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Potential Ecological Risk of Swamps Sediments in Illegal Refineries Sites: A Case Study of Isoko South, Delta State, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author ORA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author HU managed the analyses of the study and managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

This study was carried to determine the level of heavy metals toxicity in swampy forest of Isoko South, Delta State, Nigeria. Sediments samples were collected from nine spatial points, within the swampy forest of Enwhe community of Delta State, Nigeria. The study area contained clusters of illegal crude oil refineries, before they were destroyed by the Nigeria military, during the first quarter of 2020. A total area of 1 km^2 of the swampy environment was covered in this study. Six toxic heavy metals (Cu, Zn, Cr, Cd, Pb, and Ni) contents, in the sediments were determined in accordance to international approved standards. The results revealed that the activities of the illegal refineries located in the study area, significantly increased the heavy metals toxicity in the sediments. When compared with the results obtained from a reference point, the concentrations of the heavy metals were significantly higher, across the study area. Within the study area, spatial points B and D sediments contained the highest heavy metals concentrations. In addition, the study revealed that contamination factor of the sediments ranged between moderate and high degree of heavy metals contamination. This portrayed the potential ecological risks of the illegal

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refineries activities, to the environment of the region. Therefore, if these illegal refineries activities are allowed to continue unabated, they will cause a serious ecological risk to the Niger Delta region ecosystems.

Keywords: Assessment; ecological risk; heavy metals; sediments; toxicity.

1. INTRODUCTION

Environmental conservation involves all the actions taken to protect the earth's planet and conserve its natural resources. Environmental conservation strives to protect the earth by protecting its vital resources [1]. Polluting the environment can sets off a negative chain of events that will hinders the growth and performance of plants and animals growing naturally. The accumulation of the poisonous heavy metals in sediments and their successive discharge into the underground or surface water bodies poses a serious threat to the environmental. The extent to which heavy metals contaminate the water bodies is highly influenced by their initial concentration, microbe's activities, chemical reactions, and the physicochemical properties of soil sediments [2]. Swamps and rivers sediments usually serve as a natural reservoir for heavy metals and other compounds [3].

Heavy metals are those elements with specific gravity greater than 4.0; while some help in sustaining human life in large quantity; others are poisonous to the body even in minute quantity [4]. Among the poisonous heavy metals are: cobalt (Co), copper (Cu), iron (Fe), manganese Mn), molybdenon (Mo), Zinc (Zn), etc. The occurrences of high concentration of poisonous heavy metals in sediments are mainly caused by human perturbations, and not through natural processes like rocks weathering [5]. These heavy metals pose a significant health hazards to plants and animals (including human beings) that inhabit in the environment. The health implications of heavy metals depend on the type of the heavy metal and amount of consumed by plants and animals. Cadmium even in small dosage can leads to kidney damage and hypertension; while mercury can leads to brain damage, speech impairment, and vision problem [6].

Heavy metals, just like other inorganic elements are non-biodegradable and they can persist in the environment for a long time [7]. Hence, they will accumulate in sediments and become concentrated within the food web, with the fishes accumulating them in their tissues, which human beings will finally consume [3,8]. According to Shuhaimi [9], sediment is a carrier and source of contaminants in aquatic environment; therefore if it is contaminated, it can leads to severe environmental problems. Sediment accumulate contaminants from untreated domestic and industrial effluents discharged onto the surface water, seepage from agricultural chemicals, atmospheric deposition, mining activities, indiscriminate discharge of petroleum hydrocarbons into the environment, etc. [10].

In the Niger Delta, illegal refineries are constructed locally with substandard materials to refine "stolen" crude oil. These illegal refineries lack basic wastes treatment systems; therefore, their wastes generated are discharge discriminately into environment (mostly the waters bodies), without proper treatment [11]. Studies have shown that indiscriminate disposals of petroleum products into the environment have led to increment in the heavy metals concentrations in the soils, waters bodies and their sediments. Oyo-Ita et al. [12] reported that sediments collected within the vicinity of crude oil spill sites contain significant amount of heavy metals [12]. Chukwujindu [10] stated that bioavailability and toxicity of heavy metals are influenced by the various forms and amount bound to the sediment matrices.

The waters bodies in the Niger Delta region of Nigeria serve as fishing grounds, and sources of domestic water supply. Therefore, it is essential have good information on the quality of the swamps and rivers sediments, since the region is not littered with clusters of illegal refineries. The principal objective of this study was to measure the contamination and investigate the distribution of six toxic heavy metals (Cr, Cd, Ni, Cu, Zn, and Pb), in sediments collected from swamps, where illegal refineries were located in Delta state. The results obtained from the study will provide vital information on the actual state of sediments contamination in the area; and identify the potential ecological risk levels of these heavy metals to the ecosystems. In addition, the results will be useful in planning effective remediation of the environment.

2. MATERIALS AND METHODS

2.1 Study Site Description

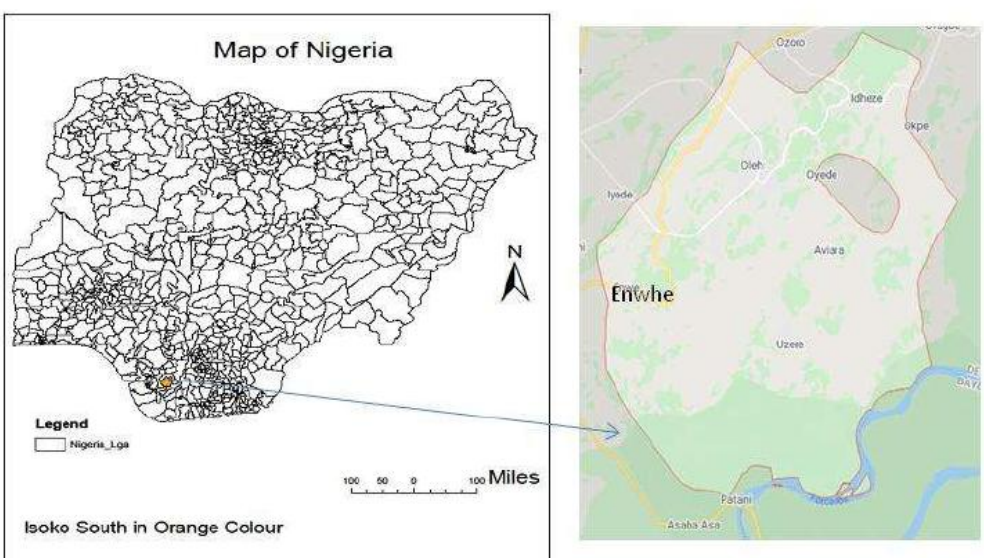
Delta state contains hundreds of active illegal refineries clusters, within the Niger Delta region of Nigeria. Apart from the wastes they discharged indiscriminately into the environment, during the process of crude oil refining into diesel and kerosene. Any petroleum products found within an illegal refinery site, are discharged in the environment untreated, during the its destruction by the Nigeria military (Fig. 1). The study area is located at Enwhe community, Isoko South Local Government Area of Delta State, Nigeria; with the following geographical coordinates Lat. 5°23'0" North and Long. 6°7'0" (Fig. 2). All the water bodies within the study area have seasonal flow pattern. They only flow during the peak of the rainy season (May to October); when the area experienced flooding due to robust runoffs from consistent heavy rainfalls.

2.2 Sample Collection and Preparation

Sediments samples were collected from eight designated sampling points. At each designated sampling point, three sediment samples were randomly taken. The sediment was collected by using the Van-Veen grab sampler at a depth of 0-10 cm. The sediments were coded in accordance to where they were collected, and stored in a specimen bag at a temperature of about 4^0C. All the designated points were located within the swampy environment where the illegal refineries were sited. A total area of 1 km^2 of the swampy environment was covered in this study. The samples were collected during the dry season in Nigeria (from February 2020 to March 2020), when the water volume was very low.

Fig. 1. Abandon Illegal crude oil refinery site

Another swampy environment about 40 km from study site was selected as the reference point (control). The control site has not history of crude oil pollution, and has no direct water flow interconnection with the study area. All the collected sediments samples were air-dried in the laboratory under ambient temperature (27±4^0C), before they were chemically analyzed for their heavy metals concentration.



Source: Google mapdata 2020

Fig. 2. Map of Nigeria showing Enwhe community

2.3 Soil Chemical Analysis

The dried sediment sample was grounded and sieved with a 2 mm gauge stainless sieve, to remove all roots, stones and other foreign bodies. Then 10 g of the sieved sample was transferred into a round bottom conical flask. The sediment sample inside the flask was digested with a mixture of concentrated HNO_3, HCl, and H_2SO_4; mixed together in the ratio of 5:1:1. The digested sediment was then filtered with a filter paper (Whatman No. 42), and the filtrate poured into a volumetric flask, before it was diluted with distilled water up to the 100 ml mark. The heavy metals (Cu, Zn, Cr, Cd, Pb, and Ni) concentrations in the sediment were then determined in accordance with ASTM D1971/4691 standard procedures, using the Atomic Absorption Spectrophotometer [13,14].

The laboratory tests were carried out at ambient laboratory temperature of 27±3°C, at the Soil and Water Laboratory of Delta State Polytechnic, Ozoro, Nigeria. All tests were done in triplicate and the average values recorded.

2.4 Pollution Indices

To access the contamination level of the heavy metals in the sediments, two major pollution assessment indices; Contamination Factor and Pollution Load Index were used.

2.5 Contamination Factor (C_f)

This is a ratio of the concentration of the heavy metal in the sediment to the concentration in the reference point, and it is calculated using Equation 1 [15].

$$\text{Contamination factor} = \frac{C_1}{C_2} \quad (1)$$

Where:

C_1 = concentration of heavy metal at a contaminated point;
C_2 = concentration of the same heavy metal at the reference point.

Contamination factor is classified as:

Low ($C_f < 1$);

Moderate ($C_f < 3$);

Considerable ($C_f < 6$);

Very high ($C_f \geq 6$) [16, 17].

2.6 Pollution Load Index (PLI)

This evaluates the pollution level of a sample by considering the combine effect of all the heavy metals present in the sample. It represents the rate at which the contaminant in the sample surpasses the mean reference point concentration. It is calculated as the nth root of the n contamination factors (C_{Fn}) for all the metals multiplied together, as shown in Equation 2 [17].

$$\text{PLI} = \sqrt[n]{\text{CF1} \times \text{CF2} \times \text{CF3} \times \text{CF4} \ldots \times \text{CFn}} \quad (2)$$

Where:

CF = contamination factor of each metal;
n = total number of metals.

If PLI is greater than 1 (PLI >1) it indicates a polluted condition and a deterioration of the environmental quality; and if PLI is less than 1 (PLI < 1) it indicates that there is no metal pollution in the area; while is PLI is equal to 1 (PLI=1), it indicates a baseline level of pollution [18,19].

2.7 Statistical Analyses

All the results obtained from the study were subjected statistical analysis using the SPSS 20.0 for Windows. The means were separated and compared with the aid of the Duncan's Multiple Range Test (DMRT) at ($p \leq 0.05$).

3. RESULTS AND DISCUSSION

The results of the heavy metals evaluated in the sediments collected from the study area are presented in Table 1. Generally, the spatial distribution of heavy metals in the sediments was highest in the samples collected from spatial points B and D (Table 1). The high heavy metals concentrations at spatial points B and D, compared to other spatial points could be attributed to the proximity of the collection points, to the point of discharge of the petroleum products. In related development, sediments samples collected from spatial points G and H, recorded the lowest concentrations of heavy metals. The concentrations of heavy metals in sediment differ significantly ($p \leq 0.05$) at the various spatial locations. This variation in the heavy metals concentrations in the study area could be attributed to the volume of wastes, and other effluents the spatial points received from the activities of the illegal crude oil refiners. Petroleum products can significantly altered the concentration of heavy metals in soils and sediments, and the concentrations of the heavy metals are highly influenced by the concentration of the petroleum products discharged into the environment and the soil physic-biological properties [20].

The study revealed that the activities of the illegal crude oil refineries, significantly ($p \leq 0.05$) increased the heavy metals concentrations of the swamp sediments. Apart from Nickel and cadmium, all the other heavy metals concentrations evaluated in the sediments collected were within the maximum permissible limits approved by international bodies like Department of Petroleum Resources (DPR), Canadian Environmental Quality Guidelines (CCME), etc. Nickel concentration was observed to be above DPR maximum limit at spatial points B and D; while cadmium concentration at all the nine spatial points sampled was above DPR limit of 0.8 mg/kg. The highest Lead concentration (48.97 mg/kg) was observed at spatial point B, while the lowest Lead concentration (20.24 mg/kg) was observed at spatial point A. According to the results, the lowest Zinc concentration (24.14 mg/kg) was record at spatial point G; while spatial point B recorded the highest zinc concentration (92.28 mg/kg). These heavy metals even though they are within the DPR limits, can accumulate with time and become toxic to the aquatic ecosystems.

Similar results were obtained by Akan et al. [21], when sediments collected from spatial locations close to points of effluents discharge, have higher heavy metals concentrations; when compared to results obtained from spatial locations. Heavy metals mobility and bioavailability in sediments are highly dependent on their chemical and mineralogical forms in which they occur [22]. Toxicity of heavy metals is a top priority in aquatic ecosystems; hence, international bodies such as: Administration of Quality Supervision, Inspection and Quarantine (AQSIQ), United States Environmental Protection Agency (USEPA), DPR, CCME, etc., have established standards regulations for aquatic sediments, in order to regulator the contamination of ecosystems, and protect the aquatic biological resources [23, 24].

3.1 Evaluation of the Pollution Indices

3.1.1 Contamination factor

The contamination factors for the sediments, collected from the study area are presented in Fig. 3. Contamination factor is used to express the level of heavy metals contamination in the sediments collected from the swampy forest. With reference to the contamination factor results, spatial point B and D have very high degrees of Cr, Ni and Cd contaminations. In addition, there was very high degree of Ni contamination at spatial points F and H. Generally, Ni had the highest contamination factor across the 9 spatial points; while Zn recorded the lowest contamination factor, across the 9 spatial points investigated in this study. Considerable degrees of contamination of Cr and Cd were recorded at spatial points C, E, F and H. Likewise, Zinc contamination was moderate at

Table 1. Heavy metals concentrations of sediments (0–10 cm depth) collected from the study area

Spatial point	Heavy metals					
	Cr (mg/kg)	Ni (mg/kg)	Cu (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Point A	22.03^{c}±0.03	39.83^{c}±0.22	20.31^{d}±b0.26	3.23^{b}±0.27	20.24^{f}±0.64	55.18^{c}±0.91
Point B	34.87^{a}±0.01	52.08^{a}±0.13	24.22^{a}±b0.11	4.24^{a}±0.15	48.97^{a}±0.05	92.28^{a}±0.56
Point C	19.71^{e}±0.12	28.11^{d}±0.24	20.11^{d}±b0.13	2.41^{d}±0.38	25.45^{d}±0.48	31.43^{f}±0.22
Point D	31.92^{b}±0.02	44.92^{b}±0.09	24.14^{a}±b0.51	4.02^{a}±0.24	40.23^{b}±0.17	88.94^{b}±0.64
Point E	20.08^{e}±0.01	25.19^{b}±0.08	22.22^{b}±b0.42	2.17^{a}±0.61	28.55^{a}±0.52	45.37^{d}±0.92
Point F	23.71^{c}±0.13	28.12^{d}±0.08	19.43^{e}±b0.38	3.05^{c}±0.32	32.33^{c}±0.18	32.15^{e}±0.22
Point G	15.03^{a}±0.12	20.25^{b}±0.11	16.42^{f}±b0.15	1.24^{f}±0.11	22.04^{a}±0.73	24.14^{a}±0.11
Point H	21.79^{d}±0.22	27.44^{d}±0.06	21.09^{c}±b0.32	2.61^{e}±0.71	25.14^{d}±0.38	35.38^{e}±0.03
Point I	11.22^{f}±0.02	19.76^{e}±0.02	14.87^{g}±b0.53	1.15^{f}±0.02	21.33^{e}±0.31	30.44^{f}±0.19
Control	4.17^{h}±0.04	4.08^{f}±0.33	7.23^{h}±b0.09	0.49^{g}±0.01	9.23^{g}±0.41	19.18^{g}±0.44
DPR [25]	100	35	36.00	0.80	85	140

Means followed by a different letter(s) in the same column differ significantly ($p \leq 0.05$) according to Duncan's Multiple Range Test the spatial points A, C, E, E, F, G, H and 1; and spatial points B and D recorded considerate level of contamination. For all cases, no spatial point investigated in this study recorded low degree of heavy metal contamination. This revealed the severity of the illegal refineries activities to the environment.

According to Akoto et al. [26], high value of contamination factor (C_f ≥2) in a soil or sediment sample indicated that the major source of contamination is anthropogenic; however is the contamination factor value ranged between 0.5 and 1.5, it indicates that the contamination is from crust materials or natural sources.

3.1.2 Pollution Load Index (PLI)

The Pollution load index of the toxic heavy metals in the sediment is presented in Table 2. Pollution load index provides information on the total level of heavy metal toxicity in the sediment [19]. As shown in Table 2, the pollution rate of the heavy metals fluctuated across the study area; this portrayed variation in the heavy metals concentration across the site. Furthermore, the study revealed that all the10 sampled points were heavily polluted, as their PLI values were greater than 1 (PLI > 1). In respect to all 9 spatial points sediments investigated in this study, spatial point B was the most polluted point (PLI ~ 6.55); while spatial point I was the least polluted (PLI ~ 2.48). This could be attributed to the volume and concentration of wastes it received. This study results are similar to those obtained for sediment collected from lake Hongfeng in China [27].

3.1.3 Regression analysis

Table 3 showed that correlation relationships between the toxic heavy metals in sediments and the spatial points. Correlation (r) determines the relationship between the major sources of pollution of contaminant (heavy metals). A strong positive correlation (r ≥0.80) value pointed to similar sources of heavy metal pollution [28, 29]. The study showed that the highest correlation (0.965) was obtained between Cr and Cd. The correlation results revealed that Ni and Cr, Cu and Cr, Cd and Cr, Cd and Ni, Zn and Ni contamination may have resulted from one major source. This major contamination source is likely petroleum products discarded indiscriminately in the swamps, by the illegal crude oil refiners. Petroleum products have the capacity of increasing the heavy metals concentration in soils, sediments and water bodies [30, 31]. Furthermore, the correlation results showed that Ni and Pb, Cu and Pb, Cd and Pb contamination did not originated from one major source. Therefore, study has help in the identification of the potential causes of pollution in the illegal refineries environment. This is important for developing control methods for environmental conservationists, and remediation efforts.

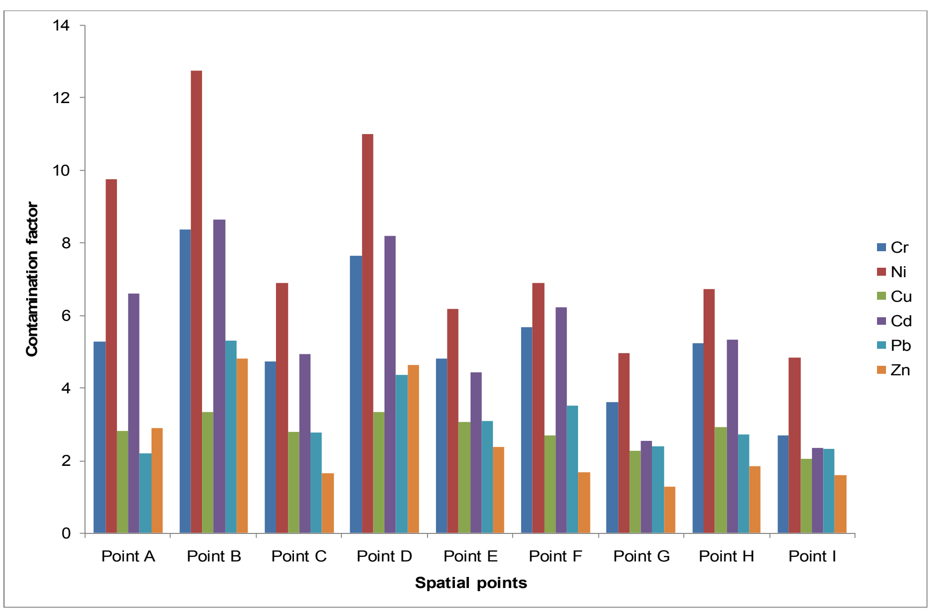


Fig. 3. Contamination factors of the toxic heavy metals in the sediments

Table 2. Pollution load index of heavy metals in the swamp sediments

Sampling point	PLI	Level	Remark
Point A	4.26	PLI ≥1	Location Polluted
Point B	6.55	PLI ≥1	Location Polluted
Point C	3.55	PLI ≥1	Location Polluted
Point D	6	PLI ≥1	Location Polluted
Point E	3.79	PLI ≥1	Location Polluted
Point F	3.96	PLI ≥1	Location Polluted
Point G	2.6	PLI ≥1	Location Polluted
Point H	3.74	PLI ≥1	Location Polluted
Point I	2.48	PLI ≥1	Location Polluted

Table 3. Correlation of heavy metals in swamp sediments collected from the study arera

	Cr	Ni	Cu	Cd	Pb	Zn
Cr	1.000					
Ni	0.924	1.000				
Cu	0.903	0.801	1.000			
Cd	0.965	0.940	0.870	1.000		
Pb	0.897	0.776	0.753	0.785	1.000	
Zn	0.887	0.940	0.804	0.854	0.826	1.000

4. CONCLUSION

This study was carried out to evaluate the potential ecological risk of illegal crude oil refineries wastes, on the sediments of swampy forests in Isoko South Local Government Area of Delta state, Nigeria. The results revealed that the wastes discarded indiscriminately, by the illegal crude oil refiners, significantly increased the toxic heavy metals (Cr, Cd, Ni, Cu, Zn, and Pb) concentration of the sediments. The contamination factor of the sediments collected swamp revealed that the area had moderate to high degree of heavy metals contamination; while the pollution load index showed that the area under study was heavy polluted with the toxic heavy metals. The contamination factor and pollution load index results portrayed the severity of the illegal refineries activities to the environment. These results have revealed the negative implications of these illegal crude oil refiners' activities on the swamps and streams sediments; and the need for the regions elders to stop the growing trend. The study only covered a small area of the swampy forest of the Niger Delta region, where illegal crude oil refining is taken place, due to denial of access to others sites by the illegal refineries operators. Therefore, more research should be done in active illegal refineries sites not covered in this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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