

# Evaluation of the impact of anthropogenic activities on wetland soil qualities: A case study of Isoko South Area of Delta State, Southern Nigeria

Ogbaran, A. N.\* and Joseph-Akwara, I. E.

Department of Civil Engineering Technology, Delta State Polytechnic, Nigeria.

\*Corresponding author. Email: [erobo2011@gmail.com](mailto:erobo2011@gmail.com)

Copyright © 2021 Ogbaran and Joseph-Akwara. This article remains permanently open access under the terms of the [Creative Commons Attribution License 4.0](#), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Received 2nd April, 2021; Accepted 28th April, 2021

**ABSTRACT:** This research was carried out to evaluate the impact of dumpsite and farming methods (anthropogenic Activities) on wetland soil qualities. Soil samples were collected from three strategic locations in Irri and Uzere communities at Delta State of Nigeria, and a reference station (control) about 5 km away from the study site. The sampling was done at the end of the rainy season (September, 2020), when the flood water had started rescinding, at two soil depths (5 to 10 cm and 45 to 50 cm). The concentration of iron, nickel, copper and cadmium concentration of the soil samples were determined with the Atomic Absorption Spectrophotometer (AAS), according to procedures approved by ASTM International. Results obtained from the chemical analysis revealed irregular concentration and distribution of the heavy metals within the studied area. Regardless of the sampling depth, the highest heavy metal concentrations were observed around the active dumpsite. Ranking order of the heavy metals' concentrations in all the sampling locations was Fe > Cu > Ni > Cd. It was observed from the results that the profile concentrations of the heavy metals increased with an increase in the soil depth. Using the contamination factor to assess the heavy metals contamination of the wetland, the results showed that the area ranged from moderate to considerable level of contamination, while pollution load index revealed that wetland soils were moderately polluted with the heavy metals. In terms of the soil pollution, the overall results revealed that area closed to the wastes dumpsite (site 1) was heavy polluted with the heavy metals.

**Keywords:** Anthropogenic, distribution pattern, heavy metals, pollution index, wetland.

## INTRODUCTION

Wetland is marshland or peatland that is formed from the decomposition biological materials through anaerobic processes. According to Mitsch and Gosselink (2007), total world wetlands covered about 1.3 million hectares, which is about 10% of the earth's terrestrial surface. Wetlands are associated with three major landform types: inland depression, alluvial plains, and coastal plains. Wetlands are one of the most important ecosystems in the world, as they provide diverse range of essential services to human beings (Okusami and Rust, 1992; RCS, 2007; Keddy, 2010); and have the capability of maintaining the global ecological balances, through providing the enabling thriving environment for wild animals (Laga et al., 2014).

Wetlands have dual-purpose, which are: a major source of essential nutrients for crops, and natural reservoir for pollutants (e.g. heavy metals). Accumulations of heavy metals in wetlands have serious deadly effects on plants growing on the wetlands, and the human beings that consume those plants that were grown on the contaminated wetlands (Egwu et al., 2018). The Niger Delta region of Nigeria has very fragile wetlands due to years of environmental pollution caused by petroleum exploration and other anthropogenic activities. Wetland sediments contamination has become a widespread environmental problem. Wali et al. (2018) reported that petroleum explorations and exploitation, poor environ-

mental laws implementation, poor knowledge of the wetland values, indiscriminate industrial effluents discharge into environment, etc. are some of the major factors that are contributing to the degradation of wetlands in Nigeria (Ohimain et al., 2002; Akpomrere and Uguru, 2020a).

Heavy metals can occur naturally in wetland soil environment through the pedogenetic processes of rock weathering of parent materials, or through anthropogenic sources like agricultural practice, poor waste management, etc (Pierzynski et al., 2000). According to Shiwatana et al. (2001), heavy metals are initially adsorbed at a faster rate inside the soil or sediments, but slow down after some times and may continue this slow reaction rate for years; hence, the heavy metals are restructured into different chemical natures with varying degree of bioavailability, mobility, and toxicity. Heavy metals (cadmium "Cd", lead "Pb", zinc "Zn", nickel "Ni", copper "Cu", iron "Fe", etc.) are needed by plants and human beings in minute quantities, for their proper growth and development. But they become toxic to the both plants and human beings, when they accumulate in body above the permissible limits (Masindi and Muedi, 2018; Akpokodje et al., 2019). The negative impact of toxic heavy metals on human beings cannot be over-emphasized, as they can cause irreparable damage to vital organs of the human body (Chibuike and Obiora, 2014). Studies had shown that high nickel concentration in the soil can hinder chickpea germination rate, while high cobalt concentration in the soil hinders seeds radicle and plumule growth rates (Khan and Khan, 2010; Cruz et al., 2013; Jayakumar and Vijayarengan, 2006).

The buildup of toxic heavy metals in wetlands sediments, and their successive absorption by plants and animals or seepage into the water bodies, is a serious threat to the environmental safety. The extent at which soils or water bodies accumulate heavy metals is dependent on the initial concentration and volume of the contaminants, biological properties of the sediments, and the physicochemical properties of the sediments (Dousova et al., 2012; Akpomrere and Uguru, 2020b). Additionally, Iwegbue et al. (2007) reported that the toxicity and mobility of heavy metals in soils and sediments are highly influenced by the forms and chemical bounds of the heavy metals in the sediment matrices. Niger Delta wetlands of Nigeria are major farming hub in the country, due to their high fertility. Therefore, it is necessary to have adequate information on the quality of the wetland soils. Although, some researchers (Nwankwoala, 2012; Egwu et al., 2018; Wali et al., 2019) had investigated the qualities of wetland soil samples, much have not been done on wetlands located in Isoko region of Nigeria. Hence, the main objective of this study was to determine the concentration and distribution of heavy metals in wetland soils collected from Isoko South region of Delta State. Results obtained from the study will be helpful in identifying the possible

environmental risks of these heavy metals to plants and human beings.

## MATERIALS AND METHODS

### The study area

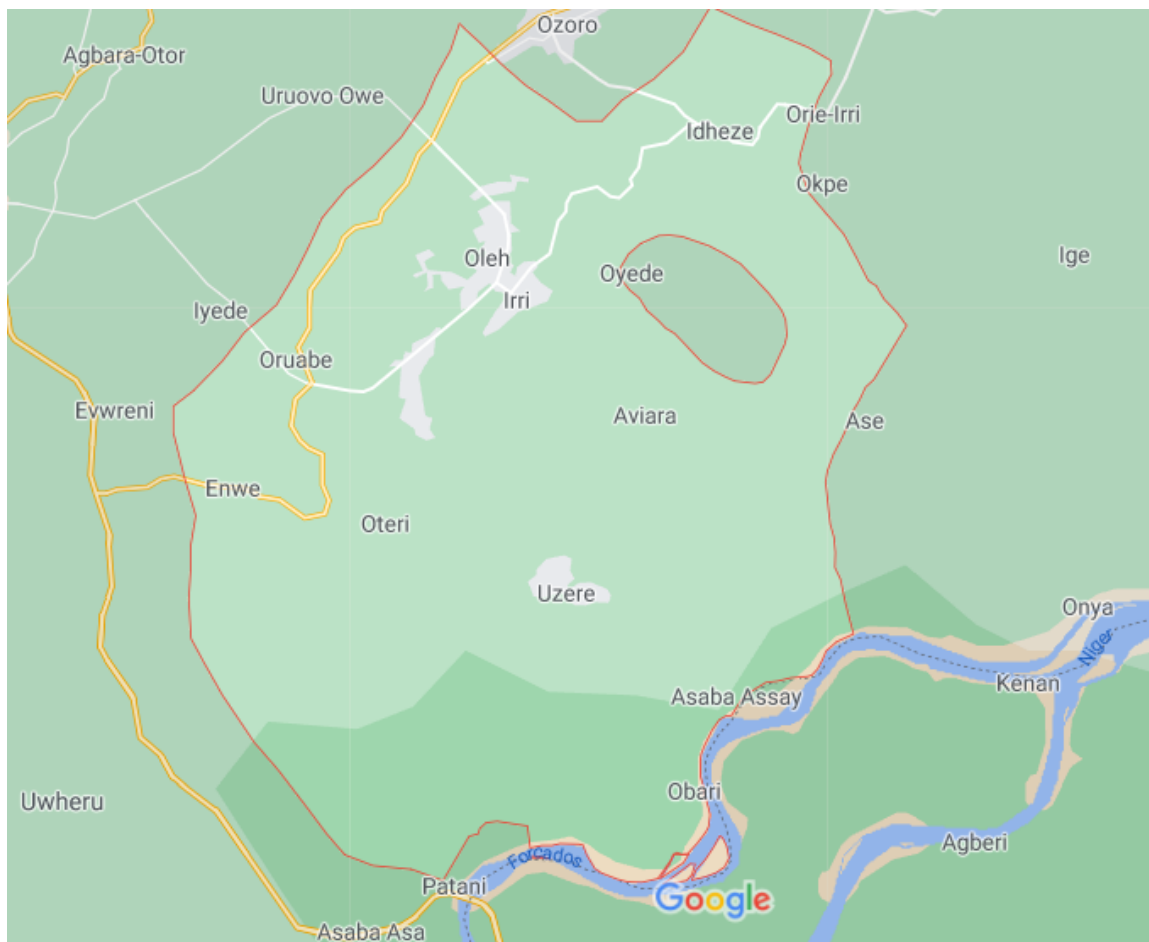
The Irri-Uzere wetland is a wide expanse of flood plain wetlands situated in the Isoko South region of Delta State, Southern Nigeria (Figure 1). The area covers about 500 hectares and it is susceptible to flooding during the rainy season (May to November). According to Eboibi et al. (2018), Isoko region is characterized by two major climatic seasons, which are: the rainy season with an average rainfall of about 1800 mm, and the dry season with an average temperate of 28°C. The wetland is widely subjected to dry season farming during the dry season, and fishing during the rainy season.

### Sample collection

The wetland soil sampling was done during the end of the rainy season (September, 2020), when the flood water has started rescinding (Figure 2). Soils were collected below the water surface, with the aid of a calibrated soil auger, at two depths of 5 to 10 cm and 45 to 50 cm, from three strategic locations, in Irri and Uzere communities of Delta State. Then from another point, about 5 km upstream from the sampled points was chosen as the control (reference) point. The description of all the sampled points was presented in Table 1. All the sediments samples were poured into black polyethylene bag and stored in a cooler at a temperature of  $2\pm3^{\circ}\text{C}$ , and taken immediately to the laboratory for analytical analysis.

### Sample preparation and digestion

The soil samples were air-dried in the laboratory under ambient temperature for two weeks, grind and sieved with a 2 mm gauge stainless steel sieve. The heavy metals concentrations in the soil samples were determined in accordance with ASTM International (D1971/4691) recommendations. 10 g of the sieved soil sample was poured into a glass beaker. Then, a mixture of  $\text{HNO}_3$  (5 mL),  $\text{HCl}$  (10 mL) and distilled water (40 mL) was poured into the sediments in the beaker, heated on an electric hot plate, until a near clear solution was obtained. It was cool to room temperature under ambient room temperature, filtered into a volumetric flask with a filter paper (Whatman No. 42), and diluted with distilled water up to the 100 mL mark of the flask. Then the heavy metals concentrations in the soil samples were determined using a Flame Atomic Absorption Spectrophotometer (FAAS).



**Figure 1.** Map of Isoko region of Delta State showing Irri-Uzere communities (Google earth map).

### Contamination assessment of the wetland soil samples

#### Contamination factor (Cf)

Heavy metal contamination factor is calculated by using the expression given in Equation 1 (Akpomrere and Uguru, 2020b).

$$\text{Contamination Factor} = \frac{\text{Conc.at sampled point}}{\text{Conc.at control point}} \quad (1)$$

The contamination factor scale is as presented below:

- Cf < 1 = low contamination,
- 1 < Cf < 3 = moderate contamination,
- 3 < Cf < 6 = considerable contamination,
- Cf > 6 = high contamination

#### Enrichment factor (EF)

The enrichment factors of the heavy metals in the soil sampled collected from the dumpsite vicinity is calculated by using the expression in Equation 2 (Li et al., 2013).

$$\text{Enrichment factor} = \frac{C_x/C_{fe}(\text{Sample})}{C_x/C_{fe}(\text{Control})} \quad (2)$$

Where:  $C_x$  = heavy metal concentration at the sampled point and  $C_{fe}$  = Concentration of the reference element.

Iron has been adopted as the reference metal by many researchers. The reference metal should be particularly stable in the soil; hence its concentration should not be affected by anthropogenic activities (Barbieri, 2016). The enrichment factor scale is as presented below:

- EF ≤ 2 = low minimal
- 2 < EF ≤ 5 = moderate
- 5 < EF ≤ 20 = significant
- EF > 20 = very high

#### Pollution load index (PLI)

This is the rate at which the soil sample heavy metal concentration exceeded the heavy metal concentration at the control point. It is calculated using the formula stated



**Figure 2.** Sampling location 2 (site 2).

in Equation 3 (Khan et al., 2017; Ogbaran and Uguru, 2021).

$$PLI = \sqrt[n]{CF_1 \times CF_2 \times CF_3 \times CF_4 \times \dots \times CF_n} \quad (3)$$

Where: CF = contamination factor of each metal and n = total number of metals.

Pollution Load Index is classified as:

PLI < 1 = unpolluted

PLI = 1 baseline level of pollution

1 > PLI ≤ 2 moderately polluted

2 > PLI ≤ 4 highly polluted

PLI > 4 very highly polluted (Thomilson et al., 1980)

## RESULTS AND DISCUSSION

### Heavy metals characterization

The average concentrations of Fe, Ni, Cu and Zn in the wetland alluvial soils are summarized in Table 2. The results revealed irregular spatial distribution of the heavy metals within the studied area, with the highest concentration around the dumpsite area (site 1). Additionally, it was observed in the results that the heavy metals concentrations were higher in the sub-surface soils, than the concentration recorded at the surface soils. This could be attributed to the leaching of the heavy metals into the sub-surface soil by the flood water, and the remediation activities of the organic materials at the soil

**Table 1.** Description of the sampling points.

| Sampling point        | Description  | Latitude | Longitude |
|-----------------------|--|----------|-----------|
| Ref (control station) | Natural vegetation   | 5.413°   | 6.205°    |
| Site 1                | Active dumpsite of about 0.5 ha, natural vegetation, no sign of farming activities | 5.409°   | 6.201°    |
| Site 2                | Open space and it is used expansively for dry season farming                       | 5.385°   | 6.212°    |
| Site 3                | Thick vegetation cover, and it is used for dry season farming                      | 5.385°   | 6.229°    |

**Table 2.** Concentration of heavy metals in the wetland soil.

| Location | Position    | Heavy metal |            |            |            |
|----------|-------------|-------------|------------|------------|------------|
|          |             | Fe (mg/kg)  | Ni (mg/kg) | Cu (mg/kg) | Cd (mg/kg) |
| Site 1   | Surface     | 2133        | 4.25       | 32.11      | 4.32       |
|          | Sub-surface | 2844        | 4.92       | 34.23      | 4.58       |
| Site 2   | Surface     | 1853        | 3.24       | 24.08      | 3.83       |
|          | Sub-surface | 2115        | 3.58       | 29.05      | 3.19       |
| Site 3   | Surface     | 1285        | 2.91       | 18.93      | 1.09       |
|          | Sub-surface | 1552        | 2.94       | 22.58      | 1.25       |
| Control  | Surface     | 2082        | 1.94       | 9.45       | 0.95       |
|          | Sub-surface | 2433        | 2.02       | 10.55      | 1.03       |
| DPR      |             | NA          | 35         | 36         | 0.8        |

surfaces. Uguru et al. (2020) and Vidali (2001) stated that green vegetation and organic materials have the ability of remediating contaminated soil samples. Similarly, Lee et al. (2003), stated that organic materials act as bio-stimulant, hence enhancing the remediation of contaminated soil. The ranking order of the heavy metals concentrations in all the sampling locations including the control site was Fe > Cu > Ni > Cd. Irrespective of the sampling depth; iron had the highest concentration. Within the wetland, the iron concentration ranges from 1853 to 2844 mg/kg, the nickel concentration ranged between 2.91 and 4.92 mg/kg, while the copper concentration ranges from 18.93 to 34.23 mg/kg, then the cadmium concentration ranged between 1.09 and 4.58 mg/kg. The study further revealed that, the iron concentration at the control site was higher than iron concentration recorded at the sites 2 and 3. The high heavy metals concentrations recorded at sampling location 1 (site 1) can be attributed to its proximity to the dumpsite. Ogbaran and Uguru (2021) reported that leachates from the solid waste dumpsites have the capacity of contaminating the environment; hence, increasing the soil and water heavy metals concentrations.

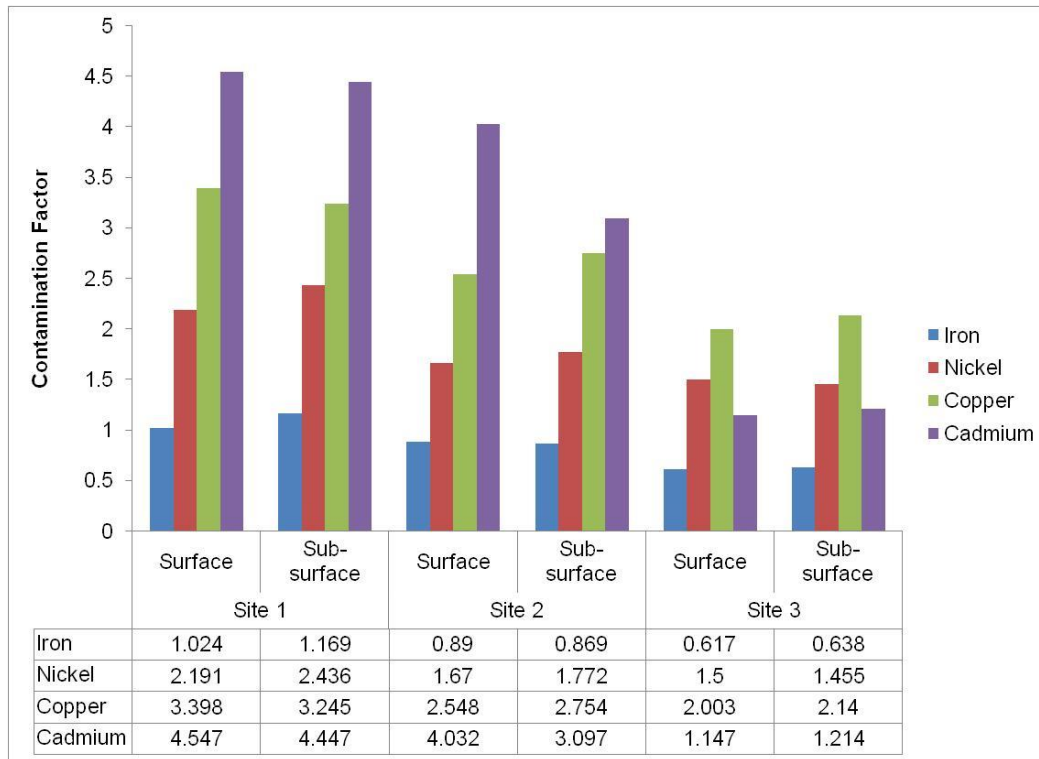
The study further revealed that lowest heavy metals concentrations were obtained at sampling location 3 (site 3). The lowest heavy metals contamination observed at this sample location (site 3), despite its similar geographical locations with the remaining sampling locations can be attributed to the thick vegetation (trees and scrubs) cover around the location. Schnoor (2002)

and Akpokodje and Uguru (2019a) stated that plants vigorously growing on contaminated soils have the ability to accumulate large contaminants in their bodies, hence cleansing the environment of the toxic elements. Likewise, the fairly high heavy metals contamination recorded at sampling location 2 (site 2), although there is no dumpsite or effluent discharge points close by may be attributed to the residue chemicals (herbicides, fertilizers, etc. used by the farmers in the area. According to Raven et al. (1998) and Akpokodje and Uguru (2019b), farming methods, such as the application of fertilizers and herbicides inadvertently increased the heavy metals concentrations of the soils. However, the results depicted that the concentration of Fe, Ni and Cu at sites 1, 2 and 3 were within the maximum limits approved by the Nigeria Department of Petroleum Resources (DPR) for soils, while the Cd concentration at sites 1, 2 and 3 was above the limits approved by DPR. Compared to previous studies results, the Ni, Cu and Cd concentrations obtained in this study were lower than the values reported by Egwu et al. (2018) where the Cd concentration of wetland soil ranged from 1.63 to 24.95 mg/kg.

### Evaluation of the pollution indices of the wetland soil samples

#### Contamination factor (CF)

Figure 3 showed the contamination factor of the heavy



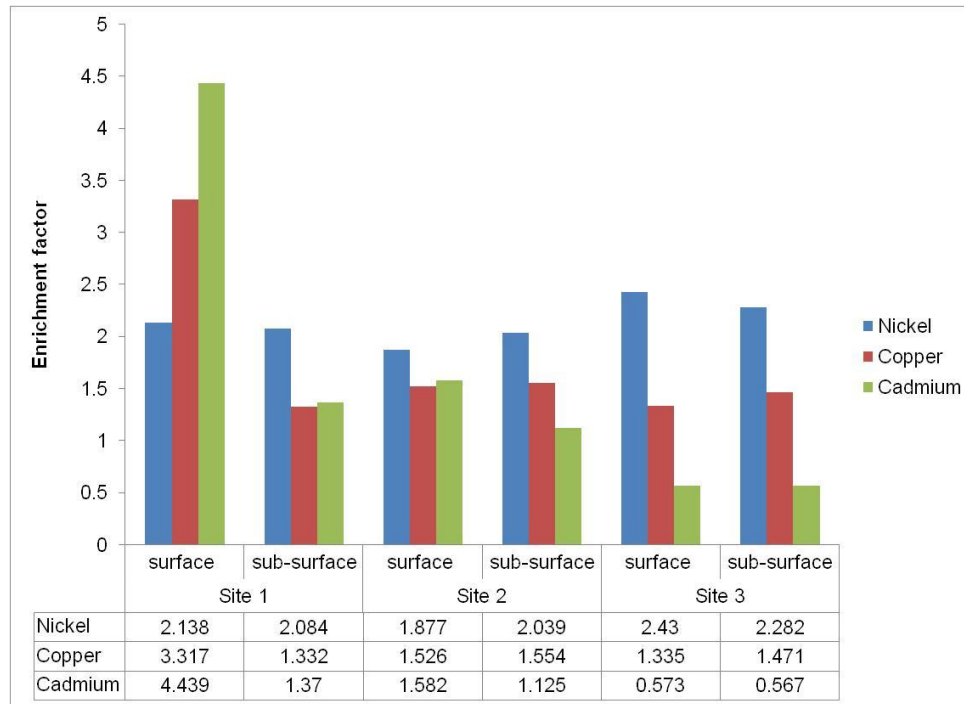
**Figure 3.** contamination factor of the wetland soil samples.

metals across the study. As seen in Figure 3, the contamination factor varied across the wetland, and was higher at the surface soils at some sampling locations. Irrespective of the heavy metals, site 1 had the highest contamination factor, which was followed by site 2, while site 3 had the lowest contamination factor. The contamination factor showed that at sites 2 and 3, iron had a low contamination (0.89, 0.869 and 0.617, 0.638) both at the surface and sub-surface soils, respectively. Then at site 1, the contamination factor of iron increased to moderate degree of contamination (1.024 and 1.169) both at the surface and sub-surface soils. Nickel was at moderate degree of contamination across the wetland studied, irrespective of the soil depth. It was observed from the results that the contamination factor of copper was at considerable degree at site 1, both at the wetland surface soil (3.398) and the wetland subsurface soil (3.245); while at sites 2 and 3, the contamination factor of copper declined to moderate level of contamination, both at the surface and subsurface wetland soil profile. Similarly, the results revealed that cadmium was at considerable degree of contamination at sites 1 and 2, both at the wetland surface and subsurface region, then it declined to it was moderate level of contamination at the sampling location 3; with the soil surface recording contamination value of 1.147 and, the subsurface soil recording contamination value of 1.214. For all cases, none of the sampling location recorded high degree of contamination. The general

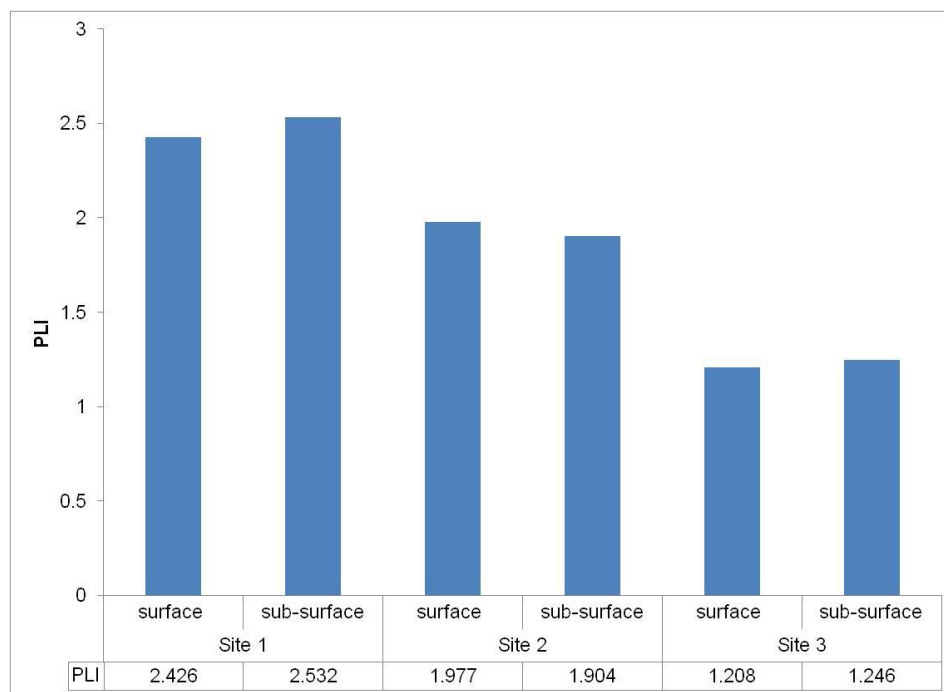
higher contamination factors recorded at sites 1 and 2, compare to site 3 portrayed that anthropogenic activities were responsible for the pollution of the wetland soils, as earlier confirmed by Sha'Ato et al. (2020).

### **Enrichment factor**

The enrichment factor values of the metals are presented in Figure 4. It can be seen in Figure 4 that the enrichment factor varied widely across the wetland. Generally, site 1 had the highest enrichment factors, compared to the values obtained at sites 2 and 3. Irrespective of the sampling depth, the order of the enrichment factor was  $Cd > Cu > Ni$  at site 1, while at site 2 the order was  $Ni > Cu > Cd$ . Then at site 3, the enrichment factor order was  $Ni > Cu > Cd$ . As presented in Figure 4, the enrichment factor values of the three metals at site 1 were at the moderate level at the soil surface; then at the subsurface, Ni maintained the moderate level, while Cd and Cu dropped to low minimal level. The enrichment factor at site 2 indicated that Cu and Cu were in the low minimal range both at the soil surface and subsurface; while Ni was at low minimal degree at the soil surface, but increased to moderate degree at the subsurface soil. Likewise, at site 3, Cu and Cu enrichment factors were at low minimal degree both at the soil surface and subsurface; while Ni was at moderate degree both at the soil surface and



**Figure 4.** Enrichment factors of the wetland soil samples.



**Figure 5.** pollution load index of the wetland soil samples.

subsurface. The high enrichment factors ( $EF > 2$ ) obtained at sites 1 and 2 portrayed that, artificial sources probably anthropogenic activities were responsible for the contamination of the wetland soils.

#### ***Pollution load index (PLI)***

The pollution load index of the wetland soil is presented in Figure 5. The PLI of site 1 was the highest, while site 3 had

the lowest PLI regardless of the soil sampling depth. Irrespective of the wetland depth, all the sampled sites (1, 2 and 3) were moderately polluted with the heavy metals. As seen in the results, site 1 was polluted with the metals, compared to sites 2 and 3. Pollution load index revealed the amount of the contaminant in the environment (soil); thus, proving necessary information of the toxicity of the metal toxicity in the environment (Muzerengi, 2017). The high PLI values obtained at sampling locations 1 and 2 further affirmed that anthropogenic activities (dumpsites and farming methods) may be responsible for the contamination of the wetland soils.

## Conclusion

Generally, the study results revealed that the subsurface soil had higher heavy metals concentrations than the top soil. It was also observed from the results that regardless of the soil depth, the heavy metals contamination was in the order of  $Fe > Cu > Ni > Cd$ . The pollution indices results revealed that site 1 had the highest contamination factor compared to sites 2 and 3, irrespective of the heavy metal. Similarly, the enrichment factors of the heavy metals ranked  $Cd > Cu > Ni$  at site 1,  $Ni > Cu > Cd$  at site 2, and  $Ni > Cu > Cd$  at site 3, regardless of the soil depth. The PLI values revealed that the area was generally polluted with the studied heavy metals. The high PLI values obtained at sampling locations 1 and 2 further affirmed that the dumpsites and farming methods (anthropogenic sources) is responsible for the contamination of the wetland soils.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

## REFERENCES

- Akpokodje, O. I., & Uguru, H. (2019b). Impact of farming methods on some anti-nutrients, nutrients and toxic substances of cassava roots. *International Journal of Scientific Research in Science, Engineering and Technology*, 6 (4), 275-284.
- Akpokodje, O. I., Uguru, H., & Esegbuyota, D. (2019). Evaluation of phytoremediation potentials of different plants' varieties in petroleum products polluted soil. *Global Journal of Earth and Environmental Science*, 4(3), 41-46.
- Akpokodje, O., I., & Uguru, H. (2019a). Phytoremediation of petroleum products contaminated soil. *Archives of Current Research International*, 18(1), 1-8.
- Akpomrere, O. R., & Uguru, H. (2020a) Ecotoxicity effect of illegal refineries on the environment: A case study of Delta State, Nigeria. *International Journal of Innovative Agriculture & Biology Research* 8(2), 40-49.
- Akpomrere, O. R., & Uguru, H. (2020b). potential ecological risk of swamps sediments in illegal refineries sites: A case study of Isoko South, Delta State, Nigeria. *Journal of Engineering Research and Reports*, 16(2), 1-9.
- Barbieri, M. (2016). The Importance of enrichment factor (EF) and geoaccumulation index (Igeo) to evaluate the soil contamination. *Journal of Geology and Geophysics*, 5, 237-344
- Chibuike, G. U., & Obiora, S. C. (2014). Heavy metal polluted soils: Effect on plants and bioremediation methods. *Applied and Environmental Soil Science*, Volume 2014, Article ID 752708.
- Cruz, J. M., Lopes, P. R., Montagnolli, R. N., Tamada, I. S., Silva, N. M. M., & Bidoia, E.D. (2013). Toxicity assessment of contaminated soil using seeds as bioindicators. *Journal of Applied Biotechnology*, 1(1), 1-10.
- Dousova, B., Buzek, F., Rothwell, J., Krejcova, S., & Lhotka, M. (2012). Adsorption behavior of arsenic relating to different natural solids: soils, stream sediments and peats. *Science of the Total Environment*, 433, 456-461.
- Eboibi, O., Akpokodje, O. I., & Uguru, H. (2018). Growth performance of five bean (*Phaseolus* spp) varieties as influenced by organic amendment. *Journal of Applied Sciences and Environmental Management*, 22(5), 759-763.
- Egwu, G. N., Okunola, O. J., & Ugwoke, K. C. (2018). Evaluation of some heavy metals in wetland soils of Uguru, Yobe State, Nigeria. *Journal of Applied Sciences and Environmental Management*, 22(6), 987-992.
- Iwegbue, C. M. A., Nwajei, G. E., & Arimoro, F. O. (2007). Assessment of contamination by heavy metals in sediments of Ase River, Niger Delta, Nigeria. *Research Journal of Environmental Sciences*, 1(5), 220-228.
- Jayakumar, K., & Vijayarengan, P. (2006). Influence of cobalt on seed germination and seedling growth of *Vigna mungo* (L.) Hepper. *Plant Archives*, 6(2), 681-682
- Keddy, P. A. (2010). *Wetland Ecosystem: principles and conservation* (2nd edition). New York: Cambridge University Press. 497
- Khan, M. R., & Khan, M. M. (2010). Effect of varying concentration of nickel and cobalt on the plant growth and yield of chickpea. *Australian Journal of Basic and Applied Sciences*, 4(6), 1036-1046.
- Khan, M. Z., Hasan, M. R., Khan, M., Aktar, S., & Fatema K. (2017). Distribution of heavy metals in Surface sediments of the Bay of Bengal Coast. *Journal of Toxicology*. Volume 2017, Article ID 9235764.
- Laga, T., Xin, L. X., Ying, F., & Shuang, L. (2014). Wetland changes and their responses to climate in "Three -River Headwaters Region of China Since the 1990's. *Energies*, 7, 2515-2534.
- Lee, K., Park, J. W., & Ahn, I. S. (2003). Effect of additional carbon source on naphthalene biodegradation by *Pseudomonas putida* G7. *Journal of Hazardous Materials*, 105(1-3), 157-167.
- Li, F., Zeng, X. Y., Wu, C. H., Duan, Z. P., Wen, Y. M., Huang, G. R., Long, X. L., Li, M. J., Li, M. J., & Xu, J. Y. (2013). Ecological risks assessment and pollution source identification of trace elements in contaminated sediments from the Pearl River Delta, China. *Biological Trace Element Research*, 155(2), 301-313.
- Masindi, V., & Muedi, K. L. (2018). Environmental contamination by heavy metals. In: Saleh, H. E-D. M., & Aglan, R. F. (eds.). *Heavy Metals*. IntechOpen. Retrieved May 19, 2019 from <https://www.intechopen.com/books/heavy-metals/environmental-contamination-by-heavy-metals>.
- Mitsch, W. J., & Gosselink, J. G. (2007). *Wetlands*. 4th edition. Hand book (N.J): Wiley
- Muzerengi, C. (2017). Enrichment and geoaccumulation of Pb,

- Zn, As, Cd and Cr in soils near New Union Gold Mine, Limpopo Province of South Africa. In: Wolkers-dorfer, C., Sartz, L., Sillanpää, M., & Häkkinen, A. (eds.). *Mine Water and Circular Economy* (pp. 720-727). Finland: Lappeenranta.
- Nwankwoala, H. O. (2012). Case studies on coastal wetlands and water resources in Nigeria. *European Journal of Sustainable Development*, 1(2), 113-113.
- Ogbaran, A. N., & Uguru, H. (2021). Assessment of groundwater quality around an active dumpsite using pollution index. *Civil Engineering Research Journal*, 11(3), 1-8.
- Ohimain, E. I., Imoobe, T. O. T., & Benka-Coker, M. O. (2002). Impacts of dredging on zooplankton communities of Warri River, Niger Delta. *African Journal of Environmental Pollution and Health*, 1(1), 37-45.
- Okusami, T. A., & Rust, R. H. (1992). Occurrence, characteristics and classification of some hydromorphic soils from south Nigeria. In: Kimble, J. M. (ed.). *Characterization, classification and utilization of wet soils* (p. 185-197). USDA, Soil Conservation Service: Proceedings VIII ISCOM.
- Pierzynski, G. M., Sims, J. T., & Vance, G. F. (2000). *Soils and Environmental Quality*, CRC Press, London, UK, 2nd edition.
- Ramsar Convention Secretariat (RCS) (2007). Wise use of wetlands: A conceptual framework for the Wise use of wetlands. Ramsar handbooks for the wise use of wetlands. 3rd ed. Gland (Switzerland): RCS.
- Raven, P. H., Berg, L. R., & Johnson, G. B. (1998). *Environment*. Saunders College Publishing, New York, NY, USA, 2nd edition.
- Schnoor, J. L. (2002). Technology evaluation report: Phytoremediation of soil and groundwater. GWRTAC Series.
- Sha'Ato, R., Benibo, A. G., Itodo, A. U., & Wuana, R. A. (2020). Evaluation of bottom sediment qualities in Ihetutu minefield, Ishiagu, Nigeria. *Journal of Geoscience and Environment Protection*, 8(04), 125-142.
- Shiowatana, J., McLaren, R. G., Chanmekha, N., & Samphao, A. (2001). Fractionation of arsenic in soil by a continuous- flow sequential extraction method. *Journal of Environmental Quality*, 30(6), 1940-1949.
- Thomilson, D. C., Wilson, D. J., Harris, C. R., & Jeffrey, D. W. (1980). Problem in heavy metals in estuaries and the formation of pollution index. *Hel WissMeeresunlter*, 33(1-4), 566-575.
- Uguru, H. Akpokodje, O., & Esegbuyota, D. (2020) Remediation potency of charcoal block and sawdust in petroleum products contaminated soil. *Trends in Technical & Scientific Research*, 4(4), 107-115.
- Vidali, M. (2001). Bioremediation: An overview. *Pure and Applied Chemistry*, 73(7), 1163-1172.
- Wali, E., Nwankwoala, H. O., Ocheje, J. F., & Chinedu, J. O. (2019). Oil spill incidents and wetlands loss in Niger Delta: implication for sustainable development goals. *International Journal of Environment and Pollution Research*, 7(1), 1-20.
- Wali, E., Phil-Eze, P. O., & Nwankwoala, H. O. (2018) Saltwater-Freshwater wetland ecosystem and urban land use change in Port Harcourt metropolis, Nigeria. *Earth Sciences Malaysia*, 2(1), 01-07.