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Elucidation of the Physicochemical Characteristics and Health Risk Assessment of Heavy Metals in the Sediment of Ajoki River, Ikpoba-Okha Local Government Area in Edo State, Nigeria

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ABSTRACT: Sediments play a critical role in aquatic pollution studies, functioning both as sinks and potential secondary sources of contaminants. Over time, pollutants become embedded within sediment layers, serving as historical records of environmental pollution. This study assessed the physicochemical properties, pollutant levels and associated health risks in sediment from the Ajoki River, located in Ikpoba-Okha Local Government Area, Edo State, Nigeria. Samples were collected over a 12-month period, covering both the wet (May-October 2022) and dry (November 2022–April 2023) seasons. A total of 84 samples were obtained from seven stations spaced 100 meters apart along the river. All samples were analyzed using standard procedures. The results showed there was no significant seasonal variation ($p > 0.05$) in the levels of the physicochemical properties except for sulphate and phosphate. Whereas, there was significant seasonal variations in the concentrations of pollutants such as PAHs, Mn, Zn, Pb, Cd and Cu. Notably, cadmium concentrations in the sediment exceeded the permissible limits set by the Nigerian Upstream Petroleum Regulatory Commission. Health risk assessments of the sediment revealed significant risks associated with Cd and Pb for both children and adults, particularly with children being more susceptible. These findings underscore the urgent need for environmental remediation, stricter regulatory enforcement, and proactive public health interventions to mitigate associated risks and protect the aquatic ecosystem.

Keywords: Physicochemical properties, Pollutants, PAHs, Heavy metals, Ajoki river, Risk

Introduction

Petroleum remains a vital industrial resource, widely utilized across numerous sectors due to its high energy content and economic value. However, its extensive use has led to significant environmental concerns, particularly regarding contamination stemming from hydrocarbon compounds. Petroleum products - such as gasoline, diesel, fuel oil, and lubricants—can infiltrate soil and groundwater through surface spills, leaking storage tanks, faulty pipelines, and accidental discharges, resulting in subsurface environmental pollution (Yang *et al.*, 2015).

In the Niger Delta region of Nigeria, hydrocarbon pollution of surface water bodies has become a recurring environmental challenge. This is largely attributed to pipeline failures, acts of sabotage, and the illegal siphoning of petroleum products. One notable contributor to this pollution is the release of brine waste—also referred to as produced water—generated during oil and gas extraction activities. Such effluents typically contain a complex mixture of contaminants, including heavy metals, sodium, calcium, ammonia, boron, and elevated concentrations of total dissolved solids (Adesuyi *et al.*, 2015). The discharge of these pollutants into surface waters poses serious threats to aquatic ecosystems and public health, especially in communities that rely on these water bodies for drinking, fishing, and other domestic purposes. Globally, trace metal (TM) pollution in

aquatic environments has garnered increasing attention due to the persistence, toxicity, and bioaccumulative nature of these metals (Ololade *et al.*, 2024).
Sediments play a critical role in aquatic pollution studies, acting both as sinks and potential secondary sources of pollutants. Contaminants can become embedded in sediment layers over time, serving as historical records of pollution. However, disturbances such as dredging or shifts in water chemistry can remobilize these pollutants, releasing them back into the water column and intensifying their environmental impact (Udosen *et al.*, 2016). This dynamic interplay between water and sediment underscores the importance of a comprehensive approach to pollution assessment, considering both matrices for a more accurate understanding of environmental risks.
The Ajoki River, situated within a prominent oil-producing community in the Niger Delta, exemplifies such a vulnerable aquatic system. The river is subject to various anthropogenic pressures, including the transportation of crude oil across its waters and the frequent use of its banks for domestic activities. Additionally, the washing of motorcycles and vehicles directly in the river introduces hydrocarbons and heavy metals into the water. These cumulative practices likely contribute to the degradation of water quality and pose significant ecological and public health risks.
This study aims to assess the contamination levels in the Ajoki River, with a focus on evaluating both ecological and human health risks associated with pollutants in the sediment. By analysing the presence and behaviour of contaminants, particularly trace metals, this research seeks to provide critical insights for environmental management and policy development in oil-impacted regions.

Materials and methods

Study area: The Ajoki River is situated in the Ajoki community, part of the Ikpoba-Okha Local Government Area in Edo State, Nigeria. It runs along the boundary separating Edo and Delta states. This river plays a vital role in the daily lives of the local people, functioning as a key source of water and a major route for fishing, transportation, and commerce. Positioned at approximately 6°01'47" North and 5°26'42" East, Ajoki is predominantly known as a fishing village. In addition to fishing, trade is a significant economic activity in the area, with many inhabitants engaged in the sale of fish, farm produce, and other goods within the local markets.
Sampling of sediment: The Eckman sediment grab was used to collect sediment samples from seven sites along the river. Polyethylene bags were used to hold sediment samples. Oil and grease sediment samples were gathered in a glass jar that had been previously cleaned and covered with aluminum foil (Inyang *et al*. 2018). All the samples were brought to the laboratory and kept at 4 °C.

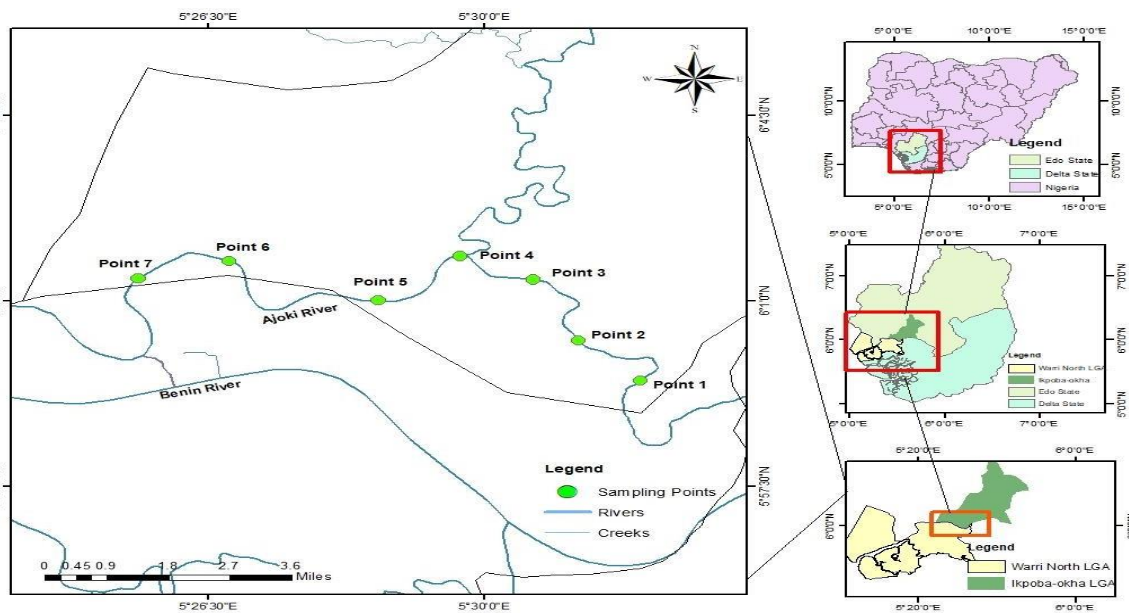

Figure.1: Map of the study area

Sediment sample preparation: The pH, temperature, and conductivity of the sediment were measured using wet sediment samples. The sediment samples were air-dried, ground, and then sieved to determine additional physicochemical properties of the sediment.

Quality control and quality assurance: To ensure the reliability and accuracy of the analytical results, strict quality control and quality assurance procedures were followed throughout the processes of sample preparation and analysis. All laboratory activities were conducted in a clean and contamination-free environment. Glassware used in the procedures was thoroughly cleaned using a detergent, rinsed with tap water, and subsequently rinsed with distilled water to eliminate any residual contaminants. Only analytical-grade reagents were employed during the analyses. Accuracy of the analytical methods was also assessed through spike recovery experiments.

Analytical method: The analytical procedures employed in this study followed standard methods to ensure accurate and reliable data collection. pH and electrical conductivity were measured using a Water Quality Tester (Model C600) in sediment to water suspension. The concentrations of polycyclic aromatic hydrocarbons (PAHs) and total petroleum hydrocarbons (TPH) in sediment samples were determined using Soxhlet extraction. A 100 g portion of air-dried, sieved sediment was wrapped in filter paper and placed in a thimble, then extracted with dichloromethane for 24 hours. The resulting extracts underwent cleanup through column chromatography using a 10 mm internal diameter and 30 cm long column packed with 10 g of activated silica gel topped with a 2 cm layer of anhydrous sodium sulphate. The hydrocarbon fraction was eluted with 20 mL of n-hexane, while the aromatic fraction was eluted with dichloromethane. The eluates were then concentrated to approximately 2 mL using a rotary evaporator at 30°C before analysis with Gas Chromatography coupled with a Flame Ionization Detector (GC-FID) (Inyang *et al.,* 2018). Heavy metals were analyzed following the APHA 3400 method, while oil and grease concentrations in water and sediment were determined using the API RP 45 extraction and photometric method. Sulphate concentrations were measured by the turbidity method (APHA 4500 SO_4^{2-}E), and phosphate levels were assessed using the Ascorbic Acid method.

Health risk assessment of heavy metals in the sediment: Cancer risk (CR) and Hazard Quotient (HQ) are indices developed by USEPA (Okafor *et al.* 2024). Risk assessment models for the evaluation of carcinogenic and non-carcinogenic health risks in adults and children in relation to sediment samples are shown in Equation (1) to (6) while Tables 1 and 2 gives the definition of variables and reference values for health risk assessment (Okafor *et al.* 2024). The heavy metal composition of sediment samples was assessed for probable health risk conditions that might influence adults' and children's biochemical function of their body using bodyweight, age, period of exposure, concentration of heavy metal in addition to reference values as stipulated by USEPA using upper and lower limits of assessment (Akoglu, 2018; Okafor *et al.* 2024). Lower limit and Upper limit of 1.00E-06 and 1.00E-04 respectively are for cancer risk assessment while Lower limit and Upper limit of 0 and 1 respectively for health hazard quotient (Okafor *et al.,* 2024).

$$CR_{ingestion} = \frac{C \times EF \times ED \times IRx \times RBA* \times 10-6 \times CSF}{BW \times AT} \quad (1)$$

$$HQ_{ingestion} = \frac{C \times EF \times ED \times IRS \times RBA* \times 10-6}{BW \times AT \times RfD} \quad (2)$$

$$CR_{dermal} = \frac{C \times EF \times ED \times SAx \times AF \times Kp* \times 10-6 \times CSF}{BW \times AT \times GIABS*} \quad (3)$$

$$HQ_{dermal} = \frac{C \times EF \times ED \times SAx \times AF \times GIABS* \times Kp* \times 10-6}{BW \times AT \times RfD} \quad (4)$$

$$CR_{inhalation} = \frac{C \times EF \times ED \times ET \times 106 \times IUR}{AT \times PEF \times VF} \quad (5)$$

$$HQ_{inhalation} = \frac{C \times EF \times ED \times ET \times 106 \times IUR}{AT \times PEF \times VF \times RfC} \quad (6)$$

Table 1: Definition of variables for risk assessment

Symbol	Description
C	Concentration of heavy metal in sample
EF	Exposure frequency (350 day/year)
ED	Exposure duration (30 years for adults and 6 years for children)
IRS	Ingestion rate of sediment sample (100 mg/day for adults and 200 mg/day for children);
SA	Skin surface area (6,032 cm2/day and 2,373 cm2/day for adults and children respectively);
RBA	Relative bioavailability for sediment (1)
AF	Adherence factor (0.07 mg/cm2 and 0.2 mg/cm2 for adults and children
Kp	Dermal permeability constant (0.001)
GIABS	Gastrointestinal absorption factor for sediment calculation only
ET	Inhalation exposure time (6 h/day and 9 h/day for adults and children respectively)
AT	Average time (25,550 days/ yr– carcinogen for both adults and children; 10,950 days/yr and 2,160 days/yr.– non-carcinogen for adults and children
BW	Body weight (80 kg and 15 kg for adults and children respectively)
	Particulate emission factor (6.79 × 10^8m3/kg and 1.36 × 10^9m3/kg for adults and children respectively)
PEF	Particulate emission factor (6.79 × 10^8m3/kg and 1.36 × 10^9m3/kg for adults and children respectively)
VF	Volatilization factor (1.00 × 10^5m3/kg and 1.00 × 10^5m3/kg for adults and children respectively)

Table 2: Reference values for health risk assessment heavy metals

Heavy metal	CSF (mg/kg/day) $^{-1}$	RfD (mg/kg/day)	IUR (mg/m^3) $^{-1}$	RfC (mg/m^3)	RBA	GIABS
Cd	6.3	0.0005	1.8	0.00001	1	0.05
Cr (III)	No CSF	1.50	No IUR	0.005	1	0.013
Cr (VI)	0.5	0.003	84	0.0001	1	0.025
Cu	No CSF	0.04	No IUR	0.004	1	1
Fe	No CSF	0.70	No IUR	0.8	1	1
Ni	0.84	0.02	0.26	0.00009	1	0.04
Pb	0.0085	0.0035	0.0085	0.0035	1	1
Zn	No CSF	0.30	No IUR	0.03	1	1

Note: No CSF; No IUR – reference value unavailable (Okafor *et al.,* 2024)

Results and Discussion

The results of the physicochemical properties and pollutants in the sediments of the Ajoki river are presented in Table 3. There was no significant seasonal variation ($p > 0.05$) in the levels of the physicochemical properties except for sulphate and phosphate. Whereas, there was significant seasonal variations in the concentrations of pollutants such as PAHs, Mn, Zn, Pb, Cd and Cu.

Physicochemical properties: pH affects the dynamics of contaminants within the sediment matrix; for example, at very low pH heavy metals is released from the sediment back into the water column (Khayatzadeh and Abbasi, 2010; Adesuyi *et al.,* 2016). The pH values ranged from 6.90 to 8.72 during the wet season and 6.30 to 8.72 in the dry season, with mean values of 7.58 ± 0.50 and 7.49 ± 0.57, respectively. Lower pH values in the range of 4.51 – 5.02 was reported by Onajite and Ovie, (2022) in a study conduction on surface Okpare Creek in Niger Delta, Nigeria. Electrical conductivity (EC) ranged between 88.00 – 110.00 µS/cm in the wet season and 89.00 – 114.00 µS/cm in the dry season, with mean values of 98.65 ± 5.13 µS/cm and 99.73 ± 6.20 µS/cm, respectively. The P-value ($P > 0.05$) suggests no significant seasonal difference, implying that ion concentrations remain relatively stable. Higher EC values in the range 23.0 - 567.0 uS/cm was reported by Adesuyi *et al.,* (2016) in a study conducted on the physicochemical characteristics of sediment from Nwaja Creek, Niger Delta, Nigeria. Salinity showed a non-detectable (ND) to 0.30 ppt range in the wet season and 0.01 – 0.20 ppt in the dry season, with mean values of 0.071 ± 0.56 ppt and 0.09 ± 0.01 ppt, respectively. The low salinity levels suggest freshwater dominance, with slight variations likely due to dilution effects in the wet season.

Table 3: Levels of physicochemical properties and pollutants concentrations in sediment of the Ajoki river

	WET SEASON		DRY SEASON	
Physicochemical Parameters	**Range**	**Mean ± SD**	**Range**	**Mean ± SD**
pH	6.90 – 8.72	7.58 ± 0.50	6.30 – 8.72	7.49 ± 0.57
Electrical Conductivity, µS/cm	88.00 – 110	98.65 ± 5.13	89.00 – 114	99.73 ± 6.20
Salinity, ppt	N.D - 0.30	0.071 ± 0.56	0.01 – 0.20	0.09 ± 0.01
Chloride, (Cl^-) (mg/kg)	6.00 – 14.00	8.44 ± 2,09	5.63 – 14.00	9.16 ± 2.20
Sulphate, (SO_4^{2-}) (mg/kg)	0.50 – 8.50	5.03 ± 1.22	3.10 – 10.40	5.87 ± 1.45
Nitrate, (NO_3^-) (mg/kg)	0.01 – 0.20	0.06 ± 0.45	0.02 – 0.18	0.07 ± 0.04
Phosphate, (PO_4^{3-}) (mg/kg)	N.D – 0.08	0.04 ± 0.02	0.01 – 0.16	0.06 ± 0.01
Total Hydrocarbon Content (mg/kg)	N.D – 0.01	0.0007 ± 0.003	N.D – 0.03	0.002 ± 0.01
Oil & Grease (O&G) (mg/kg)	N.D – 0.06	0.02 ± 0.12	N.D - 0.04	0.02 ± 0.01
Total Organic Content (mg/kg)	2.30 – 5.60	4.23 ± 0.66	2.30 – 5.90	4.04 ± 0.87
Polyaromatic Hydrocarbons (mg/kg)	N.D - 0.07	0.03 ± 0.02	0.02 – 0.10	0.06 – 0.01
Total petroleum hydrocarbon (mg/kg)	N.D – 0.36	0.16 ± 0.08	0.09 – 0.29	0.16 – 0.05
Calcium, (Ca^{2+}) (mg/kg)	2.10 – 4.10	2.76 ± 0.45	2.10 – 4.30	2.88 ± 0.45
Magnesium, (Mg^{2+}) (mg/kg)	3.56 – 7.32	4.82 ± 0.944	3.40 – 7.32	4.93 ± 1.19
Manganese, (Mn) (mg/kg)	0.32 – 119.20	18.91 ± 0.59	0.20 – 3.60	0.92 ± 0.15
Iron, (Fe) (mg/kg)	0.72 – 130.20	56.07 ± 4.6	0.05 – 134	56.33 ± 5.10
Zinc, (Zn) (mg/kg)	N.D – 0.96	0.40 ± 0.12	0.11 – 3.90	0.99 ± 0.03
Lead, (Pb) (mg/kg)	N.D – 8.60	3.89 ± 0.61	1.8 – 12.00	5.57 ± 0.91
Cadmium, (Cd) (mg/kg)	N.D - 0.19	0.09 ± 0.01	0.07 – 8.00	2.18 ± 0.70
Copper, (Cu) (mg/kg)	0.04 – 1.90	1.32 ± 0.41	N.D - 1.90	0.89 ± 0.10

Chloride levels ranged from 6.00 to 14.00 mg/kg in the wet season and 5.63 to 14.00 mg/kg in the dry season, with mean values of 8.44 ± 2.09 mg/kg and 9.16 ± 2.20 mg/kg, respectively. Sulphate concentrations ranged from 0.50 to 8.50 mg/kg in the wet season and 3.10 to 10.40 mg/kg in the dry season, with mean values of 5.03 ± 1.22 mg/kg and 5.87 ± 1.45 mg/kg, respectively. Nitrate levels ranged from 0.01 to 0.20 mg/kg in the wet season and 0.02 to 0.18 mg/kg in the dry season, with mean values of 0.06 ± 0.45 mg/kg and 0.07 ± 0.04 mg/kg, respectively. Phosphate levels were non-detectable to 0.08 mg/kg in the wet season and 0.01 to 0.16 mg/kg in the dry season, with mean values of 0.04 ± 0.02 mg/kg and 0.06 ± 0.01 mg/kg, respectively. Higher nitrate and phosphate average values in the range of 5.50 – 15.50 mg/kg and 0.45 – 11.90 mg/kg respectively was reported by Adesuyi *et al.* (2015) in a study conducted Nwaja Creek, Niger Delta, Nigeria. Adesuyi *et al.* (2015) attributed this high level of nutrient concentration to domestic waste input from human settlements near these stations and surface run-offs. Calcium levels ranged from 2.10 to 4.10 mg/kg in the wet season and 2.10 to 4.30 mg/kg in the dry season, with mean values of 2.76 ± 0.45 mg/kg and 2.88 ± 0.45 mg/kg, respectively. Magnesium (Mg^{2+}) levels varied between 3.56 – 7.32 mg/kg in the wet season and 3.40 – 7.32 mg/kg in the dry season, with mean values of 4.82 ± 0.944 mg/kg and 4.93 ± 1.19 mg/kg.

Organics: Total Hydrocarbon Content was detected at ND – 0.01 mg/kg in the wet season and ND – 0.03 mg/kg in the dry season, with mean values of 0.0007 ± 0.003 mg/kg and 0.002 ± 0.01 mg/kg, respectively. Oil & Grease levels were ND – 0.06 mg/kg in the wet season and ND – 0.04 mg/kg in the dry season, with mean values of 0.02 ± 0.12 mg/kg and 0.02 ± 0.01 mg/kg, respectively. No significant seasonal variation was observed. Total Organic Carbon (TOC) is a key indicator of organic matter content in sediments and is commonly used to evaluate the degree of organic enrichment in aquatic ecosystems; however, when present in excessive concentrations, it can disrupt ecological balance by promoting the dominance of opportunistic species that outcompete other benthic organisms, ultimately leading to a decline in biodiversity (Marguerite *et al.*, 2011). TOC values ranged from 2.30 to 5.60 mg/kg in the wet season and 2.30 to 5.90 mg/kg in the dry season, with mean values of 4.23 ± 0.66 mg/kg and 4.04 ± 0.87 mg/kg, respectively. Polycyclic aromatic hydrocarbon (PAHs) area class of organic chemical comprised of two or more benzene rings bonded in linear, cluster, or angular arrangements (Festus-Amadi *et al.*, 2021). PAH ranged from ND – 0.07 mg/kg in the wet season and 0.02 – 0.10 mg/kg in the dry season, with mean values of 0.03 ± 0.02 mg/kg and 0.06 ± 0.01 mg/kg, respectively. Higher value of 0.154 mg/kg was reported by Inengite *et al.* (2013) from a study conducted on the Sources of polycyclic aromatic hydrocarbons in sediments from Koko creek around a flow station. Inengite *et al.* (2013) noted that the values obtained were below the critical value of 4.0mg/Kg by Australian and New Zealand guidelines for total PAHs in sediment. Total Petroleum Hydrocarbons (TPH) ranged from ND – 0.36 mg/kg in the wet season and 0.09 – 0.29 mg/kg in the dry season, with mean values of 0.16 ± 0.08 mg/kg and 0.16 ± 0.05 mg/kg, respectively. Etesin *et al.*, (2013) reported Higher TPH mean values of 377.5 mg/kg during the dry season and 288.7 mg/kg during the wet season from a study conducted in Iko River, Nigeria. Etesin *et al.*, (2013) attributed the high concentration of TPH to inputs from anthropogenic sources such as oil spills, oil slicks and seepage.

Heavy metals: Heavy metals contamination of sediment is a threat to benthic organisms found in the sediments and this can affect the food availability for larger aquatic species such as fish in the water body. Benthic organism in sediment easy ingests heavy metals and when they are eaten by higher organisms in the food chain, it results in bioaccumulation and biomagnifications (Increase concentration of heavy metals in the tissues of organism) (Khayatzadeh and Abbasi, 2010). Manganese concentrations ranged from 0.32 – 119.20 mg/kg in the wet season and 0.20 – 3.60 mg/kg in the dry season, with mean values of 18.91 ± 0.59 mg/kg and 0.92 ± 0.15 mg/kg, respectively. Iron concentrations ranged from 0.72 – 130.20 mg/kg in the wet season and 0.05 – 134.00 mg/kg in the dry season, with mean values of 56.07 ± 4.6 mg/kg and 56.33 ± 5.10 mg/kg, respectively. Zinc levels were ND – 0.96 mg/kg in the wet season and 0.11 – 3.90 mg/kg in the dry season, with mean values of 0.40 ± 0.12 mg/kg and 0.99 ± 0.03 mg/kg, respectively. Lead (Pb) levels ranged from ND – 8.60 mg/kg in the wet season and 1.8 – 12.00 mg/kg in the dry season, with mean values of 3.89 ± 0.61 mg/kg and 5.57 ± 0.91 mg/kg, respectively. Cadmium was detected at ND – 0.19 mg/kg in the wet season and 0.07 – 8.00 mg/kg in the dry season, with mean values of 0.09 ± 0.01 mg/kg and 2.18 ± 0.70 mg/kg, respectively. Copper concentrations ranged from 0.04 – 1.90 mg/kg in the wet season and ND – 1.90 mg/kg in the dry season, with mean values of 1.32 ± 0.41 mg/kg and 0.89 ± 0.10 mg/kg, respectively. Heavy metals levels in the sediment were in the order of magnitude Fe > Mn > Pb > Cu > Zn > Cd in the wet season and Fe > Pb > Cd > Zn > Mn > Cu in the dry season. Cadmium was the only heavy metals that exceeded NUPRC target value of 0.8 mg/kg in the wet and dry season (Table 2). Similar exceedances of cadmium in the range of 0.31 – 6.39 mg/kg was reported by Etim and Adie, (2012) from a study conducted on selected major rivers in south-western Nigeria. According to Adesiyan *et al.* (2018) elevated concentration of cadmium in the sediment maybe due to geological formation of the soil and run-off from agriculture activities or as result of anthropogenic activities around the reservoir. Nwanekezi *et al.* (2024) reported comparable values of 5.6±0.76 mg/kg and higher mean value of 8.91 mg/kg from a study on heavy metals concentrations in sediment from creek road market Landing-Bay in the Bonny estuary Port Harcourt Rivers State, Nigeria.

Health risk of heavy metals in sediment: The heavy metal composition of sediment samples was evaluated to determine potential health risks that could affect both adults and children. This assessment considered various factors, including body weight, age, duration of exposure, metal concentration, and established reference values, based on the lower and upper limits recommended by the USEPA (Okafor *et al.,* 2024). The outcomes of the hazard quotient and cancer risk index are presented in Tables 4 and 5. The hazard quotient results indicated that concentrations of all analysed heavy metals in the sediments remained within safe bounds, falling below both the lower and upper threshold values. This suggests negligible health risks for adults and children through ingestion, dermal contact, and inhalation pathways. In contrast, the cancer risk analysis revealed significant risks associated with cadmium and lead. Cadmium presented elevated cancer risk levels in both adults and children, with ingestion-related values of 7.05×10^{-6} and 1.51×10^{-5} respectively. These findings are consistent with the earlier results reported by Okafor *et al.* (2024), where ingestion-related cancer risks were 1.60×10^{-4} for adults and 3.41×10^{-4} for children in a similar study conducted in Ifite Ogwari, Southeastern Nigeria.

Table 4: Hazard quotients of metals in the sediments of the Ajoki river

	WET SEASON					
	HQ $_{ingestion}$		**HQ $_{dermal}$**		**HQ $_{inhalation}$**	
	Adult	**Children**	**Adult**	**Children**	**Adult**	**Children**
Iron	1.36E-06	1.46 E-05	2.08 E-07	2.07 E-07		
Zinc	2.28E-08	2.43 E-07	3.44 E-10	3.44 E-10		
Lead	2.22 E-07	2.03 E-07	4.12 E-07	2.87 E-08	3.43 E-07	5.12 E-08
Cadmium	2.20 E-07	2.38 E-07	5.63 E-08	2.32 E-09	5.88 E-04	1.79 E-05
Copper	5.65 E-07	6.03 E-06	5.75 E-10	8.52 E-10		
	DRY SEASON					
Iron	1.38 E-05	1.47 E-02	1.74 E-06	2.08E-06	-	-
Zinc	5.65 E-08	6.03 E-01	7.15E-07	3.52E-07	-	-
Lead	3.18 E-08	2.09 E-02	3.45E-08	4.11E-08	-	7.39 E-05
Cadmium	5.33 E-07	2.09 E-02	4.73E-08	5.63E-07	1.42E-02	3.03 E-03
Copper	3.80E-07	5.69 E-02	7.72 E-08	5.75E-08	-	-

Table 5: Total cancer risk of heavy metals in sediments of the Ajoki river

	WET SEASON					
	CR $_{ingestion}$		**CR $_{dermal}$**		**CR $_{inhalation}$**	
	Adult	**Children**	**Adult**	**Children**	**Adult**	**Children**
Lead	2.00E-08	6.79 E-09	7.17 E-11	8.59 E-11	1.20 E-09	8.99 E-09
Cadmium	2.91 E-07	6.79 E-09	2.46 E-08	2.94 E-08	5.88 E-09	4.40 E-08
	DRY SEASON					
Lead	2.00 E-08	7.18 E-04	1.46 E-09	1.74 E-12	1.72 E-09	1.28 E-09
Cadmium	7.05 E-06	1.51 E-05	5.95 E-07	6.00 E-07	1.43 E-07	1.06 E-07

Conclusion

The evaluation of the physicochemical properties of sediments from the Ajoki river revealed crucial insights into the environmental quality and potential health risks associated with sediment contamination in the study area. Heavy metal analysis revealed cadmium concentrations exceeded the NUPRC target values in both seasons, indicating possible anthropogenic sources. The health risk assessment demonstrated that while the hazard quotients for all metals were within acceptable limits, cancer risk analysis identified Cd and Pb as significant concerns. These findings underscore the potential long-term public health implications of sediment contamination, especially in vulnerable populations. Continuous monitoring, source control, and sediment management strategies are essential to safeguard environmental integrity and protect public health, especially in oil-producing and industrially active regions like the study area.

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