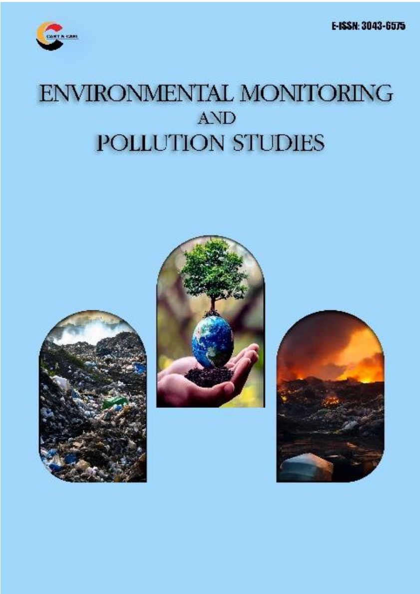
Original Research

Environmental Monitoring And Pollution Studies
https://cartcarl.com/journal/environmental-monitoring-and-pollution-studies

E-ISSN: 3043-6575



Assessment of Potentially Toxic Elements Concentration in the Bottom Sediment of the Dockyard Creek in Port Harcourt, Nigeria

Authors

[a] Ibrahim, L., [ab] Osuji, L.C., [ac] Obafemi, A.A., [ad] Hart, A. I.

[a] Institute of Natural Resources, Environment and Sustainable Development, University of Port Harcourt, Port Harcourt, Nigeria

[b] Department of Pure and Industrial Chemistry, University of Port Harcourt, Port Harcourt, Nigeria

[c] Department of Geography and Environmental Management, University of Port Harcourt, Port Harcourt, Nigeria

[d] Department of Animal and Environmental Biology, University of Port Harcourt, Port Harcourt, Nigeria

Corresponding Author

Ibrahim, L.

(latifatd007@gmail.com)

Received: 26 November 2024
Accepted: 28 December2024
Published: 20 January 2025

Citation

Ibrahim, L., Osuji, L.C., Obafemi, A.A., Hart, A. I. (2025). Assessment of Potentially Toxic Elements Concentration in the Bottom Sediment of the Dockyard Creek in Port Harcourt, Nigeria. *Environmental Monitoring and Pollution Studies, 2(1), 1-9* *https://doi.org/10.70726/emps.2025.210109*

Abstract

Various anthropogenic activities such as urbanisation and industrialisation have significantly increased the concentration of contaminants in the aquatic environment with various degrees of impact. With specific interest on the contaminants in a dockyard environment, the study assesses the potentially toxic elements-PTEs (Iron (Fe), Nickel (Ni), Cadmium (Cd), Barium (Ba), Vanadium (Va), Mercury (Hg), Zinc (Zn), Lead (Pb), Chromium (Cr) and Copper (Cu)) concentration in the bottom sediment of the dockyard creek in Port Harcourt, Nigeria using atomic absorption spectrophotometer model AA ZT 09. Results obtained from this study showed that the pH values ranged from 5.28 to 5.40 while the Electrical conductivity (EC) values varied from 15510 to 16160.53 µS/cm. The concentrations of Fe, Zn, Mn, Pb, and Cu are significantly different across the zones and control site at $P < 0.05$. The elevated levels of Fe, Zn, Mn, Pb, and Cu in Zones 1, 2, and 3 compared to the control site suggest substantial contamination in these areas. Effective monitoring and management strategies are crucial to mitigate PTEs pollution.

Keywords: Potentially Toxic Elements (PTEs), Environmental Pollution, Dockyard Creek, Sediment, Aquatic Environment

Introduction

Environmental contaminants such as Potentially Toxic Elements (PTEs) hydrocarbon are substances or compound that are present in the natural environment at levels higher than their permissible limits (Rahman et al., 2019). Industrialization and urbanization have emerged as the major causes of environmental pollution over the last few decades. The utilization of natural resources at a careless rate creates disturbances in the environment and causes several related problems (Singh et al., 2023). There are several types of pollutants, such as organic, inorganic, metallic, gaseous and biological pollutants, which contaminate the environment (Singh et al., 2023). Contamination from metallic ions in water arises due to several natural and anthropogenic activities, which harm animals and plants (Kinuthia et al., 2020). Among various environmental medium, aquatic environment remains the most polluted and sinker of several contaminants as a result of human and natural influence (Singh et al., 2023).

Potentially Toxic Elements (PTEs) consist of metals, semimetals, and non-metals that are naturally present in the human environment as a result of weathering action of parent materials, which may or may not have any biological importance to living organisms (Carvalho et al., 2022; Pan et al., 2018). PTEs are environmentally concerned due to their persistence, toxicity, bioaccumulation, and biomagnification

(Marin et al., 2022). At high concentrations, they pose health risks to organisms, including humans (Afolabi et al., 2022). Various anthropogenic actions such as mineral resources development, metal processing and smelting, industrial emissions, application of fertilisers and pesticides, sewage irrigation, and landfill systems have increased the concentration of PTEs in the global environment over the years and accumulated in environmental media (Chen et al., 2015; Afolabi and Eludoyin, 2021). Although, natural phenomena such as metal corrosion, atmospheric deposition, soil erosion of metal ions, volcanic eruptions and weathering can contribute to the concentration of PTEs in the environment (Omutange et al., 2022; Goher et al., 2019; Sharma et al., 2021).

Various anthropogenic activities such as urbanisation and industrialisation have significantly increased the concentration of contaminants in the aquatic environment (Martin et al., 2015; Ali et al., 2016) with various degrees of impact (Ahmeed et al., 2015). Such that in aquatic environments, sediment serves as a sinker of many of the contaminants, and is also used to monitor the environment to evaluate the extent of contaminants concentration (Islam et al., 2015). The impact of anthropogenic activities on the aquatic environment can be assessed based on the water and sediment of the ecosystem (Salem et al., 2015), and the outcome can support the management of the environment (Afolabi *et al*., 2022). In Nigeria, studies have asserted the presence of PTEs such as lead (Pb), zinc (Zn), chromium (Cr), cadmium (Cd), nickel (Ni), mercury (Hg), copper (Cu), Barium (Ba), Manganese (Mn), Vanadium (V) and iron (Fe) in the Niger Delta environment (Onakpa et al, 2018; Wongbunmak et al; 2020, Adebambo et al, 2020; Afolabi & Eludoyin, 2021). The route of entry of most contaminants into the human system can be by ingestion, inhalation, dermal absorption etc. (Wongbunmak et al; 2020; Asejeje et al, 2021; Ahmad et al, 2021; El-Zeiny and El-Hamid, 2022).

With specific interest on the contaminants in a dockyard environment due to various anthropogenic activities, Basheeru et al. (2022) reported environmental concern for Lagos dockyard due to high concentration of PTEs such as Cd, Pb and Cr which further increase human exposure. The dockyard creek being a component in the region saddled with issues of transportation, freight and other commercial activities plays host to huge pollution from adults and children on daily basis. The environmental quality, pollution and safety concerns is paramount. With limited study regarding the environmental status of dockyard creek in Port Harcourt, the present study assessed the potentially toxic elements concentration in the bottom sediment of the dockyard creek in Port Harcourt, Nigeria.

Materials and Method

Study Area

The sampling location was the Port Harcourt dockyard, which is situated along the Bonny River, approximately 30 kilometers Downstream from the Gulf of Guinea, which in turn is a large body of water connected to the Atlantic Ocean. . It is located between latitude 4° 46’59’N and 7° 01’59’E (Niger Delta Development Commission, 2023) (Figure 1). The Niger Delta is the most inhabited Delta in the World. It covers 70,000 km2 with a third being wetlands and hosts the largest Mangrove in the World (Nyananyo, 1999). The Niger Delta is also the largest river delta in Africa and the third largest in the World. The Bonny River is a major tributary of the Niger Delta, which empties into the Gulf of Guinea and the Atlantic Ocean, providing access to international shipping lanes. It was chosen mainly because of its location in the river system and networks, which is considered as an important gateway for maritime trade in the region connecting Nigeria to the global markets.

Data Collection and Procedure

Within the study area, various designated points were identified and represented in the study map (Figure 1) and positioning was carried out using a hand-held Global Positioning System.

i Upstream (4°44'33” S, 7^0 00’ 41” E) is the location at the Isaka/Ibeto axis usually busy with commercial as well as boat transportation activities, along the Bonny River network.

ii The second zone (4°45'01"N 7°01'02"E) is the midstream where the river flow is intertwined and polluted with the activities of the community dwellers at Bundu, a commercial nerve center, busy environment with boat movements, fishing activities combined with shoreline pollution due to boat fueling, scrapings and fabrications at the NPA Dockyards as well as shoreline dumping along the Bundu Ama axis by the community dwellers.

iii The Downstream (4°45'19"N 7°01'27"E) area is located at the Nembe waterside where artisanal refining, local alcohol and wood trading are carried out, lubricants sold, and local transportation networks are carried out.

iv The Control area (4°44'52"N 7°01'31"E) located at Ikpukwulu is a quiet and serene environment chosen as a control because of

Location Map [Satelite Imagery] of Dockyard Creek Showing Sampling Points

Figure 1: Overview of the Study Area and Sampling Points

little or no anthropogenic activities being carried out in this location.

Sediment samples were collected following standard procedures as described by Isaac & Nwineewii (2024) with slight modifications. Two (2) sediment samples were taken from each station in triplicates from the Bonny River over a two weeks' period in November 2023. The sampling period was dry with precipitation and average daily temperatures displaying no trend along the transect. The sediment samples were collected transversely from each station along the river using a stainless steel Eckman grab (to avoid metal contamination) to collect the top layer soft sediment (≈10 cm in depth). The samples were taken approximately 1m from the shore. Samples were put into well-labelled foil bags (indicating sampling point information and time of sampling) and placed into ice chest coolers at 4^0C and transferred to the laboratory (Tidal Flow).

Laboratory Analysis

Sediment samples collected were analysed for relevant physicochemical properties (pH and electrical conductivity) and PTEs. The pH of sediment samples was determined potentiometrically following standard methods as stipulated by Adekunle & Isaac (2019) while EC analysis followed the procedure described by Uwanta et al, (2024). For the PTEs, all analysis was based on American Public Health Association standard-APHA (APHA, 2012) and American Standard for Testing Materials- ASTM (ASTM, 2012) accepted standard procedures and analytical method described by Wogi et al (2021), while the PTEs concentration was determined by atomic absorption spectrophotometer model AA ZT 09.

Quality assurance/control (QA/QC) ensures that analyses are done at standard procedures, triplicate analyses and mean estimation for accuracy and precision. All analyses were subjected to quality reagents while instruments were sterilized, soaked in 10% HNO_3 in 1% HCl solution, washed adequately with deionized water, and desiccated. Detection limits, including LOD and LOQ, were estimated as LOD = 3 σ/S, LOQ = 10 σ/S, respectively, where σ is the SD (standard deviation) of analytical blank measurement (n = 18). At the same time, S is the slope of the calibration curve (y = mx + b) (Ahmad et al., 2021).

Results and Discussion

The concentration of Physicochemical and PTEs in the sediment of the study areas was presented in Table 1 and Table 2.

Table 1: Physicochemical Properties of the Bottom Sediment of Dockyard Creek

	Zone 1: Upstream	Zone 2: Midstream	Zone 3: Downstream	Control	F Statistic	P value
pH	5.28 – 5.4 (5.33± 0.06)	5.43 - 6.57 (6.10 ± 0.60)	5.57 - 6.28 (6.02 ± 0.39)	5.15 - 6.57 (6.18 ± 0.74)	11.32	0.01
EC (µS/cm)	15510 – 16160 (15850 ± 326.0)	10270 – 19160 (15643.3 ± 4726.9)	14430 – 21500 (17270 ± 3734.3)	430 – 5680 (4870 ±702.4)	34.45	0.0001

Table 2: PTEs Concentration in the Bottom Sediment of Dockyard Creek

Sampling Location	Fe	Zn	Mn	Pb	Cu	Cr	Cd	Ni	Ba	V
Zone 1: Upstream	2601.9 – 268317 (2645.96 ±41.05)	36.91 - 53.92 (43.92± 8.89)	54.25 - 62.84 (58.87 ±4.33)	8.27 - 10.95 (9.52 ± 0.35)	6.01 - 7.14 (6.47 ±0.59)	4.43 -7.47 (5.81 ±1.53)	0.49 - 1.06 (0.72 ±0.30)	5.08 - 6.56 (5.9 ±0.75)	0.2 - 0.38 (0.28 ± 0.09)	0.05 - 0.08 (0.07 ± 0.02)
Zone 2: Midstream	2047.9 - 2221.1 (2118.6 ±90.88)	29.87-36.33 (32.46 ± 3.41)	31.92 - 35.05 (33.89 ±1.72)	6.7 - 7.32 (7.05 ± 0.32)	7.64 - 9.08 (8.37 ±0.72)	5.16 - 6.08 (5.66 ±0.47)	0.59 - 0.72 (0.65 ±0.07)	4.08 - 5.18 (4.72 ±0.57)	0.20 - 0.22 (0.21 ± 0.01)	0.07 - 0.15 (0.11 ± 0.04)
Zone 3: Downstream	2682.9 - 3151.7 (2940.5 ±237.8)	50.93 - 61.39 (56.2 ±5.23)	49.52 - 92.2 (64.21 ±24.25)	19.35-38.92 (32.66 ±5.43)	6.31-12.1 (8.68 ±3.03)	5.46 - 8.67 (6.89 ±1.63)	6.5 -7.19 (6.96 ±0.40)	2.19 - 5.05 (3.78 ±1.45)	0.13 - 0.16 (0.143 ± 0.02)	0.03 - 0.06 (0.043 ± 0.01)
Control	59.33 - 73.92 (67.71 ±7.53)	34.25 - 36.92 (35.74 ±1.36)	16.7 - 24.27 (20.20 ±3.82)	5.97 - 7.14 (6.75 ± 0.67)	3.97- 4.63 (4.37 ±0.35)	0.81 - 0.82 (0.82 ±0.01)	0.21 - 0.34 (0.26 ±0.07)	0.19 - 0.22 (0.21 ±0.02)	0.08 - 0.09 (0.08 ± 0.01)	ND
F statistics	21.6	15.04	19.98	19.68	16.01	56.29	55.6	56.89	54.75	53.98
P-value	0.0001	0.0017	0.0002	0.0002	0.0012	0.000001	0.000001	0.000001	0.000001	0.000001
***FEPA**	50000	200	1000	100	1.00	43.4	0.6	18.1	51.8	17.4
****TEL**	20000	120	460	30.24	18.7	111.4	3.5	36.1	170.4	34.6
*****PEL**	40000	120	1100	112.2	108	100	5.0	50	500	50

*All parameters measured in mg/kg, *FEPA: Federal Environmental Protection Agency, **TEL: Threshold Effect Level, ***PEL (Probable Effect Level)*

Physicochemical Properties

The results obtained in this study show the trend in pH as Upstream (Zone 1) < Downstream (Zone 3) < Midstream (Zone 2) < Control. The lowest pH (5.33 ± 0.06), suggesting a higher acidity level in the Upstream of dockyard is consistent with other studies showing Upstream areas often receive runoff and pollutants, leading to lower pH.

Again, sandy areas might support burrowing organisms, while muddy (clay and silt) areas might support different types of benthic fauna. The midstream showed a higher pH (6.10 ± 0.60), indicating a less acidic environment compared to Upstream. The wide standard deviation suggests variability, possibly due to fluctuating pollution levels or natural buffering capacity while the pH (6.02 ± 0.39) of the Downstream is slightly lower than Midstream but higher than Upstream, reflecting a moderate acidity level. This could be due to less pollution and more natural water sources. However, the control location has the highest pH (6.18 ± 0.74), suggesting a relatively neutral environment. The large standard deviation indicates variability, potentially from different water sources or seasonal changes.

Electrical conductivity (EC) is a measure of the ability of a system to conduct electricity, which is directly related to the concentration of dissolved ions in the water sediment. High EC values typically indicate high levels of dissolved salts and pollutants, which can be linked to anthropogenic activities such as industrial discharge, agricultural runoff, and sewage effluent.in Zone 1 which comprises the Upstream area under study, a high mean EC value of 15850 ± 326.0 μS/cm, varying from 15510 to 16160 μS/cm suggests significant contamination, likely due to the accumulation of pollutants from Downstream and midstream sources. This could be as a result of industrial discharges, urban runoff, and other human activities that introduce contaminants into the water.

In Zone 2 (midstream), a high mean EC value of 15643.3 ± 4726.9 μS/cm suggests variable contamination levels (varying). This zone might be receiving intermittent discharges from industrial or agricultural sources, leading to fluctuating conductivity levels. Obvious contamination of the shorelines by heavily polluted debris is as indicator for high EC. This zone directly interfaces with the NPA Dockyard where there are occurrences of boat scrapings, fueling and boat suggests that at times, the contamination can be as severe as Upstream. EC data is much higher in the Downstream area varying from 14430 to 21500 with a mean of 17270 ± 3734.3 μS/cm. The highest value Downstream is indicative of significant contamination right from the source. This could point to direct fabrications. The high upper range (19160 μS/cm) pollution inputs from nearby industrial facilities, agricultural runoff, or wastewater discharges close to the Downstream region.

Expectedly, the impact of various anthropogenic activities ranging from commercial activities, wood trading, alcohol trading and lubricants to artisanal refining of crude petroleum oil and transportation business in this zone, posed a good attribute for the observed trend in EC. On the contrary, result of EC obtained at the Control location (4870 ± 702.4 μS/cm: 430 – 5680) implies the control site is presumably free from direct anthropogenic influences. This stark difference highlights the extent of contamination in the monitored zones, emphasizing the impact of human activities on water quality. A study conducted by Johnson et al. (2018) reported EC values in dockyard sediments that are similar to the current study, with EC ranging from 15000 to 16500 μS/cm across different zones. In contrast, Smith and Lee (2015) observed lower EC values in their investigation of dockyard sediments, where EC ranged from 4000 to 7000 μS/cm, significantly lower than our findings. Conversely, the research by Brown et al. (2020) documented higher EC levels in dockyard sediments, with measurements ranging from 18000 to 22000 μS/cm, indicating more saline conditions compared to our report on the current study.

PTEs Concentration

The Kruskal-Wallis test revealed that the concentrations of Fe, Zn, Mn, Pb, and Cu are significantly different across the zones and control site at $P < 0.05$. The elevated levels of Fe, Zn, Mn, Pb, and Cu in Zones 1, 2, and 3 compared to the control site suggest substantial contamination in these areas. This contamination likely results from anthropogenic activities, possibly including industrial discharges, urban runoff, artisanal refining and maritime activities common in the dockyard region. Study in the Port of Rotterdam, Netherlands, found comparable metal concentrations, linked to industrial and shipping activities (Klein & Hulscher, 2008). Study conducted on sediments in the Lagos Lagoon exhibited lower heavy metal concentrations, suggesting less industrial influence compared to the studied zones (Adekoya et al., 2006). A study in the San Francisco Bay reported lower heavy metal levels, reflecting effective pollution control measures (SFEI, 2012). Higher heavy metal concentrations were found in sediments of Warri River due to extensive industrial and urban activities (Aghoghovwia & Ohimain, 2014). The Sydney Harbour in Australia showed higher contamination levels, attributed to historical industrial discharges (Birch & Taylor, 2000). High concentrations of Fe across the zones indicate possible sources such as industrial effluents, which can pose ecological risks by affecting aquatic life and sediment quality.

Iron concentration was found to be highest Downstream (2940.5 mg/kg) and lowest at the control site (67.71 mg/kg). This significant variation ($F = 21.6$; $p < 0.05$) implies industrial/ artisanal or agricultural activities Downstream could be contributing to elevated iron levels. The low concentration of Fe in the control site suggests minimal anthropogenic influence. The ranges in our study are quite consistent with those observed by Zhang et al. (2018). However, our range falls within the lower end of findings of Kumar et al. (2018), with the range of 100 - 3500 mg/kg suggesting less severe iron contamination cu concentrations. Zinc levels are highest Downstream (56.2 mg/kg) and lowest midstream (32.46 mg/kg), with the control site having 35.74 mg/kg. The significant difference ($F = 15.04$) may indicate pollution sources Downstream affecting zinc concentration. The Upstream increase suggests possible accumulation as the river flows. Increased Zn levels could result from industrial and urban runoff, impacting the health of aquatic organisms and possibly accumulating in the food chain.

The findings of Zhang et al. (2014) with range of 30 - 60 mg/kg concentration was consistent with our finding, thus indicating comparable zinc pollution levels. The current study shows slightly lower zinc levels than Kumar et al., (2018) suggesting less zinc contamination in the current sites. Manganese (Mn): Elevated Mn levels, especially Downstream, could be linked to both natural geological sources and industrial discharges, affecting sediment quality and water chemistry. Manganese concentration follows a similar pattern, peaking Downstream (64.21 mg/kg) and being lowest at the control site (20.20 mg/kg). The significant variance ($F = 19.98$) indicates substantial Downstream contamination, possibly from mining or industrial runoff, with Upstream transport and deposition. The manganese levels in the current study are within the same range (15 - 70 mg/kg) as those reported by Zhang et al., (2014) indicating similar contamination sources or levels.

Lead (Pb): High Pb concentrations, particularly Downstream, raise concerns about its toxic effects on aquatic life and potential human health risks through water and food consumption. Lead shows a notable peak Downstream (22.66 mg/kg) and much lower levels midstream (7.05 mg/kg) and at the control site (6.75 mg/kg). This significant variation ($P < 0.05$) in concentrations of Pb across the zones and control underscores potential Downstream pollution sources, such as industrial waste or urban runoff, leading to contamination that diminishes Upstream due to dilution or sedimentation. The current study shows similar lead concentrations (5.8 - 25 mg/kg) to those observed by Zhang et al., (2014) suggesting comparable levels of lead pollution. Kumar et al. (2018) with concentration of 6.0 - 30 mg/kg gave higher ranges than our finding, indicating slightly less severe lead contamination.

Copper(Cu): Elevated Cu levels indicate contamination from industrial sources and antifouling paints, affecting aquatic organisms sensitive to copper toxicity. A study in the Niger Delta region reported similar ranges of heavy metals in sediments, attributing contamination to oil exploration activities (Nduka & Orisakwe, 2011). Copper concentrations are relatively high midstream (8.37 mg/kg) and Downstream (8.68 mg/kg), with the lowest at the control site (4.37 mg/kg). The statistically significant difference ($p < 0.05$) suggests midstream and Downstream sources contributing to copper pollution, possibly from agricultural runoff or industrial effluents. The concentration of Cu in the current study is similar to findings of Zhang et al., (2014) findings, indicating comparable sources or levels of copper contamination in the range of 3.2 - 9.5 mg/kg. Study shows slightly lower maximum values than Kumar et al., (2018) suggesting lesser copper contamination in our study compared to their finding with Cu concentrations in the range of 5.1 - 12.7 mg/kg. The Kruskal-Wallis ANOVA test indicates that there was no statistical ($p > 0.005$) significant difference between concentrations of Cr across zone 1 and zone 3.

However, the ANOVA test revealed significant differences in Cr levels across zones and the control site ($p < 0.05$). The concentration of Cr is significantly higher in the Upstream and Downstream zones compared to the midstream zone and control site. This could indicate a potential source of contamination either Downstream or from surrounding industrial activities such as boat scrapping and maintenance activities. Studies in Nigeria, such as the one by Onianwa et al. (2001) in Lagos dockyard sediments, reported similar high Cr levels, especially in areas with significant industrial activity. Study in dockyard sediments from the UK and Europe, such as in the Thames Estuary (Holt et al., 2009), showed lower Cr concentrations compared to the levels in this study. Studies in industrial areas in India and China, such as in Mumbai (Muley et al., 2015) and Shanghai (Li et al., 2018), have documented higher Cr concentrations due to intense industrial discharge.

High Cr levels, particularly in Zone 1, suggest possible contamination from industrial activities. This could have serious environmental and health implications, including potential risks to aquatic life and human health through bioaccumulation. In less polluted regions, such as rural or less industrialized areas, global studies have reported lower levels. For example, in a study by Smith et al. (2015) in rural areas of Canada, Cr levels were found to be significantly lower, ranging from 0.5 to 2.0 mg/kg. Recent studies have reported higher levels in areas with severe contamination. For example, a study by Adediran et al. (2018) reported Cr concentrations as high as 10.0 mg/kg in heavily polluted dockyards. Studies in industrial dockyards worldwide often show Cr and Ni concentrations in similar ranges. For example, a study in the UK by Adams et al. (2012) reported Cr concentrations between 5.0 and 8.0 mg/kg in contaminated dockyard sediments.

Cd levels are markedly elevated in the Downstream zone compared to the Upstream and midstream zones, and the control site. Zone 3 shows a dramatic increase in Cd concentration compared to other zones and the control site. This indicates significant contamination at Zone 3. The concentrations in Zone 1 and Zone 2 are also elevated compared to the control site, suggesting that contamination is present but less severe than in Zone 3. High Cd levels in Zone 3 could be due to localized sources of pollution or industrial activities affecting that area specifically. This is evidenced by the magnitude of anthropogenic activities ongoing in this area ranging from various commercial activities (alcohol and boat fueling) to artisanal refining activities. High Cd concentrations in the Downstream zone could indicate significant pollution sources, such as industrial discharge activities. Cd is highly toxic, especially to aquatic organisms, and can lead to severe environmental and health issues. Studies in Nigeria have shown similar ranges for Cr and Cd. For example, a study by Omosun et al. (2005) reported Cr levels ranging from 5.0 to 7.0 mg/kg in industrial areas.

In highly industrialized or polluted dockyards, such as those studied in China by Zhang et al. (2019), Cr and Cd levels can reach significantly higher values, often exceeding 10.0 mg/kg for Cr. V levels are relatively low but vary slightly across the zones, with the highest concentration in the midstream zone. The variability in V concentrations is less pronounced compared to Cr and Cd. Studies in less industrialized areas or less polluted regions have shown lower ranges. For instance, Efe et al. (2007) reported lower Cr and Cd levels in less industrialized regions of Nigeria. However, the presence of V in detectable quantities could still reflect minor pollution or natural variability in sediments.

Ba concentrations are higher in all zones compared to the control site, with Zone 1 having the highest concentration. The decreasing trend from Zone 1 to Zone 3 could indicate a dilution effect or a reduction in Ba contamination Downstream. Elevated Ba levels could be linked to geological factors or specific pollution sources. Ba concentrations decrease from Upstream to Downstream, with the lowest values observed in the Downstream zone. Ba is generally less toxic compared to other heavy metals but can accumulate in the environment. Lower levels in the Downstream zone could be due to dilution effects or reduced contamination sources.

Ni concentrations are significantly higher in all zones compared to the control site. Zone 1 has the highest concentration of Ni, with a decreasing trend observed in Zone 2 and Zone 3. The higher Ni levels suggest that there may be industrial activities or pollution sources contributing to these elevated concentrations. Ni levels are significantly higher in the Upstream zone and decrease progressively Downstream, with the lowest concentration at the control site. Elevated Ni levels, particularly in the Upstream zone, suggest potential contamination sources such as industrial activities or vehicular emissions.

The contamination levels observed in the studied zones highlight the need for effective pollution control and remediation strategies. Continuous monitoring and stricter regulatory measures are essential to mitigate the adverse effects of heavy metal contamination on the environment and public health. The comparison with other regions emphasizes the global nature of sediment contamination and the importance of localized studies to address specific pollution sources and impacts.

Conclusion

The concentrations of Fe, Zn, Mn, Pb, and Cu are significantly different across the zones and control site. The elevated levels of Fe, Zn, Mn, Pb, and Cu in Zones 1, 2, and 3 compared to the control site suggest substantial contamination in these areas. This contamination likely results from anthropogenic activities, possibly including industrial discharges, urban runoff, artisanal refining and maritime activities common in the dockyard region. The concentration of Cr was significantly higher in the Upstream and Downstream zones compared to the Midstream zone and control site. This could indicate a potential source of contamination either Downstream or from surrounding industrial activities and from boat fabrication and maintenance.

Cd levels are markedly elevated in the Downstream zone compared to the Upstream and Midstream zones, and the control site. Zone 3 shows a dramatic increase in Cd concentration compared to other zones and the control site. This indicates significant contamination at Zone 3 which could be due to localized sources of pollution or industrial and commercial activities affecting that area specifically. Effective monitoring and management strategies are crucial to mitigate heavy metal pollution. Identifying and regulating pollution sources, promoting sustainable industrial and agricultural practices, and implementing sediment remediation techniques can help reduce heavy metal contamination and protect aquatic ecosystems and public health.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Credit Authorship Contribution Statement

Ibrahim, L: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Visualization, Project administration, Writing - original draft. **Osuji, L.C., Obafemi, A.A** and **Hart, A. I.**: Supervision, Methodology, Validation, Formal analysis, Data curation, Visualization, Review & Editing.

References

Adebambo TH, Fox DT, Otitoloju AA (2020) Toxicological Study and Genetic Basis of BTEX Susceptibility in Drosophila melanogaster. Frontiers in Genetics 11:594179. https://doi.org/10.3389/fgene.2020.594179

Afolabi, O. O. and Eludoyin, S. O. (2021). Evaluation of heavy metals and contamination status of soil around abandoned and active Nigerian dumpsites. *Journal of Geography, Environment and Earth Science*, 25; 1-11. https://doi:10.9734/JGEESI/2021/v25i1030310

Afolabi, O. O., Wali, E., Ihunda, E. C., Orji, M. C., Emelu, V. O., Bosco-Abiahu, L. C., Ogbuehi, N. C., Asomaku, S. O., & Wali, O. A. (2022). Potential environmental pollution and human health risk assessment due to leachate contamination of groundwater from anthropogenic impacted site. *Environmental Challenges*, *9*, 100627. https://doi.org/10.1016/j.envc.2022.100627

Ahmed, Md. K., Shaheen, N., Islam, Md. S., Habibullah-al-Mamun, Md., Islam, S., Mohiduzzaman, Md., & Bhattacharjee, L. (2015). Dietary intake of trace elements from highly consumed cultured fish (Labeo rohita, Pangasius pangasius and Oreochromis mossambicus) and human health risk implications in Bangladesh. *Chemosphere*, *128*, 284–292. https://doi.org/10.1016/j.chemosphere.2015.02.016

Ali, M. M., Ali, M. L., Islam, Md. S., & Rahman, Md. Z. (2016). Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. *Environmental Nanotechnology, Monitoring & Management*, *5*, 27–35. https://doi.org/10.1016/j.enmm.2016.01.002

American Public Health Association – APHA (2012). American Water Works Association – AWWA; Water Pollution Control Federation -WPCF. *Standard methods for the examination of water and wastewater.* 22th ed. Washington DC.

American Society Testing Materials – ASTM (2012). *Annual Book of ASTM Standards.* 2012. Vol. 11.01. Available in: http://www.astm.org

Asejeje GI, Ipeaiyeda AR, Onianwa PC (2021) Health risk assessment of Ubeji Creek residents' exposure to BTEX from consumption of locally sourced foods. Environmental Pollutants and Bioavailability 33:449–459. https://doi.org/10.1080/26395940.2021.2007795

Carvalho, M. de A. R., Botero, W. G., & de Oliveira, L. C. (2022). Natural and Anthropogenic Sources of Potentially Toxic Elements to Aquatic Environment: A Systematic Literature Review. *Research Square*. https://doi.org/10.21203/rs.3.rs-1389124/v1

El-Zeiny AM, Abd El-Hamid HT (2022) Environmental and human risk assessment of heavy metals at northern Nile Delta region using geostatistical analyses. The

Egyptian Journal of Remote Sensing and Space Science 25:21–35. https://doi.org/10.1016/j.ejrs.2021.12.005

Goher M. E., Ali, M. H. H., El-Sayed S. M. (2019). Heavy metals contents in Nasser Lake and the Nile River, Egypt: An overview. The *Egyptian Journal of Aquatic Research*, 45(4):301-312

Islam, M. S., Ahmed, M. K., Raknuzzaman, M., Habibullah -Al- Mamun, M., & Islam, M. K. (2015). Heavy metal pollution in surface water and sediment: A preliminary assessment of an urban river in a developing country. *Ecological Indicators*, *48*, 282–291. https://doi.org/10.1016/j.ecolind.2014.08.016

Kinuthia, G. K., Ngure, V., Beti, D., Lugalia, R., Wangila, A., & Kamau, L. (2020). Levels of heavy metals in wastewater and soil samples from open drainage channels in Nairobi, Kenya: community health implication. *Scientific Reports*, *10*(1), 8434. https://doi.org/10.1038/s41598-020-65359-5

Martín, R., J. A., De Arana, C., Ramos-Miras, J. J., Gil, C., & Boluda, R. (2015). Impact of 70 years urban growth associated with heavy metal pollution. *Environmental Pollution*, *196*, 156–163. https://doi.org/10.1016/j.envpol.2014.10.014

Omutange, E. S., Manyala, J. O., Wekesa, A. N., Odipo Osano, T Munyao, Otieno, A. A., & Lazare Etiegni. (2022). Distribution of Potentially toxic elements in Water, Sediment and Soils in the Riparian Zones around a Kraft Pulp and Paper Mill in Western Kenya. *IntechOpen EBooks*. https://doi.org/10.5772/intechopen.102440

Onakpa MM, Njan AA, Kalu OC (2018) A Review of Heavy Metal Contamination of Food Crops in Nigeria. Annals of Global Health 84:488–494. https://doi.org/10.29024/aogh.2314

Pan, L., Fang, G., Wang, Y., Wang, L., Su, B., Li, D., & Xiang, B. (2018). Potentially Toxic Element Pollution Levels and Risk Assessment of Soils and Sediments in the Upstream River, Miyun Reservoir, China. *International Journal of Environmental Research and Public Health*, *15*(11), 2364. https://doi.org/10.3390/ijerph15112364

Saleem, M., Iqbal, J., & Shah, M. H. (2015). Geochemical speciation, anthropogenic contamination, risk assessment and source identification of selected metals in freshwater sediments—A case study from Mangla Lake, Pakistan. *Environmental Nanotechnology, Monitoring & Management*, *4*, 27–36. https://doi.org/10.1016/j.enmm.2015.02.002

Sharma P, Purchase D, Chandra R. (2021). Residual pollutants in treated pulp paper mill wastewater and their phytotoxicity and cytotoxicity in Allium cepa. Environmental Geochemistry and Health, 43 (5):2143-2164

Wongbunmak A, Khiawjan S, Suphantharika M, Pongtharangkul T (2020) BTEX biodegradation by Bacillus amyloliquefaciens subsp. plantarum W1 and its proposed BTEX biodegradation pathways. Scientific Reports 10. https://doi.org/10.1038/s41598-020-74570-3