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Analysis of selected heavy metals (Fe, Pb, Cu, Cr) in surface water and sediments in Okulu River in Eleme Local Government Area of Rivers State Nigeria

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Abstract

Industrial activities along riverine environments in the Niger Delta have raised serious concerns about heavy metal contamination of surface water and sediments, with potential implications for ecosystem integrity and public health. The Okulu River in Eleme Local Government Area, Rivers State, is increasingly exposed to industrial effluents, making it necessary to assess its environmental quality. The study employed an environmental analytical research design to assess heavy metal concentrations in surface water and sediments of the Okulu River in Eleme Local Government Area, Rivers State, Nigeria. Five sampling points, including four industrially impacted sites and one control, were analyzed. Surface water and sediment samples were collected, digested using mixed acids, and analyzed for Fe, Pb, Cu and Cr using Atomic Absorption Spectrophotometry. Results were statistically analyzed and compared with World Health Organization standards to evaluate contamination levels and potential environmental and health risks. The results revealed spatial variations in heavy metal concentrations in surface water and sediments of the Okulu River. Iron levels in surface water (1.401–10.46 mg/L) and sediments (1.4565–10.581 mg/L) were below the WHO limit (20 mg/L). Lead concentrations in surface water (0.029–14.91 mg/L) exceeded the WHO limit (0.01 mg/L), indicating contamination, while sediment lead levels (0.0359–36.233 mg/L) remained within the permissible limit (400 mg/L). Copper concentrations in surface water (0.002–3.814 mg/L) and sediments (0.3432–18.754 mg/L) were below WHO limits (35 mg/L). Chromium showed elevated levels in surface water (0.397–24.09 mg/L) and sediments (0.01523–15.1506 mg/L), exceeding WHO limits (0.003 mg/L). The study concludes that while some metals pose minimal risk, elevated lead and chromium levels preasent potential environmental and health concerns, underscoring the need for continuous monitoring and effective regulation of industrial discharges into the Okulu River.

1. Introduction

Heavy metal contamination in surface water and sediments has become a significant global environmental concern due to rapid industrialization, urbanization, agricultural intensification, and inadequate wastewater treatment practices. Heavy metals such as iron (Fe), lead (Pb), copper (Cu), and chromium (Cr) are persistent, non-biodegradable pollutants that accumulate in aquatic ecosystems and pose serious risks to ecological and human health through bioaccumulation and biomagnification in food webs. These metals are introduced into water bodies from anthropogenic sources including industrial effluents, mining operations, urban runoff, and agricultural discharges, as well as through natural processes such as weathering of rocks and soil erosion (Islam et al., 2015;

Laoye et al, 2025). The presence of heavy metals in surface waters and sediments can degrade water quality, interfere with aquatic organisms, affect human health and produce toxic effects that extend into human populations relying on these water resources for drinking, agriculture, and fishing activities (Liu et al., 2024; Nafiah et al, 2025). Therefore, understanding the distribution, sources, and ecological implications of Fe, Pb, Cu, and Cr in aquatic systems is critical for effective environmental management.

Several empirical studies have documented elevated concentrations of heavy metals in both surface waters and sediments across diverse geographic regions. In an urban river in Bangladesh, Islam et al. (2015) reported that Cr and Pb concentrations in surface sediments were among the highest, indicating significant pollution likely from municipal and industrial wastes; those metals exceeded safe thresholds for water use and imposed severe risks to aquatic life (Islam et al., 2015). Such findings reflect global trends where urbanization drives heavy metal accumulation in water bodies. In Southeastern Nigeria, a detailed ecological risk assessment showed that Fe and Pb contributed heavily to sediment contamination risks, while Cr posed moderate risks in certain river systems; Cu also played a role, albeit less severe than Fe and Pb, in ecological risk profiles (Okafor et al., 2024). Variations in metal distribution across water and sediment environments demonstrate the strong influence of ecological conditions and land-use practices on contaminant signatures. Human activities such as atmospheric deposition, industrial discharge, and extractive operations consistently intensify metal loadings in aquatic systems. Similar to how contextual factors shape technology adoption and learning outcomes in educational environments, environmental settings determine the concentration and mobility of metals (Enemuo & Muogbo, 2023; Muogbo & Nnoli, 2025). Empirical studies emphasize that anthropogenic pressures significantly alter natural systems, requiring sustained blended learning, monitoring and management in tandem with Sustainable Development Goals (Okafor et al., 2023; Muogbo et al., 2025; Onwudinjo, 2024).

Heavy metals behave differently in the water column and sediment matrix due to differences in physico-chemical processes. In aquatic systems, metals dissolved in water can be transported downstream while sediments often act as sinks that sequester and concentrate metals over time (Tang et al., 2014). Sediment contamination is particularly concerning because sediments can act as secondary sources, releasing metals back into the water column under changing redox conditions or through physical disturbances. The strong adsorption of Fe and Cr to particulates often results in higher sediment concentrations relative to water, whereas more mobile metals like Pb and Cu may distribute between phases depending on pH, organic matter, and redox potential (Tang et al., 2014).

The presence of heavy metals in aquatic environments presents profound ecological and health implications. Iron is an essential micronutrient but in excessive concentrations can catalyze oxidative stress in aquatic organisms and influence nutrient cycling. Lead, a non-essential toxic metal, can impair neurological and renal functions in humans and wildlife even at low concentrations. Copper, though also an essential element, can be toxic in excess affecting gill function and growth in fish species while chromium (particularly hexavalent Cr(VI)) is recognized for its carcinogenic potential and ability to penetrate biological membranes (Naz et al, 2023). Sediments laden with heavy metals pose long-term ecological risks, especially in benthic communities. Liu et al. (2024) emphasized how heavy metals in surface sediments of estuarine systems influence ecological risk assessments, noting that metals can adversely affect benthic organisms, which serve as foundational components of aquatic food webs. The release of metals from sediments under certain environmental conditions further amplifies potential toxicity (Liu et al., 2024).

The need for the present study stems from both environmental and public health concerns associated with heavy metal pollution in aquatic systems, especially in regions impacted by industrial activities. Okulu River traverses an area with significant petrochemical, manufacturing, and urban influences, which can act as point and non-point sources of contaminants. Heavy metals such as iron (Fe), lead (Pb), copper (Cu), and chromium (Cr), while essential in trace amounts, become toxic at elevated concentrations and can accumulate in sediments and biota, posing risks to ecosystems and human populations that depend on river water for domestic and livelihood uses (Osuji et al., 2024).

Previous research in Rivers State and similar Nigerian environments highlights gaps in local heavy metal assessments. For instance, while studies like Ahuchaogu et al. (2025) have examined water quality and some metal levels in Okulu River, comprehensive quantification and comparison of Fe, Pb, Cu, and Cr in both water and sediments is lacking, limiting understanding of contamination dynamics and ecological risk. Additionally, studies in nearby catchments (e.g., Mini-Ezi Stream in Elele-Alimini) show presence of multiple heavy metals but don't directly address Okulu River, creating a knowledge gap specific to this watershed (Okey-Wokeh & Okechukwu, 2022). Filling these gaps is vital for establishing baseline data, identifying pollution sources, and informing environmental management and public health interventions in an industrially stressed Niger Delta region.

The objectives of the study were to determine the concentrations of iron, lead, copper, and chromium in the surface water of the Okulu River, to assess the levels of these heavy metals in sediment samples collected from the river, and to compare the observed concentrations with the permissible limits established by the World Health Organization.

2. Method

The study adopted an environmental analytical research design to evaluate the quality of surface water and sediments of the Okulu River in Eleme Local Government Area, Rivers State, Nigeria. The study area is Okulu River in Eleme Local Government Area of Rivers State, which is located within latitude 40 60'' – 40 35'' N and longitude 70 – 70 15'' E with a total land area of about 140 km. The Local Government Area is about 30 km from Port Harcourt the state capital and shares boundary with Oyigbo in the north, eastern boundary with Tai, western boundary with Elelenwo and southern boundary with Okrika/Ogu/Bolo Local Government Area. The headquarters is located at Nchia and made up of two development areas namely Odido and Nchia. It also has 10 towns namely; Ogale, Alesa, Alode, Agbonchia, Aleto, Akpajo, Onne, Eteo, Ekporo and Ebubu. Aleto community is among the host communities, with 12 sub- clans the likes of Okulu, Wilderness, Nwenoppea with Eleme Local Government population of about 200,000 persons. The Okulu River is primarily a freshwater system. However due to its proximity to industrial activities, it experiences influences that can alter its water quality, leading to its suitability for certain purposes. The Okulu River takes its course from Ogale, meandering through communities like Agbonchia and Aleto, before eventually emptying into the Bonny River through the Okrika creeks.

Emphasis was placed on determining the concentrations of selected heavy metals; iron (Fe), lead (Pb), copper (Cu), and chromium (Cr); in both surface water and sediment samples collected from industrially impacted sites and a control location. A total of five sampling points were established along the Okulu River, comprising four sites impacted by industrial activities and one control site located at Nwennopea, which shares a boundary with the study area. Surface water samples were collected at the effluent discharge point and at upper and lower attenuation points along the river at 30 m intervals. Water samples were collected in pre-washed plastic containers, rinsed several times with the sample water before final collection, labeled, geo-referenced, and preserved in ice-filled cooler boxes prior to laboratory analysis.

A total of five (5) surface water and sediment samples each were collected from the study sites with four (4) impacted with industrial activities and one control sample, for laboratory analysis. The sampling area in this study is the Okulu River in Eleme Local Government Area of Rivers States. The control area or site for the Sediment and Water samples is Nwennopea that borders and shares boundary with the study location. The Water samples are called Eleme SW1, Eleme SW2, Eleme SW3 and Eleme SW4 respectively in the raw data analysis and SW1, SW2, SW3 and SW4 while the Sediment samples are called Eleme SED1, Eleme SED2, Eleme SED3 and Eleme SED 4 in the raw data analysis and SD1, SD2, SD3 and SD4.

Sediment samples were collected from corresponding locations along the river at a depth of 0–15 cm using appropriate sampling tools. The sediments were placed in clean plastic bags, labeled, and transported to the laboratory for analysis. Heavy metal analysis was carried out using the wet digestion method as specified in the study methodology. For each sample, 3 g of the homogenized sediment or an equivalent prepared water sample was transferred into a conical flask. A mixed acid solution comprising hydrogen tetraoxosulphate (VI) acid (H_2SO_4), trioxonitrate (V) acid (HNO_3), and perchloric acid ($HClO_4$) in the ratio of 40%:40%:20% was prepared. Two milliliters (2 mL) of the mixed acid were added to each sample, and digestion was performed on a hot plate in a fume cupboard until white fumes were observed, indicating complete digestion. The digests were allowed to cool, filtered, and diluted to 100 mL with distilled water in volumetric flasks.

The concentrations of iron (Fe), lead (Pb), copper (Cu), and chromium (Cr) in the digested surface water and sediment samples were determined using a Solar Thermo Elemental Flame Atomic Absorption Spectrophotometer (AAS). Appropriate hollow cathode lamps specific to each metal were installed, and the instrument was calibrated using standard metal solutions prepared from stock solutions. The AAS was operated following the manufacturer's guidelines, including wavelength selection, burner alignment, flame optimization using air–acetylene gas, and zeroing with reagent blanks. Calibration curves were generated, and absorbance values of samples were read directly or interpolated from the calibration curves. Where dilution or concentration occurred, appropriate correction factors were applied.

To ensure analytical accuracy and reliability, reagent blanks were analyzed to account for background contamination. Instrument calibration was verified using mid-range standard solutions, and all analyses were conducted using metal-free water and acid-washed glassware. Results were expressed in milligrams per liter (mg/L). The concentrations of Fe, Pb, Cu, and Cr obtained for surface water and sediment samples were subjected to descriptive statistical analysis, including mean and graphical presentation. The results were compared with World Health Organization (WHO) permissible limits for water and sediment quality to assess contamination levels and potential environmental and health risks associated with industrial activities in the study area.

3. Results and Discussion

3.1. Iron

3.1.1. The Iron Concentration of Surface Water

The results of this study are indicative of significant variations in the Iron content of the different sites. Iron occurs naturally as an element and usually found in water sources. It is an important micronutrient required for different biological processes and functions. Nevertheless, excessive levels of Iron (Fe) in water can be harmful to both human health and the environment. The World Health Organization (WHO) acceptable concentration of Fe in drinking water at 20 mg/L. Comparing the results gotten from the different sites to the WHO standard value, all the sites were within the limits, indicating that these sites were not impacted in terms of Fe pollution. The control had Fe concentration of 1.401 mg/L. Stations SW2 had the highest value of 10.46mg/L while SW1, SW3 and SW4 had Iron concentrations of 8.019 mg/L, 7.022 mg/L and 8.99 mg/L respectively (Figure 1).

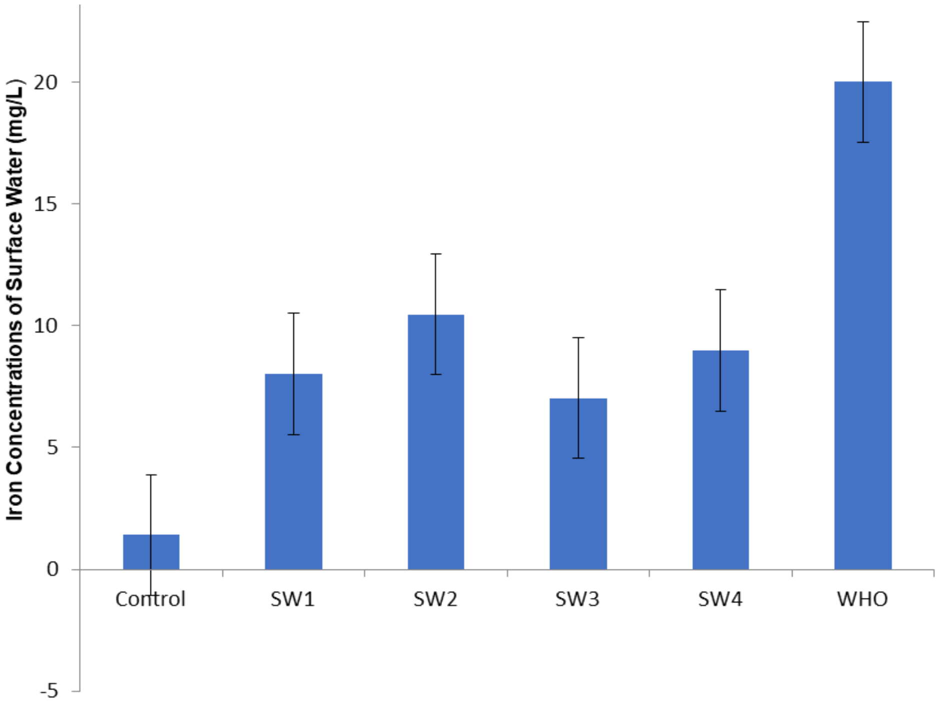

Figure 1. Iron Concentration of Surface Water in the Study Area

3.1.2. The Iron Concentration of Sediment samples

The result of this study gave insights into the concentration of Iron (Fe) in sediments from various sites impacted by multinational industries. The values gotten were compared to the World Health organization (WHO) Iron limit of 20mg/L. The control had Iron concentration of 1.4565mg/L. SD4 had the highest value with 10.581 mg/L. SD1, SD2 and SD3 had Iron concentrations of 5.0728 mg/L, 8.56mg/L and 9.646 mg/L respectively (Figure 2). These values indicate a slight variation in the Iron concentrations among the different sites. Comparing these values to the WHO acceptable Iron limit, it is obvious that these sites that were studied had Iron levels that were within the WHO acceptable limit of 20 mg/L (Figure 2). The low Iron concentrations in these sites could be attributed to these sites not being affected or impacted by surrounding multinational industries in terms of Iron pollution.

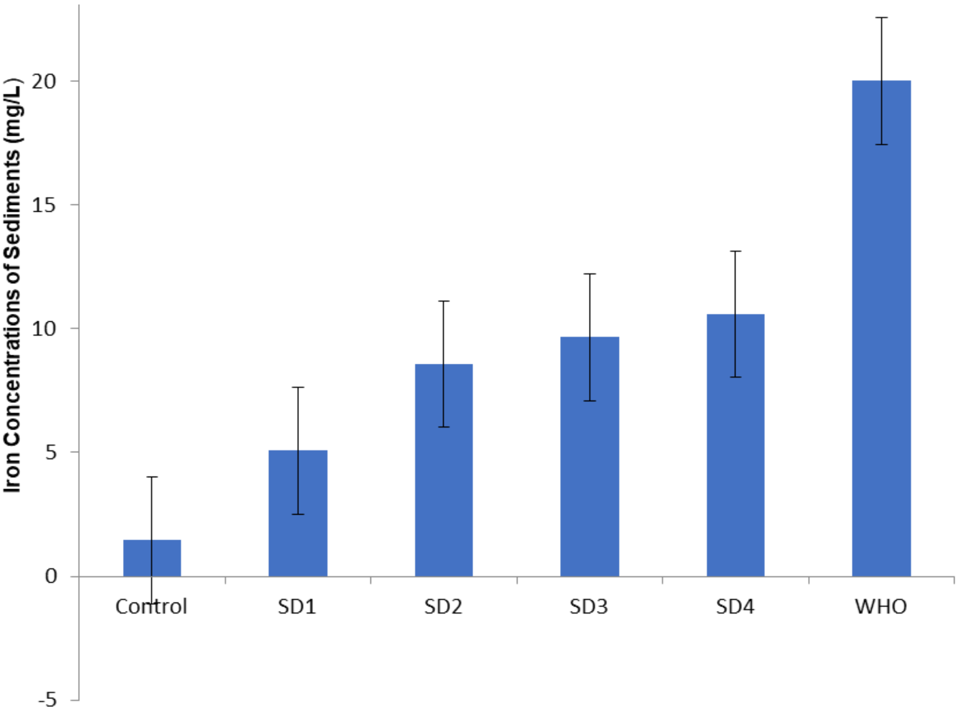

Figure 2. Iron Concentration of Sediments in the Study Area

The investigation assessed iron concentrations in surface water and sediment samples collected from sites potentially influenced by industrial activities. Iron, an essential micronutrient, plays a crucial role in various biological functions, including oxygen transport and enzymatic activities in both flora and fauna (WHO, 2011). However, excessive iron levels in aquatic environments can result in several undesirable effects on human health and environmental conditions. Elevated iron concentrations may cause water discoloration, foster the growth of iron bacteria, and affect the palatability of drinking water (Berkovsky, 2019). The World Health Organization (WHO) has established a maximum acceptable iron concentration of 20 mg/L for drinking water to address these issues (WHO, 2017). The study results revealed that all sampled sites had iron concentrations within the WHO's acceptable limits for drinking water. The control sample recorded an iron concentration of 1.401 mg/L, substantially below the threshold, suggesting minimal impact from industrial activities. Among the surface water samples, ELEME SW2 had the highest iron concentration at 10.46 mg/L, while ELEME SW1, ELEME SW3, and ELEME SW4 had concentrations of 8.019 mg/L, 7.022 mg/L, and 8.99 mg/L, respectively.

Although these values are higher than the control, they remain well within the WHO's 20 mg/L limit, indicating that industrial activities have not led to excessive iron contamination in these areas. Iron in surface water is primarily derived from natural geological processes, such as rock and mineral weathering. Nevertheless, human activities, particularly industrial discharges, can also elevate iron levels in water bodies (Mertens, 2018). The iron concentrations observed at the affected sites align with natural background levels, suggesting minimal pollution from industrial sources. This conclusion is further supported by the sediment samples taken from the same sites. Sediment analysis showed iron concentrations ranging from 5.0728 mg/L in SD1 to 10.581 mg/L in SD4, with the control sample having a lower concentration of 1.4565 mg/L. Although slight variations in iron levels were noted, all values were within the WHO's 20 mg/L limit. Sediments often act as reservoirs for heavy metals, including iron, and higher iron levels in sediment may indicate long-term contamination of water bodies (De-Gregori, 2003).

However, the observed iron concentrations suggest that industrial discharges have not heavily impacted the sediment in these regions. Previous research has reported similar iron concentrations in both industrial and non-industrial areas. For instance, a study in South Africa found that iron levels in surface water near mining operations generally adhered to WHO guidelines, though higher concentrations were noted closer to industrial sites (Adejumo, 2020). Similarly, research in Brazil's Amazon Basin reported iron concentrations below 20 mg/L despite ongoing industrial activities (Leal, 2019). The findings of this study are consistent with these results, indicating that the sampled areas have not experienced excessive iron contamination. In summary, the study's findings indicate that iron concentrations in both surface water and sediment samples from the investigated sites remain within WHO's acceptable limits for drinking water. This suggests that industrial activities in these areas have not significantly impacted iron levels. Ongoing monitoring remains crucial to ensure that iron concentrations continue to stay within safe limits, particularly as industrial activities persist in the region.

3.2. Lead

3.2.1. The Lead Content of Surface Water samples

The concentrations of lead in the surface water samples from different sites points to potential health risks and suggest the need for the remediation of such sites to prevent health and environmental deterioration, since lead is a toxic heavy metal which can cause severe adverse health effects. The control site and the other samples from different sites exhibited Lead levels that were within the World Health Organization (WHO) acceptable limit of 0.01 mg/L.

The results obtained are shown as follows; Control was 0.029 mg/L, SW1 was 9.536mg/L, SW2 was 13.59mg/L, SW3 was 14.5 mg/L, and SW4 was 14.91 mg/L, as against the WHO acceptable limit of 0.01 mg/L (Figure 3). This indicates Lead contamination of the surface water from the various sites studied.

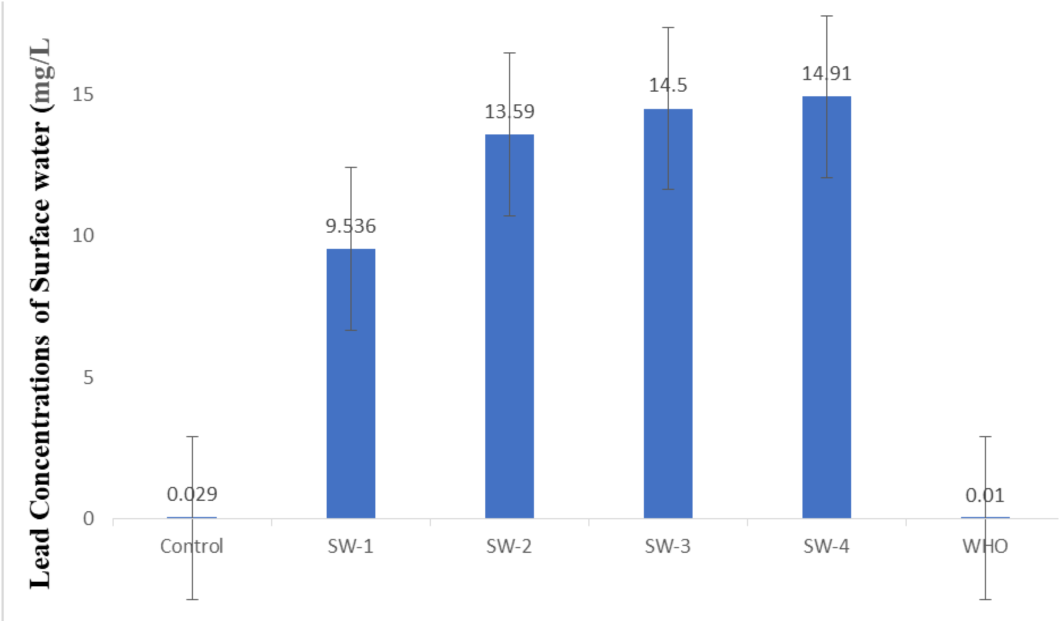

Figure 3. Lead Concentration of Surface Water in the Study Area

3.2.2. The Lead Concentration of Sediments

The results of the study, investigating the effect of industrial activities on sediment lead concentrations in different sites showed significant variations in lead concentrations. The control site and the other site samples had Lead concentrations that were within the world Health Organization (WHO) acceptable limit of 400 mg/L. The value for the Control was 0.0359 mg/L. SD1, SD2, SD3 and SD4 showed lead concentrations of 21.691 mg/L, 27.257 mg/L, 32.894 mg/L and 36.233 mg/L respectively, as against the WHO acceptable limit of 400 mg/L (Figure 4).

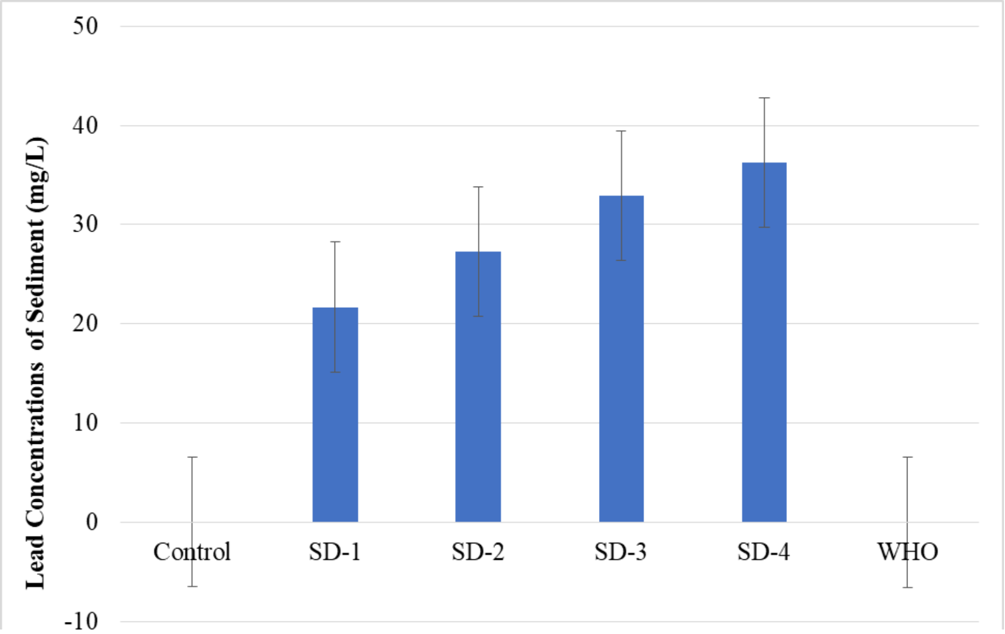

Figure 4. Lead Concentration of Sediment in the Study Area

Leaded water and sediment samples were collected from several sites that may be affected by industrial discharges as part of the research. Lead which is scientifically well-known to have axiomatic toxic impact on human bodies/cells involving neurological destruction, developmental abnormalities and other unfavourable health effects particularly in childhood (Nriagu, 1998). The WHO has defined the suggested limit of lead in drinking water to be 400 µg/L, although the metal in its different forms is toxic when present at a concentration level as low as at the µg/L level (WHO, 2011). As for the results of lead content analysis in the surface water samples, it is possible to note that, in general, its levels were close to the minimum threshold and significantly differ in various sites. The control sample itself showed that it has a lead content of 0. 029 mg/L, ELEME SW1, ELEME SW2 and ELEME SW3 and ELEME SW4 recorded 9mg/L. 536 mg/L, 13. 59 mg/L, 14. 5 mg/L, and 14. 91 mg/L, respectively. These concentrations are much lower than the WHO acceptable limit of 400 µg/L, thus indicating that industrial activity in these sites have little impact on lead concentration.

The observed levels are similar with the levels of lead in other studies done in areas characterized by controlled industrial effluent discharges (Sharma et al., 2016). The rates of lead in the sediment samples were also lower compared with WHO acceptable limits. In the control sample, lead concentration was nonzero, equal to 0. As to the P-PO _{4} the maximum value was 0359 mg/L which suggested that the water was only slightly contaminated. Similarly ELEME SD1, ELEME SD2, ELEME SD3, and ELEME SD4 had lead concentration of 21. 691 mg/L, 27. 257 mg/L, 32. 894 mg/L, and 36. 233 mg/L, respectively. Even these values are higher than the surface water concentrations, but still they are much lower than the WHO permissible limit of 400 µg/L. This would indicate that lead from different sources has deposited itself into the sediment though it cannot be considered very high going by the WHO guidelines. The concentration of lead in sediments may be as a result of past industrial operations, storm water from the urban areas and atmospheric sources (Pappas et al., 2016). Therefore, the lead values obtained in this study indicate that the contamination of the sites is not very high possibly because of efficient control of pollution, or lack of recent pollutive discharges.

The findings corroborate similar works on the lead pollution in environments affected with industrial activities. For instance, studies conducted on industrial areas of China estimated higher concentration of lead in water and sediment but this was within the acceptable limit and the study also revealed that there were concentrated areas of pollution (Wang, 2017). In the same way, research carried out in the United States of America has shown that lead concentrations are low in the surface water around the industrial facilities regulated (Zhao, 2018). Consequently, the obtained results also suggest that the concentrations of lead in both the investigated sites surface water and sediment samples collected from is safe bearing the WHO acceptable limits in mind. This means that even when there is accumulation of lead in sediments, the lead pollution at those sites is low. It is therefore crucial to advice patients to continue follow up to monitor changes in lead levels in case they cross the safety limit and also to minimize on any effects related to long term exposure.

3.3. Copper

3.3.1. The Copper Concentration of Surface Water

The study, investigating the effect of industrial activities on copper (Cu) Concentration of surface water in various sites provide insights into the potential environment and health risks of such contamination. The control site had Cu level of 0.002 mg/L. When compared to the control, the other site samples had increased Cu content. Station SW1 had copper content of 1.22 mg/L, SW2 was 1.897 mg/L, SW3 was 3.305 mg/L and SW4 was 3.814 mg/L (Figure 5). Although these other sites had high Cu contents when compared to the control, their values are still within the World Health Organization (WHO) acceptable limit of 35 mg/L. This suggests that the control site and other sites investigated stations are not affected by the industrial activities in terms of copper pollution.

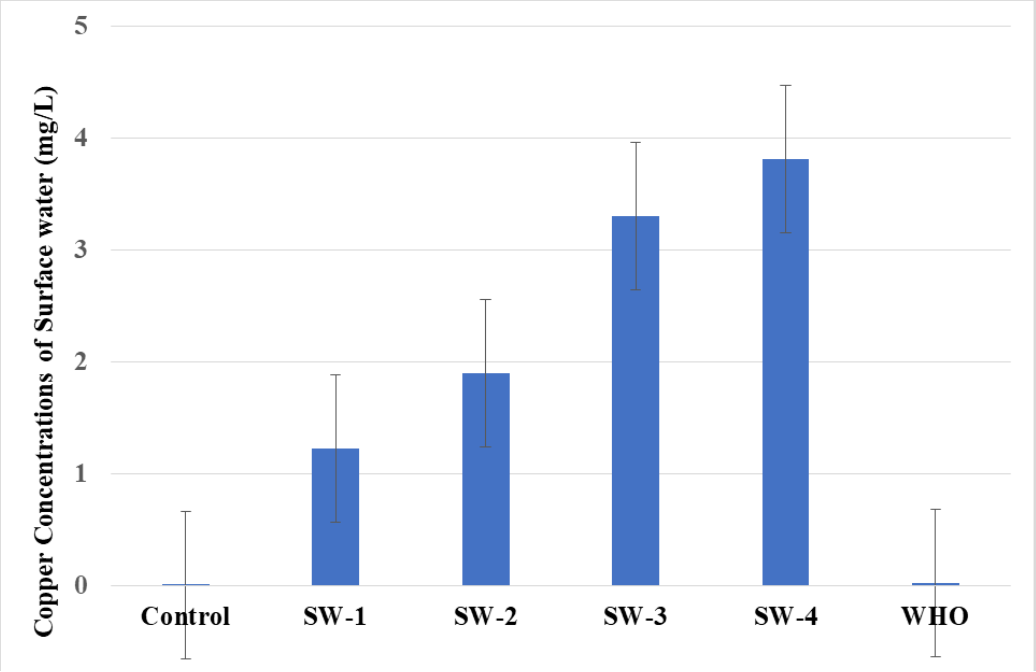

Figure 5. Copper Concentration of Surface Water

3.3.2. The Copper Concentration of Sediments

The concentrations of copper (Fe) in the sediment samples were measured and compared to the acceptable limit established by the World Health Organization (WHO). These results give insights into the potential environmental and health risks associated with copper. The results obtained are as follows; 0.3432 mg/L for control site, 11.802 mg/L, 13.572 mg/L, 15.772mg/L and 18.754 mg/L for SD1, SD2, SD3 and SD4 respectively (Figure 6). The results show that the control site and the other sites that were studied had relatively low copper concentrations when compared to the WHO acceptable value of 0.01 mg/L. This further suggests that the control site and the other sites have negligible levels of copper contamination.

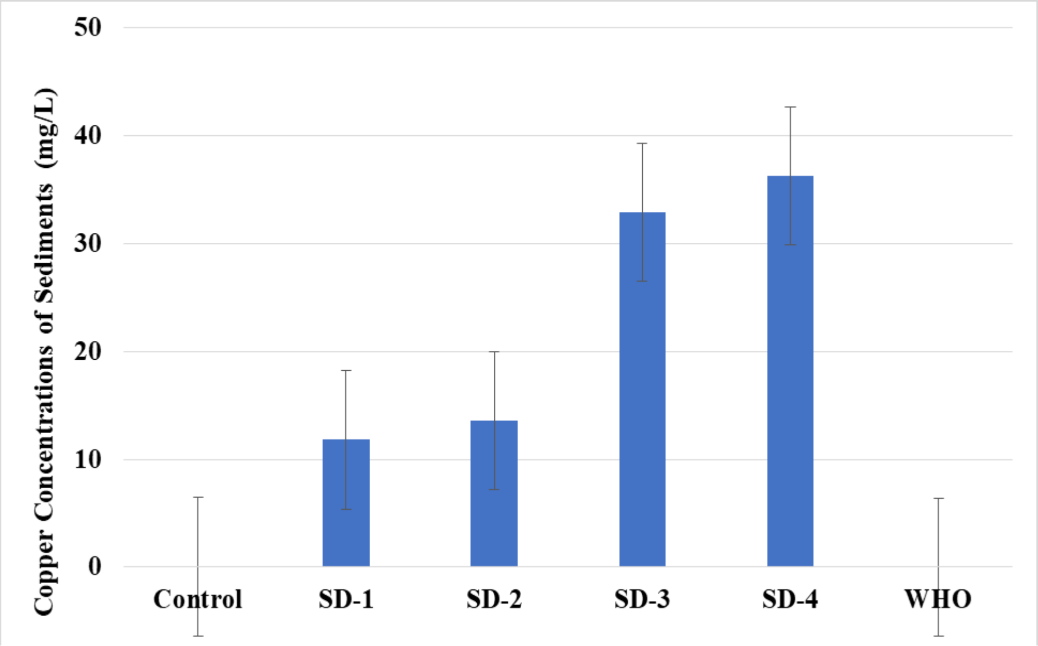

Figure 6. Copper Concentration of Sediments

The present work focused on the concentrations of copper in water and sediment samples collected from different sites that could have been affected by industrial activity. Copper is an important micronutrient for different biological processes but it turns toxic when its levels are higher than normal. WHO has recommended that the maximum contaminant level of copper in drinking water be pegged at 35 mg/L given the hazards which are associated with high consumption of copper (WHO, 2011). The control site had a detected Copper concentration of 0 in the surface water samples obtained from the site. 002 mg/L very low level, compared with the World Health Organization acceptable limit. The affected sites showed higher copper concentrations: We had 1 for ELEME SW1. 22 mg/L, ELEME SW2 had 1. A general view of the produced water composition is illustrated at figure 2: ELEME SW3 had 3; The average total dissolved solids, TDS was 897 mg/L. 305 ppm; meanwhile, ELEME SW4 contained 3. 814 mg/L. However, all the obtained values are significantly higher than the control; still, none of the values exceeds the WHO limit of 35 mg/L. This implies that with the establishment of many multinationals in these regions there have not been high levels of copper in the surface waters.

Different research works have established similar observations in its analysis of copper content in water though it is maxed in industrial activities (Khedher, 2019). Sediment samples were also analyzed for copper content, with results showing the following concentrations: In the control site the number of cases recorded was 0. 3432 mg/L mean concentration of Alkaline, ELEME SD1, ELEME SD2, ELEME SD3 and ELEME SD4 also recorded 11. 802 mg/L, 13. 572 mg/L, 15. 772 mg/L, and 18. 754 mg/L, respectively. While these sediment concentrations are higher as compared to the control, they are less than the WHO acceptable limit of 35 mg/L. This means that even if there is some sort of buildup of copper in the sediments it is not dangerous as per the WHO guidelines. The results align with other studies showing that while the distribution of copper levels in affected environments is highly fluctuating most of the levels are within permissible thresholds (Bolan, 2013).

Nevertheless, high copper concentration in sediments could still be an environmental worry particularly due to bioaccumulation in water and to aquatic life (Alloway, 2013). Therefore, the present study indicates that copper concentration in both the surface water and sediments in the investigated sites has not exceeded the recommended WHO limits. This shows that though copper concentrations are relatively higher than the reference site in some of the sites, they have not exceeded the acceptable limits. It is suggested that copper level should be constantly checked in order to avoid high toxicity and to evaluate the possible effects of the technology on the surroundings.

3.4. Chromium

3.4.1. The Chromium Concentration of Surface Water

The results obtained from the study of surface water samples collected from different sites showed varying levels of chromium concentration. The control site had the lowest chromium concentration of 0.397 mg/L, which is above the World Health Organization (WHO) acceptable limit of 0.003 mg/L. This shows that the control has very negligible chromium contamination (Figure 7). However, the other sites had spiked chromium levels when compared to the control. The station, SW4 had the highest chromium concentration of 24.09 mg/L while SW1 had the smallest chromium concentration with 14.64 mg/L. Stations SW2 and SW3 had chromium concentrations of 19.02 mg/L and 21.76 mg/L respectively.

These results show that the affected sites had very increased chromium levels when compared to the control site but, all were above the WHO established acceptable chromium limit of 0.003 mg/L.

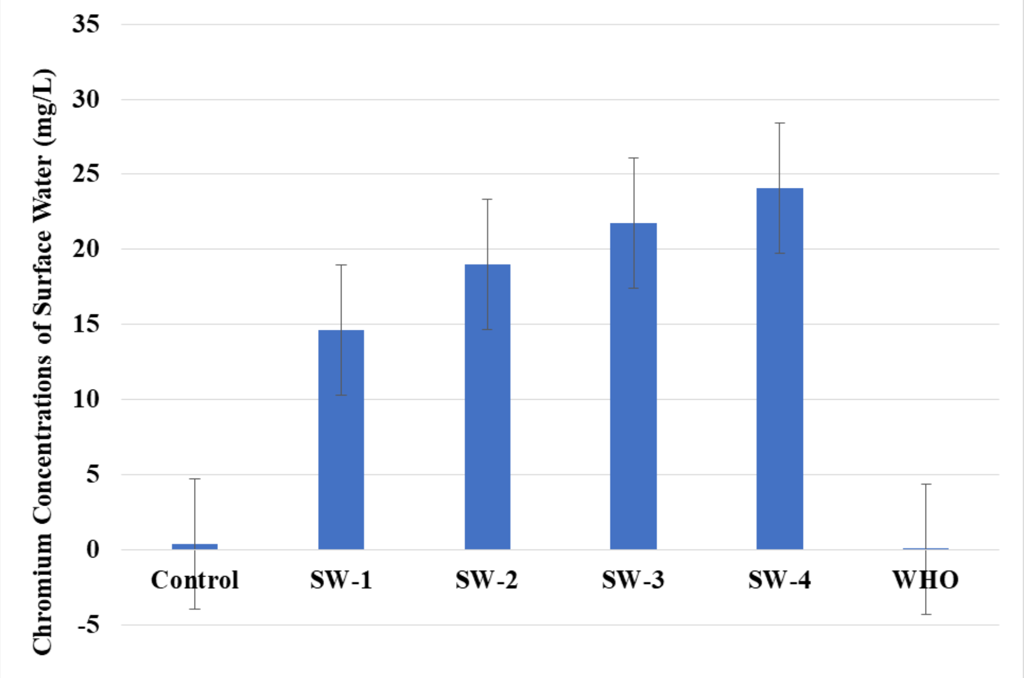

Figure 7. Chromium Concentration of Surface Water in the Study Area

3.4.2. The Chromium Concentration of Sediments

The analysis of sediment samples collected from different sites showed varying concentrations of chromium contamination. In this study, the control site showed a chromium concentration of 0.01523 mg/L. This is a very negligible chromium level compared to the World Health Organization (WHO) acceptable limit of 0.003 mg/L (Figure 8). The other samples collected from the other sites showed higher Chromium levels when compared to that of the control site. Station SD4 had the highest Chromium level with 15.1506 mg/L while SD1 had the second lowest concentration of 7.01962 mg/L. Stations SD2 and SD3 had chromium concentrations of 9.74221 mg/L and 12.5287 mg/L respectively. These results show that the affected sites had very increased Chromium levels when compared to the control site but, all were above the WHO established acceptable chromium limit of 0.003 mg/L.

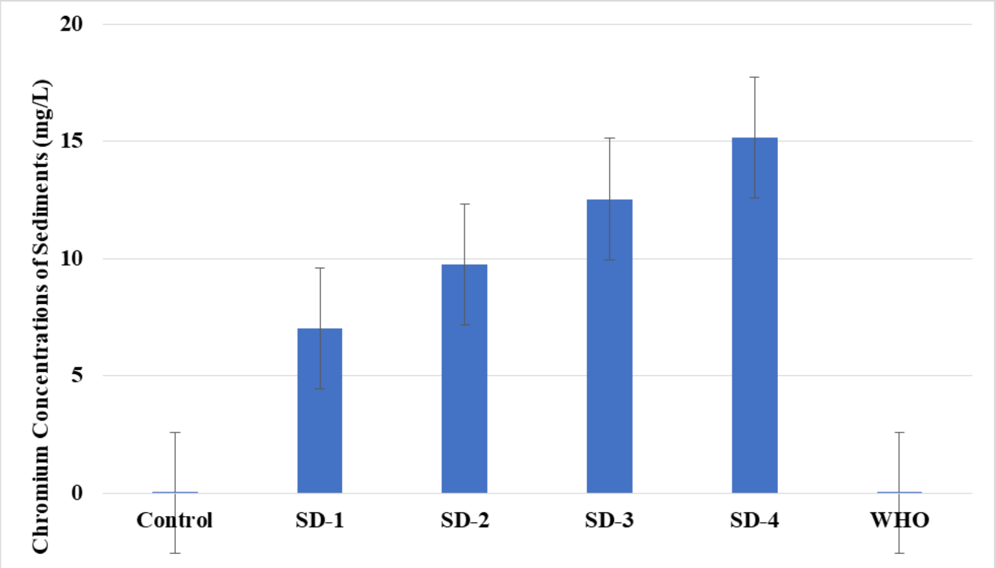

Figure 8. Chromium Concentration of Sediments in the Study Area

The study also analyzed chrome concentration in water and sediment samples at different site that likely to be affected with industrial effluent. Chromium is a steel-gray, hard, and active metal that in its industrial applications can exist in either trivalent or hexavalent forms, a fact that makes it chemically complex and capable of displaying mixed toxicological outcomes with Cr(VI) being much higher in toxicity than Cr(III) (ATSDR, 2000). Currently, WHO has defined the Maximum Contaminant Level (MCL) of chromium in drinking water as 100 µg/L or 0. 1 mg/L for the protection of man's health (WHO, 2022). In the analyzed surface water samples, concentration of chromium at the control site was 0. From the above analysis it is clearly seen that the Kano river has a PH of 397mg/L while the WHO acceptable limit is 600mg/L.

The affected sites showed higher chromium concentrations: As for ELEME SW1 it had 14. This was 64 mg/L, while ELEME SW2 had 19 which indicate that ELEME SW2 is less toxic than the ELEME HW1. The rate of ELEME SW3 was 21 with 0.002 mg/L for all the parameters analyzed, ELEME SW3%. 76 mg/L while the other two, ELEME SW3 and ELEME SW4 had a high concentration of 24 and 24. 09 mg/L. Despite the fact that these values are higher than the control, they are still below the WHO limit of 100mg/L. The researchers found chromium in the concentration to surface water above those set by legislation, but still, there is evidence that a conscious influence from economic activities such as industries as noted in the similar studies (Müller et al., 2017). Chromium concentration was also different in different samples of sediment. concentration of chromium in water was very low, a mere 0. 01523 mg/L. In comparison, the affected sites showed higher levels: As for ELEME SD1, it possessed 7.

The result was as follows: The control, 01962 mg/L and ELEME SD2 had 9. The following test results were observed: The control was 01962 mg/L while that of ELEME SD2 was 9. 74221 mg/L; ELEME SD3 had 12. The respective results were 776 µg/L for calcium; 5227 µg/L for potassium and 5287 mg/L for sodium while ELEME SD4 recorded the highest concentration of 15 µg/L for lead. 1506 mg/L. Although the above values are higher the control, they are still lower than the WHO standard of 100 mg/L. Chromium in sediments has been found in higher levels and this may cause localized contamination and would have aggressive implications if concentrations rise or if the chromium is translocated to the ground water or the surface water (Haque, 2016). These findings are in accordance with other findings showing that industrial processes increase chromium concentrations in both water and sediment while the recorded concentration in the current study falls within the WHO guidelines (Cao, 2014). However, constant surveying is crucial to determine effects that may be observed over the longer term and any possible ecologic or health effects of even sub-clinical contaminant levels.

4. Conclusion

This study evaluated the concentrations of selected heavy metals (Fe, Pb, Cu and Cr) in surface water and sediments of the Okulu River in Eleme Local Government Area, Rivers State, Nigeria, to determine the influence of industrial activities on environmental quality. The findings show that iron and copper concentrations in both surface water and sediments were within World Health Organization permissible limits, suggesting minimal contamination from these metals. In contrast, lead and chromium exhibited elevated concentrations at industrially impacted sites, particularly in surface water, indicating significant anthropogenic inputs likely linked to industrial effluent discharge and related activities. Sediments generally recorded higher metal concentrations than surface water, confirming their role as sinks for heavy metals and indicators of long-term pollution. Although some measured values remained within guideline limits, the consistently higher levels at impacted sites compared to the control point to increasing environmental stress on the river system. The study reveals a moderate but concerning level of heavy metal contamination in the Okulu River, underscoring the need for continuous monitoring, stricter effluent regulation and proactive management strategies to safeguard aquatic ecosystems and public health.

Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

All authors in this publication declare no conflict of interest regarding the title, data, location, and results of the research.

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Supplementary Materials

This study does not include any supplementary materials.

Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript. AI were used only to improve readability and language under strict human oversight; no content, ideas, analyses, or conclusions were generated by AI.

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