AYAFA, TIMINIPRE COMFORT

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godpower.onwugbuta@uniport.edu.ng

Department of Biochemistry/Chemistry Technology,
University of Port Harcourt, Nigeria.

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Ecological Risk Assessment of Heavy Metals Contamination of Sediments of Obunagha River in Bayelsa State, Nigeria

Ayafa, Timinipre Comfort[1] and *Onwugbuta, Godpower Chukwuemeka[2]
[1]Department of Biochemistry/Chemistry Technology,
University of Port Harcourt, Nigeria.

*** Corresponding author email address**: godpower.onwugbuta@uniport.edu.ng

ABSTRACT

The study assessed the ecological risks of heavy metal contamination in sediment samples from the Obunagha river. The study aims to evaluate the Ecological Risk Assessment of Inorganic Contaminants of Sediments in Obunagha River. Eight sediment samples were collected from four sampling points in the Gbarain Clan community river. Heavy metals such as Zinc, Manganese, Cadmium, Chromium, Nickel, Lead, and Copper were analysed. Pollution Indices such as Contamination Factor, Heavy Metal Potential Ecological Risk Coefficient, Potential Ecological Index, The Nemerow Multi-Factor Index, Potential Contamination Index, Geo Accumulation Index and Enrichment Factor analysis were used. The mean Contamination Factors (CF) indicated a moderate contamination levels across all metals, with Zn (3.224), Mn (CF = 2.352), Cd (2.483), Cr (2.686), Ni (2.701), Pb (2.689), and Cu (0.976). The ecological risk landscape is complex, with moderate levels of zinc, manganese, and Cadmium, and varying degrees of contamination for Chromium, Nickel, Lead, and Copper. The Pollution Contamination Index (PCI) values reveal significant contamination, especially for Nickel and Lead. The Geo-Accumulation Index (Igeo) values indicated low to moderate pollution levels in sediment samples, with Zn (0.275), Cd (0.168), Pb (0.168), and Ni (0.275), while the Enrichment Factor shows moderate enrichments that could warrant close monitoring. It is recommended that more detailed investigations using artificial intelligent approach (AI) should be done. The work is important for decision making and policy formulations on environmental sustainability.

Keywords: Risk, Assessment, Contaminants, Sediments.

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INTRODUCTION

Rivers and sediments are contaminated through recipients of industrial wastes and municipal sewage (Reis *et al.,* 2019). Changes in water chemistry occur due to anthropogenic sources via domestic, sewage, industrial and agricultural releases that may in turn result to degradation of the aquatic ecosystems (Sonone *et al.,* 2020). One of the most life-threatening problems of developing countries is improper management of huge amount of wastes generated by several anthropogenic activities. More challenging is the unsafe disposal of these wastes into the ambient environment (Ansari *et al.*, 2019). This has often rendered these natural reservoirs unsuitable for both primary and secondary usage (Vaverková *et al.,* 2020). These effluents can alter the physical, chemical and biological nature of the receiving water bodies (Vardhan *et al.,* 2019). Therefore, evaluation of contamination risks of rivers and sediments is of ecotoxicological importance. In the aquatic ecosystem (Huang *et al.,* 2020), water soluble wastes and other materials that are dumped, spilled or stored on the surface of the land or in sewage disposal pits can be dissolved by precipitation, irrigation (Akhtar *et al.,* 2021). Sediment sources in aquatic ecosystem include soil erosion, decomposition of plants and animals and discharge of effluents (Dar *et al.,* 2022). Sediments are contaminated with different contamination from industrial and agricultural waste discharge and run off into the Obunagha River. The percentage of silt and clay in river sediments can have impact on the structure of the biotic accumulation. Inorganic contaminants such as heavy metals are wide spread contaminants of great environmental concern as they are non-degradable, toxic and persistent with serious ecological implications (Wang *et al.,* 2020). Humans have always depended in aquatic resources for food, medicines and materials as well as recreational and commercial purposes such as fishes and tourism. Aquatic ecosystems are strongly influenced by long term discharge of untreated domestic and industrial wastewater, storm water runoff, accidental spill and direct solid waste dumping (Akhtar *et al.,* 2021). The main sources of these contaminants in the environment include forest fire, natural petroleum seeps, combustion of fossil fuels, coal burning and use of oil for cooking and heating (Kularathne *et al.,* 2019). Other sources include domestic and industrial waste waters and sewage (Kishor *et al.,* 2021). Contamination of river bodies has become major and global problem due to inadequacy of environmental protection measures (Preisner, 2020). The aim of this Research is to assess the Ecological Risk of Inorganic Contaminants in Sediments of Obunagha River in Gbarain Clan, Bayelsa State, Nigeria.

MATERIALS AND METHODS

The study was carried out in Obunagha community in Gbarain Clan, Bayelsa State, South-South Geopolitical Zone of Nigeria. Obunagha is situated inbetween Okolobiri and Korama communities. The community is located at Latitude 5.03223^{o} or 5^{o} 1’ 56’’ N and Longitude 6.3104^{o} or 6^{o} 1’ 37’’ E. The Obunagha River flows through Okolobiri down to Korama. The major occupation of the people is fishing and farming. Other occupations include palm oil milling, local gin making, trading and carving.

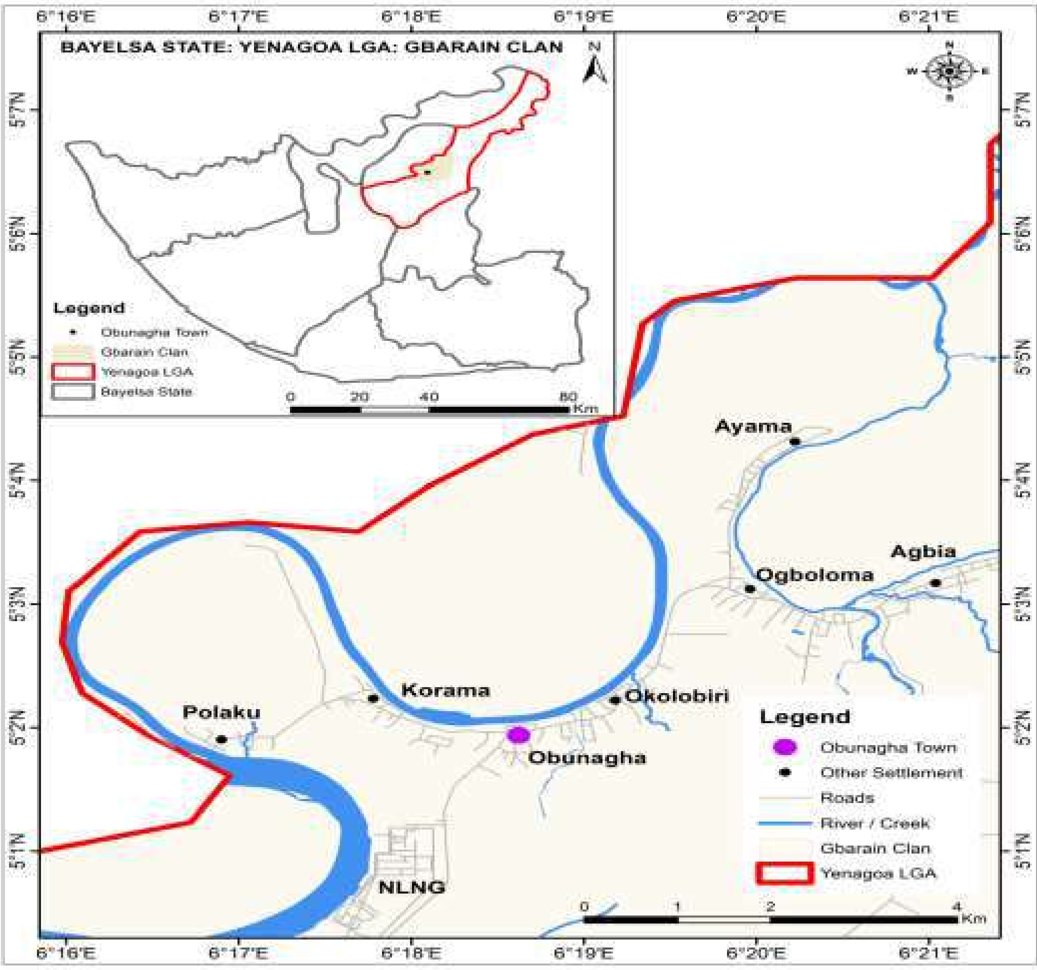

Figure 1: Map of Bayelsa State Showing Sample Location

Sediment samples were randomly collected at each sampling station using grab sampling method. Replicate samples were taken at each sampling station to account for variability.

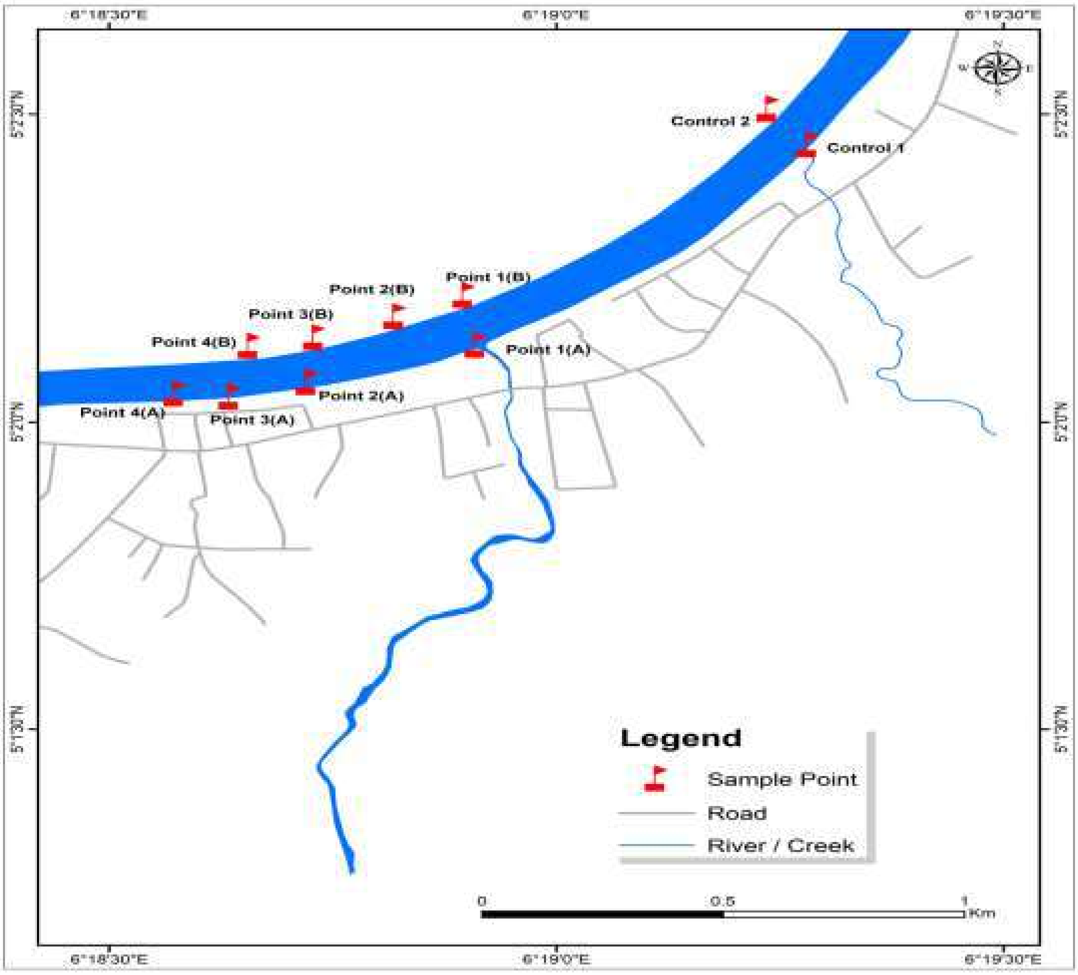

Figure 2: Map Showing Sampling Points (Stations)

Sediment Sample Preparation

Collected sediment samples were air-dried for 72 hours at room temperature and then was taken to the oven for further drying at 105°C for 24 hours. The dried sediment samples were grinded with laboratory porcelain mortar and pistle and sieved with 0.2nm mesh. The sieved samples were kept in an air tight plastic sample container and labeled appropriately. The sediment samples were digested, and 2.0 g of sample was measured into 100mL beaker mixed with 30 mL acid solution (3:1 of HNO_3 and H_2SO_4), heated on a hot plate in a fume cupboard. The digested samples were filtered through watchman filter paper; the filtrate was diluted with 50 mL of distilled water and were taken to the laboratory for metal analysis using Atomic Absorption Spectrophotometer (AAS) model (IS 1622 (1981).

In this study, contamination factor (CF), heavy metal potential ecological risk coefficient and potential ecological index, Nemerow Multi Factor Index, potential contamination index, geo-accumulation index, and enrichment factor (EF) were used to assess the metal pollution levels in the sediment samples. Reference values (Earth crust averages) of the studied metals which were used as background values were taken from different locations where no activities are taking place.

The contamination factor is an expression of the level of metal contamination in the surface sediment. It is the quotient attained by dividing the concentration of each metal in the soil by the reference value. It is given by the formula (Mirzaei *et al.,* 2020).

$$CF = \frac{C_{metal}}{C_{\text{background}}} \quad \text{........} \quad (1)$$

Where C_{metal} is the concentration of a given metal in the sediment and $C_{background}$ is the metal concentration of a control sample.

Potential ecological risk index is an approach to evaluate the heavy metal contamination and also associates ecological and environmental effects with toxicology. The potential ecological risk is related to individual pollution coefficient, heavy metal toxicity response coefficient, and its formula is as follows:

$$RI = \sum E_r^i = T_r^i \text{ X } C_f^i \quad \text{..........} \quad (2)$$

$$C_f^i = \frac{C_{Surface}}{C_n^i} \quad \text{.............} \quad (3)$$

Where E^r_i is potential ecological risk individual coefficient, $T_r{}^I$ is toxicity response coefficient of a certain kind of metal toxicity using standard heavy metal toxicity coefficient development as reference, in accordance with the normalized toxic response factor of 30, 5, 5,5, 2 and 1 respectively for Cd, Cu, Pb, Ni, Cr, and Zn. C_f^i is the accumulating coefficient of element I, and RI is the potential ecological risk index (Panghal *et al.,* 2021). To assess the degree of heavy-metal contamination, pollution index (P_i) for each metal and Nemerow multi-factor or integrated pollution index *(P_c or NIPI),* the single contamination (Hao *et al.,* 2022) index,

$$P_i = C_i / S_i \quad \text{…………} \quad (4)$$

Where p_i is the contamination index of soil contamination, C_i is the measured value of soil contaminants in mg/kg, S_i is the background value of the soil contaminants *I* in mg/kg. The soil is not contaminated when $P_i \leq 1$, but contaminated where I, and the higher the P_i, the more serious the soil contamination (Yang *et al.,* 2018).

The Nemerow multi-factor index,

$$P_c = \left\{ \left[\left({C_i}/{S_i} \right)^2_{ave} + \left({C_i}/{S_i} \right)^2_{max} \right] \Big/ 2 \right\}^{1/2} \quad \ldots\ldots\ldots \quad (5)$$

Where P_c is the comprehensive contamination index of the soil contaminant, $(C_i/S_i)_{ave}$ is the average value of the pollution index of soil contaminants, and $(C_i/S_i)_{max}$ is the maximum value of the single contamination index (Yang *et al.,* 2018).

The potential contamination index (Cp) can be evaluated by the equation;

$$C_p = \frac{M_{Sample}}{M_{reference}} \quad \ldots\ldots\ldots\ldots \quad (6)$$

Where $M_{sample\ max}$ is the maximum concentration of an element in the soil, and $M_{reference}$ is the value of same element in a reference soil. Cp value were explained as proposed, where $Cp \leq 1$ indicates low pollution; $1 < Cp \leq 3$ is moderate pollution; and $Cp > 3$ is severe or very severe pollution (Kumar *et al.,* 2019).

The geo- accumulation index (I_{geo}) was utilized to evaluate the degree of element pollution in soils by balancing the present with original concentrations; however, it is hard to find original soil.The I_{geo} values of a sample can be evaluated with the following equation:

$$Igeo = log_2 \left[{C_i}/{(1.5Bi)} \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Where C_i is the current elements concentration in the soil samples and B_i is the geochemical reference value as defined. The modified coefficient constant 1.5 was utilized to characterize the effect of accumulation and geological characteristics and determine the consequence of human activities. I_{geo} can be separated into seven classes (Nour *et al.,* 2019).

Enrichment factor (EF) is one of the indicators most often used for estimating anthropogenic inputs. Using this techniques, the sediment's EF ratio can be used as a pollution index by comparing the concentrations of selected metals to the background levels of metal in sediments or suspended particulate matter from local or worldwide rivers. The advantage of using measurement concentration of local sediments as background values is that they can be better for comparison. The widely used elements for normalization are Al and Fe. EF is important indicators that quantitatively assess the levels and sources of heavy metal pollution.

$$EF = \frac{(Me/Fe)_{simple}}{(Me/Fe)_{\text{background}}} \quad \text{……….. (9)}$$

Where $(M/Fe)_{\text{sample}}$ is the sample value of metal of interest to Fe,
$(M/Fe)_{\text{background}}$ is the background value of metal to Fe.
Iron was chosen as the element of normalization because natural sources (1.5%) vastly dominate its input (Kahal *et al.,* 2020).

RESULTS AND DISCUSSION

The observed contamination levels in the sediment samples reveal potential risks for both human populations and aquatic ecosystems and was calculated using **Eqn. 1 .** The mean values of the metals, particularly Zinc, Manganese, Cadmium, Chromium, Nickel, Lead, and Copper, provide valuable insights into the extent of their presence in the environment (Fig. 3)**.** Zinc, with a mean Contamination Factor (CF) of 3.224 **mg/Kg**, suggests a moderate level of contamination across the sampled stations. While Zinc is an essential trace element for humans, excessive exposure can lead to adverse health effects. Prolonged high intake of Zinc may result in gastrointestinal discomfort and interfere with the absorption of other essential minerals. In aquatic environments, elevated Zinc levels can be detrimental to aquatic organisms, disrupting their metabolic processes and overall well-being. Manganese, with a mean CF of 2.352 **mg/Kg**, indicates a moderate level of contamination. Excessive exposure to Manganese can lead to neurological issues, especially in children. It is crucial to note that Manganese is an essential nutrient, but excessive levels can pose risks. In aquatic ecosystems, elevated Manganese levels can negatively impact the respiratory and metabolic processes of aquatic organisms. Cadmium, with a mean CF of 2.483 **mg/Kg**, is a highly toxic metal with severe implications for both humans and aquatic life. Chronic exposure to Cadmium can result in kidney damage, respiratory problems, and even fatalities. Children are particularly vulnerable to its effects. In aquatic environments, elevated Cadmium levels can be devastating for aquatic organisms, disrupting their growth, reproduction, and survival. Chromium, with a mean CF of 2.686 **mg/Kg**, poses potential risks to human health and aquatic ecosystems. Hexavalent Chromium (Cr (VI)) is a known carcinogen and can lead to respiratory problems. Long-term exposure may lead to serious health issues. In aquatic environments, high Chromium levels can be toxic to aquatic organisms, affecting their respiratory and reproductive systems. Nickel, with a mean CF of 2.701 **mg/Kg**, warrants attention due to its potential health implications for both humans and aquatic organisms. Chronic exposure to Nickel can result in allergic reactions, dermatitis, and respiratory issues, particularly inhaled Nickel. In aquatic environments, elevated Nickel levels can negatively impact aquatic organisms, affecting their growth, reproduction, and overall health. Lead, with a mean CF of 2.689 **mg/Kg**, is highly toxic to both humans and aquatic life. Chronic exposure to Lead can lead to a range of health issues, including neurological damage, developmental delays in children, and cardiovascular problems in adults. In aquatic environments, Lead can be detrimental to aquatic organisms, affecting their nervous and reproductive systems. Copper, with a mean CF of 0.976 **mg/Kg**, indicates a relatively lower level of contamination. While Copper is an essential nutrient, excessive exposure can lead to gastrointestinal discomfort. Children may be more susceptible to copper toxicity. In aquatic environments, high Copper levels can be toxic to aquatic organisms, affecting their respiration and reproduction.

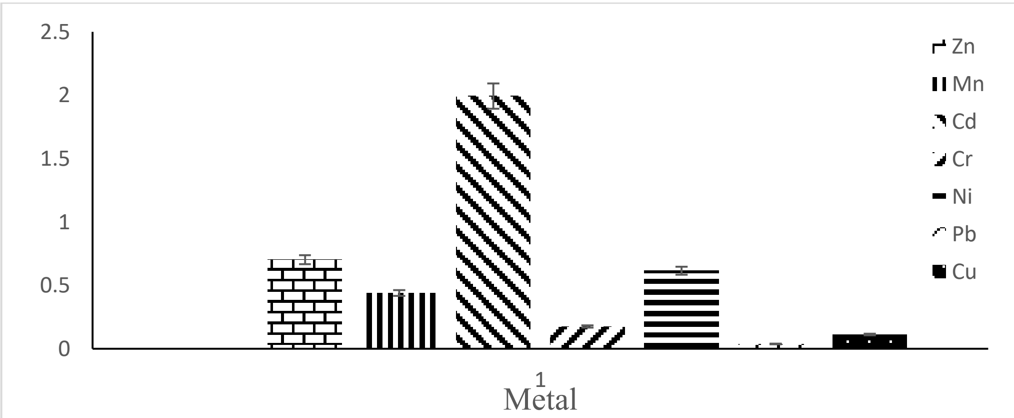

Fig. 3: Contamination Factor of Sediment Samples.

The data presented below was obtained using **Eqns. 2 & 3** and this shows a comprehensive assessment of the Heavy Metals Potential Ecological Risk Coefficients (E^i_r) and resulting Potential Ecological Index (Ri) values across four distinct sampling stations. Analyzing the mean values per metal provides critical insights into the potential ecological risks associated with heavy metal contamination in the sediment samples. Among the metals examined (Fig.4), Zinc exhibits a moderate ecological risk with a mean E^i_r of 3.224 **mg/Kg**. This is mirrored in the Ri values, which consistently remain below 4 across all stations. This suggests that while Zinc contamination is present, it poses a relatively lower ecological risk compared to other metals. In contrast, Manganese demonstrates a higher ecological risk, indicated by its mean E^i_r of 4.714 **mg/Kg**. The Ri values corroborate this assessment, consistently exceeding 4 across all stations. Cadmium shows a moderate ecological risk with a mean E^i_r of 2.484 **mg/Kg**,. The Ri values further support this evaluation, with Station 3 displaying the highest Ri value for Cadmium. This station may require specific attention to address the potential ecological risk associated with Cadmium contamination. Chromium presents a moderate ecological risk, as indicated by its mean E^i_r of 2.573 **mg/Kg**. This assessment is validated by the Ri values, which consistently surpass 2 for all stations. This underscores that Chromium contamination is an ecological concern and warrants close monitoring and potential remediation measures. Nickel emerges as a notable concern with the highest mean E^i_r value of 7.803**mg/Kg**, signifying a higher ecological risk. This is substantiated by the Ri values, particularly at Station 1, where an exceptionally high Ri value for Nickel is observed. This station poses a significant ecological risk due to Nickel contamination, necessitating targeted intervention. Lead also exhibits a moderate ecological risk, with a mean E^i_r of 4.1056 **mg/Kg**. The Ri values align with this assessment, consistently exceeding 4 across all stations. This indicates that Lead contamination is a notable ecological concern and should be closely monitored to prevent potential environmental impacts. Copper presents the highest ecological risk among the metals, with a mean E^i_r value of 5.801 **mg/Kg**. This assessment is confirmed by the Ri values, which consistently exceed 5 across all stations. Copper contamination poses a significant ecological threat and demands immediate attention and mitigation efforts. The analysis of the mean of E^i_r values and resulting Ri trends emphasizes the potential ecological risks associated with heavy metal contamination. Nickel, Copper, and Manganese emerge as particularly concerning elements, demonstrating higher ecological risks. Stations with elevated Ri values for specific metals require targeted intervention to mitigate potential environmental impacts.

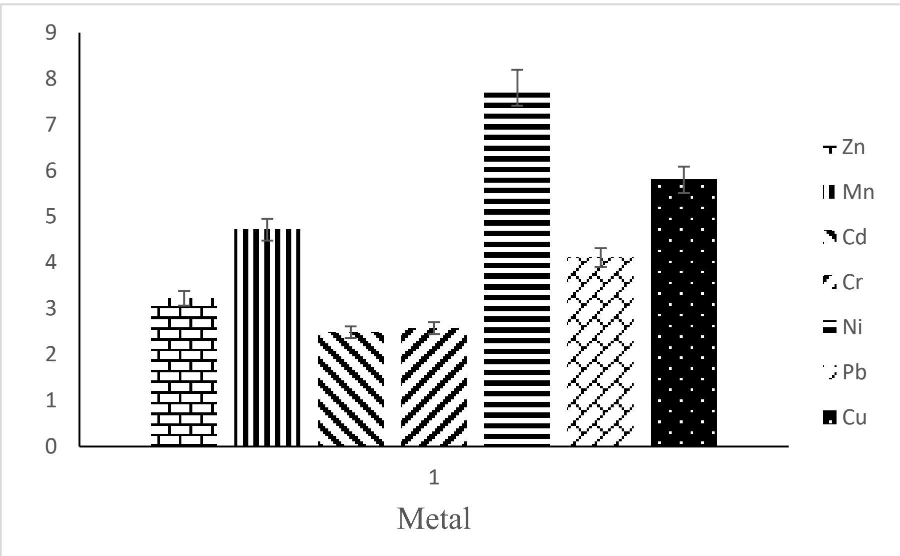

Fig. 4: Potential Ecological Risk Coefficient and Potential Ecological Index.

The Nemerow Pollution Index (NPI) values (Table 1) obtained using **Eqns. 4 & 5**, provides a comprehensive evaluation of metal pollution levels across all four stations shown below. Zinc has a low NPI value of 0.76, indicating that its concentration is within acceptable limits. This is a positive sign, suggesting that Zinc does not pose a significant threat to the environment at current levels. On the other hand, Manganese has a moderately elevated NPI value of 1.39. This indicates that the concentration of Manganese in the samples is slightly higher than desired. Cadmium has a relatively low NPI value of 0.30, which is encouraging considering its high toxicity. The current concentration levels of Cadmium appear to be within safe limits. However, strict monitoring protocols must be maintained to prevent any rise in Cadmium levels that could be harmful to the environment. Similarly, Chromium demonstrates a moderate NPI value of 0.99, suggesting moderately elevated concentrations. Nickel has an NPI value of 0.62, indicating that its concentration in the samples is within acceptable limits. This is important because high levels of Nickel can be toxic. Lead has an NPI value of 1.11, which shows a moderately elevated concentration. Given the well-known toxicity of Lead, it is crucial to closely monitor its levels. Although the current levels may not pose an immediate threat, preventive measures should be taken to avoid potential adverse effects and to ensure that Lead levels do not increase to harmful levels for the environment. Copper has an NPI value of 0.84, indicating a moderate concentration in the samples. While it may not pose an immediate danger, it is recommended to continue monitoring and implementing control measures to keep Copper levels within safe limits.

Table 1: Nemerow Pollution Index (NPI) for Sediment Samples

Metals	NPI	Contamination Level	Contamination Factor
Zn	0.76	Save	Clean
Mn	1.39	Light	Slightly contaminated
Cd	0.30	Save	Clean
Cr	0.99	Save	Slightly contaminated
Ni	0.62	Save	Clean
Pb	1.11	Light	Slightly contaminated
Cu	0.84	Save	Clean

The Pollution Contamination Index (PCI) values (Table 2) were obtained using **Eqn. 6.** The PCI which evaluates the degree of contamination of various metals in the sediment across the examined stations are as shown below. Zinc exhibits a significantly high PCI of 3.228, indicating a substantial contamination compared to the background concentration. Manganese shos a moderately high PCI of 2.428, showing a significant contamination relative to the background concentration. While Manganese is an essential element, its increased presence in the sediment may have ecological implications. Continuous monitoring is recommended to gain a better understanding of its impact on the aquatic environment. Cadmium displays a relatively high PCI of 2.481, indicating a substantial contamination of this heavy metal in the sediment. Considering the potential adverse effects of Cadmium on aquatic life and ecosystem health, it is imperative to implement measures to mitigate its presence and prevent further contamination. Chromium exhibits a lower PCI of 0.858, suggesting a comparatively lower level of contamination in relation to the background concentration. Although Chromium levels appear to be lower. Nickel presents a relatively high PCI of 2.699, indicating a significant contamination level compared to the background concentration. The elevated levels of Nickel emphasize the need for proactive measures to mitigate its potential adverse effects on aquatic organisms and overall ecosystem integrity. Lead displays a moderate PCI of 1.063, indicating notable contamination of this heavy metal in the sediment. Elevated Lead levels can have detrimental effects on aquatic life and ecosystem.

Table 2: Pollution Contamination Index (PCI) for sediment Samples

Metals	**CPI**	**Pollution Levels**
Zn	3.225	Severe pollution
Mn	2.428	Moderate pollution
Cd	2.481	Moderate pollution
Cr	0. 858	Not polluted
Ni	2.699	Moderate pollution
Pb	1.063	Moderate pollution
Cu	0.968	Not polluted

The mean Igeo values obtained using **Eqn. 7 (**Fig. 5**)** reveal that Zinc has a relatively low pollution level with a mean value of 0.275, indicating generally low levels of Zinc contamination in the sediment samples. Manganese follows with a mean Igeo of 0.225, signifying a low to moderate level of pollution. Some stations show slightly elevated Manganese levels, warranting further investigation. Cadmium, on the other hand, has a mean Igeo of 0.168, indicating a low level of pollution. The sediment samples display relatively low levels of Cadmium contamination, suggesting a less polluted environment in terms of this metal. However, Chromium stands out with a mean Igeo of 0.500, indicating a moderate level of pollution. This highlights the need for closer scrutiny and potential mitigation measures to address Chromium contamination across the sampled stations. Nickel and Lead both exhibit mean Igeo values of 0.275 and 0.168 respectively, indicating low levels of pollution.

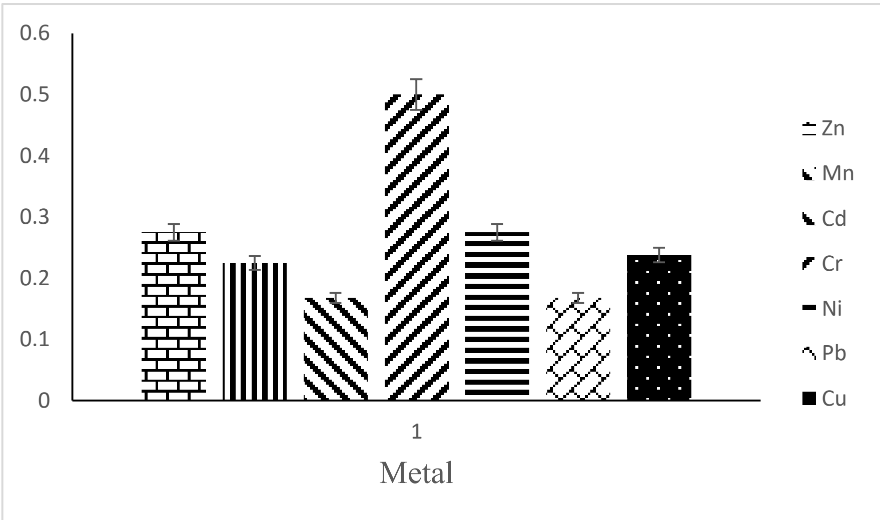

Fig. 5: Geo-Accumulation Index for Sediments

The enrichment factors of all the metals which were obtained using **Eqn. 8** are as shown in Fig.6 below. Among the metals, Zinc exhibits the highest mean EF of 3.224, indicating a substantial enrichment compared to natural background levels. This suggests a notable anthropogenic influence or localized geological conditions contributing to heightened Zinc concentrations. Cadmium follows with a mean EF of 2.485, signifying a significant enrichment and potential ecological risks associated with its presence in the sediment. Nickel also demonstrates a notable enrichment with a mean EF of 2.699, highlighting the need for careful monitoring and management. Manganese, while showing an elevated mean EF of 2.359, is an essential element and its presence may not necessarily imply contamination. Chromium, with a mean EF of 0.857, indicates concentrations closer to background levels, but ongoing monitoring remains essential. Lead and Copper exhibit mean EF values of 1.063 and 0.967 respectively, suggesting moderate enrichments that warrant further investigation.

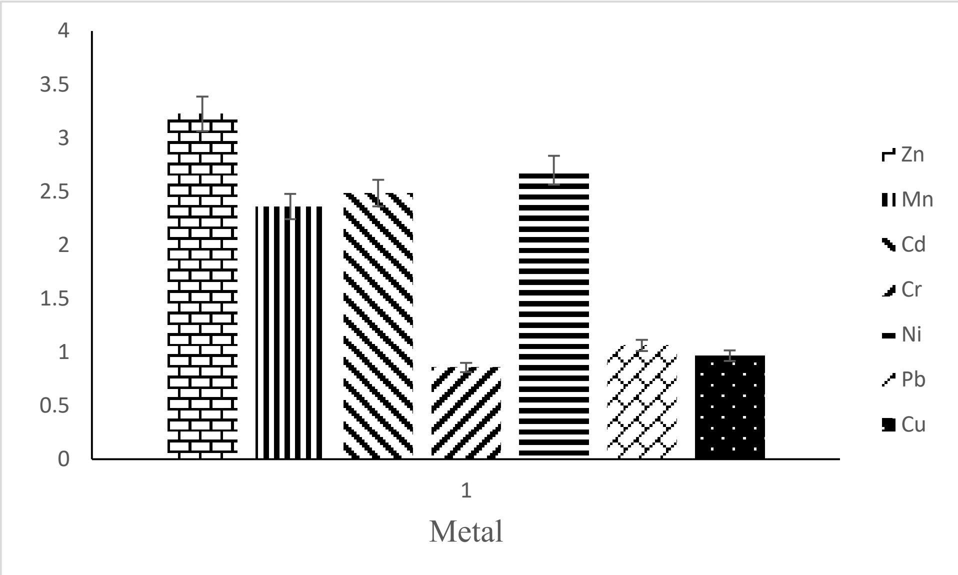

Fig. 6: Enrichment Factor (EF) for Sediment Samples

CONCLUSION

The observed contamination levels in the sediment samples reveal potential risks for both human populations and aquatic ecosystems. The Pollution Load Index (PLI) values provide crucial insights into the potential impacts of heavy metal contamination on both human populations and aquatic ecosystems. By analyzing the mean PLI values for each metal across the sampled stations, we understood the overall pollution levels and their potential ramifications. The analysis of the mean of E^i_r values and resulting Ri trends emphasizes the potential ecological risks associated with heavy metal contamination, while the Geo-Accumulation Index (Igeo) values offer valuable insights into the extent of heavy metal pollution in sediment samples across all stations. Summarily, the assessment reveal that the area studied is moderately polluted.

REFERENCES

Ansari, M., Ehrampoush, M. H., Farzadkia, M., & Ahmadi, E. (2019). Dynamic Assessment of Economic and Environmental Performance Index and Generation, Composition, Environmental and Human Health Risks of Hospital Solid Waste in Developing Countries; A State of the Art of Review. *Environment International*, 132, 105073.

Dar, S. A., Bhat, S. U., Rashid, I., Kumar, P., Sharma, R., & Aneaus, S. (2022). Deciphering the Source Contribution of Organic Matter Accumulation in an Urban Wetland Ecosystem. *Land Degradation & Development*, 33 (13), 2390-2404.

Hao, H., Zhang, M., Wang, J., Jiang, S., Ma, J., Hu, Y., & Sun, Y. (2022). Distribution Pattern and Enrichment Mechanism of Selenium in Topsoil in Handan Se-Enriched Belt, North China. *Sustainability*, 14 (6), 3183.

Kahal, A., El-Sorogy, A. S., Qaysi, S., Almadani, S., Kassem, O. M., & Al-Dossari, A. (2020). Contamination and Ecological Risk Assessment of the Red Sea Coastal Sediments, Southwest Saudi Arabia. *Marine pollution bulletin*, 154, 111125..

Kishor, R., Purchase, D., Saratale, G. D., Saratale, R. G., Ferreira, L. F. R., Bilal, M., & Bharagava, R. N. (2021). Ecotoxicological and Health Concerns of Persistent Coloring Pollutants of Textile Industry Wastewater and Treatment Approaches for Environmental safety. *Journal of Environmental Chemical Engineering*, 9 (2), 105012.

Kularathne, I. W., Gunathilake, C. A., Rathneweera, A. C., Kalpage, C. S., & Rajapakse, S. (2019). The Effect of Use of Biofuels on Environmental Pollution—A Review. *International Journal of Renewable Energy Resources*, 9 (3), 1355-1367.

Kumar, V., Sharma, A., Kaur, P., Sidhu, G. P. S., Bali, A. S., Bhardwaj, R., & Cerda, A. (2019). Pollution Assessment of Heavy Metals in Soils of India and Ecological Risk Assessment: A state-of-the-Art. *Chemosphere*, *216*, 449-462.

Mirzaei, M., Marofi, S., Solgi, E., Abbasi, M., Karimi, R., & Riyahi Bakhtyari, H. R. (2020). Ecological and Health Risks of Soil and Grape Heavy Metals in Long-term Fertilized Vineyards (Chaharmahal and Bakhtiari Province of Iran). *Environmental Geochemistry and Health*, 42, 27-43.

Nour, H. E., El-Sorogy, A. S., Abd El-Wahab, M., Mohamaden, M., & Al-Kahtany, K. (2019). Contamination and Ecological Risk Assessment of Heavy Metals Pollution from the Shalateen Coastal Sediments, Red Sea, Egypt. *Marine pollution bulletin*, 144, 167-172.

Panghal, V., Singh, A., Kumar, R., Kumari, G., Kumar, P., & Kumar, S. (2021). Soil Heavy Metals Contamination and Ecological Risk Assessment in Rohtak Urban Area, Haryana (India). *Environmental Earth Sciences*, 80, 1-20.

Preisner, M. (2020). Surface Water Pollution by Untreated Municipal Wastewater Discharge due to a Sewer Failure. *Environmental Processes*, 7 (3), 767-780.

Reis, M. M., Tuffi Santos, L. D., da Silva, A. J., de Pinho, G. P., & Montes, W. G. (2019). Metal Contamination of Water and Sediments of the Vieira River, Montes Claros, Brazil. *Archives of Environmental Contamination and Toxicology*, 77 (4), 527-536.

Sonone, S. S., Jadhav, S., Sankhla, M. S., & Kumar, R. (2020). Water Contamination by Heavy Metals and their Toxic Effect on Aquaculture and Human Health through Food Chain. *Letter of Applied NanoBioScience*, 10 (2), 2148-2166.

Vardhan, K. H., Kumar, P. S., & Panda, R. C. (2019). A Review on Heavy Metal Pollution, Toxicity and Remedial Measures: Current Trends and Future Perspectives. *Journal of Molecular Liquids*, 290, 111197.

Vaverková, M. D., Paleologos, E. K., Dominijanni, A., Koda, E., Tang, C. S., Małgorzata, W., & Singh, D. N. (2020). Municipal Solid Waste Management under COVID-19: Challenges and Recommendations. *Environmental Geotechnics*, 8 (3), 217-232.

Wang, X., Jin, Z., Zhao, J., Zhu, Y., Hu, Z., Liu, G., & Shi, S. (2020). Depositional Environment and Organic Matter Accumulation of Lower Jurassic Nonmarine Fine-grained Deposits in the Yuanba Area, Sichuan Basin, SW China. *Marine and Petroleum Geology*, 116, 104352.

Yang, Y., Wu, P., Li, X. X., & Zha, X. F. (2018). Distribution and Ecological Risk Assessment of Heavy Metals in Selenium-Rich Soil with High Cadmium Content of Coal Mining Area in Upper Reaches of Guancheng River in Zhijin County, Guizhou. *Chinese Journal of Ecology*, 37 (6), 1797.