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Diagnosis of Crude Oil Impacted Soil in Eleme Local Government Area, Rivers State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study assessed the potential effects of crude oil on soil quality in Eleme Local Government Area of Rivers State. Soil samples were collected from 10 geopolitical wards of the Eleme Local Government Area of Rivers State, Nigeria. The soil and water samples were subjected to physicochemical and microbial analyses to test for pH, heavy metal content (Cadmium, Iron, Lead, Copper, and Chromium), Total Petroleum Hydrocarbon (TPH), Benzene, Toluene, Ethylbenzene and Xylene (BTEX) contents and Total Viable Count (TVC). Parameters of the soil were determined and compared to the control site and the permissible World Health Organization (WHO) limits. The soil pH varied across location, ranging from 5.5-7. TPH varied in across the different communities

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studied, ranging from 1.275-4889.29 mg/kg, and exceeding the WHO limit of 10mg/kg in all polluted soils. The result for the heavy metals showed that the soil samples of the studied sites showed increases in all heavy metals, when compared to the control. Cd values ranged from 0.01 - 0.32 mg/kg; Fe from 1325.23 - 9364.76 mg/kg, Pb from 0.001 mg/kg to 0.93 mg/kg and Cr from 0.001 - 5.08 mg/kg, all with WHO limits. The result for the microbial showed increases in TVC content in polluted soil. Results indicate that crude oil spillage has led to significant contamination of soil in the study area which could affect soil fertility.

Keywords: Crude oil; heavy metals; hydrocarbons; soil.

1. INTRODUCTION

Large quantity of petroleum resources is deposited in the Niger-Delta region of Nigeria where oil was first discovered in 1956 and since its exploration, it has dominated the country's economy in the early 1970s. The presence of the oil in this region has led to the establishment of lots of companies specializing in the oil and gas sector. Geographically, the Niger Delta is in the southern part of the country and bordered to the Atlantic Ocean where it releases several tributaries of River Niger and River Benue. This region is made up of nine (9) states of which Rivers State appears to be at the centre and heart of petroleum production activities. Oil exploration has over the years improved the lives of people and impacted negatively on the physical environment of the oil-bearing communities [1]. These negative impacts on the physical environment (environmental degradation) are caused due to some operational discharge, accidental wastes, pipeline explosion and vandalization, exploration spillage and many more [2].

Petroleum pollution is a growing environmental challenge which affects both terrestrial and aquatic ecosystems and the ozone layer. Recently, there has been an increase in the ecological and global health concern regarding environmental contamination by heavy metals caused by petroleum oil spills [3,4].

The pollution of the environment caused by crude oil and refined products has drawn the attention of researchers and environmentalists at all levels [5-7]. Cocâr ta *et al*. [8] proposed that the assessment of health hazards produced by oil exploration is an important environmental issue in order to ensure the wellbeing of people. Petroleum spills which could also result from damage, transportation accidents and other industrial and mining activities otherwise known as hazardous wastes [9] are considered to be the most frequent organic pollutants of aquatic [10], terrestrial [5] and the ozone layer. This has subsequently caused physical damage to the habitats of plants and animals within such areas of spillage.

Majority of the oil producing countries of the world today are experiencing hydrocarbon spillages on land and sea [11] with developing countries having the worst cases. Despite the availability and use of advanced technology in the petroleum industry, several forms of accidents such as blow-outs of production wells, explosions and pipeline ruptures which are worsened by vandalization of oil installations and pipelines [11,12] and illegal refineries [13].

Over the years there have been increasing concerns over the environmental effects of petroleum industry because its environmental impacts are mainly negative. This is due to the toxicity of petroleum which contributes to climate change and various illness in humans. It is true that oil spillage and its components are toxic to human life and the environment [7,14]. According to Onwuna et al. [13], the petroleum industry holds a major potential of hazards for the environment and may impact air, water, soil and consequently all living beings on the planet.

The major impact of petroleum spills is contamination of soil in the affected areas, destruction of farmlands, poisoning of both surface and ground waters, destruction of aquatic life and other economic livelihood [15]. When oil is spilled on land and water, it rapidly sinks into the soil and on landing, some volatile fractions escape into the surface (water or soil) and this may result in leaching depending on the soil. Furthermore, it also has devastating effect on the soil, vegetation, and air of the affected area [16].

Petroleum spills continue to occur in alarming proportion in the Niger Delta communities, particularly in Ogoniland who are living in a chronic state of pollution [1]. This is the case of Eleme; a neighbour of the Ogonis; located in the heart of oil exploration and petroleum production activities, because of its high industrial (petroleum) state and local refinery operations. Against this backdrop, this study aims to assess the potential effects of crude oil and refined product on soil quality in Eleme Local Government Area of Rivers State, Nigeria.

2. MATERIALS AND METHODS

2.1 Study Area

Eleme Local Government Area is located within latitude 4^0 60'' – 4^0 35'' N and longitude 7^0 – 7^0 15'' E with a total land area of about 140 km^2. The Local Government Area is about 30 km from Port Harcourt the state capital and shares boundary with Oyigbo in the north, eastern boundary with Tai, western boundary with Elelenwo and southern boundary with Okrika/Ogu/Bolo Local Government Area. The headquarters is located at Nchia and made up of two development areas namely Odido and Nchia. It also has 10 towns namely; Ogale, Alesa, Alode, Agbonchia, Aleto, Akpajo, Onne, Eteo, Ekporo and Ebubu. There are other settlements including; Agbeta-Ebubu, Okerewa, Njuru, Ejama-Ebubu, Akpakpa, Ollorte, Wuwu, Agborta, Okori, Ngejolowa, Oku-beke, Nsi-Okulu and Ekpan-eta. The major tribe is Eleme but highly populated by Igbo, Effik and Urhobo immigrants. Eleme Local Government has a 2006 population of about 200,000 persons.

2.2 Sample Collection

A total of 20 soil samples were collected from each of the 10 spillage sites at 2 samples per site for laboratory analysis. The sampling areas in this study are the spillage sites across Eleme LGA. The soil types are the same across the area and shares equal experience of spillage. The control area is Ekporo and Rumuokwurusi that shares boundary with Eleme neighbouring community. Soil samples were bagged and transported to the laboratory after collection for analysis.

The sampling areas in this study are the spillage sites across Eleme LGA. The soil types are the same across the area and shares equal experience of spillage. The control area is Ekporo and Rumuokwurusi and Rumuokwurusi that shares boundary with Eleme neighbouring community but suffers no spillage due to absent of petroleum related facilities.

2.3 Chemical Analysis

The soil pH was determined in both distilled water and a 0.1 potassium chloride solution using soil/liquid ratio of 1:2:3; the pH values was on Beckman Zerometic pH meter.

Heavy metals (iron, manganese, lead, copper, Cadmium, zinc, Boron and Chromium) were determined by Atomic Absorption Spectrophotometer (AAS).

Total Petroleum Hydrocarbon (TPH) was determined as per EPA 8015 [17].

2.4 Microbiological Analysis

The total viable count was carried out by the spread plate method, using nutrient agar. Plates were incubated for 24 hours at 30^{o}C.

2.5 Statistical Analysis

Descriptive analysis of data was employed for this study. Analysis of variance was conducted to evaluate variation of data over locations in the study area.

3. RESULTS AND DISCUSSION

3.1 Effect of Crude Oil Pollution on the pH of Soil

Fig. 1 shows the pH of crude oil impacted soil. The pH values ranged from 5.5 to 7.

3.2 Effect of Crude Oil Pollution on the Total Petroleum Hydrocarbon of Soil Samples

Fig. 2 shows the TPH levels of crude oil impacted soil. Ekuluebo-1 Ogale had the highest TPH value of 4889.29 mg/kg while Nsioken Akpajo showed had the least value of 34.7 mg/kg.

3.3 Effect of Crude Oil Pollution on the BTEX Content of Soil Samples

Fig. 3 shows the BTEX levels of crude oil impacted soil. BTEX values, ranged from 0.001 mg/kg to 4.8 mg/kg.

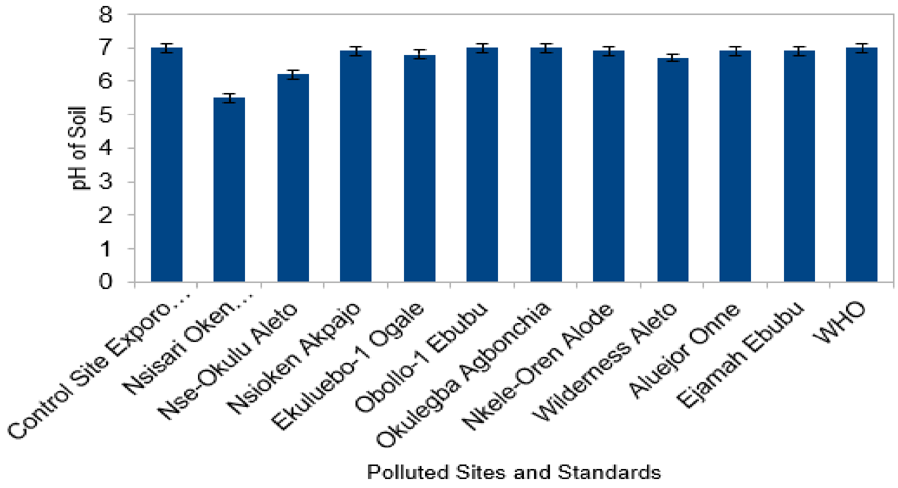

Fig. 1. Comparison of soil pH

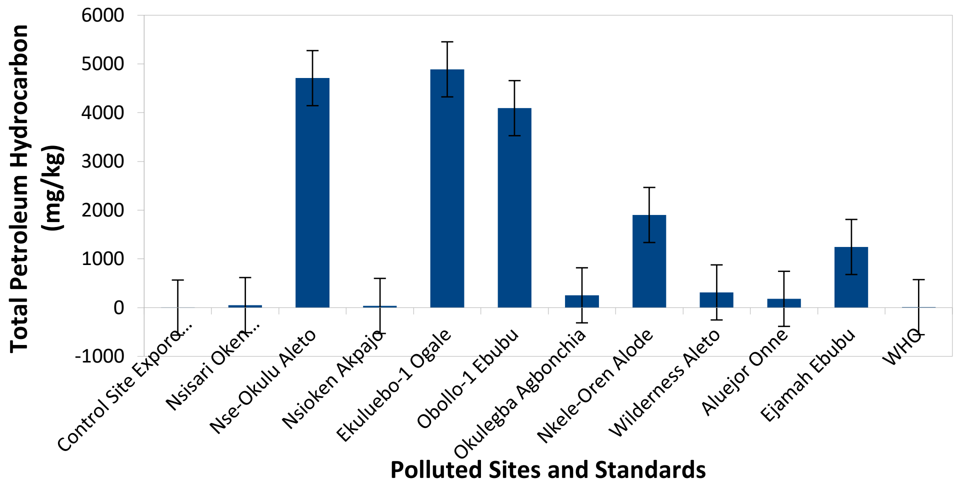

Fig. 2. Comparison of TPH concentrations in soil

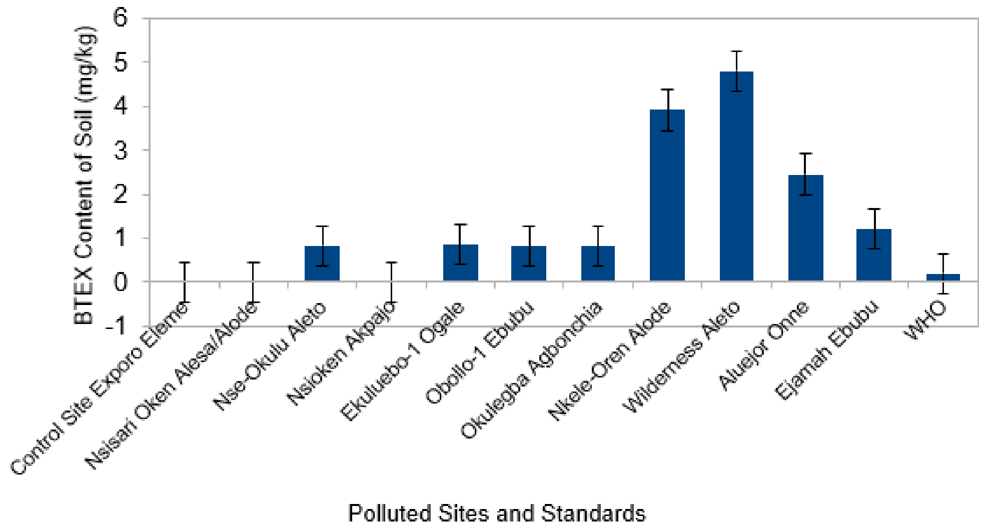

Fig. 3. Comparison of BTEX concentrations in soil

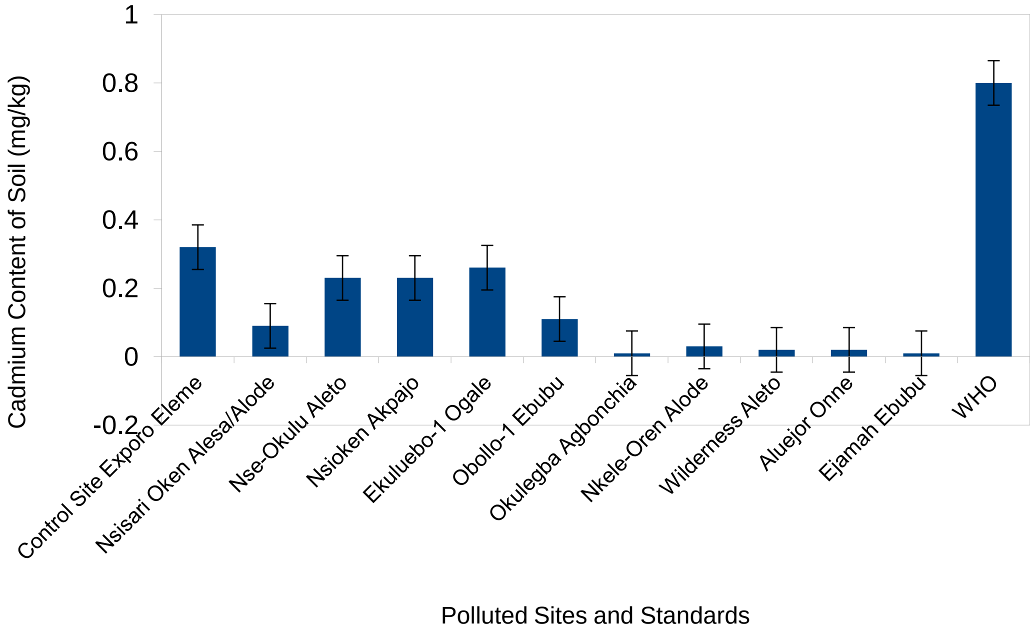

Fig. 4. Comparison of cadmium concentrations in soil

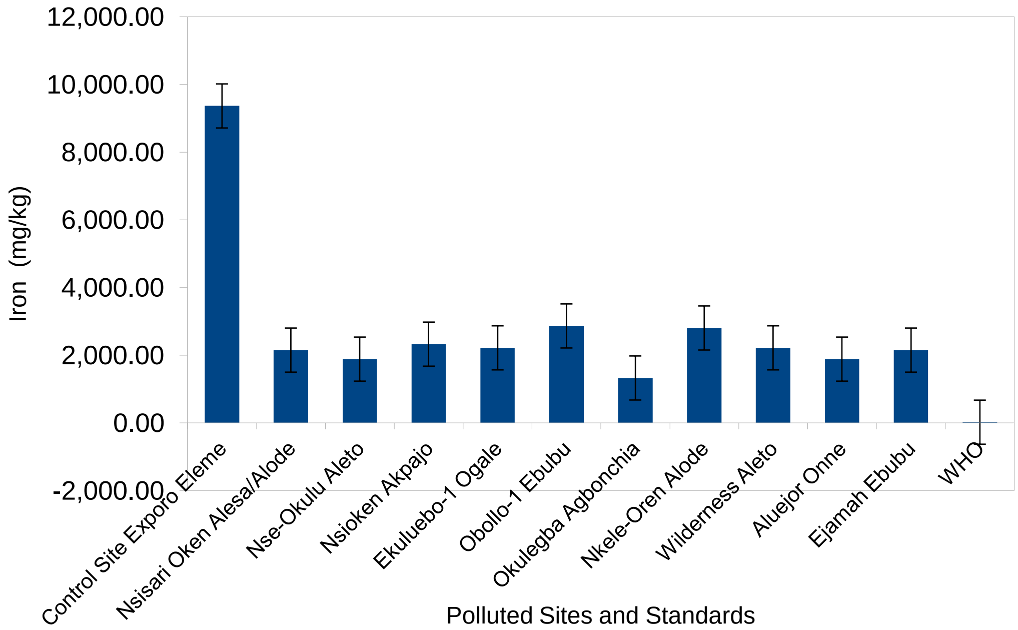

Fig. 5. Comparison of Iron concentrations in soil

3.4 Effect of Crude Oil Pollution on the Cadmium Content of Soil

Fig. 4 shows the Cd concentrations in crude oil impacted soil. The Cadmium levels were observed to be relatively low, ranging from 0.01 mg/kg (Ejamah Ebubu) to 0.32 mg/kg (Control).

3.5 Effect of Crude Oil Pollution on the Iron Content of Soil

Fig. 5 shows the Fe concentrations in crude oil impacted soil. The Iron levels ranged from 1325.23 mg/kg (Okulegba Agbonchia) to 9364.76 mg/kg (control).

3.6 Effect of Crude Oil Pollution on the Lead Content of Soil

Fig. 6 shows the Pb concentrations in crude oil product impacted soil. The values ranged from 0.001 mg/kg to 0.93 mg/kg.

3.7 Effect of Crude Oil Pollution on the Copper Content of Soil

Fig. 7 shows the Cu concentrations in crude oil impacted soil. The values ranged from 0.1-3.51 mg/kg.

3.8 Effect of Crude Oil Pollution on the Chromium Content of Soil

Fig. 8 shows the Cr concentrations in crude oil impacted soil. Results ranged from 0.001 - 5.08 mg/kg.

3.9 Effect of Crude Oil Pollution on the Total Viable Count of Soil

Fig. 9 shows the effect of crude oil on TVC of soil. The TVC ranged from 100-380 CFU/g.

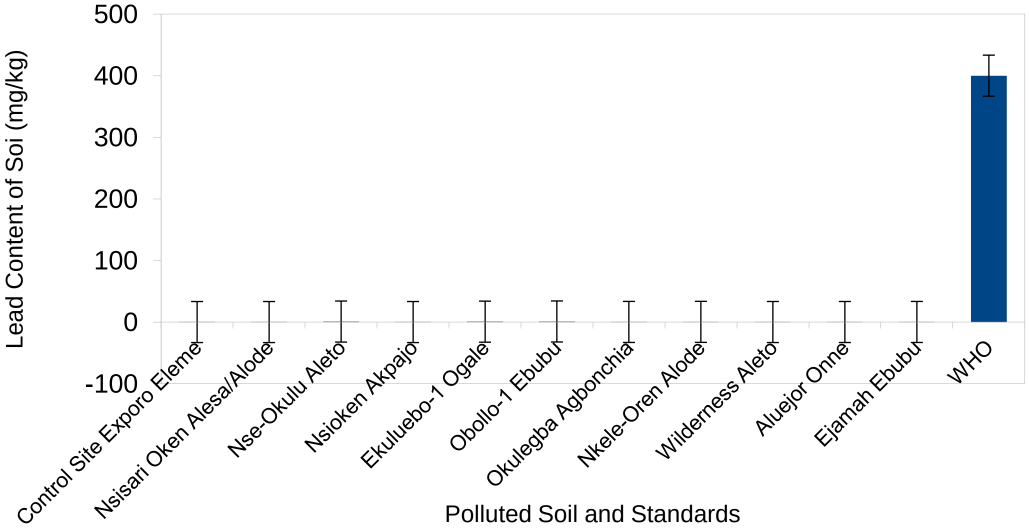

Fig. 6. Comparison of lead concentrations in soil

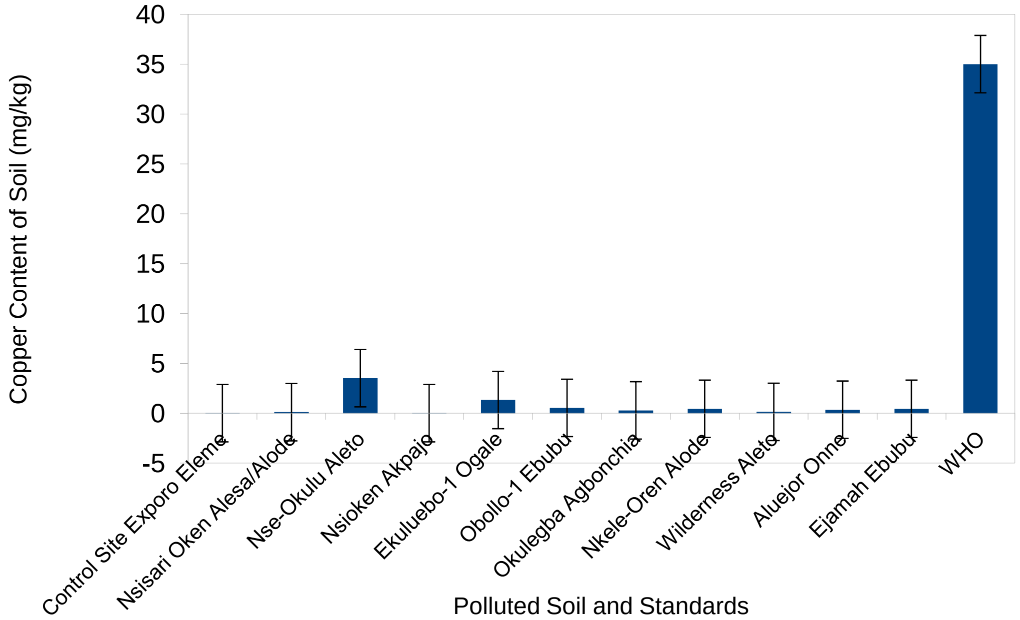

Fig. 7. Comparison of copper concentrations in soil

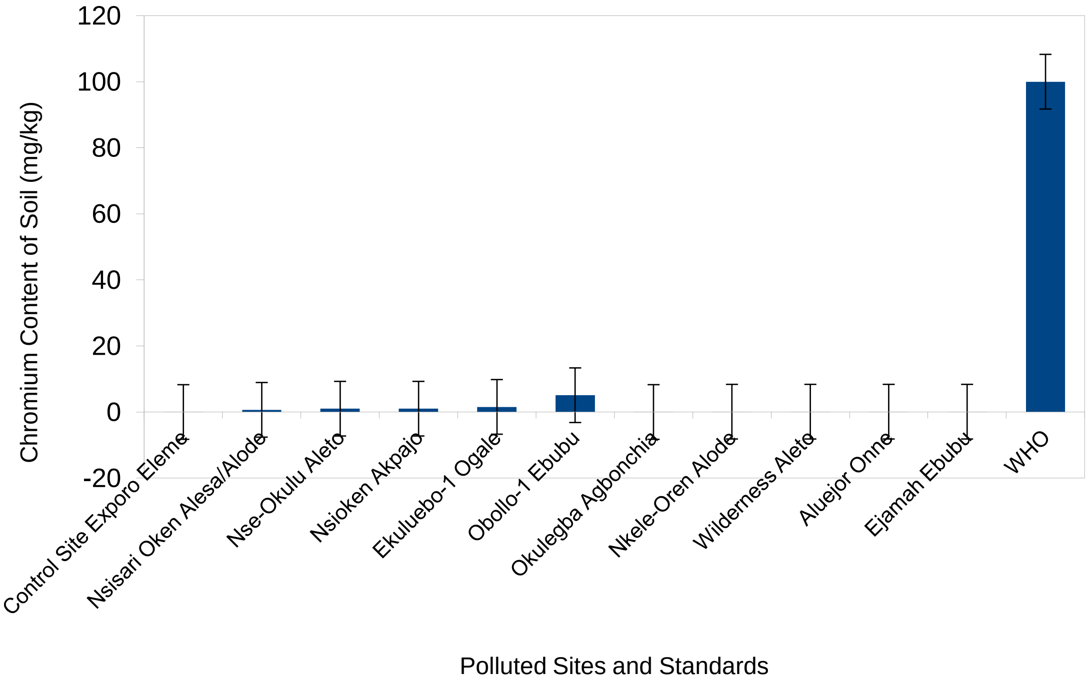

Fig. 8. Comparison of chromium concentrations in soil

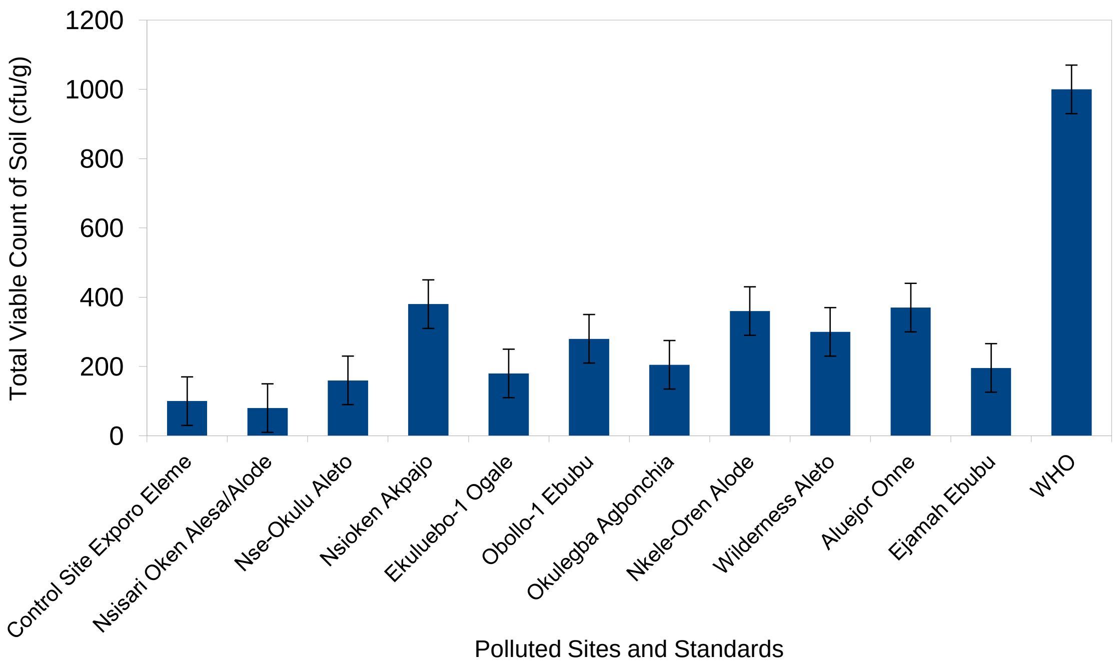

Fig. 9. Effect of crude oil on the total viable count of soil

3.10 Effect of Crude Oil Spillage on pH

The findings of this study reveal significant variations in soil pH among different communities affected by crude oil spillage. The control site, Exporo Eleme, exhibited a pH value of 7, which falls within the acceptable pH range set by the WHO. However, several communities showed pH values either below or above the recommended range. Nsisari Oken Alesa/Alode displayed a pH of 5.5, indicating a relatively acidic soil environment. Similarly, Nse-Okulu Aleto and

Ekuluebo-1 Ogale exhibited pH values of 6.2 and 6.8, respectively, indicating slightly acidic conditions. On the other hand, Nsioken Akpajo, Obollo-1 Ebubu, Okulegba Agbonchia, Nkele-Oren Alode, Wilderness Aleto, Aluejor Onne, and Ejamah Ebubu all demonstrated pH values within the neutral to slightly alkaline range, ranging from 6.7 to 6.9.

The variations in soil pH observed among these communities can have significant ecological implications: Acidic soil conditions, such as those found in Nsisari Oken Alesa/Alode, can adversely affect soil fertility and nutrient availability. Acidic soils are often associated with reduced microbial activity, hampering nutrient cycling processes and negatively impacting plant growth [18,19]. The lower pH in these areas may be attributed to the presence of oil-related contaminants, which could have leached into the soil and affected its chemical composition. In contrast, communities with slightly alkaline soil conditions, such as Nsioken Akpajo, Obollo-1 Ebubu, and Ejamah Ebubu, may indicate the presence of alkaline substances introduced by the oil spillage. The influx of certain components from crude oil, such as basic minerals, can increase soil pH. Although alkaline soils are generally more conducive to plant growth than acidic soils, the presence of crude oil contaminants may still have negative effects on soil health and overall ecosystem functioning [19].

3.11 Effect of Crude Oil Spillage on TPH Content of the Soil

In the control site, Exporo Eleme, a TPH value of 1.275 mg/kg was observed. This relatively low TPH level suggests minimal or no contamination in the soil, indicating that the site is unaffected by crude oil spillage. However, the other communities exhibited significantly higher TPH values, indicating varying degrees of contamination.

Comparing the obtained TPH values to the WHO acceptable value of 10 mg/kg, it is evident that all the communities studied exceed the recommended limit. The high TPH values observed in Nse-Okulu Aleto, Ekuluebo-1 Ogale, Obollo-1 Ebubu, and other communities highlight the extensive contamination and environmental risks associated with crude oil spills. These findings emphasize the urgent need for remediation and restoration efforts to mitigate the environmental and health risks associated with crude oil spillage.

3.12 Effect of Crude Oil Spillage on BTEX Content of the Soil

The results of the experiment reveal the levels of BTEX compounds (Benzene, Toluene, Ethylbenzene, and Xylene) in different communities affected by crude oil spillage. BTEX compounds are volatile organic compounds (VOCs) commonly found in petroleum products. Their presence in soil can indicate contamination and potential risks to human health and the environment.

In the control site, Exporo Eleme, Nsisari Oken Alesa/Alode, and Nsioken Akpajo, low BTEX values of 0.001 mg/kg were observed. These values suggest minimal contamination in the soil, indicating that these sites are relatively unaffected by crude oil spillage. However, the other communities exhibited higher BTEX values, indicating varying degrees of contamination.

Nse-Okulu Aleto, Ekuluebo-1 Ogale, and Obollo-1 Ebubu displayed relatively higher BTEX values, ranging from 0.82 mg/kg to 0.85 mg/kg. These values suggest moderate levels of BTEX contamination, indicating that crude oil spillage has impacted the soil in these areas. While these values are higher than those observed in the control sites, they are still within a manageable range. Nkele-Oren Alode, Wilderness Aleto, Aluejor Onne, and Ejamah Ebubu showed higher BTEX values, ranging from 1.21 mg/kg to 4.8 mg/kg. These values indicate a significant degree of BTEX contamination, suggesting a greater environmental risk and potential health concerns for individuals residing in these communities.

When comparing the obtained BTEX values to the WHO acceptable value of 0.2 mg/kg, it is evident that all the communities studied (except Exporo Eleme, Nsisari Oken Alesa/Alode, and Nsioken Akpajo) exceeded the recommended limit. These findings highlight the urgent need for remediation measures to mitigate the adverse effects of BTEX contamination on the environment and human health.

The results of the experiment indicate the levels of Cadmium (Cd) in soil from different communities affected by crude oil spillage. Cadmium is a toxic heavy metal that can pose significant risks to human health and the environment when present in excessive amounts. The values obtained for Cadmium concentration in the soil samples were compared to the WHO acceptable value of 0.8 mg/kg.

In the control site, Exporo Eleme, Nsisari Oken Alesa/Alode, Nse-Okulu Aleto, Nsioken Akpajo, Ekuluebo-1 Ogale, Obollo-1 Ebubu, Okulegba Agbonchia, Nkele-Oren Alode, Wilderness Aleto, Aluejor Onne, and Ejamah Ebubu, the Cadmium levels were observed to be relatively low, ranging from 0.01 mg/kg to 0.32 mg/kg. These values indicate minimal contamination in the soil, suggesting that the control sites are relatively unaffected by the crude oil spillage in terms of Cadmium pollution. When comparing these values to the WHO acceptable value, it is evident that all the communities studied exhibit Cadmium levels well below the recommended limit. This suggests that the concentrations of Cadmium in the soil from these communities do not pose significant risks to human health and the environment.

3.13 Effect of Crude Oil Spillage on Heavy Metals Content of the Soil

The results of the experiment showed levels of Fe in soil from different communities impacted by crude oil spillage, ranging from 1325.23 mg/kg to 9364.76 mg/kg. Iron is an essential nutrient for plants and plays a crucial role in various biological processes. However, excessive concentrations of Iron in soil can have detrimental effects on soil quality and plant growth. The values obtained for Iron concentration in the soil samples were compared to the WHO acceptable value of 20 mg/kg.

The elevated Iron levels in the soil can have both positive and negative implications. On one hand, Iron is an essential micronutrient for plants and is involved in important physiological processes, such as photosynthesis and enzyme activation. Adequate Iron availability in the soil is crucial for promoting plant growth and development. However, when Iron concentrations exceed the optimal range, it can result in toxicity and negatively impact plant health.

The control site, Exporo Eleme, Nsisari Oken Alesa/Alode and all other sample sites exhibited lead levels below the WHO acceptable value of 400 mg/kg. Summarily, all sites studied fell within the WHO permissible limits.

Reports show that the presence of lead in the soil can be attributed to various factors, including anthropogenic activities such as industrial processes, improper waste disposal, and the accidental release of lead-containing substances like crude oil. Lead contamination in soil poses significant risks to both human health and ecosystems. Chronic exposure to elevated lead levels can have detrimental effects on the neurological development of children, leading to cognitive impairments and behavioural disorders [20]. This risk is averted in this case study, as most all the study sites (including the control site) has lead concentrations lower than the WHO limit.

The results of the study reveal varying levels of copper contamination in the soil of different communities affected by crude oil spillage. The concentrations of copper in the soil samples were measured and compared against the WHO acceptable values for copper in soil. The findings provide insights into the potential environmental and health risks associated with copper contamination resulting from crude oil spills.

The results obtained from the analysis of soil samples collected from various sites revealed varying levels of Chromium contamination. These findings have important implications for both environmental and human health considerations. The control site (Exporo Eleme) exhibited the lowest Chromium concentration of 0.001 mg/kg, which is within the acceptable range set by the WHO at 100 mg/kg. This indicates that the control site has not been significantly impacted by the crude oil spillage in terms of Chromium contamination. However, other sites showed elevated levels of Chromium, suggesting the influence of crude oil spillage on the soil's chemical composition.

The observed Chromium concentrations in the affected communities raise concerns about potential ecological and human health risks. Chromium is a well-known toxic metal that can have detrimental effects on organisms and ecosystems. Hexavalent Chromium [Cr(VI)] is particularly hazardous due to its high solubility and ability to penetrate biological tissues. Long-term exposure to elevated Chromium levels in soils can lead to the accumulation of this toxic metal in crops and subsequent bingestion by humans through the food chain [21].

The findings of this study are consistent with previous research that highlights the adverse effects of crude oil spillage on soil quality and the accumulation of heavy metals such as

Chromium. Studies conducted in similar environments have reported elevated levels of Chromium in soils affected by oil spills [22,23]. These studies reinforce the importance of addressing and mitigating the environmental consequences of crude oil spillage to protect ecosystems and human health.

3.14 Effect of Crude Oil Spillage on Soil Total Viable Count

The impact of crude oil spillage on soil microbial communities, including the Total Viable Count (TVC), is a topic of significant interest due to its implications for ecosystem health and soil fertility. TVC represents the total number of viable microorganisms, including bacteria, fungi, and other microorganisms capable of growth under favourable conditions. The result of the investigation of the effect of crude oil spillage on TVC in different communities indicated varying levels of TVC in the studied sites, with some communities showing a decrease in TVC compared to the control site.

The TVC values obtained from the different communities indicate a range of microbial abundance and diversity, with values ranging from 100 to 380 cfu/g. The decrease in TVC observed in certain communities suggests a potential negative impact of crude oil spillage on soil microbial populations, considering that crude oil is a complex mixture of hydrocarbons, which can exert toxic effects on microorganisms. Hydrocarbons present in crude oil, such as polycyclic aromatic hydrocarbons (PAHs), can inhibit microbial growth and disrupt microbial communities. Studies have shown that PAHs have detrimental effects on soil microbial diversity, enzymatic activities, and overall microbial function [24]. The lower TVC values in Nsisari Oken, Nse-Okulu Aleto, and Ejamah Ebubu may be attributed to the toxic effects of crude oil components on the indigenous microbial populations.

However, it is important to consider that microbial communities are highly resilient and can adapt to environmental stressors, including crude oil contamination. The observed variations in TVC among the different communities may be influenced by various factors such as the duration and intensity of oil exposure, the microbial community composition prior to the spill, and the presence of indigenous microorganisms capable of degrading hydrocarbons. In some communities, the higher TVC values compared to the control site suggest the potential presence of hydrocarbon-degrading microorganisms that can utilize crude oil as a carbon and energy source. These microorganisms, known as hydrocarbonoclastic bacteria, have the ability to degrade and metabolize hydrocarbons, thus contributing to the natural attenuation of oil contamination in soil [25,26].

4. CONCLUSION

Crude oil pollution in Eleme, impacted the physicochemical and microbiological parameters of soil. Leading to general increase in heavy metals, TPH, BTEX and microbial population in the soil. The pollution status reaffirmed the need to remediate the soil to restore its productive capacity to sustain life.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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