Journal of Science Research and Reviews
PRINT ISSN: 1595-9074
E-ISSN: 1595-8329
DOI: https://doi.org/10.70882/josrar.2025.v2i2.106
Homepage: https://josrar.esrgngr.org
Original Research Article

Physicochemical and Metal Profiles of Soils as Influenced by Crude Oil Contamination in Abraka, Delta State, Nigeria

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KEYWORDS
Physicochemical parameters,
Metal profile,
Contaminated soils.

ABSTRACT
An assessment of the physicochemical and metal profiles of soils as affected by crude oil contamination in Abraka, Delta State, Nigeria was carried out using five levels of oil treatments (0, 30, 60, 90 and 120 ml per 2 kg of soil). Soil samples were dried after proper missing at ambient temperature and crushed in a porcelain mortar and sieved through 2mm stainless sieve. The air dried soils were stored in polythene bags for subsequent analysis. Soils physicochemical analysis was done following the methods of the Association of Analytical of Chemist (AOAC, 2010) while the heavy metals using Atomic Absorption Spectrophotometer. The results showed that crude oil impacted soil properties variedly significant increases ($P \leq 0.05$) were observed in bulk density, total pH, organic carbon, nitrogen while significant reductions were observed for phosphorous, calcium, magnesium, potassium, total porosity, electrical conductivity and hydraulic conductivity. There was however a buildup of trace metals including Cu, N, Ma, Pb, Zn, Cr and Cd. The study established that these alternatives can have great implications on plant production, yield and food security impacting human health and environment due to their toxicity, persistence and bioaccumulation potentials. The study recommends environmental monitoring and education on a regular basis.

CITATION
Agbogidi, O. M., Ogbe, O., & Usen, E. N. (2025). Physicochemical and Metal Profiles of Soils as Influenced by Crude Oil Contamination in Abraka, Delta State, Nigeria. *Journal of Science Research and Reviews*, *2*(2), 140-144. https://doi.org/10.70882/josrar.2025.v2i2.106

INTRODUCTION

Soil is characterised by a complex physical, chemical, mineralogical and biological factors which are influenced by the climate and actions of living organisms. Soil plays a vital role in the protection of ground water, acting as a filter to both organic and inorganic residues hence helping to sequester possible toxic substances (Agbogidi *et al.*, 2021). Soil is regarded as the wealth prosperity and treasure of nations because of its immense roles in ensuring food security (Agbogidi, 2022). Soil is one of the most important resources of nature. Life without soil is regarded as lifeless because beside acting as a reservoir of nutrient and moisture for the production of plants for day to day activities it is a major component of the ecosystem. Soil is not a dead inert waste of matters but typically intermixed with living organisms. Soil differs distinctively from place to place depending on the colour, depth, composition and other factors. The health of soil depends on the soil quality controlled by the physical, chemical and biological characteristics. A fertile soil is essential for develop optimum land use for maximizing agricultural production to meet up with the goal of zero hunger of the United Nations Sustainable Goals.

The farmland ecosystem is facing unprecedented changes due to hazardous human activities and land use practices, which severely impact crop productivity. A significant contributor to this issue is the increasing incidence of crude oil spillage on arable land, which has become a major threat to global food security (Obech and Odesiri-Eruteyan, 2016). The Niger Delta region of Nigeria is particularly vulnerable to the devastating effects of oil spillage, which has become a recurring feature of life in the area. The pollution caused by crude oil exploitation has far-reaching consequences for agricultural productivity, with toxic chemicals contaminating the soil and posing a significant risk to farmland (Environmental Pollution Centers).

According to Okwakpam (2021), mineral oil and heavy metals are the primary contaminants responsible for soil pollution, accounting for approximately 60% of contamination cases. The frequency of crude oil spillages in recent times is alarming, and the lack of prompt action to address these incidents exacerbates the problem (Orji *et al.,* 2011). The pipelines used to transport oil and gas through farmlands are a significant source of crude oil spillage, with severe consequences for cassava growth, yield, and productivity (Babalola *et al.*, 2010). The economic and environmental impacts of oil spillage are dire, causing economic ruin, destroying occupational livelihoods, and constituting a major environmental hazard (Osuji and Nwoye, 2007; Atakpo and Ayolabi, 2009; Obech and Odesiri-Eruteyan, 2016). The residual effects of oil spillage on farmland are particularly hazardous, altering the physical, chemical, and biological characteristics of the terrestrial environment and rendering it unsuitable for agricultural purposes for extended periods. This has led to compounded land use degradation and a loss of soil fertility.

Crude oil is one of the most serious pollutions in Nigeria as an oil consists of complex hydrocarbons some of which are toxic, persistent and have biomagnification potentials in the ecosystem (Agbogidi *et al.,* 2007a). Although heavy metals occur naturally in ecosystem, the heightened anthropogenic activities of man among other causes have intensified crude oil contamination of soils in both producing and non-producing communities leading to various deleterious effects on soil, the foundation of all life activities. Although studies including the one of Adieze *et al*. (2012), Baruah *et al*. (2013) and Han *et al*. (2016) have noted the immense effects oil activities on soils, there is scarcity of documented information on the impact of crude oil pollutions of soil in Abraka. It is against this background that this study has been embarked upon to investigate the physicochemical and heavy metal profiles of crude oil contaminated soil with a view to documenting some as agricultural community involved in the cultivation of aerable crops.

MATERIALS AND METHODS

Abraka hosts the Delta State University, Abraka. It has a tropical wet and dry climate with lengthy wet season and relatively constant temperatures from march through October while the remaining months form the city dry season. It experiences the harmattan between the months of November and February. It enriches the tropic rain forest climate, the vegetation is evergreen, the soil is acidic and varies from coarse medium to fine grained oils. The colour is greenish brown to reddish brown and then to brown. It is drained by two rivers, River Ethiope and River Ovwuvwe.

Soil Preparation and Physichochemical Analysis

The collected soil samples were dried at ambient temperature (22 – 25 ^{0}C) and were crushed in a porcelain mortar and sieved through a 2mm (10mesh) stainless sieve. The air dried soils were stored in polythene bags for subsequent analysis. Less than 2mm fractions were used to determine selected soil physicochemical parameters. The following physicochemical analysis were carried out following the procedures of Association of Analytical Chemist (2010). Total carbon, soil pH, electrical conductivity, soil colour, temperature, BOD, organic carbon, nitrogen, phosphorus, chlorine and sulphates.

Heavy Metal Determination

Heavy metal analysis was performed using a Varian AA240 Atomic Absorption Spectrophotometer, following the protocol outlined by the American Public Health Association (APHA, 1995). 1g of each sample was digested in aqua regia for 5 days. The resulting extract was then centrifuged at 30,000 rpm for 15 minutes, and the heavy metal content was determined using calibration curves generated from standard metal solutions in an identical acid matrix, optimized for atomic absorption spectrophotometry.

Statistical Data Analysis

The data were analysed using one-way analysis of variance (ANOVA), and when significant differences were detected, Duncan's Multiple Range Test was employed to separate treatment means using SAS software (version 2000).

Quality Assurance and Quality Control

Sample collection were carried out using standard methods and all data were subjected to strict control procedures. For the samples, procedural bank and a sample duplicate were used. In quality assurance and quality control program, standard checks were used to overcome interference in the analysis. All glass wares were washed with distilled water and detergent and soaked again overnight with chromic acid and later rinsed with water, all the glass ware ere baked in the oven for 6 hours at 105 °C.

RESULTS AND DISCUSSION

The results of the work are presented in Table 1 and 2. Table 1 shows the effects of soil contamination with crude oil on the physicochemical parameters of soils in Abraka, Delta State, Nigeria.

Table 1: Physicochemical properties of soils as affected by crude oil contamination

Soil properties	Treatment levels (ml)				
	0	30	60	90	120
Sand(gkg^{-1})	69.0	69.0	69.0	69.0	69.0
Silt (gkg^{-1})	11.0	11.0	11.0	11.0	11.0
Clay (gkg^{-1})	20.0	20.0	20.0	20.0	20.0
Textural class	Sandy and browny	Sandy and browny	Sandy and browny	Sandy and browny	Sandy and browny
pH	9.48	5.21	5.35	5.51	5.80
Organic carbon	0.56	1.67	2.24	3.46	3.81
N	0.04	0.08	0.10	0.16	0.20
Temperature	28.3	28.3	28.3	28.3	28.3
EC	0.27	0.20	0.18	0.16	0.02
Nitrogen	0.04	0.15	0.18	0.19	0.20
Phosphorus	58.00	56.24	52.60	48.71	40.72
Calcium	5.60	5.26	5.00	4.68	4.22
Mg	4.00	3.81	3.62	3.46	2.89
Potassium	0.18	0.16	0.14	0.11	0.08
Sodium	0.16	0.15	0.12	0.10	0.08
Carbonate	0.68	0.68	0.68	0.68	0.68
Bicarbonate	73.10	73.10	73.10	73.10	73.10
Chloride	12.18	12.18	12.18	12.18	12.18
Bulk Density	1.50	1.65	1.71	1.74	1.82
Total porosity	43.67	40.23	40.00	35.41	32.62
Hydraulic conductivity	3.89	3.91	3.01	2.46	2.01
Gravimetric mean	47.9	47.9	47.9	47.9	47.9
Moisture content	13.5	13.3	12.6	12.02	11.40
Water holding capacity	50.40	49.6	48.0	46.0	45.2

Table 2: Heavy metal content of crude oil contaminated soil in Abraka, Delta State, Nigeria

Heavy metal	Treatment levels (ml)					WHO permissible limits
	0	30	60	90	120	
Cu	0.19	0.20	0.21	0.24	0.25	10
Ni	0.97	0.98	0.20	1.01	1.13	0.05
Mn	5.49	5.40	5.52	5.61	5.76	0.48
Pb	0.06	0.07	0.07	0.09	0.10	0.117
Zn	1.22	1.23	1.25	1.27	1.29	0.60
Cr	0.14	0.15	0.17	0.19	0.20	1.30
Cd	0.06	0.07	0.08	0.09	0.11	0.48
Fe	0.002	0.001	0.01	0.12	0.16	0.01
Co	0.004	0.002	1.00	1.13	1.19	1.00

Values with the same superscript in the same column are significantly different at $P < 0.05$ using the Duncan's Multiple Range Tests.

The soil is predominantly sandy (69.0%), silt (11.0%), and clay (20.0%), with a textural class of sandy loamy soil. Oil in the soil increased the pH from 4.48 in the control to as high as 6.80 in soils that received 120ml of oil showing oil-level dependent increase (Table 1). Similarly, the presence of oil in the soil significantly increased the values of nitrogen and organic carbon. The values increased with increasing oil levels in the soil (Table 1). Bulk density significantly decreased, and decreases were observed in the values recorded for phosphorus, calcium, magnesium, potassium, total porosity, and hydraulic conductivity with increasing amounts of oil in the soil. Other parameters that had reduced values are moisture content and water-holding capacity of the soil. Table 2 presents the observed increase in pH values following crude oil application, which is in harmony with earlier research findings of Osayande and Nwokedi (2019) who noted that application of crude oil or its distillates could even cause the pH to be as high as 8.0. The implications of increased pH on agricultural lands are varied. The amounts of carbonates, bicarbonates, aluminum, iron, and other elements are toxic to plants. Nutrient deficiency is also likely to be an issue, which could reduce soil fertility and plant yield, and consequently lead to food insecurity. Similarly, the observed increase in organic carbon and nitrogen in oil-polluted plots could enhance soil physical properties but may not enhance the performance of crop plants, as the effects of oil in soils and plants depend on many other factors. The observed decrease in the values recorded for phosphorus, calcium, magnesium, and potassium agrees with the work of Osipova (2020), who noted a decrease in phosphorus, potassium, and other macro elements in soil following contamination with crude oil. This could be due to decreased microbial activities. The observed decrease in total porosity and hydraulic conductivity is similar to the findings of Ismail *et al*. (2021) who noted the same. The pore spaces clogged following oil in the soil could reduce aeration, infiltration/percolation of water, caused by increased bulk density, and hence restrict permeability, which can culminate in reduced performance of the soil, leading to reduced yield and productivity.

The effects of soil chemistry alteration and yield reduction have been documented by Agbogidi *et al*. (2007) for maize. It could also be attributed to the leakage of oil and its components, which have a drastic influence on soil properties, and hence affect the engineering nature of the soil, including clogging of pore spaces, poor water percolation, can lead to poor drainage, waterlogging, and increased electrical conductivity. The soil profile values were within the UNEP permissible limits but if not maintained and crude oil pollution controlled, can cause different degrees of adverse ecological effects on man and crop plants, stemming from the decreased relationship between crop plants and human beings. The concentrations of the trace heavy metals in the soil varied depending on the metal. A buildup of metal elements was observed with increasing concentration of oil in the soil relative to the control (Table 2). This observation agrees with earlier reports that increased heavy metal contact is sure in soil contaminated with crude oil and its distillates. Similar findings have been reported by Ihenetu *et al*., (2017), who noted a buildup of trace elements in soils treated with crude oil and its products. The presence of trace metals in control plots indicates that heavy metals are natural components of the ecosystem, hence used by plants at minute amounts for their metabolic processes. The observed buildup of these metals with increasing concentrations of oil in the soil indicates that crude oil is a vast reservoir of heavy metals in soil (Agbogidi *et al.*, 2024). When present at higher levels, these metals have some deleterious effects on plants, including chlorosis, dropping of leaves, necrosis, and eventual death of the plant. Death of crop plants subjected to crude oil has been reported by various researchers, including Agbogidi *et al*. (2007a), in their work on *Dacryodes edulis*. Okechalu *et al*. (2014) noted that diesel affected the growth and yield of maize but those that received higher fraction of poultry manure structured better than those treated with cow dung. Agbogidi noted that cowpea did poorly in crude oil polluted soils mineral nutrient elements of maize were significantly affected include mg^{2+}, v-t, p and Na^{+} as well as the grain yield stemming from reduced performance in plant height, number of leaves, leaf area, numbers of tassels and size of cob (Agbogidi *et al.*, 2007b).

CONCLUSION

The results indicate that the application of crude oil on soil has deleterious effects on soil physical and chemical properties. While it increased bilk density, reduced total porosity, moisture retention of the soil, pH, organic carbon, nitrogen, crude oil application decreased phosphorous, calcium, magnesium, potassium, total porosity, hydraulic conductivity as well as electric conductivity of the affected soil. These alterations in the soil parameters have great complications on crop production, yields and food security. The study also reported a buildup of heavy metals in the soil impacted with crude oil which can affect soil properties and crops via their yields because heavy metals are toxic, non-degradable and can bioaccumulate to lethal levels impacting human health and the environment. The study has established that crude oil contamination of soil has great impacts on soil physicochemical parameters and leads to a buildup of heavy metals which if not monitored has drastical impacts on human health and great environmental implications.

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