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Assessment of Soil Physico-Chemical Properties in a Selected Oil Spill Environment of Nigeria

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ABSTRACT
Background and Objective: The increase in soil pollution problems with reported cases of oil spills draws significant attention that must be addressed in most oil-reaching communities in Nigeria. This study considers the assessment of soil properties in some selected oil spill environments in Ilaje Local Government Area, Ondo State, Nigeria. **Materials and Methods:** Four sample sites of oil spills (Ugbo, Etikan and Aheri) and non-polluted adjacent fields (Mahin) were selected for the study. Forty composite soil samples were collected from a pre-determined depth of 0-30 cm of the soil profile. Soil properties examined include particle size distribution, bulk density, water holding capacity, soil organic matter, pH, $Ca^{2+,}$ Mg^{2+} K^{+} Na^{+}, CEC, base saturation, total hydrocarbon, oil and grease, available phosphorus and total nitrogen. Co-efficient of variation and correlation analysis techniques determined variability and relationship among soil properties. **Results:** The study reveals that, silt and clay contents have over 25% of the textural composition with the homogeneous spread of soil in the study area. The polluted soils have low water holding capacity, acidic values between 4.14 and 4.79 and low nutrient cations, with extreme variabilities of silt, Mg^{2+}, H^{+}, SOM, Ca^{2+}, K^{+}, Na^{+}, oil and grease. **Conclusion:** However, a significant concentration of soil nutrients at the control site was recorded. With the trends of spills and impacts on soils in the study area, this study recommends urgent efforts in averting further spill occurrence to ensure soil protection and revitalization.

KEYWORDS
Oil spill, physico-chemical, soil pollution, soil properties, oil spill environment, soil micro-nutrients, composite soil

INTRODUCTION

Ilaje communities in Ondo State is one of the oil-producing locations in Nigeria There are recorded cases of oil spills, which involved loss of farmlands in most cases. Soil pollution is one of the observed problems associated with spills. Though, it has been established that oil spillage is one of the age-long disastrous phenomena bedevilling the growth and development of most oil-reaching communities in Nigeria. However, the recent increasing level of soil pollution in the study area is a great concern and calls for an investigation. Ilaje Local Government Area in Ondo State is a region well known for oil exploration activities with over 1000 production oil wells and over 47,000 km of oil and gas flow lines[1]. In another study, it was noted that oil spillage incidents could have negative consequences on vegetation and soil through the ingestion and absorption of harmful petrochemical substances that can affect the growth of plants[2].

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Also, the changing nature of soil as relates to many other biochemical factors calls for a reassessment of soil's Physico-chemical composition because of its current status. Researchers have studied trends in oil spills over the years in the study area[3]. The negative effects of oil activities in the region are enormous as it usually destroys wildlife, loss of fertile soil, pollution of air and water and damage to the ecosystem of the host communities. Among all other components of the environment, the soil is directly affected by the oil spill and impacts are enormous on the cropping system and food production. It is imperative to examine the extent of soil pollution by spills and assess the Physico-chemical components of soil to identify affected soil nutrients towards suggested ways of soil protection and revitalization for sustainable national development.

It was further noted that oil spillage, through leakage from oil pipelines with gas flaring has taken an ugly toll on the social and economic lives of the people of the region[4]. Apart from soil pollution where oils that are denser than water might reduce and restrict soil permeability[5], effects of the oil spill could include poverty and deprivation, environmental abuse and degradation, which have threatened the survival of the people in the oil-bearing region. As a consequence, the people have over the years engaged in different forms of agitations and conflicts, to attract the attention of the government for development and socio-economic emancipation project.

As it has been spelt out from the foregoing, it should be noted that cases of environmental degradation being threatened as a result of these elicit activities of the oil spill have resulted in a serious loss of agricultural lands, food crops, plants and soil fertility in the area call for more urgent attention. This study is essential because of the general nature of soils of which their formation changes both in space and time. It is adequate to note that there are devastating effects of spills on soil in terms of soil fertility changes and the extent of changes is the focus of this study.

MATERIALS AND METHODS

Study area: The Ilaje Local Government Area, Ondo State, Nigeria is the study area. It is located within the Niger Delta region of Nigeria between latitude 6°00'N and 6°20'N and longitude 4°45°E and 5°45'E. The study was carried out at the Department of Agronomy, Faculty of Agriculture, University of Ilorin, Nigeria from January, 2021 to February, 2022.

The period of the rainy season is usually longer than the dry season with an annual rainfall of 2500 mm between April and November of each year. The trees grow rapidly in the rainy season, shed their leaves during the hot/dry season and remain comparatively inactive in the warm season. The regular shedding of leaves has given a distinctive soil type in the study area. The distinctiveness of soil in this area lies in categorized soil zones, which include, the zone of coastal beaches along the coastline of lowland sandy plains of light grey sandy soil. The soil is very porous and forms the most dominant soil in the entire area. The zone of hydomorphic and organic soils covers the depressions, which are muddy and change into the swampy waterlogged group along the coast. The third zone is the reddish and brown loamy soils of the upland areas. This soil type was derived from deeply weathered quartzite and sandstone formations.

The dynamic nature of the study area is known for its various economic activities in support of human livelihood. Fishing constituted the mainstay of the local economy as a result of the availability of numerous rivers, creeks and lagoons where fishes were caught in abundance. Fishing remains the primary occupation and means of sustenance of the people, even after the emergence and subsequent dominance of the hydrocarbon industry. Manufacturing activities (local craft) were in the form of weaving of mat, canoe and boat building and production. Trading activities involve the selling of fish and woven materials within and outside the area, while the cultivation of food crops and palm tree plantations form major parts of farming activities.

Methods: The primary data for this study were soil samples from both the oil field and the adjacent site. The dominant oil spill communities (Ugbo, Etikan and Aheri) were selected using the purposive sampling technique. However, the Mahin community was selected as the control site. Seven (7) transients each measuring 15×15 m were demarcated and systematically selected on the three polluted and non-polluted sites, respectively. A composite sample was prepared from a pre-determined depth of 0-30 cm of the soil profile. The soil depth for samples was considered adequate because this is where the bulk of plant nutrients is concentrated. A total of 40 soil samples were collected in polyethene bags and air-dried to conform to the laboratory test procedure. Particle size distribution, bulk density, water holding capacity, soil organic matter (SOM), pH, Ca^{2+}, Mg^{2+} K^{+}, Na^{+}, CEC, base saturation, potassium, total hydrocarbon, oil and grease (OG), available phosphorus, total nitrogen were examined. Co-efficient of variation (CV) was used to establish variation in the characteristics of soil properties of polluted and control sites. The correlation analysis technique was used to determine the relationship among soil properties.

RESULTS AND DISCUSSION

Physical properties of the soils: The particle size of any soil (the proportion of sand, silt and clay) is a very important and permanent feature of any soil type because plants have no control over it. In some cases, the proportion of each of these particles serves as an indicator of the fertility level of the soil. The proportions of sand, silt and clay particles in the control site and the three polluted sites are shown in Table 1. The overall contents of sand for the polluted site were shown with mean values that ranged between 47.9 and 65.7, while the mean values for silt and clay were between 10.8 and 14.9 and 22.9 and 37.3, respectively. The study reveals that silt and clay content accounts for more than 25% of the textural composition of the soil in the study area. This is an indication that the bulk of the soil is sand. It was however observed that an increasing percentage of sand content in soils is a result of probable high drainage of oil[6].

It was revealed in Table 1 that sand, silt and clay are homogeneous in both the control site and the polluted sites. The coefficient of variation statistics shows the highest percentage of sand, silt and clay with 11.2, 7.6 and 9.9%, respectively. The C.V. results are generally less than 33% and particle distribution of soil has a homogenous spread. The relative homogeneous nature and characteristics of the soil parent material in the study area might be the reason for the results.

The study equally indicates a similar spatial pattern of homogeneous distribution for the bulk density and water holding capacity of soils among the sampled locations. However, the mean values of the water holding capacity (27.76) of the adjacent soil sample are higher than those of locations affected by an oil spill. The mean values for water holding capacity for oil-affected locations range between 5.6 and 5.7. The capacity of soil to hold water is poor in Ugbo, Etikan and Aheri due to the activities of oil spillage. However, the active presence of soil organic matter could be responsible for soil capacity to absorb water in the control site for plant growth. The water holding capacity is an essential property of soil because it measures the amount of water soil can hold for proper plant growth and development.

Table 1: Mean, coefficient of variation of soil physical properties for control and polluted sites

	Mahin (control site)			Ugbo			Etikan			Aheri		
Soil properties	Mean	STD	CV	Mean	STD	CV	Mean	STD	CV	Mean	STD	CV
Sand (%)	65.70	5.90	8.9	63.3	2.60	4.3	47.9	5.49	11.2	48.7	5.40	10.8
Silt (%)	11.40	0.54	3.3	10.8	0.69	4.4	14.8	1.11	7.6	14.9	0.90	6.1
Clay (%)	22.90	2.15	9.3	25.9	1.70	9.9	37.3	1.11	6.3	36.4	1.11	6.5
BD (mg)	1.70	0.10	4.5	1.6	0.16	10.0	1.6	0.18	12.6	1.4	0.41	2.8
WHC	27.76	1.42	4.9	5.7	0.64	11.6	5.6	0.67	12.1	5.6	0.71	12.9

BD: Bulk Density, WHC: Water holding capacity, CV>33%

Table 2: Mean, coefficient of variation of soil chemical properties for control and polluted sites

	Mahin (control site)			Ugbo			Etikan			Aheri		
Soil properties	Mean	STD	CV	Mean	STD	CV	Mean	STD	CV	Mean	STD	CV
SOM	2.70	0.78	28.80	0.09	0.11	125.0*	0.70	0.78	28.8	0.77	0.02	20.00
pH	5.29	0.58	7.90	4.14	1.09	26.3	4.29	0.58	7.9	4.79	1.07	22.44
Ca^{2+}	3.83	0.50	13.10	0.56	0.58	103.1*	0.83	0.50	13.1	0.52	0.42	81.40*
Mg^{2+}	2.30	0.65	28.90	2.25	0.65	29.0	2.24	0.57	25.2	2.37	0.65	57.00*
K^{+}	1.35	0.13	0.004	0.35	0.13	36.0*	0.29	0.15	50.2*	0.10	000	10.00
Na^{+}	0.15	0.01	7.20	0.35	0.10	67.3*	0.45	0.02	10.2	0.26	0.09	38.00*
CEC	6.15	0.92	14.90	1.15	0.92	14.9	1.43	0.99	15.4	1.36	0.16	12.00
BS	91.89	2.23	7.70	67.89	2.23	7.7	96.01	1.51	1.6	92.10	0.02	7.00
AP	10.32	3.92	9.50	9.32	3.92	9.5	9.23	2.45	14.2	8.29	0.79	15.10
THC	000.00	000	000.00	0.83	0.50	13.1	0.21	0.01	52.4*	21.76	1.77	8.10
Potassium	19.10	2.20	11.50	19.10	2.20	11.5	2.16	1.04	48.0*	1.48	0.43	29.43
TN	0.22	0.04	16.00	0.22	0.04	16.0	0.09	0.06	59.4*	0.50	0.02	50.00*
OG	0.15	0.01	7.20	2.70	0.78	28.8	0.0186	0.01	48.4*	3.12	0.38	12.30

SOM: Soil organic matter, MC: Moisture content, CEC: Cation exchange capacity, BS: Base saturation, AP: Available phosphorus, THC: Total hydrocarbon, TN: Total nitrogen, OG: Oil and grease and *Highly variable CV<33% homogeneous

Chemical properties of the soils: The soil pH is a chemical property that measured the degree of acidity and alkalinity in the soil. The mean value of the pH for the control site is 5.29 (Table 2). The value of the coefficient of variation is 7.9%. This simply depicts that soil is acidic with the homogeneous distribution. The polluted soils of Ugbo, Etikan and Aheri have pH mean values of 4.14, 4.29 and 4.79 with CV values ranging between 7.9 and 26.3. The values of the coefficient of variation show that the pH of the soils is homogeneous in the study area. The range of the pH specified in this study falls strongly acidic. It is worthy of note that soil pH is both a symptom of soil condition and the type of soil chemical reactions occurring in the soil body. In a study, soil pH was compared to the temperature of a patient during medical diagnoses because it readily gives a hint of the soil condition and the expected direction of many soil processes[7]. Generally, soils in the polluted sites have been affected by the oil spill and could not properly support crop growth and development.

Among the micronutrients present in soil are the cations. They are an essential part of the sixteen properties of soil without which green plants cannot grow normally and reproduce. Calcium and Magnesium are the dominant cations in this soil by the mean values of both control sites (3.83 and 2.30 cmol kg^{-1}) and the polluted sites ranged between 0.50 and 2.25 cmol kg^{-1}. The reason for their dominancy could be because both calcium and magnesium, with a valency of 2^{+}, are more strongly bound to soil than potassium and sodium.

Generally, the concentration of nutrient cations is higher in the control site but lower in the polluted sites mainly because of zero impact of the oil spill in the control site. The CV values show that Ugbo (103.1*) has heterogeneous distributions of calcium, while Aheri has both calcium (81.4*) and magnesium (57*) highly varied in the polluted locations. The value of sodium shows an increase in the soil of the oil-spill affected samples of Ugbo, Etikan and Aberi with values of 0.35, 0.45 and 0.26, respectively. This is in contrast to the 0.15 obtained from the control site (Mahin). This higher proportion of sodium in soil, despite its being one of the essential trace elements needed by plants is not an index for effective productivity[8].

The values of the coefficient of variation of the Available Phosphorus for the Mahin control site (10.32%) and polluted sites include Ugbo (9.32%), Etikan (9.23%) and Aheri (8.29%), respectively. The CV generally reflects the homogeneous distribution of soils. The results reflect an improved quantity of AP in the control site over the polluted soils. This observation could mean that oil spill has a significant impact on the amount of AP available in the soil.

The mean values of the CEC are 1.15, 1.43 and 1.36 for the polluted sites, while an increased mean value of 6.15 was recorded for the control site (Table 2). This shows that the soil element is higher in the Mahin control site. The results of the CV (14.9, 14.9, 15.4 and 12%) for the control site and polluted sites, respectively are an indication that the distribution of CEC is relatively homogeneous in the entire soil of the study area. However, the 6.15 value for CEC in the control site is an indication that the soil element can retain cations over the polluted sites. This trend is indicative of what was observed in the case of the soil cations where the soil nutrients are concentrated at the control site. In the previous research, this CEC level serves as an important property of soil fertility with nutrient retention capacity and the capacity to protect groundwater from cation contamination[9]. However, the low level of CEC recorded among the polluted sites shows the impacts of oil spills on soils in the environment.

The mean values of the Base Saturation are 91.89% for the control site, 67.89, 96.01 and 92.1% for the polluted sites, while the CV values show homogeneous distribution of soil elements (Table 2). This mean value of the BS shows that a very high rate of BS is present in the soils, except for Ugbo with moderate to high value[10]. Ugbo also shows a high level of leaching. Generally, the BS figures that ranged between 91 and 96 in this soil suggest that the level of leaching in this area is very low. This is because the higher the base saturation, the weaker the level of leaching in the soil[10].

The SOM includes both living and dead matters within and upon the soil. Generally, the content of SOM in the control site of the study area is high, far above 2% in soils. However, very low concentrations of SOM were recorded in the polluted sites of Ugbo, Etikan and Aheri. This observation shows that most of the organic materials available in soil are concentrated in the control site because of low leaching activities in the area. Similarly, the SOM content of the soils is relatively homogeneous in all the study sites, except Ugbo where the varied CV value (125*) was recorded. This observed distribution pattern of organic matter in this study followed the trends of Ca^{2+}, K^{+} and Na^{+} equally varied in soils. However, it should be noted that oil spill activities have a significant impact on the SOM of the polluted sites, considering the improved amount of SOM recorded in the soils of the control site. Therefore, sufficient organic material is necessary for the study area to improve on low organic matter recorded in the soils. The mean values of the total nitrogen in soil ranged between 0.09 and 0.50. The CV values indicate 59.4* and 50* for Etikan and Aheri, showing varying impacts of pollution in the study sites.

It was revealed in Table 2 that mean values of THC ranged between 0.21 and 21.76 in the polluted sites. However, there was no recorded mean value of THC for soils in the control site. Also, OG has a mean value of 0.15 in the soil of the control site and means of polluted sites with Ugbo (2.70), Etikan (0.019) and Aheri (3.12). It was revealed that Etikan has heterogeneous distributions of THC (52.4*) and OG (48.4*) among the selected soils. These observed results are the indication of the obvious influence of petrochemical pollution on polluted sampled soils. This current finding agrees with the previous study that crude oil and its product have been observed to contain nitrogen and phosphate, which affect the soil nutrient and bacteria diversity and that the increase in soil phosphate could affect the soil bacteria diversity[11].

Variability classes of soil properties in the study area: The coefficient of variation ranged between 0-15% for least variable, 15-35% for moderately variable and >35% for highly variable soil properties[12]. Table 3 revealed Sand, Silt, Clay, BD, WHC, pH, Ca^{2+}, K^{+}, Na^{+}, CEC, BS, AP, THC, Potassium, TN and OG as consistently least variables in the control site. However, the polluted sites of Ugbo have Sand, Silt, Clay, BD, WHC, CEC, BS, AP, THC, Potassium and TN, Etikan has Sand, Silt, Clay, BD, WHC, pH, Ca^{2+} Na^{+}, BS, AP and Aheri has Sand, Silt, Clay, BD, WHC, K^{+} CEC, BS, THC, OG as least variables. The SOM and Mg^{2+} were moderately variable in the control site, pH, Mg^{2+}, OG, SOM, Mg^{2+}, CEC, THC, TN, SOM, pH, AP, Potassium and TN varied moderately in Ugbo, Etikan and Aheri, respectively. However, it was further revealed that Silt, Mg^{2+} and H^{+} were extremely varied in soils of the control site. Also, Ugbo has SOM, Ca^{2+}, K^{+} and Na^{+}, Etikan has K^{+} and OG, Aheri has Ca^{2+}, Mg^{2+} and Na^{+} as extremely varied soil properties, respectively.

Table 3: Soil Variability Classes in the study area

		Control site	Polluted sites		
Ranking	CV range	Properties	Ugbo	Etikan	Aheri
Least variable	<15%	Sand, Silt, Clay, BD, WHC, pH, Ca^{2+}, K^+ Na^+ CEC, BS, AP, THC, K^+, TN, OG	Sand, Silt, Clay, BD, WHC, CEC, BS, AP, THC, K^+, TN	Sand, Silt, Clay, BD, WHC, pH, Ca^{2+} Na^+, BS, AP	Sand, Silt, Clay, BD, WHC, K^+ CEC, BS, THC, OG
Moderately variable	15-35	SOM, Mg^{2+}	pH, Mg^{2+}, OG	SOM, Mg^{2+} CEC, THC, TN	SOM, pH, AP, K^+, TN
Extremely Variable	>35		SOM, Ca^{2+}, K^+, Na^+	K^+, OG	Ca^{2+}, Mg^{2+}, Na^+

After Tabi and Ogunleke[12]

The least variability of Sand, Silt, Clay, BD and WHC is similar to the assumption that the soil's physical properties have a significant influence on changing situation of nutrient availability based on soil origin and formation materials in the study area. In addition, the variability status reported for sand, clay and silt is a consequence of microrelief and sources of parent materials that give rise to the entire soil composition. It was further revealed that SOM, Ca^{2+}, K^+, Na^+ and OG were extremely varied among the polluted sites. This is a direct reflection of activities of oil spills whereby the cations are mostly varied as a result of low pH values in the study area. However, the water holding capacity of soils seemed to be high, which is likely to be adequate for crop production. On contrary, this moisture condition couldn't help in the proper cropping system because of the level of pollution. The concentration of nutrient cations at the control site indicates a situation where the largest proportions of cations at the non-polluted site are being mobilized. The trend of the nutrient cations observed conforms with an ideal situation. This reflects the effectiveness of non-polluted soils with available nutrients for proper cropping.

CONCLUSION

So far, the study established that oil spillage has a direct effect on soil fertility, which necessitates observed changes that occurred in both the physical and chemical properties of soil. The effect of oil spillage on Silt, Mg^{2+}, H^+, SOM, Ca^{2+}, K^+, Na^+ and OG with extreme variability at the polluted sites was observed. However, a significant concentration of soil nutrients at the control site was recorded. With the trends of spills and impacts on soils in the study area, the urgent remedy to avert further spill occurrence was suggested through renewed soil protection and revitalization for national sustainable development.

SIGNIFICANCE STATEMENT

This study discovers a similar distribution pattern of soil organic matter (SOM) in this study with the trends of Ca^{2+}, K^+ and Na^+, which are varied in soils based on the significant impact of an oil spill on the SOM of the polluted sites, considering the improved amount of SOM recorded in soils of the control site that can be beneficial for soil fertility index.

This study will help the researcher to uncover the critical areas of soil variability classes of least, moderately and extremely variable in oil spill environments that many researchers were not able to explore. Thus a new theory on soil variability index may be arrived at.

This study discovers the possible synergistic effect of oil spillage on Silt, Mg^{2+}, H^+, SOM, Ca^{2+}, K^+, Na^+ and OG with extreme variability at the polluted sites observed. This study will help the researcher to uncover the critical area of low pH that many researchers were not able to explore. Thus, a new theory on these soil Physico-chemical parameters may be arrived at.

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