National Centre for Energy and Environment,
Energy Commission of Nigeria, University of Benin:
ISSN 2504-9593
DOI: 10.5281/zenodo.18950826
https://ijree.com/index.php/publications/article/view/52
Int. J. Renew. Energ & Environ Vol.4 (1), pp 230-242(2026)

BIO-ACCUMULATION OF HEAVY METALS AND ASSESSMENT OF HUMAN HEALTH RISKS ASSOCIATED WITH THE CONSUMPTION OF *CALLINECTES AMNICOLA* AND *PENAEUS MONODON* FROM ESCRAVOS ESTUARY, DELTA STATE, NIGERIA

***[1]Ewutanure, S.J.; [2]Olaifa,.F.E., and [2]Satimehin, F.P.D.**
[1]Department of Fisheries and Aquaculture, Faculty of Environmental Management, Nigeria Maritime University, Okerenkoko, Delta State, Nigeria
[2]Department of Aquaculture and Fisheries Management, Faculty of Renewable Natural Resources, University of Ibadan, Ibadan, Oyo State, Nigeria.
*Corresponding author: ewutanure@gmail.com. GSM: +2348101634482

Abstract

This study examined Ni and Pb concentrations in sediment, *Callinectes amnicola*, and *Penaeus monodon* from Escravos Estuary (EE), Delta State, Nigeria. The estuary was divided into three stations (X, Y, Z) based on fish landing sites, while seasonal sampling was dry (January to March) and wet (April to June) seasons in 2025. Sediment, *C. amnicola*, and *P. monodon* were collected for six months and analyzed for nickel, lead, and health risk indices—Target Hazard Quotient (THQ), and Hazard Index (HI)—using standard procedures. Data were subjected to descriptive and inferential statistics at 5% significance. Results revealed significant spatial and seasonal concentrations of nickel in sediments, which peaked at station Y (0.06±0.02 mg/kg) and were lowest at X (0.03±0.02 mg/kg). In contrast, seasonal values ranged from 0.03±0.02 to 0.05±0.01 mg/kg. Lead was highest at X (0.04±0.02 mg/kg) and lowest at Y (0.04±0.01 mg/kg), with seasonal values 0.02±0.01–0.03±0.01 mg/kg. In *C. amnicola*, Ni-THQ was 0.0758, HI 0.6754, while *P. monodon* showed Ni-THQ 0.0249, HI 0.6710. Rising Ni and Pb levels, alongside elevated risk indices, indicate threats to species abundance and human consumers. Regular monitoring of EE is recommended for sustainable fisheries and public health protection.

Keywords: Bioaccumulation, Hazard index, Sediment, Fish diversity.

1.0 Introduction

Heavy metal contamination in aquatic ecosystems is a pressing environmental issue with serious consequences for marine life and human health (Ewutanure *et al*. 2022). They are characterized by persistence, toxicity, and the ability to accumulate in biological systems, posing significant risks to both environmental and human health (Authman *et al*. 2015). They could enter the environment through geogenic and anthropogenic processes. Their ability to bioaccumulate in organisms and biomagnify through the food chain makes them a significant concern for ecosystems and human populations, particularly those reliant on contaminated food and water sources (Adeyemi *et al*. 2019). Although naturally occurring, their dispersion in Nigeria's water bodies has been intensified by human activities, including oil and gas production, mining, agrochemical use, and manufacturing (Aghoghovwia *et al*. 2016). Ali *et al*. (2019) reported that, in aquatic systems, heavy metals often accumulate in sediments at concentrations far higher than in the water column. The Escravos Estuary in the Niger Delta faces increasing industrial, agricultural, and domestic pollution (Ewutanure and Asogwa, 2024). Two commercially important fish species found in the Escravos Estuary, Callinectes amnicola and Penaeus monodon, serve as both protein sources for local communities and bioindicators of pollution. Their contamination with heavy metals could threaten biodiversity and human health; therefore, assessing heavy metal concentrations in these species is crucial for public health and environmental management. Heavy metals are non-biodegradable and accumulate in aquatic organisms, transferring toxicity to humans through the food chain (Alahabadi and Malvandi, 2019). *Ali et al*., (2019) observed that their health effects range from kidney damage to developmental delays in children. Hence, monitoring fish species consumed by coastal communities is essential. *C. amnicola and P. monodon* are particularly vulnerable to metal accumulation due to their feeding habits and habitats (Fishbase, 2024). The fisheries resources of the Escravos Estuary are highly vulnerable to heavy metal pollution due to the presence of oil and gas industries (Ewutanure and Olaifa, 2021). Fish are widely used as bioindicators of heavy metal pollution due to their position in the aquatic food chain (Ajani and Balogun, 2015). *Callinectes amnicola* and *P. monodon* are benthic species, making them suitable for assessing metal contamination in different aquatic compartments because studies have shown that heavy metals accumulate in their tissues, particularly the gills and muscles, with muscle tissue being the most relevant for human consumption (Fishbase, 2024). Fish accumulate heavy metals through direct uptake from water via the gills and ingestion of contaminated food (Li *et al*. 2020). Benthic species such as *C. amnicola and P. monodon* are particularly vulnerable due to their feeding habits, which involve consuming sediment-dwelling organisms (Jaishankar *et al*. 2024). The sources and pathways of heavy metals in these species from the Escravos Estuary are primarily linked to anthropogenic activities and natural processes (Adeyemi *et al*. (2019).

Because contaminated fish pose long-term health risks, understanding their contamination levels is vital for the development of policies and guidelines (Iwegbue *et al*., 2022). The Escravos Estuary supports rich biodiversity, and assessing pollution impacts on fish populations will contributes to both environmental and public health knowledge in the Niger Delta (Ewutanure and Binyotubo, 2021). The Escravos Estuary is heavily impacted by industrial activity and suffers from degraded sediment quality and pollution (Ekperusi *et al*. 2024). *C. amnicola and P. monodon* could bioaccumulate harmful concentrations of metals, posing risks to consumers (Ihedioha *et al*. 2017). Despite their importance, information on heavy metal concentrations and their health risks in these fish species in the estuary is limited. This knowledge gap hinders proper risk evaluation for communities reliant on them for sustenance. This study focuses on the Escravos Estuary, analyzing heavy metal concentrations in the muscles and gills of *C. amnicola and P. monodon*. It examines four metals—Pb, Cd, Hg, and Ni—due to their toxicity and prevalence, and health risks based on estimated intake from fish consumption.

2.0 Materials and methods

2.1 Study Area

The Escravos Estuary (Figure 1) lies within the mangrove swamp forest of the Niger Delta, positioned between latitudes 5°33′52″ N and 5°39′26″ N and longitudes 5°24′67″ E and 5°22′22″ E. It is characterized by dense mangrove vegetation dominated by *Rhizophora racemosa* and *Avicennia africana*, while the shoreline communities are largely dependent on fishing for their livelihood (Osagwu and Olaifa, 2018). The estuary experiences a wet season from March to October and a dry season from November to February, influenced by the South–West monsoon winds from the Atlantic Ocean and the North–East trade winds from the Sahara Desert (Ewutanure and Asogwa, 2024). Rainfall peaks in June, July, and September, with a short break in August, and the average annual temperature is about 27 °C (USEPA, 2010). Sampling stations were stratified into three zones based on anthropogenic activities, with water, sediment, and fish samples collected monthly between February and May 2025.

2.2 Sampling techniques and procedures

Escravos Estuary was spatially divided into three stations (X, Y, Z) based on proximity to key landing sites. Three subsampling points per station were randomly selected, while monthly stratification covered January – June, 2025. Sediments, *C. amnicola, and P. monodon* samples were collected monthly for six months.

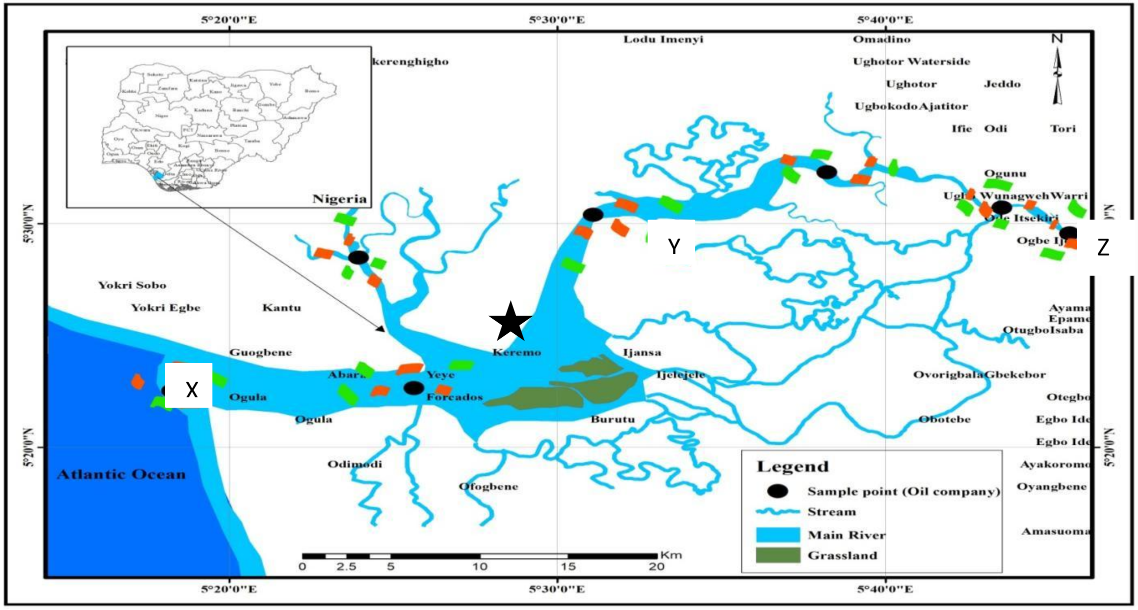

Figure 1. Map of Escravos Estuary
Source: Adapted and modified from Ewutanure *et al.* (2022)

Plate 1. Escravos Estuary showing mangrove trees
Source: Field Survey, (2025)

2.3 Sampling procedure

Sediment, *C. amnicola* and *P. monodon* samples were collected monthly for six months (January to June, 2025). Glass bottle containers for heavy metals analysis were washed with hot soapy water and rinsed. They were soaked for 4 hours in 14 % HNO_3 to prevent adsorption of heavy metals into the walls of the bottle, then rinsed thoroughly with deionized water (APHA, 1992).

Fish samples were collected from local fishers and identified using standard taxonomic keys (Fishbase, 2024). Sediment samples were obtained by using a Van Veen grab from each station at a depth of about 5 – 30 cm and stored in clean polythene bags for onward transportation to the laboratory where they were air-dried for three weeks at room temperature, ground by using an agated mortar and pestle, and sieved by using a 2 mm mesh size to remove debris (Gupta, 2001).

2.4 Analytical Technique

About 2.5g of sediment was taken, and 10 mL of nitric/perchloric acid mixture (ratio 2:1 by volume) was added before digestion (AOAC, 1990). It was heated at 150°C until a clear solution was obtained. About 10 mL of distilled water was added to the digested samples to prevent the formation of complex compounds before filtration. The filtrates were diluted with distilled water to 50 mL, and the samples were taken in a bottle and stored in a refrigerator pending analysis. A Parkin Einmer Analyst 400 (model) Atomic absorption spectrophotometer was used for the analysis of heavy metals.

2.5 Digestion of *C. amnicola* and *P. monodon* samples and determination of heavy metals

Five (5g) grammes of *C. amnicola* and *P. monodon* samples each were oven – dried at 105 ℃ in a Gallenkamp oven to a constant weight. The samples were each ground into powdery form with the aid of a pestle and mortar. The powdered samples were further dried to constant weights while 0.5g of each sample was collected for digestion with the aid of an electric sensitive weighing balance. About 0.5g of each sample was placed in a 50 mL conical flask and 20mL of HNO_3, 2 mL of H_2SO_4 and 4 ml of perchloric acid (a catalyst) were added. The samples were each transferred to hot plates in a fume cupboard and heated for one hour at 200℃ after which the temperature was reduced to 70℃ and digestion allowed to continue (APHA, 1990).

The samples which showed black fumes were further acidified with 10 mL of HNO_3 and the digestion was allowed to continue until the white fumes of per chloric acid disappeared leaving a clear yellowish solution. The resultant yellowish solutions were allowed to cool and then filtered. The filtrate in the standard volumetric flask was made up to 50 mL mark with distilled water as described by Gupta, (2001). Thereafter, heavy metals in *C. Amnicola* and *P. monodon* samples were determined using Atomic Absorption Spectrophotometer (AAS) based on AOAC, (1990).

2.6 Risk assessment of heavy metal consumption in seafood

Health risk assessment of heavy metal exposure was conducted using several indices as stated below:

2.6.1 Target Hazard Quotient (THQ)

THQ is a risk assessment model used to evaluate non-carcinogenic health risks. THQ values >1 indicate potential health risks, while values <1 suggest no significant threat (Yi, *et al.*, 2017).

$$THQ = \frac{(C\ X\ IR\ X\ EF\ X\ ED)}{(ORD\ x\ BW\ X\ AT)} \text{ x } 10^{-3}$$ - (Yi, *et al.,* 2017)

THQ = Target Hazard Quotient; C = Metal concentration in fish (mg/kg); IR = Ingestion Rate (24.7g/day); EF = Exposure frequency (365days/year); ED = Exposure duration (52.62years); ORD = Oral reference dose for each metal; BW = Body weight (60kg for an adult); AT = Averaging time (365days/year).

2.6.2 Estimated Daily Intake

The Estimated Daily Intake (EDI) assesses the daily intake of heavy metals through seafood consumption based on metal concentration and consumption rate (USEPA, 2000). If EDI exceeds the tolerable daily intake (TDI) set by regulatory bodies, the seafood is considered unsafe for human consumption.

$$EDI = \frac{IR}{BW}$$ - - - - - - -Yi *et al.* (2017)

2.6.3 Hazard Index (HI)

The sum of multiple THQs from different heavy metals is called the Hazard Index (HI), HI >1 suggests that combined exposure to multiple metals may pose a significant health risk (USEPA, 2010). The hazard index (HI) from the consumption of *C. amnicola* and *P. monodon* obtained from Escravos Estuary, Delta State was calculated as the sum of THQs of all the metals.

The Oral Reference Dose (ORD) (mg/kg/day) used are As = 0.45, Hg = 0.000426, Cd = 0.001 and Pb = 0.0035 (USEPA, 2012);

$$HI = THQAs + THQHg + THQCd + THQPb$$ - FEPA, (2011).

HI = hazard index; THQNi = the Target Hazard Quotient for Ni intake; THQAl = Target Hazard Quotient for Al intake; THQCr = the Target Hazard Quotient for Cr intake; THQPb = the Target Hazard Quotient for Pb intake,

2.7 Statistical Analysis

Statistical analysis was conducted using ANOVA and Duncan multiple range tests at a

5% significance level with SPSS software, version 22 to determine spatial and seasonal variations in contamination. This methodological framework ensured accurate assessment of heavy metal pollution in sediments and biota of the Escravos Estuary, as well as its implications for human health.

2.8 Results

The results of the heavy metal concentrations in sediments of the Escravos Estuary among stations and seasons are shown in Tables 1 and 2, respectively.

Table 1. Average heavy metal concentrations in sediment among stations for six months

	Stations			
Parameters	X	Y	Z	WHO, (2011)
Ni (mg/Kg)	0.013±0.04^{a}	0.02± 0.02^{a}	0.02± 0.01^{b}	5.9-17
Hg (mg/Kg)	0.013±0.01^{b}	0.02±0.01^{a}	0.02±0.01^{b}	0.17- 0.49
Cd (mg/Kg)	0.050±0.01^{a}	0.02±0.01^{b}	0.03±0.02^{c}	0.6-3.5
Pb (mg/Kg)	0.013±0.01^{a}	0.001±0.01^{b}	0.004±0.03^{a}	30-112

Note: Note: Means with the same alphabet along row are not significantly different (p >0.05) from each other at 5% level of significance. Ni = Nickel; Hg = Mercury; Cd = Cadmium; Pb = Lead

Table 2. Average heavy metal concentrations in sediment between seasons

	Seasons		
Parameters	Dry season	Wet season	WHO, (2011)
Ni (mg/Kg)	0.041±0.01^{b}	0.055± 0.01^{a}	5.9-17
Hg (mg/Kg)	0.011±0.01^{b}	0.031±0.05^{a}	0.17-0.49
Cd (mg/Kg)	0.015±0.02^{b}	0.084±0.03^{a}	0.6-3.5
Pb (mg/Kg)	0.012±0.01^{a}	0.033±0.01^{a}	30-112

Note: Means with the same alphabet along row are not significantly different (p >0.05) from each other at 5% level of significance. Ni = Nickel; Hg = Mercury; Cd = Cadmium; Pb = Lead

The results of the heavy metal concentrations in the gill of *Callinetes amnicola* of Escravos Estuary among stations and between seasons are presented in Tables 3 and 4, respectively.

Table 3. Mean heavy metal concentrations in the gill of *C. amnicola* among stations

	Stations			
Parameters	X	Y	Z	WHO, (2003)
Ni (mg/Kg)	0.037 ± 0.01^{a}	0.012 ± 0.01^{c}	0.019 ± 0.01^{b}	0.02-0.19
Hg (mg/Kg)	0.040 ± 0.01^{c}	0.064 ± 0.03^{a}	0.044 ± 0.03^{b}	0.16-0.64
Cd (mg/Kg)	0.042 ± 0.03^{a}	0.031 ± 0.01^{c}	0.042 ± 0.02^{b}	0.13-0.36
Pb (mg/Kg)	0.032 ± 0.01^{a}	0.012 ± 0.01^{a}	0.012 ± 0.03^{b}	0.24-1.08

Note: Means with the same alphabet along row are not significantly different (p >0.05) from each other at 5% level of significance. Ni = Nickel; Hg = Mercury; Cd = Cadmium; Pb = Lead

Table 4. Mean heavy metal concentrations in the gill of *Callinetes amnicola* between seasons

	Seasons		
Heavy metal	Dry season	Wet season	WHO, (2003)
Ni (mg/Kg)	0.036 ± 0.02^{b}	0.006 ± 0.01^{a}	0.02-0.19
Hg (mg/Kg)	0.051 ± 0.03^{b}	0.075 ± 0.03^{a}	0.16-0.64
Cd (mg/Kg)	0.065 ± 0.04^{a}	0.039 ± 0.02^{a}	0.13-0.36
Pb (mg/Kg)	0.13 ± 0.09^{a}	0.014 ± 0.01^{a}	0.24-1.08

Note: Means with the same alphabet along row are not significantly different (p >0.05) from each other at 5% level of significance. Ni = Nickel; Hg = Mercury; Cd = Cadmium; Pb = Lead

The results of the heavy metal concentrations in muscle of *Callinetes amnicola* of the Escravos Estuary, presented by station and season, are shown in Tables 5 and 6, respectively.

Table 5. Mean heavy metal concentrations in the muscle of *C. amnicola* among stations

	Stations			
Heavy metal	X	Y	Z	WHO, (2003)
Ni (mg/Kg)	0.013±0.01^a	0.014±0.01^a	0.031±0.01^a	1.0-1.2
Hg (mg/Kg)	0.027±0.02^a	0.013±0.01^c	0.032± 0.02^a	0.5-10
Cd (mg/Kg)	0.041±0.01^a	0.042±0.01^a	0.043±0.01^b	0.5-.10
Pb (mg/Kg)	0.065±0.01^a	0.008±0.00^a	0.003±0.01^b	0.3-0.5

Note: Means with the same alphabet along row are not significantly different (p >0.05) from each other at 5% level of significance. Ni = Nickel; Hg = Mercury; Cd = Cadmium; Pb = Lead

Table 6. Mean heavy metal concentrations in the muscle of *C amnicola* between seasons

	Seasons		
Heavy metal	Dry season	Wet season	WHO, (2003)
Ni (mg/Kg)	0.024±0.01^a	0.036±0.00^a	1.0-1.2
Hg (mg/Kg)	0.031±0.02^a	0.019±0.01^a	0.5-10
Cd (mg/Kg)	0.022±0.01^b	0.076±0.04^a	0.5-.10
Pb (mg/Kg)	0.009±0.00^a	0.004±0.02^b	0.3-0.5

Note: Means with the same alphabet along row are not significantly different (P >0.05) from each other at 5% level of significance. Ni = Nickel; Hg = Mercury; Cd = Cadmium; Pb = Lead

The results of the heavy metal concentrations in the gill of *Penaeus monodon* of the Escravos Estuary among station and between seasons are shown in Tables 7 and 8, respectively.

The results of grand means of heavy metal concentrations in *C. amnicola* and *P. monodon* in Escravos Estuary are presented in Table 11.

Table 7. Mean heavy metal concentrations in the gill of *P. monodon* among stations

	Stations			
Heavy metal	X	Y	Z	WHO, (2003)
Ni (mg/Kg)	0.003±0.00^a	0.004±0.00^a	0.002±0.00^a	0.1-0.2
Hg (mg/Kg)	0.003±0.00^a	0.004±0.00^a	0.003±0.00^a	0.1-0.2
Cd (mg/Kg)	0.006±0.00^a	0.005±0.00^a	0.005±0.00^a	0.1-0.3
Pb (mg/Kg)	0.007±0.01^a	0.006±0.02^a	0.003±0.00^b	0.1-0.5

Note: Means with the same alphabet along row are not significantly different (p >0.05) from each other at 5% level of significance. Ni = Nickel; Hg = Mercury; Cd = Cadmium; Pb = Lead

Table 8. Mean heavy metal concentrations in the gill of *P. monodon* between seasons

	Seasons		
Heavy metal	Dry season	Wet season	WHO, (2003)
Ni (mg/Kg)	0.003±0.00^b	0.007±0.00^a	0.1-0.2
Hg (mg/Kg)	0.004±0.00^a	0.005±0.00^a	0.1-0.2
Cd (mg/Kg)	0.003±0.00^b	0.006±0.00^a	0.1-0.3
Pb (mg/Kg)	0.006±0.00^a	0.004±0.00^a	0.1-0.5

Note: Means with the same alphabet along row are not significantly different (p >0.05) from each other at 5% level of significance. Ni = Nickel; Hg = Mercury; Cd = Cadmium; Pb = Lead

Table 9. Mean heavy metal concentrations in the muscle of *P. monodon* among stations

	Stations			
Heavy metal	X	Y	Z	WHO, (2003)
Ni (mg/Kg)	0.003±0.00^{a}	0.004±0.00^{a}	0.004±0.00^{a}	0.1-0.2
Hg (mg/Kg)	0.003±0.00^{a}	0.004±0.00^{a}	0.005±0.00^{a}	0.1-0.2
Cd (mg/Kg)	0.043±0.01^{a}	0.043±0.003^{a}	0.042±0.00^{a}	0.1-0.3
Pb (mg/Kg)	0.006±0.00^{a}	0.005±0.00^{a}	0.003±0.00^{b}	0.1-0.5

Note: Means with the same alphabet along row are not significantly different (p >0.05) from each other at 5% level of significance. Ni = Nickel; Hg = Mercury; Cd = Cadmium; Pb = Lead

Table 10. Mean heavy metal concentrations in the muscle of *P. monodon* between seasons

	Seasons		
Heavy metal	Dry season	Wet season	WHO, (2003)
Ni (mg/Kg)	0.024±0.01^{a}	0.015±0.00^{a}	1.0-1.2
Hg (mg/Kg)	0.014±0.01^{a}	0.010±0.01^{a}	0.5-10
Cd (mg/Kg)	0.053±0.03^{b}	0.042±0.03^{a}	0.5-.10
Pb (mg/Kg)	0.008±0.00^{a}	0.005±0.01^{b}	0.3-0.5

Note: Means with the same alphabet along row are not significantly different (P >0.05) from each other at 5% level of significance. Ni = Nickel; Hg = Mercury; Cd = Cadmium; Pb = Lead

Table 11. Grand mean of heavy metal concentrations in *C. amnicola* and *P. monodon*

	C. Amnicola	*P. monodon*
Ni (mg/Kg)	0.086±0.01^{a}	0.069±0.01^{b}
Hg (mg/Kg)	0.030±0.00^{a}	0.001±0.00^{a}
Cd (mg/Kg)	0.049±0.00^{a}	0.024±0.10^{b}
Pb (mg/Kg)	0.006±0.01^{a}	0.039±0.00^{a}

Note: Means with the same alphabet along row are not significantly different (p >0.05) from each other at 5% level of significance. Ni = Nickel; Hg = Mercury; Cd = Cadmium; Pb = Lead

The results of the assessment of the health risk of consuming *C. amnicola* and *P. monodon* of the Escravos Estuary are shown in Tables 12 and 13, respectively.

Table 12. Assessment of the health risk of consumption of *C. amnicola*

	Risk models		% Contribution of metals to HI (0.220)
Heavy metals	EDI	THQ	
Ni	0.119	0.024	3.9
Hg	0.007	0.793	2.1
Cd	0.236	0.961	5.7
Pb	0.132	0.216	3.2

Note: Ni = Nickel; Hg = Mercury; Cd = Cadmium; Pb = Lead; EDI = Estimated Daily Intake; THQ = Target Hazard Quotient; HI = Hazard Index (**0.215**).

Table 13. Assessment of the health risk of consumption of *P. monodon*

	Risk models		% Contribution of metals to HI (0.572)
Heavy metals	EDI	THQ	
Ni	0.0073	0.0051	3.65
Hg	0.0037	0.0583	0.25
Cd	0.0967	0.5209	5.71
Pb	0.0079	0.0154	0.45

Note: Ni = Nickel; Hg = Mercury; Cd = Cadmium; Pb = Lead; EDI = Estimated Daily Intake; THQ = Target Hazard Quotient; HI = Hazard Index (**0.572**).

2.9 Discussion

The results of the study reveal clear seasonal and spatial variations in heavy metal concentrations in sediments and in the tissues of *Callinectes amnicola* and *Penaeus monodon* from the Escravos Estuary. Sediment analysis shows that Ni, mercury, cadmium, and lead concentrations were consistently higher during the wet season compared to the dry season, reflecting the influence of increased runoff, effluent discharge, and sediment resuspension during periods of heavy rainfall (Singh and Sharma, 2024). Although the values recorded were below the World Health Organization's permissible limits, the seasonal elevation indicates that wet season dynamics enhance the mobility and bioavailability of metals in the estuary (Tchounwou *et al*. 2022). This pattern is critical because sediments act as reservoirs of contaminants, and their enrichment during the wet season increases the likelihood of transfer into aquatic organisms (Ulla *et al*. 2021).

The gill tissues of *C. amnicola* demonstrated notable differences among stations and seasons. Nickel concentrations were highest at Station X, while mercury peaked at Station Y, suggesting localized sources of contamination possibly linked to industrial or agricultural inputs. Seasonal comparisons revealed that mercury and cadmium were higher in the wet season, while Ni was reduced, indicating that different metals respond differently to hydrological changes (Yi *et al*. 2017). Lead concentrations were elevated in the dry season, which may be associated with reduced dilution and higher retention in the water column (Yuan *et al*. 2020). Importantly, while most values were below WHO limits, the presence of mercury and cadmium in gill tissues at levels approaching threshold values highlights potential risks, since gills are primary sites of metal uptake and can reflect immediate exposure conditions (Yilmaz *et al*. 2007).

Muscle tissues *of C. amnicola* also showed variations across stations and seasons. Nickel concentrations were relatively uniform across stations but increased in the wet season, while cadmium levels rose significantly during the wet season compared to the dry season. Mercury concentrations were slightly higher in the dry season, and lead levels were generally low across both seasons. Although the concentrations in muscle tissues were below WHO limits, the seasonal increase in cadmium is concerning because muscle tissue is the portion consumed by humans, and cadmium is highly toxic even at low levels (Wuana and Okieimen, 2011). These findings suggest that seasonal hydrological changes strongly influence bioaccumulation patterns in edible tissues, thereby affecting food safety.

For *P. monodon*, gill concentrations of arsenic, mercury, cadmium, and lead were generally low across stations and seasons, remaining well below WHO limits. However, seasonal differences were evident, with Ni and cadmium slightly higher in the wet season, reflecting similar patterns observed in sediments and in *C. amnicola*. Muscle tissues of *P. monodon* showed higher cadmium concentrations compared to other metals, with seasonal variation indicating greater accumulation during the dry season. Although values were below permissible limits, the consistent presence of cadmium in muscle tissue is significant because of its cumulative toxicity and potential to cause kidney damage and other health issues upon chronic exposure (Obayemi *et al*. 2023).

The grand mean comparison between the two species revealed that *C. amnicola* accumulated higher concentrations of Ni, mercury, and cadmium, while *P. monodon* showed higher lead levels. This difference may be attributed to their feeding habits and ecological niches, with *C. amnicola* being more benthic and therefore more exposed to sediment-associated contaminants (Oladeji *et al*. 2023). The health risk assessment further demonstrated that cadmium contributed the highest percentage to the hazard index in both species, underscoring its importance as the most critical contaminant of concern. Although, the overall hazard indices for both species were below one, indicating no immediate health risk from consumption, the cumulative effects of chronic exposure, particularly to cadmium and mercury, cannot be overlooked. Vulnerable populations such as children and pregnant women may be at greater risk due to bioaccumulation over time (Olmedo *et al*. 2024).

In summary, the results highlight that seasonal variations significantly influence heavy metal concentrations in sediments and fish tissues in the Escravos Estuary. Wet season conditions enhance the mobilization and bioavailability of metals, leading to higher accumulation in fish tissues, especially cadmium. While concentrations were generally below WHO limits, the consistent presence of toxic metals in edible tissues raises concerns for long-term food safety and public health (Liu *et al*. 2021). The findings emphasize the need for continuous monitoring of heavy metals in the estuary, stricter regulation of industrial and agricultural discharges, and public health awareness campaigns to mitigate risks associated with fish consumption in the Niger Delta.

3.0 Conclusion

The study demonstrates that the Escravos Estuary is undergoing significant increase of heavy metals in both sediments and aquatic organisms. The health risk assessment highlights Ni and Cd as the most concerning contaminants, with potential implications for communities that rely on fish from the estuary as a major source of protein. Although concentrations were generally below international limits, the cumulative effects of chronic exposure underscore the need for urgent intervention to safeguard public health and preserve biodiversity in the Niger Delta.

4.0 Recommendations

To address these issues, regulatory authorities must strengthen policies aimed at reducing pollution from industrial, agricultural, and domestic sources, while instituting regular monitoring programs for contaminant levels in sediments. Sustainable fisheries management practices should be developed to minimize human exposure to contaminated fish, alongside public education campaigns to raise awareness of the risks associated with consumption. Remediation strategies to lower heavy metal concentrations in the estuary are also essential. These findings provide a valuable foundation for the Federal Government of Nigeria to design targeted interventions that protect environmental integrity, ensure food safety, and promote the long-term sustainability of the Escravos Estuary ecosystem.

References

Adeyemi, S. O., Ogunjobi, A. A., and Abiodun, O. A. (2019). Bioaccumulation of heavy metals in fish species from

Ogun River, Nigeria. *Journal of Environmental Chemistry and Ecotoxicology,* 11(1): 1–7. https://doi.org/10.5897/JECE2018.0455

Aghoghovwia, O. A., Ohimain, E. I., and Izah, S. C. (2016). Bioaccumulation of heavy metals in different tissues of some commercially important fish species from Warri River, Niger Delta, Nigeria. *Biotechnological Research*, *2*(1), 25-32.

Ajani, E.K., and Balogun, K.J. (2015). Variability in levels of heavy metals in water and fish 496 (*Chrysichthys nigrodigitatus*) tissues from Badagry Creek, Nigeria. *Journal of Biology and Life Science.* 6(2):193-207. http://dx.doi.org/10.5296/jbls.v6i2.7602

Alahabadi, A., and Malvandi, H. (2018). Contamination and ecological risk assessment of heavy metals and metalloids in surface sediments of the Tajan River, Iran. *Marine Pollution Bulletin*, 133: 741-749.

Ali, H., Khan, E., and Ilahi, I. (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. *Journal of Chemistry*, 2019, 1-14.

AOAC. (1990). Official Methods of Analysis. 15th Edition, Association of Official Analytical Chemist, Washington DC.

APHA (1992). Standard Methods for the Examination of Water and Waste Water. America Public Health Association, American Water Works Association, Water Environment Federation. Greenberg, A.E., Clesceri, L.S. and A.D. Eaton Eds. 18^{th} Edition, Washington, D.C. 238 - 410.

Authman, M. M., Zaki, M. S., Khallaf, E. A., and Abbas, H. H. (2015). Use of fish as bio-indicator of the effects of heavy metals pollution. *Journal of Aquaculture Research & Development*, 6(4): 1-13.

Asuquo, P. E., Ekanem, A. P., & Ifon, H. T. (2012). Levels of some heavy metals in tissues of crustaceans (*Callinectes amnicola* and *Macrobrachium vollenhovenii*) from a tropical ecosystem in Nigeria. *Institute of Oceanography, University of Calabar.*

Ekperusi, A. O., Michael, A., Chukwurah, C. H., and Sunday, N. M. (2024). Evaluation of heavy metals and their potential risk to human health from seafood in Escravos Estuary, Southern Nigeria. *Marine Pollution Bulletin*, *208*, 117014.

Ewutanure, S. J., and Asogwa, V. I. (2024). Histopathological analyses of liver and gill of Coptodon zillii obtained from Okerenkoko Waterfront, Delta State, Nigeria. *Animal Research International*, 21(1): 5249-5256.

Ewutanure, S. J., and Binyotubo, T. E. (2021). Impacts of anthropogenic activities on the fish compositions and diversity of Okerenkoko Estuarine, Delta State, Nigeria. In *Proceedings of the Accra Bespoke Multidisciplinary Innovations Conference. University of Ghana/Academic City University College, Accra, Ghana* (pp. 9-22).

Ewutanure, S. J., Eyo, V. O., Binyotubo, E. T., and Eriegha, O. J. (2022). Heavy metal and total petroleum hydrocarbon concentrations in water, sediment and fauna of Okerenkoko Estuarine, Delta State, Nigeria. *Journal of Digital Innovations and Contemporary Research in Science Engineering and Technology*, *10*(2), 1-12.

Ewutanure, S.J. and Olaifa, F.E. (2021). Effects of effluents from Gbalegbe River, Delta State, Nigeria on the breeding performance of *Clarias gariepinus* (Burchell, 1822). Proceedings of the Accra Bespoke Multidisciplinary Innovations Conference. University of Ghana Academic Citv University College, Accra, Ghana. December 2021. Pp. 163-178

FEPA, (2011). National Environmental (Surface and ground water quality control) regulations. Printed and Published by The Federal Government Printer, Lagos, Nigeria jFGP 71/72011MOO (OL 46). 35Pp.

Fishbase (2024). Scopimera inflata. FishBase.https://www. fishbase.se/summary/1390 Accessed September 21, 2024.

Gupta, P. K. (2001). Methods in environmental analysis: Water; Soil and Air. *AGROBIOS* (India) Publisher. 1 - 408.

Ihedioha, J. N., Ukoha, P. O., and Ekere, N. R. (2017). Ecological and human health risk assessment of heavy metal contamination in soil of a municipal solid waste dump in Uyo, Nigeria. *Environmental geochemistry and health*, *39*, 497-515.

Iwegbue, C. M., Oshenyen, V. E., Tesi, G. O., Olisah, C., Nwajei, G. E., and Martincigh, B. S. (2022). Occurrence and spatial characteristics of polychlorinated biphenyls (PCBs) in sediments from rivers in the western Niger delta of Nigeria impacted by urban and industrial activities. *Chemosphere*, 291, 132671.

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., and Beeregowda, K. N. (2014). Toxicity, mechanism, and health effects of some heavy metals. *Interdisciplinary Toxicology*, 7(2): 60-72.

Jolaosho, T. L., Elegbede, I. O., Ndimele, P. E., Falebita, T. E., Abolaji, O. Y., Oladipupo, I. O., and Isaac, O. O. (2024). Occurrence, distribution, source apportionment, ecological and health risk assessment of heavy metals in water, sediment, fish and prawn from Ojo River in Lagos, Nigeria. *Environmental Monitoring and Assessment*, 196 (2): 109.

Lawal-Are, A. O., Mokwenye, C. R., & Akinwunmi, M. F. (2017). Heavy metal bioaccumulation in *Callinectes amnicola* and *Farfantepenaeus notialis* from three selected tropical water bodies in Lagos, Nigeria. *Ife Journal of Science, 19*(2), 201–210.

Li, J., Miao, X., Hao, Y., Xie, Z., Zou, S., and Zhou, C. (2020). Health risk assessment of metals (Cu, Pb, Zn, Cr, Cd, As, Hg, Se) in angling fish with different lengths collected from Liuzhou, China. *International Journal of Environmental Research and Public Health*, *17*(7): 2192.

Liu, B., Xu, M., Wang, J., Wang, Z., and Zhao, L. (2021). Ecological risk assessment and heavy metal contamination in the surface sediments of Haizhou Bay, China. *Marine Pollution Bulletin*, *163*, 111954.

Obayemi, O. E., Ayoade, M. A. and Komolafe, O. O. (2023). Health risk assessment of heavy metals in *Coptodon zillii* and *Parachanna obscur*a from a tropical reservoir. *Heliyon* 30:9(6) 1-13

Oladeji, A.A., Olarewaju, A. A., Iyabode, C.A., Madu, I. E. and Ahmad, S.R (2024). Impact of Sediment and Water Heavy Metal Concentrations on Fish Bioaccumulation in Hadejia River, Nigeria. Book of Proceedings, 14th Nigeria Association of Hydrological Sciences Conference (Okitipupa 2024) held at Olusegun Agagu University of Science and Technology, Okitipupa, Ondo State, Nigeria, November 5 - 8, 2024

Olmedo, P., Pla, A., Hernández, A. F., Barbier, F., Ayouni, L., and Gil, F. (2013). Determination of toxic elements (mercury, cadmium, lead, tin and arsenic) in fish and shellfish samples. Risk assessment for the consumers. *Environment international*, 59: 63-72.

Osuagwu, E. S., and Olaifa, E. (2018). Effects of oil spills on fish production in the Niger Delta. PLoS ONE, 13(10), e0205114. https://doi.org/10.1371/journal.pone.0205114

Singh, G., and Sharma, S. (2024). Heavy metal contamination in fish: sources, mechanisms and consequences. *Aquatic Sciences*, 86(4), 107.

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., and Sutton, D. J. (2012). Heavy metal toxicity and the environment. *EXS*, 101, 133-164.

Ullah, S., Li, Z., Hassan, S., Ahmad, S., Guo, X., Wanghe, K., and Nabi, G. (2021). Heavy metals bioaccumulation and subsequent multiple biomarkers based appraisal of toxicity in the critically endangered Tor putitora. *Ecotoxicology and Environmental Safety*, 228, 113032

USEPA. (2010). Integrated Risk Information System (IRIS); United States Environmental Protection Agency: Washington, DC, USA. Available online: http://www.epa.gov/ncea/iris/index.html (accessed on 15 August 2020).

Wuana, R. A., and Okieimen, F. E. (2011). Heavy metals in contaminated soils: A review of sources, chemistry, risks, and best available strategies for remediation. *ISRN Ecology*, 2011, 1-20.

Yi, Y., Tang, C., Yi, T., Yang, Z. and Zhang, S. (2017). Health risk assessment of heavy metals in fish and accumulation patterns in food web in the upper Yangtze River, China. *Ecotoxicology and Environmental Safety,* 145: 295-302.

Yilmaz, F., Ozdemir, N., Demirak, A., and Tuna, A. L. (2007). Heavy metal levels in two fish species *Leuciscus cephalus* and *Lepomis gibbosus*. *Food Chemistry*, 100(2), 830-835.

Yuan, Y., Sun, T., Wang, H., Liu, Y., Pan, Y., Xie, Y., and Fan, Z. (2020). Bioaccumulation and health risk assessment of heavy metals to bivalve species in Daya Bay (South China Sea): Consumption advisory. *Marine pollution bulletin*, *150*, 110717.