32 and 29.99±5.95 mg kg^{-1} at the same depths, respectively. The mean concentrations across the depths were significantly higher ($p<0.05$) in control samples. The same profile for mean

Table 3: Mean±SD physicochemical parameters of soil from Ahoada LGA

Parameters	Depth (cm)	Spillage sites		Control sites	
		Range	Mean	Range	Mean
pH	0-15	5.96-6.65	6.21±0.25	5.35-6.69	6.24±0.53
	15-30	5.54-6.12	5.88±0.23	5.34-6.69	5.97±0.52
	30-45	5.23-5.98	5.54±0.18	5.32-6.31	5.67±0.35
EC (μS cm^{-1})	0-15	44.00-66.00	54.73±8.88	86.00-156.00	132.22±33.24
	15-30	35.00-63.00	48.67±10.69	75.00-145.00	115.56±29.87
	30-45	30.00-54.00	41.87±8.73	65.00-125.00	98.00±25.07
Chloride (mg kg^{-1})	0-15	16.00-35.00	25.07±6.73	42.00-65.00	55.89±9.91
	15-30	14.00-32.00	22.07±6.42	38.00-59.00	48.44±8.82
	30-45	12.00-26.00	19.40±5.29	33.00-48.00	41.22±5.91
Total nitrogen (%)	0-15	0.05-0.23	0.12±0.07	0.44-0.70	0.58±0.11
	15-30	0.02-0.25	0.09±0.09	0.41-0.66	0.51±0.08
	30-45	0.02-0.19	0.07±0.06	0.39-0.54	0.47±0.07
Nitrate (mg kg^{-1})	0-15	0.03-0.07	0.05±0.01	0.27-0.48	0.36±0.09
	15-30	0.01-0.05	0.03±0.01	0.21-0.36	0.26±0.07
	30-45	0.01-0.04	0.02±0.01	0.10-0.27	0.17±0.07
Sulphate (mg kg^{-1})	0-15	36.65-62.60	52.34±9.02	8.80-13.00	10.56±1.75
	15-30	40.00-67.67	57.89±10.67	10.26-14.56	12.34±1.86
	30-45	45.50-72.23	63.82±10.46	12.30-16.20	14.33±1.64
Total phosphorus (mg kg^{-1})	0-15	4.32-6.65	5.27±0.87	9.87-16.66	13.57±2.89
	15-30	2.14-3.65	3.22±0.54	7.23-14.23	11.23±3.12
	30-45	1.23-2.22	1.72±0.41	5.59-10.32	8.71±2.16
Available phosphorus (mg kg^{-1})	0-15	0.16-2.60	1.42±0.86	5.56-9.91	7.43±1.70
	15-30	0.34-0.99	0.63±0.27	3.98-8.10	5.98±1.77
	30-45	0.12-0.36	0.22±0.09	2.87-5.96	4.42±1.33
CEC (meq/100 g)	0-15	0.05-0.10	0.08±0.02	0.23-0.40	0.32±0.08
	15-30	0.03-0.07	0.06±0.01	0.20-0.35	0.28±0.07
	30-45	0.02-0.04	0.03±0.01	0.16-0.31	0.25±0.06
TOC (%)	0-15	2.57-6.24	3.92±1.30	0.08-0.39	0.23±0.14
	15-30	2.73-7.02	4.23±1.54	0.16-1.01	0.52±0.38
	30-45	2.80-7.25	4.48±1.57	0.31-1.94	0.93±0.76
Oil and grease (mg kg^{-1})	0-15	5735.25-17590.5	11032.88±4690.12	BDL	BDL
	15-30	6986.25-18738.00	12230.78±4682.63	BDL	BDL
	30-45	7440.75-19138.5	12915.45±4673.86	BDL	BDL

BDL: Below detection limit, TOC: Total organic carbon

concentrations were observed for magnesium, sodium and potassium where control site samples had significantly higher ($p<0.05$) values than those of spillage site samples. Mean concentrations of exchangeable bases in samples from spillage and control sites in Ahoada and Oyigbo followed a similar pattern as observed in samples from Eleme.

DISCUSSION

The mean pH results showed that samples across both study and control sites were slightly acidic, which is typical of the soils in the southern part of Nigeria. This is ascribed to excessive precipitation leading to leaching losses of most basic cations in the soil[17].

The Electrical conductivity (EC) of soil expresses its total ionic strength and low total ionic strength of a soil solution indicates low dissolved salt contents and vice-versa. It is not likely that the spilled oil was directly responsible for the higher mean EC values in spillage site soil since crude oil does not conduct electricity very well. However, it is possible that the anoxic biodegradation mechanism through direct dehydrogenation allowed the anaerobic metabolism of hydrocarbons in the presence of electron acceptors and this may be partially responsible for the differences in EC. Mean EC, chloride, TN, nitrate, TP, AP and CEC were significantly higher ($p<0.05$) in the control samples than in the spillage samples. However, sulphate, TOC and O and G concentrations were significantly higher ($p<0.05$) in spillage site samples than in control samples. Chloride concentrations were generally higher in control samples. Being an anion, it is fully mobile except where held by soil anion exchange sites (clay, iron and aluminium oxide). Chloride in soil affects plant nutrients and is absorbed in large quantity by most crops than other macronutrients except iron.

Nitrate and ammonium are the predominant inorganic forms of nitrogen in the soils. Plants use nitrogen only in the

Table 4: Mean±SD physicochemical parameters of soil from Oyigbo LGA

Parameters	Depth (cm)	Spillage sites Range	Spillage sites Mean	Control sites Range	Control sites Mean
pH	0-15	5.56-6.80	6.13±0.47	4.98-7.23	6.28±0.84
	15-30	5.43-6.45	5.81±0.38	5.10-6.69	5.94±0.64
	30-45	4.98-6.50	5.49±0.47	4.98-6.35	5.66±0.41
EC (μS cm^{-1})	0-15	32.00-87.00	60.47±19.02	99.00-139.00	116.56±12.90
	15-30	30.00-80.00	54.33±17.39	96.00-126.00	110.56±11.94
	30-45	29.00-51.00	41.27±7.12	88.00-107.00	97.33±6.76
Chloride (mg kg^{-1})	0-15	10.00-35.00	22.67±8.15	35.00-52.00	43.89±7.00
	15-30	8.00-28.00	18.67±6.80	30.00-42.00	36.56±4.25
	30-45	8.00-20.00	14.67±4.05	28.00-39.00	33.89±4.22
Total nitrogen (%)	0-15	0.02-0.087	0.04±0.02	0.40-0.47	0.44±0.03
	15-30	0.02-0.07	0.04±0.02	0.39-0.46	0.41±0.03
	30-45	0.01-0.04	0.02±0.01	0.35-0.56	0.44±0.90
Nitrate (mg kg^{-1})	0-15	0.01-0.06	0.03±0.02	0.10-0.56	0.38±0.21
	15-30	0.004-0.04	0.02±0.01	0.09-0.35	0.26±0.13
	30-45	0.002-0.03	0.01±0.01	0.08-0.26	0.16±0.08
Sulphate (mg kg^{-1})	0-15	35.60-52.23	42.00±6.34	6.60-12.30	9.68±2.36
	15-30	38.80-55.70	45.02±5.97	8.30-13.20	11.21±2.22
	30-45	40.26-56.60	47.81±5.59	10.20-14.40	12.56±1.83
Total phosphorus (mg kg^{-1})	0-15	1.25-8.45	5.80±2.71	14.35-20.36	17.67±2.63
	15-30	0.69-6.69	3.51±2.10	12.24-16.65	14.72±1.92
	30-45	0.45-4.44	2.55±1.62	10.21-13.60	12.01±1.43
Available phosphorus (mg kg^{-1})	0-15	0.13-3.98	2.28±1.31	7.15-11.56	9.43±1.88
	15-30	0.10-2.10	1.11±0.71	6.23-9.15	7.64±1.27
	30-45	0.04-1.12	0.56±0.40	5.13-6.87	5.98±0.75
CEC (meq/100 g)	0-15	0.03-0.07	0.05±0.01	0.16-0.27	0.22±0.05
	15-30	0.02-0.05	0.03±0.01	0.13-0.21	0.17±0.03
	30-45	0.01-0.04	0.03±0.01	0.11-0.17	0.14±0.02
TOC (%)	0-15	1.79-4.52	2.93±0.92	0.08-047	0.21±0.20
	15-30	2.26-4.68	3.15±0.84	0.16-0.62	0.31±0.23
	30-45	2.81-5.07	3.51±0.83	0.23-0.70	0.42±0.22
Oil and grease (mg kg^{-1})	0-15	699.75-7481.25	4917.83±2864.24	BDL	BDL
	15-30	752.63-8122.50	5260.28±3037.26	BDL	BDL
	30-45	776.25-11283.75	6517.13±4124.18	BDL	BDL

BDL: Below detection limit, TOC: Total organic carbon

ammonium and nitrate forms. The decrease in total nitrogen and nitrate concentrations in the spillage sites may be due to high drainage of oil into the lower horizon of the soil causing aeration problem as air pores are blocked with oil, preventing easy flow of nutrients to the soil[18]. This reduction in contaminated soil is an indication that the nitrification process has reduced following the incidence of oil spillage[19].

Phosphorus is found in the soil in both organic and inorganic forms and its solubility in soil is low compared with the total amount of phosphorus in the soil. Mean total phosphorus values obtained in soils of this study areas could be termed agricultural limitations due to adsorption, precipitation and conversion to organic forms. About 80% of available phosphorus becomes immobile and unavailable for plant uptake.

Plants absorb sulphur in sulphate form and soil sulphate may originate from atmospheric deposition, fertilizer addition or mineralization of soil organic sulfur, which is the main sulfur fraction. The mean concentrations of sulphate from the spillage sites were by far, higher than those of the control sites. This is due to the amount of sulphur in crude oil which is oxidized to sulphate.

Cation exchange capacity, CEC is the total capacity of soil to hold exchangeable cations. It is a very important soil property influencing soil structure stability, nutrient availability, soil pH and soils reaction to fertilizers[20]. Clay minerals and organic components of soil have negatively charged sites on the surfaces which adsorb and hold positively charged ions (cations) by electrostatic force. This electrical charge is critical to the supply of nutrient to plants because many nutrients exist as cations (magnesium, calcium and potassium). Soil with large quantities of negative charges are more fertile because they retain more cations[21]. However, productive crops and pastures can be grown on low CEC soils. Generally, the CEC values obtained in this study were low. Higher CEC soils generally have greater water holding capacity[22]. Soils with low CEC are more likely to develop deficiencies in potassium, magnesium and other cations while high CEC soils are less susceptible to leaching of these cations[23].

Total organic carbon (TOC) is the carbon stored in soil organic matter (SOM). Organic carbon (OC) enters the soil through the decomposition of plant and animal residues, root exudates, living and dead microorganisms and soil biota. Expectedly, TOC was higher in spillage samples compared to control samples and there was increase in TOC with increase in depth, indicating percolation of oil down the soil horizon. Oil and Grease captures the amount of oil contained by the soil and it was exponentially higher in spillage samples as expected. The levels of O and G makes the soils in the spillage sites unfit for crop farming.

There is a significant variation in the mean concentrations of exchangeable cations across depths and sites in both sites. This may be due to blockages of the exchange sites by hydrocarbon residues[24]. Calcium dominated the exchange complex in all the samples which is an indication of tropical weathered soil and is further confirmed by a calcium/ magnesium ratio greater than unity[25].

The foregoing results show that the soils in the three areas have been heavily impacted by oil spill and cannot be used for crop farming without effective remediation.

CONCLUSION

Oil spillage leads to the release of pollutants into the environment resulting in the destruction of vegetation and pollution of underground water, thereby affecting agricultural production and sustenance of people's livelihood. Oil spill impacted more on agricultural soil of Eleme LGA compared to Ahoada and Oyigbo areas. Oil and grease levels revealed high hydrocarbon pollution of the spillage sites which rendered the affected soils unsuitable for crop farming. Timely intervention of oil companies, governments at all levels and regulatory agencies is needed to restore the impacted sites to a state that the can be used for crop farming.

SIGNIFICANCE STATEMENT

This study discovered high hydrocarbon pollution of the spillage sites. Agricultural soil at the sites in Eleme LGA were impacted more than the sites in Ahoada and Oyigbo areas. This study provides baseline information for remediation efforts and future research in oil and gas pollution in the three LGAs. It will help the researchers to adequately plan a proposed future comparative research on the use of nanomaterials for the removal of hydrocarbons from contaminated soil in the 3 areas.

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