BENIN JOURNAL OF PHYSICAL SCIENCES
BJPS Vol. 2(1), June, pg. 88-107 (2025)
ISSN 3043-6931(Print)
3043-694X(Online)
www.bjps.org.ng

Heavy Metals and Hydrocarbon Assessment in Soil; Implication as Source of Contaminants in Okerenkoko Community Warri South-West, Delta State, Nigeria.

T. J. GERMAN*, B. J. OWONARO, and J. CAESER

Department of Marine Geology, Nigeria Maritime University, Okerenkoko, Warri, Nigeria

Received: 01/04/2025 ***Accepted:*** 19/06/2025

Abstract

Heavy metal and hydrocarbon proportion in Okerenkoko Community, Delta State is alarming. Five (5) soil samples were collected randomly from the community, the collected samples were investigated to determine the effects of these substances in the soil to living things at large using Atomic Absorption Spectrometer (AAS) and Gas Chromatography respectively. The Heavy metal concentration investigated result show a range of: Fe (386.6 - 665.6 with mean value 502.3) mg/kg, Cu (11.3 - 29.8 with mean value 21.1) mg/kg, Pb (0.388 - 0.523 with mean value 0.46) mg/kg, Cr (6.53 - 8.24 with mean value 7.23) mg/kg, Zn (37.5 - 63.3 with mean value 50.1) mg/kg, the average proportion of the heavy metals occurred in order of Fe>Zn>Cu>Cr>Pb. From the study, it showed that the concentration of most of the heavy metals in the soil falls below the level, meanwhile Zn has high concentration level when compared with the standard of World Health Organization (WHO) permissible limit. This implies that Okerenkoko Community is still contamination free with respect some specific heavy metals and notwithstanding, caution has to be taken to prevent potential future contamination and Zn with high concentration of about 50 mg/kg should call for immediate remediation. Furthermore, the concentration of hydrocarbon (TOC and THC) ranges from: TOC (18.28 - 31.53 with mean value 24.52) %, THC (250.53 - 874.74 with mean value 566.74) g/kg, the investigation of Total Organic Carbon (TOC) and Total Hydrocarbon Content (THC) showed the community has an carbonate soil as the Total Organic Carbon level goes beyond 12 - 18% in concentration which is considerably high in concentration.

However, under different conditions, this TOC level can be considered both beneficial and harmful to the survival of plants. From the THC investigation, it was also observed that

*Corresponding author e-mail: joshua.german@nmu.edu.ng

the soil in Okerenkoko Community is Highly Contaminated and this contamination is believed to be associated with petroleum spills from oil tankers, local means of production and transportation of petroleum products.

Keywords: *Heavy metal, Concentration, Okerenkoko, Limit, WHO, TOC, THC*

1. INTRODUCTION

Oil Spills and Leaks accidental releases from oil extraction, transportation, and storage processes can contaminate soils with hydrocarbons. The research on heavy metals assessment and total hydrocarbons in soils of Okerenkoko community, The Niger Delta Basin, investigates the extent of environmental contamination in the area. Nigeria, is of particular interest due to its proximity to oil exploration and production activities. These activities often result in the introduction of heavy metals and hydrocarbons to the environment, posing serious threats to human health and ecosystem integrity.

The research involves soil sampling from various locations within the community and subsequent analysis to determine heavy metals (Iron, Copper, Lead, Chromium and Zinc) concentrations together with total hydrocarbons derived from petroleum products. By assessing the levels of these contaminants in the soil, the study seeks to understand the magnitude and extent of pollution in Okerenkoko with potential implications on the local environmental and the physical wellbeing of the local population.

Niger Delta Basin, Nigeria has about over 31 million people population and is described as Nigeria's economic heartbeat owing to its rich oil and gas deposits (Atubi, 2015; Boris, 2015). Heavy metals assessment and total hydrocarbons in soils is a pressing environmental challenge with profound consequences for ecosystems, agriculture, and human health. Heavy metals like Lead, Iron, Manganese, Chromium and Copper are introduced into the soil through industrial activities, agricultural practices, and atmospheric deposition. Simultaneously, total hydrocarbons, including petroleum-derived compounds, enter the soil from sources like oil spills, industrial discharges, and urban runoff.

Effects: The Effects which the presence of Hydrocarbons in soils may pose can be sub-divided into two Environmental Impact (Soil quality degradation, toxicity to soil organisms, water contamination, air quality risk) and Health Impact (Human exposure through direct ingestion of contaminated soil or water, Inhalation of volatile hydrocarbons can affect respiratory health).

These contaminants persist in the environment, disrupting soil health, reducing agricultural productivity, and causing severe risks to wildlife as well human populations. Knowledge of the sources, effects, heavy metals interactions and hydrocarbons in soils is of utmost importance for developing effective remediation strategies and mitigating their adverse impacts on the environment.

Geological Setting

The location of study is situated in the Niger Delta region of Nigeria, a geologically significant area known for its rich hydrocarbon resources and complex geological formations. The geology of Okerenkoko, like much of the Niger Delta, is characterized by sedimentary processes and formations that have evolved over millions of years.

Okerenkoko Community is the location area is a major and one of the most populated Community in Gbaramatu Kingdom, Warri South-West Local Government Area, Delta State, Nigeria. The area falls within the coordinate of latitude 05°37’39.22” to 05°37'10.12” N and longitude 05°23'30.64" to 05°23’08.79” E sitting over a surface area of about 1.32 square kilometers. This area can be best described as a transitional environment which is an environment that lies between the continental environment and the marine environment.

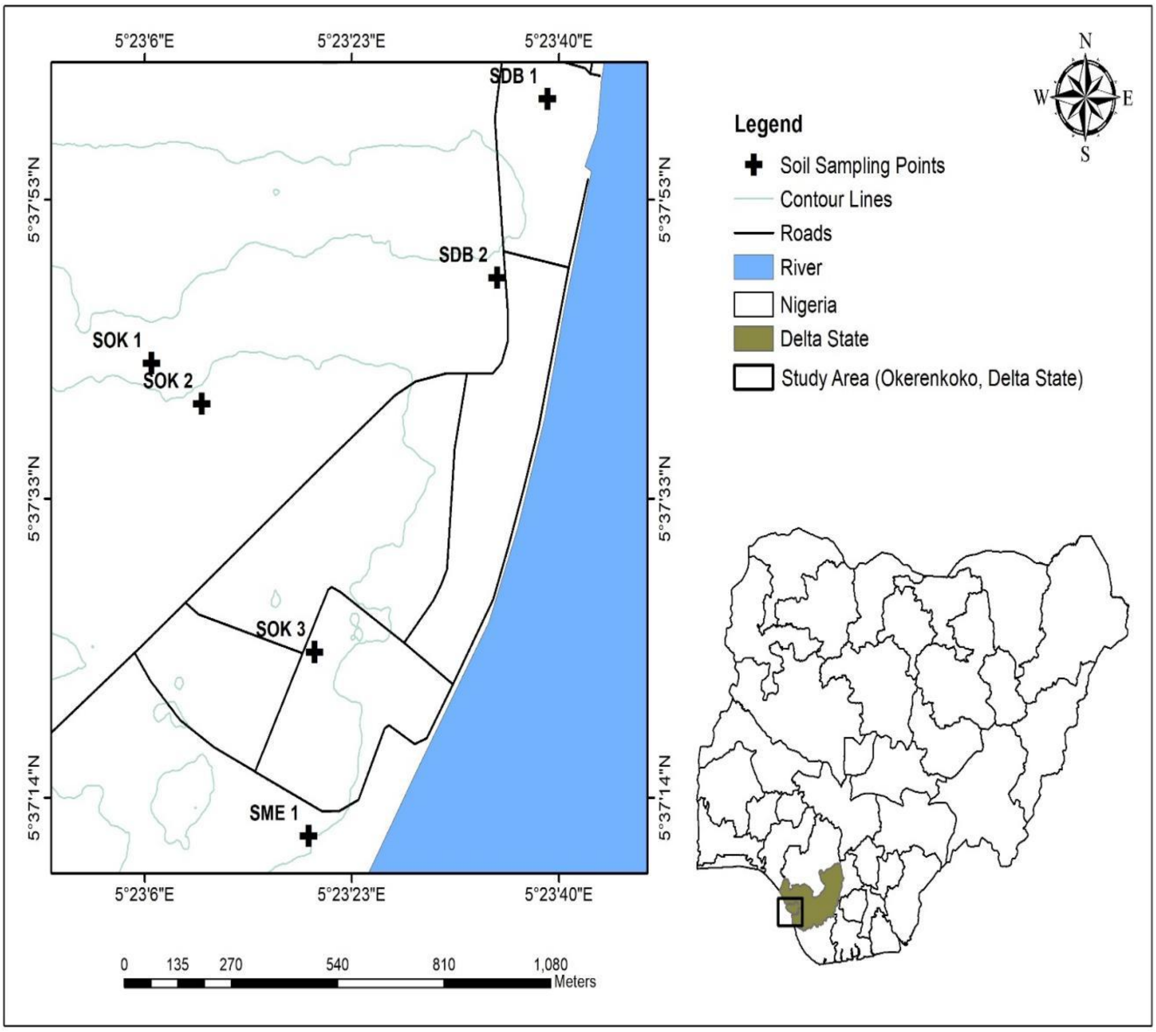

Figure 1: *Map of Study Area (Source: Prepared by author using ArcGIS v10.7; data extracted from USGS (STRM Water Bodies), BBBike Extracts, Google Earth Pro and Hand-Held GPS Receiver, 2025.)*

2. MATERIALS AND METHOD

A total five (5) samples were collected randomly from depth 1 ft in Okerenkoko Community and appropriately bagged in a well labeled sample collection bag for preservation before analysis in a laboratory. The co-ordinates of the sampling locations were correctly acquired and recorded using a portable Global Positioning System (GPS) Device.

Materials: The materials used for sample collection are; Soil auger, Sampling bags, Field notebook, Masking tape, Pen, Marker, Measuring tape and Global Positioning System (GPS)

Sample Preparation: The samples were well dried under monitored temperature to remove water, prevent microbial activity, easy handling and for appropriate preservation. The dried samples were then crushed. The prepared samples were kept in a well labeled sachet sample bags according to sampling points.

Analytical Procedure: The laboratory analysis was carried out at the laboratory in Benin, Edo State, Nigeria. By virtue of the research, the following heavy metals and hydrocarbon parameters were analyzed Iron (Fe), Copper (Cu), Lead (Pb), Chromium (Cr), Zinc (Zn), TOC and THC, Hydrocarbons: TOC and THC

Heavy Metals: Atomic absorption spectrophotometer (AAS) was utilized in determining the heavy metals in the sample. AAS is an analytical procedure utilized in establishing the quantitative chemical elements that use the absorption of optical radiation (light) by free atoms in the gaseous state. AAS can be utilized in generating more than 70 important elements in solution.

Atomic absorption spectrophotometer's working principle is based on the sample being aspirated into the flame and atomized when the AAS's light beam is directed through the flame into the monochromator and onto the detector that measures the level of absorbed light by the atomized element in the flame. Since metals have their own characteristic absorption wavelength, a source lamp composed of that element is used, making the method relatively free from spectral or radiational interferences. The quantity of energy of the featuristic wavelength absorbed in the flame is proportional to the concentration of the elemental sample.

TOC: Equipments includes Burettes, Pipette, Conical flask, Beaker, Retort stand, Weighing Balance**,** Spatula**,** Glass funnel. Analytical reagent and samples were prepared for analysis then measured and calculated after analysis (Organic matter (%) = % TOC × 1.724)

THC: Labortory Equipments include; A Hewlett Packard (HP) 5980 chromatograph equipped with Flame Ionization Detector or Upgrade, Computer system with Agilent Chem-station application software, Fume hood, Beaker, Volumetric flasks, Rotary evaporator, Measuring cylinder, 2mL GC vial bottles, Mechanical shaker, Weighing balance, Spatula, Glass stirring rod, Micro syringe, Micropipette, Pipette, Pipette filler, Glass funnel, Separatory funnel, Retort stand, Fractionating column, Mortar and pestle. Sample preparation involves extraction of soil sample followed by an injection into the gas chromatography which seperates the components based on interaction the detector generates a signal proportional to the concentration of each hydrocarbon component passing through it.

3. RESULT AND DISCUSSION

Results

Table 1: *Analytical Result in comparison with W.H.O allowable limits*

PARAMETERS	UNIT	SOIL SAMPLES					MEAN	W.H.O PERMISSIBLE LIMIT IN SOILS
		SDB 1	SOK 3	SDB 2	SOK 1	SME 1		
Iron (Fe)	**mg/kg**	386.6	531.6	435.4	665.6	492.4	**502.3**	**50,000**
Copper (Cu)	**mg/kg**	29.8	16.9	11.3	24.6	23.0	**21.1**	**36**
Lead (Pb)	**mg/kg**	0.523	0.388	0.467	0.512	0.422	**0.462**	**85**
Chromium (Cr)	**mg/kg**	8.24	6.98	7.23	6.53	7.17	**7.23**	**100**
Zinc (Zn)	**mg/kg**	54.8	63.3	37.5	43.6	51.3	**50.1**	**50**
TOC	%	18.28	27.62	31.53	21.54	23.65	**24.52**	
THC	**g/kg**	250.53	702.10	874.74	404.21	602.11	**566.74**	

The result shows the concentration of heavy metals; Iron (Fe), Copper (Cu), Lead (Pb), Chromium (Cr) and Zinc (Zn), as well as the Total Organic Content and Total Hydrocarbon Content TOC and THC respectively contained in soil samples from five sampling stations. The result shows heavy metals concentration; Iron (Fe), Copper (Cu), Lead (Pb), Chromium (Cr), Zinc (Zn), as well as Total Organic Content and the Total Hydrocarbon Content TOC and THC respectively contained in the soil samples from the five sampling stations.

From the result (Table 1), the concentration of Iron (Fe) ranges from 386.6 to 665.6 mg/kg and 502.3 mg/kg average concentration. Copper (Cu) ranges from 11.3 to 29.8 mg/kg and 21.1 mg/kg mean concentration. Lead (Pb) ranges from 0.388 to 0.523 mg/kg and 0.462 mg/kg average concentration. Chromium (Cr) ranges from 6.53 to 8.24 mg/kg and 7.23 mg/kg average concentration. Zinc (Zn) ranges from 37.5 to 63.3 mg/kg and 50.1 mg/kg mean concentration. The mean concentration of the heavy metals occurred in the order Fe>Zn>Cu>Cr>Pb. The maximum mean concentration was exhibited by Iron (Fe) (502.3 mg/kg) while the least mean concentration was exhibited by Lead (Pb) (0.462 mg/kg)

The Total Organic Content (TOC) of the soil samples ranges from 18.28 to 31.53 % with a mean percentage of 24.52 % and the Total Hydrocarbon Content (THC) ranges from 250.53 to 874.74 g/kg with a mean hydrocarbon concentration of 566.74 g/kg.

Discussion

Iron (Fe): Iron Concentration in soil samples analyzed is maximum in SOK 1 (665.6 mg/kg) sample and minimum in SDB 1 (386.6 mg/kg) sample. Comparing the result with WHO maximum allowable limit of 50,000 mg/kg for Iron in soil, none of the samples collected exceeds the recommended level of 50,000 mg/kg, they are all still within the limit. This implies that the concentration of Iron in all sampling location of Okerenkoko Community is still permissible.

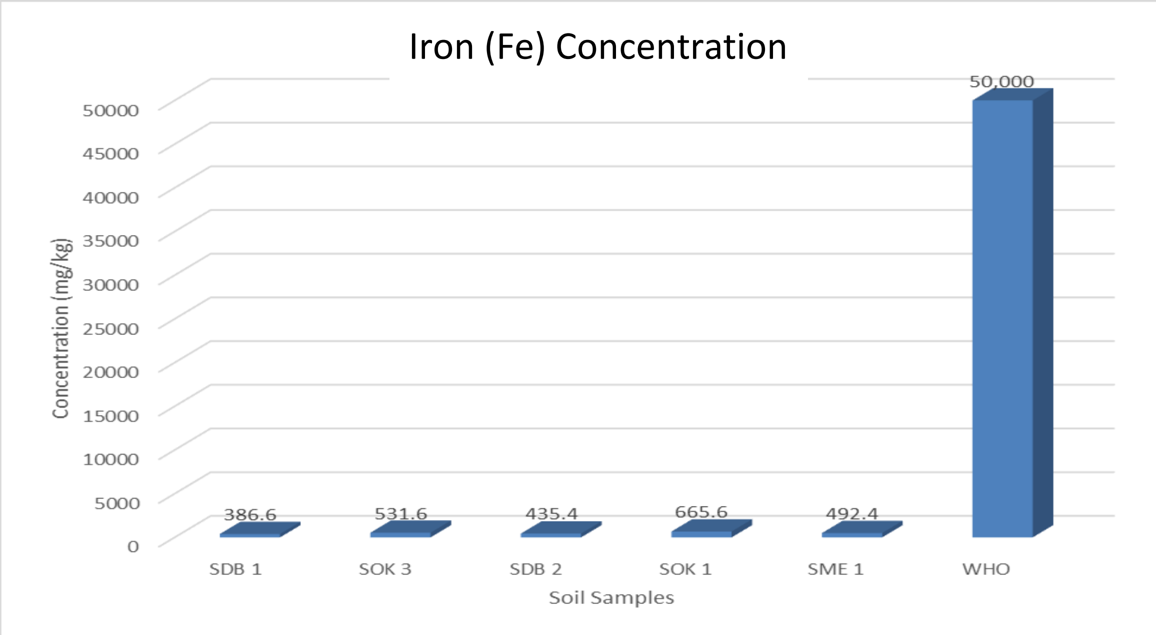

Figure 2: *Sample Result showing Concentration of Iron (Fe)*

Lead (Pb): Lead concentration in soil samples collected and analyzed has the maximum in sample SDB 1 (0.523 mg/kg) and the lowest concentration in sample SOK 3 (0.388 mg/kg) comparing the result with WHO maximum allowable limit for Lead in soil which is 85mg/kg, none of the samples collected exceeds the recommended level, they are all still within the limit. This implies that the concentration of Lead in all sampling location of Okerenkoko Community is still permissible.

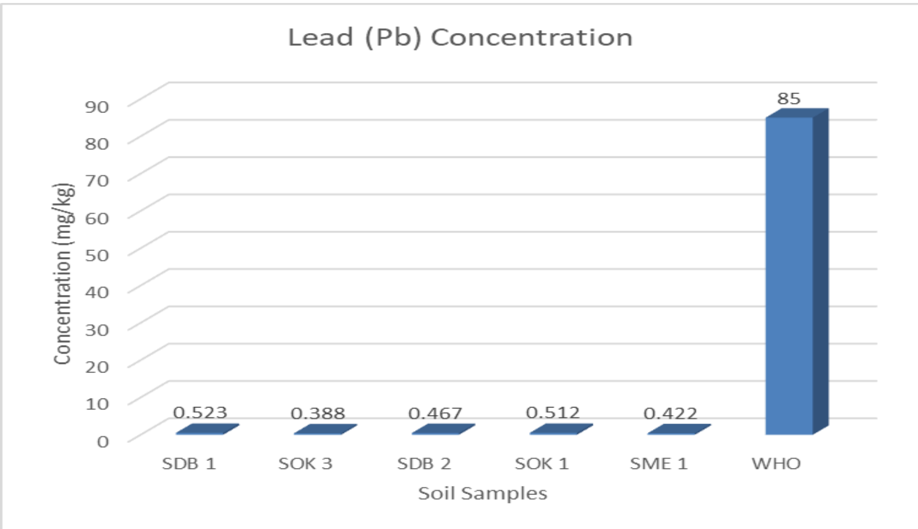

Figure 3: *Sample Result showing Concentration of Lead (Pb)*

Copper (Cu): Copper concentration in soil samples analyzed has the maximum in sample SDB 1 (29.8 mg/kg) and the minimum concentration in sample SDB 2 (11.3

mg/kg) comparing the result with WHO maximum permissible limit for Copper, none of the samples collected exceeds the recommended level of 36 mg/kg, they are all still within the limit. This implies that the concentration of copper in all sampling location of Okerenkoko Community is still permissible.

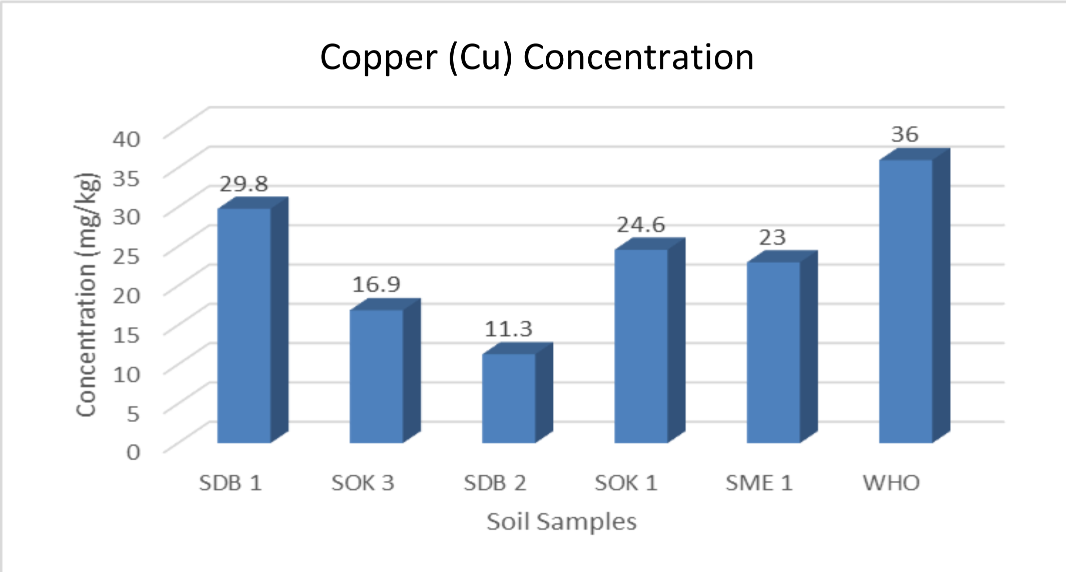

Figure 4: *Sample Result showing Concentration of Copper (Cu)*

Chromium (Cr): Chromium concentration in soil samples analyzed has the highest in sample SDB 1 (8.24 mg/kg) and the minimum concentration in sample SOK 1 (6.53 mg/kg) comparing the result with WHO highest permissible limit of 100 mg/kg for Chromium in soil, none of the samples collected exceeds the recommended level of 100 mg/kg, they are all still within the limit. This implies that Chromium concentration in all sampling location of Okerenkoko Community is still permissible.

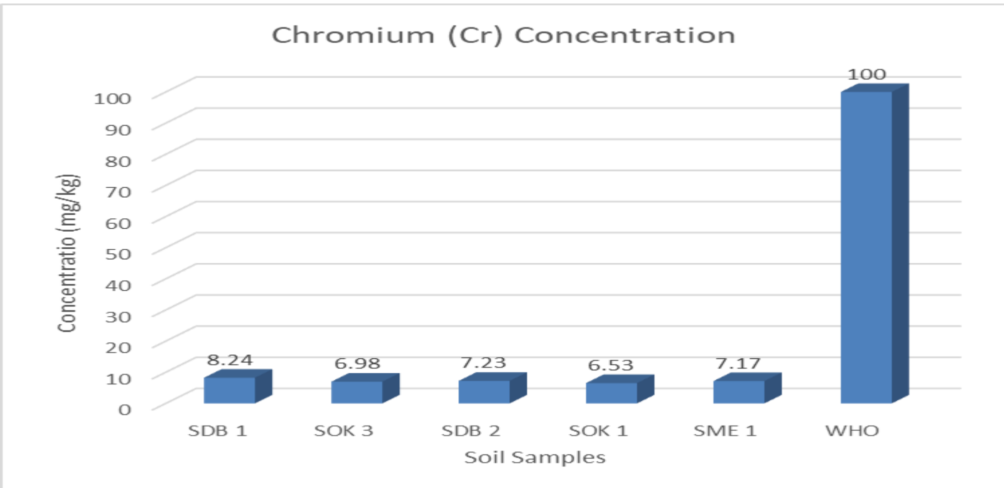

Figure 5: *Sample Result showing Concentration of Chromium (Cr)*

Zinc (Zn): Zinc concentration in soil samples analyzed has the highest in sample SOK 3 (63.3 mg/kg) and the lowest concentration in sample SDB 2 (37.5 mg/kg) comparing the result with WHO maximum permissible limit for Lead in soil which is 50 mg/kg, samples SDB 1, SOK 3 and SME 1 exceeds the recommended level, they are not within the limit. This implies that the concentration of Lead in these three (3) samplings locations of Okerenkoko Community is not permissible.

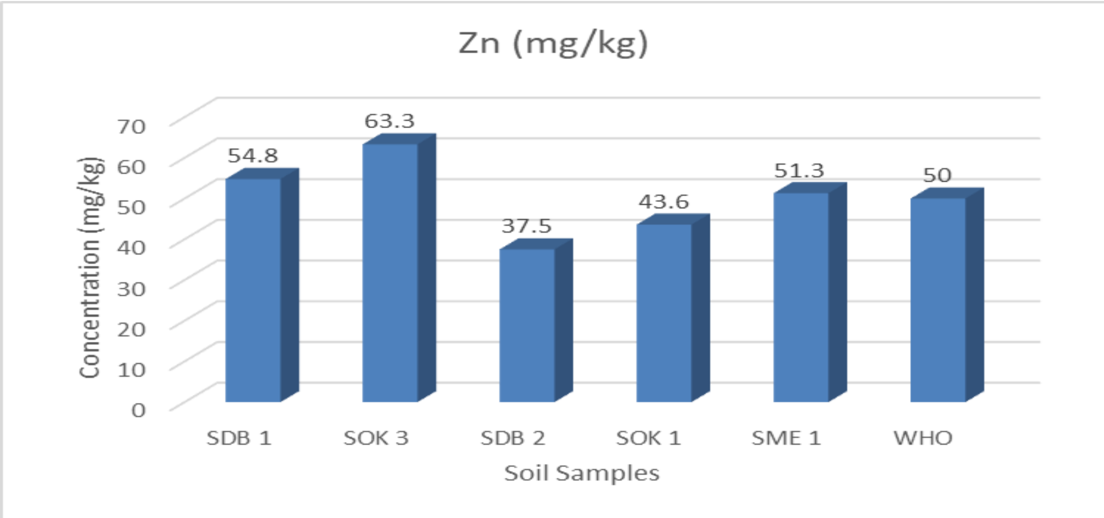

Figure 6: *Sample Result showing Concentration of Zinc (Zn)*

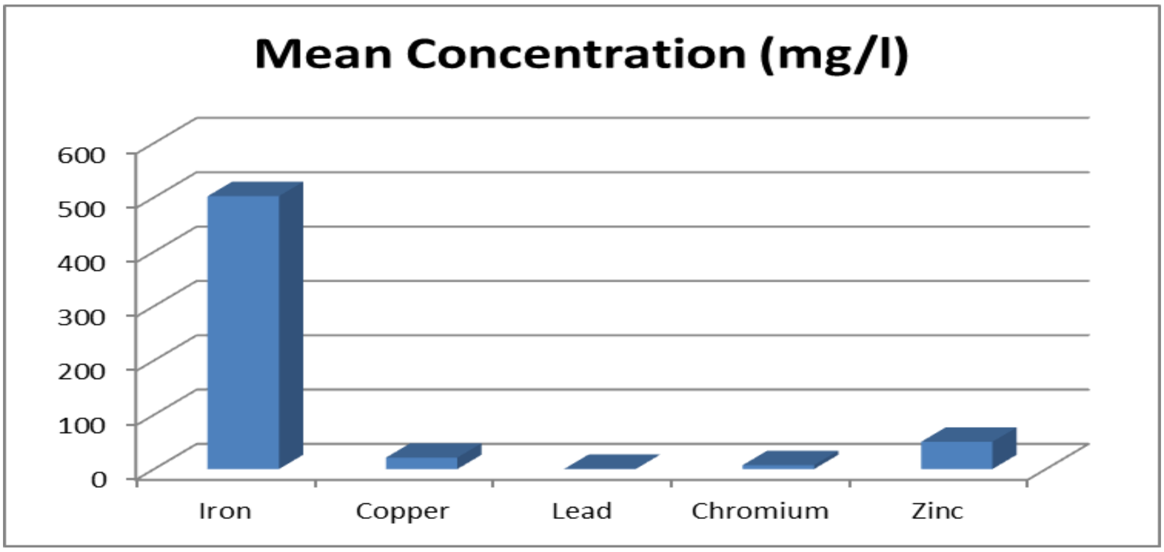

Figure 7: *Mean Concentration of Heavy Metals across the Study Area of Five Sampling Points*

Heavy metals (Fe, Cu, Pb, Cr, and Zn) concentration in soil samples within the scope of this study was determined, and the degree of the heavy metal contamination in the soil was assessed after correlation with the highest permissible limit of the World Health Organization (WHO). Over permitted levels, heavy metals in soil can be considered extremely dangerous (Ogbulie, 2021). Since toxic heavy metals like Pb, Co, and Cd cannot be broken down by the body and can accumulate in living things, they can be distinguished from other contaminants. This allows them to cause a variety of illnesses and problems, even at very low doses (Pehlivanet *et al.*, 2009).

Geologically, during the rock weathering process, heavy metals are released into the soil and rivers. For example, sulfide minerals in igneous and geology. Areas with mineral-rich rocks, like sulfide deposits, are likely to have higher concentration of certain metals.

Volcanic eruptions releases gases and ash that contains heavy metals that settle on the landscape, where they can be incorporated into the soil and washed into the nearby river thereby, concentrating both soils and rivers.

The natural process of erosion especially in mountainous or hilly regions, can carry metal-rich sediments into rivers which circulates in river beds and floodplains creating natural contamination zones. Heavy metals bound to these sediments can be released over time.

The geological occurrence of hydrothermal vents can carry metal-rich deposits from deep down the earth's crust for deposition on the oceanic or continental crust thereby concentrating the surround soil or river with these metals.

The mean concentration of the heavy metals across all locations in the study area occurred in the order Fe>Zn>Cu>Cr>Pb. Maximum mean concentration is exhibited by Iron (Fe) (502.3 mg/kg) while the least mean concentration was exhibited by Lead (Pb) (0.462 mg/kg).

This abnormal concentration of Zinc in these locations and study area at large may pose a variety of risks to both plants and animals (Chen et al., 2022)

i. Toxicity to Aquatic Life: Over time, due to the nature of the environment of this study (Transitional Environment), factors such as erosion may aid the movement of this Zinc-rich soil in form of sediments into the nearby water body as earlier discussed thereby in turn increasing the Zinc concentration in the water. Elevated levels of Zinc in water bodies can be toxic to aquatic organisms such as fishes, invertebrates, algae, etc. this toxicity can disrupt ecosystems by affecting food chain and biodiversity
ii. Impact on Soil Health: Zinc can contaminate soils especially through manufacturing activities, mining and agricultural work utilizing Zinc-

containing fertilizers. Great poportion of Zinc in soil can practically slow plant growth and affect soil microbial communities.

iii. Disruption of Nutrient Balance: Zinc contamination can disrupt nutrient cycles in aquatic ecosystems and soils, altering essential nutrients presence like phosphorus and nitrogen. This imbalance can further impact the development of plant as well as overall ecosystem health.

iv. Human Health Concerns: While primarily an environmental concern, high levels of zinc in water sources can leads human health risk from contaminated drinking water or eating contaminated fish and crops.

Although, zinc is an essential mineral that plays a crucial role in numerous physiological functions within the human body such as helping in; immune function, cell growth and division, wound healing, hormone regulation, sensory functions, bone health, brain functions etc (Ganz, *et al.,* 2012). however as the saying goes, "Too much of everything is bad" the presence of this essential mineral in the body in an abnormal ratio may also lead to Gastrointestinal Disturbance, Copper deficiency, Immune system dysfunction, Neurological Symptoms, Kidney and Liver Damage, Hormonal Imbalance amongst others.

TOC: The TOC reported for the area has the highest concentration in sample SDB 2 (31.53%), the lowest concentration at SDB 1 (18.28%) and a mean concentration of 24.52%.

Soils having more than 12–18% organic carbon are generally classified as organic soils. Hence from Figure 9 below, the result for the study area indicates the presence of an Organic Soil in the study area. An organic soil, also known as peat or histosol, is a type of soil that contains a relatively great level of organic matter derived from decomposed plant material. Organic soils form under specific conditions where the amount of accumulated organic matter exceeds the rate of decomposition. These conditions typically occur in waterlogged or poorly drained environments such as bogs, marshes, and wetlands as in the studied location.

The organic nature of the soil in the studied location may affect plants negatively in terms of;

I. Nutrient Availability: Organic soils can have low nutrient availability, especially nitrogen and phosphorus, due to the acidic and anaerobic (low oxygen) conditions that slow down decomposition and nutrient release.

II. Acidic pH Tolerance: Organic soils tend to have high acidic pH levels, which can affect nutrient uptake by plants. Acid-loving plants (acidophiles) are better adapted to these conditions, while plants that prefer neutral to alkaline soils may struggle.

III. Compaction: If improperly managed, organic soils can become compacted, which hinders root growth and water infiltration.

However, this soil nature can also affect the growth of plants positively in terms of;

I. Water Management: The high water-holding capacity of organic soils can be beneficial for plants that prefer consistently moist conditions. However, excessive waterlogging can restrict oxygen availability to plant roots, which can be detrimental if not properly managed.

II.Organic Matter Benefits: Organic soils are rich in organic matter, which provides nutrients as it decomposes. This can benefit plant growth once decomposition processes release these nutrients, although the availability may be slower compared to mineral soils.

Species of plants that survive best in organic soils include Bog Plants (Mosses, Carnivorous Plants), Grasses and Sedges, Wetland Shrubs, Aquatic Plants (Water Lilies, etc), Ferns amongst others.

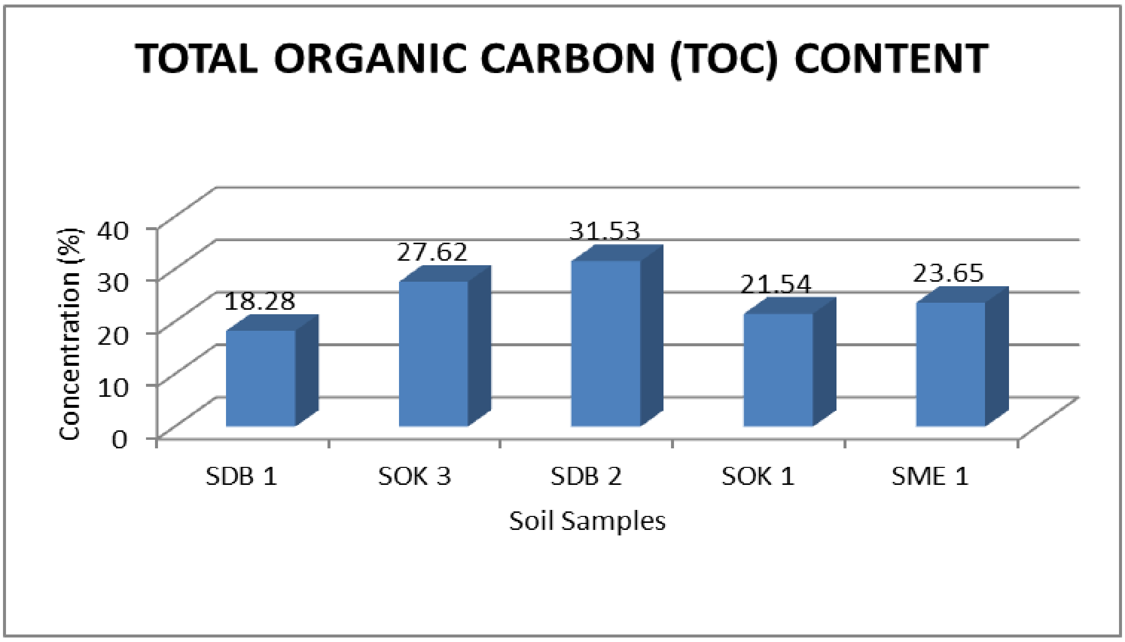

Figure 8: *Sample Result showing TOC Concentration*

THC: The THC from the result in the study area had the highest concentration in soil sample SDB 2 (874.74 g/kg), the least concentration in soil sample SDB 1 (250.53 g/kg) and a mean concentration of (566.74 g/kg).

The concentration of the Total Hydrocarbon Content analyzed in the soil samples surpasses DRP set limit of 50mg/kg, this concentration level suggests serious contamination in the study area. This contamination is associated with gas flaring, industrial pollutants and oil spills of petroleum contaminants from oil tankers, flow stations, etc. which somehow finds its way into the soils in the community possibly during high tides or by artificial tides or waves generated by moving sea vessels and speed boats plying the routes around the community. Ejiogu *et al.*, (2019) in a similar work on garden soils of Bonny Island reported same observation. From this result, the pollution of aquatic ecosystems in the study area with crude oil and other petroleum products lowers the major functions of the fauna and flora. It has caused the destruction of aquatic habitats in some communities in Gbaramatu kingdom and great level of swamps and rivers contamination making them unsuitable for fishing (Asadu, 2022).

The soil pollution by hydrocarbon components from local crude oil refineries, has caused lower agricultural yield by the loss of soil quality, leaching and erosion. The Total Hydrocarbon contamination in the location area has caused crude oil spillage to soils from local crude oil refineries which disturbs healthy microbial interactions, and causes high human health risks owing to their toxic, mutagenic and carcinogenic properties. The Niger Delta Basin, Nigeria is known for its great amount of crude oil production (Okpo and Eze, 2012). By the abundance, the region still suffers from low supply of petroleum products like gasoline, kerosene, diesel oil and lubricating oil owing to great request for diesel and other petroleum products The inadequate supply of refined petroleum products (diesel, kerosene and gasoline) has resulted to increased prices, leading consumers to result to cheap, low quality, adulterated fuels which are locally refined by sub-standard processes.

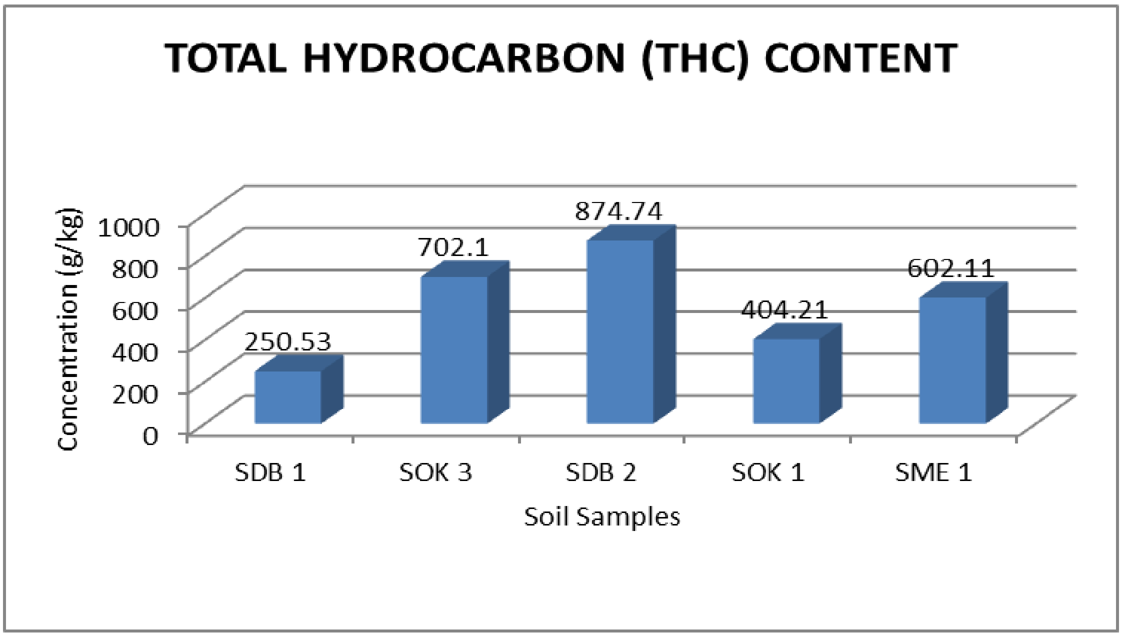

Figure 9: *Sample Result showing THC Concentration*

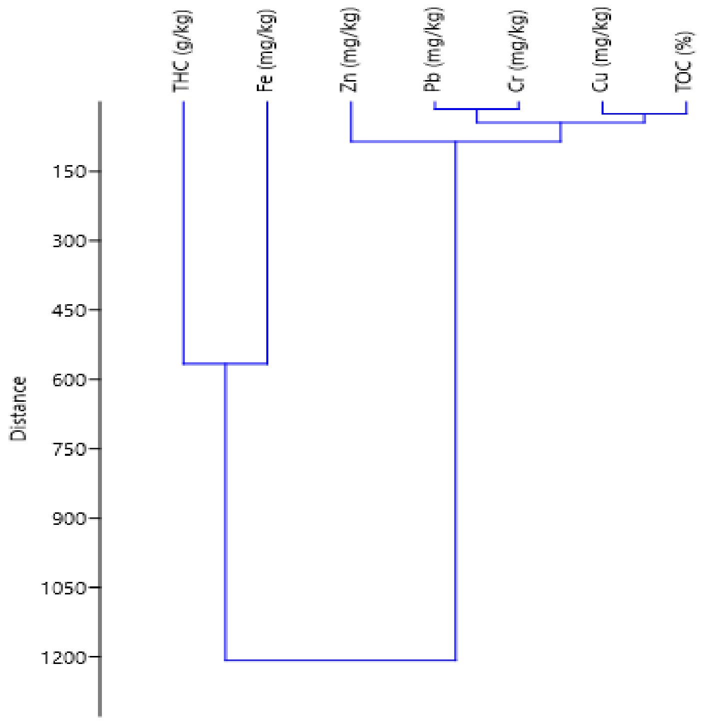

Figure 10: *Cluster plot showing Heavy Metal Contaminants Concentration*

The above figure illustrates a clustered plot that shows the concentration pattern of parameters including heavy metals as well as contaminants (Hydrocarbons) analyzed from the samples retrieved from the study area. From the representation in figure (10s), the TOC, Copper, Chromium (Cr) and Lead (Pb) show similarities in concentration range while Zinc (Zn) stands on its own. THC and Iron (Fe) respectively, are on the same concentration level.

The study findings indicate that the soil samples' mean concentration of heavy metals ranged from about 0.462 through 502.3 mg/ kg. This may be considered a rather low outcome when compared to the WHO's acceptable limits for some of the heavy metal analyzed. (Table 1) above shows the concentration of heavy metals and analyzed hydrocarbon parameters in the soil samples collected (Wang et al., 2017; Omorogieva and Imasuen, 2013) from selected locations in Okerenkoko Community, Delta State. Heavy metals (Fe, Cu, Pb, Cr, and Zn) concentration in soil samples within the scope of this study was determined, and the degree of the heavy metal contamination in the soil was assessed after correlation with the highest allowable point of the World Health Organization (WHO). Over permitted levels, heavy metals in soil can be considered extremely dangerous (Ogbulie, 2021). Since toxic heavy metals like Pb, Co, and Cd cannot be broken down by the body and can accumulate in living things, they can be distinguished from other contaminants. This allows them to cause a variety of illnesses and problems, even at very low doses (Pehlivanet et al., 2009).

Geologically, during the process of weathering of rocks, heavy metals are released into soil and rivers. For example, sulfide minerals in igneous and geology. Areas with mineral-rich rocks, like sulfide deposits, are likely to have higher concentration of certain metals.

Volcanic eruptions releases gases and ash that contains heavy metals that settle on the landscape, where they can be incorporated into the soil and washed into the nearby river thereby, concentrating both soils and rivers.

The natural process of erosion especially in mountainous or hilly regions, can carry metal-rich sediments into rivers which circulates in river beds and floodplains creating natural contamination zones. Heavy metals bound to these sediments can be released over time.

The geological occurrence of hydrothermal vents can carry metal-rich deposits from deep down the earth's crust for deposition on the oceanic or continental crust thereby concentrating the surround soil or river with these metals.

4. CONCLUSION

The investigation on the evaluation of the accumulation and occurrence of heavy metals as well as total hydrocarbons in the soil samples extracted from Okerenkoko Community in Delta State, Nigeria. Heavy metals contamination assessment (Fe, Pb, Cu, Zn and Cr) in the soils from the location area was made in comparison and profiled according to the WHO maximum allowable limit for heavy metals in soil, and was observed that the concentration of most of the heavy metals in the soil falls below the level, meanwhile Zn has high concentration level when compared with the World Health Organization (WHO) allowable limit. this implies that Okerenkoko Community is still contamination free with respect some specific heavy metals and notwithstanding, caution has to be taken to prevent potential future contamination and Zn with high concentration of about 50 mg/kg should call for immediate remediation.

However, under different conditions, this TOC level can be considered both beneficial and harmful to the survival of plants. From the THC investigation, it was also observed that the soil in Okerenkoko Community is Highly Contaminated and this contamination is believed to be associated with petroleum spills from oil tankers, local means of production and transportation of petroleum products. It is feasible to conclude that regular and continuous monitoring of these heavy metals and hydrocarbon concentration in soils is necessary in order to keep the long-term effect of influence from oil industries and their contribution to the contamination of soils in check.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

REFERENCES

[1] Asadu, K. O. (2022). Organic geochemistry of Gbaramaatu mangrove sediments, Warri *South West, Delta State, Nigeria. Department of Marine Geology, Nigeria Maritime* University, Okerenkoko.

[2] Atubi, A. O. (2015). Effects of oil spillage on human health in producing communities of Delta State, Nigeria. *European Journal of Business and Social Sciences*, 4(8), 14-30.

[3] Boris, O. H. (2015). Upsurge of oil theft and illegal bunkering in the Niger Delta region of Nigeria: Is there a way out? MCSER Publishing.

[4] Chen, H., Tang, D., Chen, S. and Tang, S. (2022). Geochemical characteristics of mudstones from the lower cretaceous strata of the Jixi Basin, NE China: implications for organic matter enrichment. *Int. J. Coal Geol.,* 249, 103904.

[5] Ejiogu, B.C., Opara, A.I., Nwosu, E.I., Nwofor, O.K., Onyema, J.C and Chinaka, J.C. (2019). Estimates of aquifer geo-hydraulic and vulnerability characteristics of Imo State and environs, Southeastern Nigeria. *Environmental monitoring and assessment*, 191,1-19.

[6] Ganz, T. and Nemeth, E (2012) Iron homeostasis in host defense and imflammation. *Nature Reviews immunology*, 12(3): 233-238

[7] Ogulie, T.E., Okore, C.C and Ejele, A.E. (2021). Comparative assay on heavy metals surfactant, crude biosurfactant and the producing bacteria. Animals of Oradea University 28(1).

[8] Okpo, O. C., & Eze, R. C. (2012). Vandalization of oil pipelines in the Niger Delta region of Nigeria and poverty: An overview. *Studies in Sociology of Science*, 3(2): 18.

[9] Omorogieva, O. M., & Imasuen, O. I. (2013). Comparative study of heavy metals distribution in a mechanic workshop and a refuse dumpsite in Oluku and Otofure, Benin City, Edo State, southwestern Nigeria. *Journal of Applied Sciences and Environmental Management*, 17(3): 425-430.

[10] Onumajuru, A., Ogbulie, J., & Nweke, C. (2021). Molecular characterization and toxicity of heavy metal quinary mixtures on Enterobacter cloacae isolate from Nworie River. *Asian Journal of Biotechnology and Bioresource Technology,* 7(4): 52-61.

[11] Pehlivan, EAlton, T., Cetin, S. and Bhangra, M.I. (2019). Lead sorption by waste biomass of hazardoud and almond shell. *Journal of hazardous materials*, 167(1-3): 1203-1208.

[12] Reijers, T. J. A., Petters, S. W., & Nwajide, C. S. (1997). The Niger Delta Basin. In R. C. Selley (Ed.), African basins: Sedimentary basins of the world 3 (pp. 151-172). *Elsevier Science*.

[13] UNEP. (2011). Oil spills injustices in the Niger Delta region: Reflections on oil industry failure in relation to the United Nations Environment Programme (UNEP) report. *UNEP Report*, 2(1), 26-37.

[14] Wang, S., Wu, W., Liu, F., et al., (2017). Accumulation of heavy metals in soil-crop systems: A review for wheat and corn. *Environmental Science and Pollution Research*, 24(15), 15209–15225.

[15] World Health Organization. (2006). Permissible limits of heavy metals in soil and plants. Geneva, Switzerland.