

Research Article

Comparative Assessment of Heavy Metal Bioaccumulation in Crabs and Prawns from Selected Creeks in Trans-Amadi, Port Harcourt, Nigeria: Implications for Ecological Risk Assessment

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Abstract

This study assessed comparative heavy-metal bioaccumulation in crabs and prawns collected from five creek systems within the Trans-Amadi area of Port Harcourt, Rivers State, Nigeria, and evaluated the associated human-health and ecological risks. Ten metals comprising Pb, Cd, Cr, Ni, Cu, Zn, Fe, Mn, Co and Hg were determined in crab and prawn tissues. Mean concentrations in crabs ranged from 0.14–0.98 mg/kg for Cd, 0.36–0.53 mg/kg for Cr, 0.63–0.84 mg/kg for Ni, 3.84–5.03 mg/kg for Cu, 16.85–22.14 mg/kg for Zn, 28.74–39.17 mg/kg for Fe, 5.17–6.88 mg/kg for Mn, 0.26–0.39 mg/kg for Co and 0.016–0.031 mg/kg for Hg, while Pb ranged from 0.67–0.98 mg/kg. Prawn concentrations were comparatively lower across the investigated metals. All metals showed bioaccumulation factors greater than unity, with Zn recording the highest BAF in crabs (2.43) and prawns (1.82). The combined hazard index was 1.91 for adult crab consumers and 1.28 for adult prawn consumers, increasing to 5.69 and 3.84, respectively, among children. Total carcinogenic risks were 9.0×10^{-5} and 6.2×10^{-5} for adult crab and prawn consumers, respectively, and 2.70×10^{-4} and 1.86×10^{-4} for children. Potential ecological risk indices ranged from 96.9 at Ntawogba Creek to 146.3 at Okujagu/Okuruama. The findings indicate species- and location-dependent metal accumulation and highlight the need for continued monitoring of seafood safety and ecological quality within the creek system.

1. Introduction

Heavy-metal contamination of aquatic environments remains an important environmental and public-health concern because metals released into surface waters can persist in sediments and biological compartments and may subsequently enter aquatic food chains. In rapidly developing urban and industrial environments, contamination may arise from multiple sources, including industrial activities, urban runoff, wastewater discharge, transportation and other anthropogenic pressures. Studies conducted within the Niger Delta have continued to demonstrate the occurrence of heavy metals and other contaminants in aquatic systems, sediments and associated environmental media [1–5].

The Trans-Amadi area of Port Harcourt is particularly relevant to aquatic contamination studies because it contains interconnected creek and drainage systems situated within an environment characterised by residential, commercial and industrial activities. Such settings provide several potential pathways through which potentially toxic elements can enter surface waters and become associated with sediments and aquatic organisms. Previous investigations in the wider Niger Delta have reported heavy-metal contamination and associated ecological or human-health concerns in rivers, estuaries and other aquatic environments [6–8]. The occurrence of heavy metals in aquatic environments is therefore not only an issue of water quality but also one of food-chain exposure where contaminated organisms are consumed by local populations.

Aquatic organisms such as crabs and prawns are useful indicators of metal contamination because of their close association with water, suspended particles and sediments. Their feeding behaviour and physiological characteristics can facilitate the uptake and retention of metals within tissues. Consequently, the analysis of edible aquatic organisms provides information that complements measurements obtained from water and sediment alone. Evidence from the Niger Delta has demonstrated the capacity of aquatic organisms to accumulate potentially toxic elements, with studies reporting metal bioaccumulation in fish and edible crabs [2, 6, 9, 10]. In particular, the reported accumulation of nickel, lead and cadmium in *Callinectes sapidus* from the Iko River demonstrates the relevance of crustaceans in evaluating both environmental contamination and potential human exposure [10].

The environmental significance of heavy metals depends not only on their concentrations but also on their persistence, mobility, bioavailability and biological effects. Some elements, including Fe, Zn, Cu and Mn, are essential micronutrients at appropriate concentrations but may become harmful when exposure is excessive. Other elements, such as Pb, Cd and Hg, have no established beneficial biological role and are of particular toxicological concern. Investigations of heavy-metal contamination in sediments have similarly shown that the ecological significance of individual metals can vary according to their concentrations and toxic-response characteristics [1, 11]. This distinction is important when interpreting metal concentrations in edible organisms because a metal with a relatively low tissue concentration may still contribute substantially to ecological risk when it has a high toxicity weighting.

Bioaccumulation provides an additional perspective on environmental contamination. The presence of metals in organism tissues does not necessarily indicate the same degree of exposure among species because uptake and retention may differ according to physiology, feeding strategy, habitat association and other biological characteristics. Comparative assessment of different aquatic organisms can therefore reveal species-specific patterns that may not be apparent from environmental concentrations alone. Recent work on edible crabs from the Ibotirem Waterway demonstrated the usefulness of assessing potentially toxic elements together with human-health risk indicators [9]. Similarly, comparative investigations of farmed and river-caught catfish have shown that differences in environmental exposure can be reflected in tissue-metal concentrations and associated health-risk estimates [12].

The public-health dimension is particularly important where crabs and prawns form part of the local diet. Consumption of contaminated aquatic organisms provides a direct pathway for human exposure to accumulated metals. The magnitude of this exposure depends on the concentration of contaminants in edible tissues, consumption rate and body weight. Recent studies in the Niger Delta have consequently incorporated human-health risk assessment into investigations of contaminated water, fish and other aquatic resources [6, 8, 9, 12, 13]. Studies of seafood from coastal markets have likewise demonstrated the importance of evaluating essential and toxic metals in relation to potential dietary exposure [14].

Heavy-metal contamination may also have consequences beyond human health. Metals accumulated in aquatic organisms can reflect the transfer of contaminants from environmental compartments into biological systems and may contribute to ecological stress. Research on the Orashi River and Qua Iboe River has demonstrated the value of combining metal concentrations with ecological-risk indices to evaluate the potential ecological significance of contamination [1, 11, 15]. Such approaches are particularly useful in heterogeneous creek systems where contamination may vary spatially as a result of differences in hydrology, sediment characteristics and intensity of human activities.

Although several studies have investigated heavy metals in Niger Delta waters, sediments and fish, comparatively less attention has been given to the simultaneous comparison of metal accumulation between crabs and prawns across multiple creek systems within an urban-industrial setting such as Trans-Amadi. This gap is important because different organisms may accumulate metals at different rates, and spatial variation in contamination may influence the exposure of organisms inhabiting individual creek systems. Existing evidence from the Niger Delta supports the need for integrated assessment of environmental contamination, bioaccumulation and health risk rather than consideration of individual environmental compartments in isolation [2, 4, 10].

Therefore, this study comparatively assessed the concentrations and bioaccumulation of Pb, Cd, Cr, Ni, Cu, Zn, Fe, Mn, Co and Hg in crabs and prawns collected from five selected creek systems in Trans-Amadi, Port Harcourt, Nigeria. The study further evaluated differences in metal accumulation between the two organisms, estimated bioaccumulation factors, assessed potential human-health risks associated with consumption, and determined potential ecological risks across the investigated creek systems.

2. Methods

2.1. Study Area

The study was conducted in selected creek systems within the Trans-Amadi area of Port Harcourt, Rivers State, Nigeria. The area forms part of the lower Niger Delta and is characterised by a network of tidal creeks, drainage channels and interconnected surface-water systems. The environment is influenced by residential, commercial, industrial, transportation and other anthropogenic activities. Five sampling locations were selected to provide spatial coverage of the study area: Amadi Creek, Woji Creek, Ntawogba Creek, Elekahia Creek and the Okujagu/Okuruama creek system. The sampling locations were selected based on accessibility, ecological characteristics, human activities

and the presence of crab and prawn populations Figure 1.

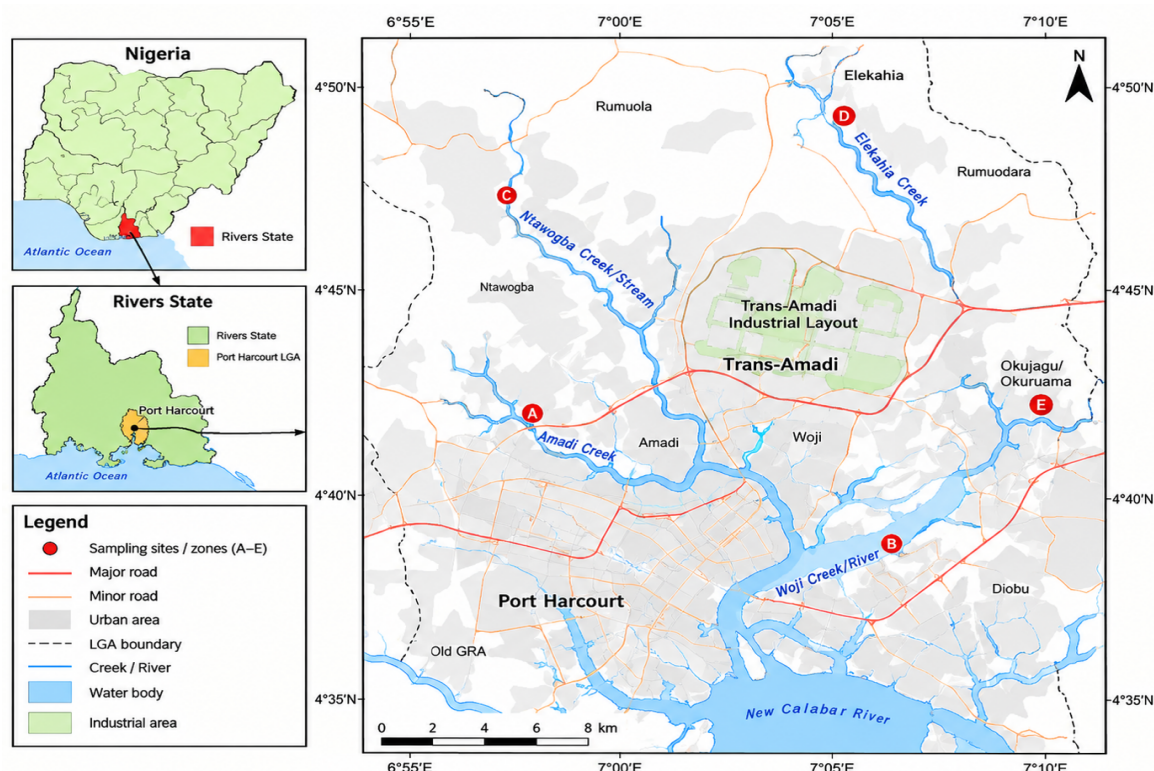


Figure 1: Map of the Study Area Showing the Sampling Locations in Trans-Amadi, Port Harcourt, Rivers State, Nigeria

2.2. Study Design and Sampling Strategy

A comparative cross-sectional environmental sampling design was adopted. The design enabled comparison of heavy metal concentrations between crabs and prawns and among the five selected creek systems.

Sampling was conducted during the defined study period. At each creek, representative specimens of crabs and prawns were collected from designated sampling points. Where possible, specimens of comparable size and maturity were selected to minimise variation associated with age, body size and physiological condition.

The sampling points were positioned to represent areas influenced by different levels of anthropogenic activity. Samples were collected using clean, metal-free sampling equipment to minimise external contamination.

2.3. Collection and Identification of Biological Samples

Crabs and prawns were collected from each selected creek using appropriate local fishing gear, traps or hand collection, depending on the accessibility and characteristics of each location. Immediately after collection, specimens were placed in pre-cleaned polyethylene containers, labelled according to sampling location, organism type and sampling date, and transported to the laboratory in an ice-packed cooler.

The organisms were identified to the lowest practical taxonomic level using standard taxonomic identification keys. Specimens that were damaged, decomposed or taxonomically uncertain were excluded from the analysis.

2.4. Laboratory Preparation of Samples

In the laboratory, the specimens were washed thoroughly with deionised water to remove adhering sediment and other external materials. The edible tissues were carefully dissected using acid-washed stainless-steel instruments.

The tissues were homogenised separately according to organism and sampling location. Homogenised samples were placed in labelled containers and oven-dried at an appropriate controlled temperature until constant weight was achieved. The dried tissues were subsequently ground into a fine homogeneous powder and stored in clean, labelled containers until digestion.

All glassware and digestion vessels were thoroughly washed with laboratory detergent, rinsed with tap water and subsequently rinsed several times with deionised water. Where required, acid washing was performed to minimise contamination from trace metals.

2.5. Acid Digestion of Biological Samples

A known mass of the homogenised tissue sample was accurately weighed into a digestion vessel. Concentrated analytical-grade nitric acid was added to the sample, followed by controlled heating until the organic matrix was adequately digested. Where necessary, hydrogen peroxide was used to facilitate oxidation of the remaining organic matter.

The digest was allowed to cool and was filtered where necessary before being made up to a known volume with deionised water. Reagent blanks were prepared using the same digestion procedure but without biological material.

The prepared solutions were transferred into appropriately labelled acid-washed containers for instrumental determination of the selected heavy metals.

2.6. Determination of Heavy Metals

Ten metals were investigated: lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), cobalt (Co) and mercury (Hg). The concentrations of Pb, Cd, Cr, Ni, Cu, Zn, Fe, Mn and Co were determined using an appropriate calibrated atomic absorption spectrophotometer (AAS) or equivalent validated trace-metal analytical instrument. Mercury was determined using a suitable mercury-specific analytical procedure compatible with the available instrumentation.

Calibration standards were prepared from certified stock standards covering the expected concentration range of the samples. Instrument calibration was performed before sample analysis, and calibration verification standards were analysed periodically to ensure instrumental stability.

Metal concentrations were reported as **mg/kg wet weight** after conversion from the measured dry-weight concentrations where appropriate.

2.7. Quality Assurance and Quality Control

Quality assurance and quality control procedures were incorporated throughout sample collection, preparation and analysis. Analytical blanks, duplicate samples and certified or laboratory-control materials were included in the analytical batch.

Instrument calibration was checked using appropriate calibration verification standards. Samples were analysed in replicate, and the relative standard deviation was calculated to assess analytical precision.

The detection limit for each metal was established from repeated analysis of blanks and/or low-concentration standards. Results below the method detection limit were reported appropriately rather than being assigned arbitrary concentrations.

All analytical results were subjected to appropriate quality-control checks before statistical analysis.

2.8. Bioaccumulation Factor

The bioaccumulation factor (BAF) was calculated to assess the tendency of the organisms to accumulate metals from their surrounding environment. The BAF was calculated using:

$$\text{BAF} = \frac{C_{\text{organism}}}{C_{\text{water}}}$$

where:

- **C_{organism}** = Concentration of the metal in the organism tissue (mg/kg).
- **C_{water}** = Corresponding concentration of the metal in creek water (mg/L).

Where sediment-associated exposure was specifically assessed, the corresponding organism-to-sediment accumulation relationship was calculated separately and clearly identified as a biota–sediment accumulation factor rather than a water-based BAF.

2.9. Human Health Risk Assessment

Human-health risk was assessed for hypothetical consumption of contaminated crab and prawn tissues. The assessment considered both **adult and child exposure scenarios**.

Estimated Daily Intake

The estimated daily intake (EDI) of each metal was calculated as:

$$\text{EDI} = \frac{(C \times \text{IR})}{\text{BW}}$$

where:

- **C** = Concentration of the metal in edible tissue (mg/kg).
- **IR** = Ingestion rate of the organism (kg/day).
- **BW** = Body weight (kg).

Separate exposure estimates were calculated for adults and children using the selected consumption and body-weight assumptions.

Hazard Quotient

The non-carcinogenic risk associated with individual metals was estimated using:

$$\text{HQ} = \frac{\text{EDI}}{\text{RfD}}$$

where:

- **EDI** = estimated daily intake
- **RfD** = reference dose for the respective metal.

An HQ value ≤ 1 was interpreted as indicating no appreciable non-carcinogenic risk under the specified exposure assumptions, whereas $HQ > 1$ indicated potential concern requiring further evaluation.

Hazard Index

The combined non-carcinogenic risk from multiple metals was calculated as:

$$HI = \sum HQ$$

The calculated HI was used to assess the combined potential non-carcinogenic risk associated with simultaneous exposure to the investigated metals through consumption of crab or prawn tissues.

2.10. Carcinogenic Risk Assessment

Where suitable cancer slope factors were available for the investigated metals, incremental lifetime cancer risk (ILCR) was estimated using:

$$ILCR = LADD \times SF$$

where:

- **LADD** = lifetime average daily dose.
- **SF** = cancer slope factor.

The calculated values were compared with commonly applied acceptable-risk ranges for environmental exposure assessment. Metals for which a scientifically appropriate slope factor was unavailable were not assigned an artificial carcinogenic-risk value.

2.11. Ecological Risk Assessment

The ecological risk assessment was conducted using concentration-based contamination indices and potential ecological risk metrics.

Contamination Factor

The contamination factor (CF) was calculated as:

$$CF = \frac{C_{\text{metal}}}{C_{\text{background}}}$$

where:

- **C_{metal}** = measured concentration of the metal
- **C_{background}** = corresponding background or reference concentration.

The background values were selected from an explicitly identified and scientifically defensible reference source.

Ecological Risk Factor

The ecological risk factor (Er) was calculated as:

$$Er = Tr \times CF$$

where:

- **Tr** = toxic-response coefficient of the individual metal.
- **CF** = contamination factor.

Potential Ecological Risk Index

The potential ecological risk index (PERI) was calculated as:

$$PERI = \sum Er$$

The PERI was used to provide an integrated indication of the potential ecological pressure associated with the investigated metals.

2.12. Statistical Analysis

The analytical results were expressed as **mean $\pm$ standard deviation (SD)**. Descriptive statistics were used to characterise metal concentrations in crab and prawn tissues at the five sampling locations.

Differences in heavy metal concentrations between organisms and among sampling locations were assessed using appropriate inferential statistical procedures. Where the assumptions of parametric analysis were satisfied, analysis of variance (ANOVA) followed by an appropriate post-hoc test was used. Where the assumptions were not satisfied, suitable non-parametric alternatives were applied. The level of statistical significance was set at $p < 0.05$. Statistical analysis was performed using an appropriate version of SPSS or equivalent statistical software.

2.13. Ethical and Environmental Considerations

Specimen collection was conducted in accordance with applicable institutional and environmental requirements. Only the number of organisms required for the analytical objectives was collected. Sampling activities were conducted to minimise disturbance to the creek environment, and appropriate procedures were followed for the handling and disposal of biological and chemical wastes.

3. Results

3.1. Heavy Metal Concentrations in Crab Tissues

The concentrations of the ten investigated heavy metals varied considerably among the five creek systems Table 1. Iron recorded the highest concentrations, ranging from 28.74 ± 1.31 mg/kg at Ntawogba Creek to 39.17 ± 1.68 mg/kg at Okujagu/Okuruama. Zinc was the next most abundant metal, with concentrations ranging from 16.85 ± 0.68 to 22.14 ± 0.91 mg/kg. Manganese ranged from 5.17 ± 0.29 to 6.88 ± 0.37 mg/kg, while copper ranged from 3.84 ± 0.19 to 5.03 ± 0.27 mg/kg. Among the potentially toxic metals, Pb ranged from 0.67 ± 0.05 to 0.98 ± 0.08 mg/kg, whereas Cd ranged from 0.14 ± 0.01 to 0.24 ± 0.02 mg/kg. Mercury recorded the lowest concentrations, ranging from 0.016 ± 0.003 to 0.031 ± 0.005 mg/kg. In general, Okujagu/Okuruama recorded the highest concentration for most of the investigated metals, while Ntawogba Creek generally had the lowest concentrations, as shown in Table 1.

Table 1: Heavy metal concentrations in crab tissues from the five selected creek systems

Heavy metal	Amadi Creek	Woji Creek	Ntawogba Creek	Elekahia Creek	Okujagu/Okuruama
Pb	0.82 ± 0.06	0.91 ± 0.07	0.67 ± 0.05	0.76 ± 0.06	0.98 ± 0.08
Cd	0.18 ± 0.02	0.22 ± 0.02	0.14 ± 0.01	0.17 ± 0.02	0.24 ± 0.02
Cr	0.43 ± 0.03	0.49 ± 0.04	0.36 ± 0.03	0.41 ± 0.03	0.53 ± 0.04
Ni	0.71 ± 0.05	0.79 ± 0.06	0.63 ± 0.05	0.68 ± 0.05	0.84 ± 0.07
Cu	4.26 ± 0.21	4.72 ± 0.25	3.84 ± 0.19	4.18 ± 0.22	5.03 ± 0.27
Zn	18.42 ± 0.74	20.36 ± 0.83	16.85 ± 0.68	18.91 ± 0.79	22.14 ± 0.91
Fe	32.61 ± 1.42	36.24 ± 1.57	28.74 ± 1.31	31.85 ± 1.46	39.17 ± 1.68
Mn	5.84 ± 0.32	6.41 ± 0.35	5.17 ± 0.29	5.72 ± 0.31	6.88 ± 0.37
Co	0.31 ± 0.03	0.35 ± 0.03	0.26 ± 0.02	0.29 ± 0.03	0.39 ± 0.04
Hg	0.021 ± 0.004	0.027 ± 0.005	0.016 ± 0.003	0.020 ± 0.004	0.031 ± 0.005

3.2. Heavy Metal Concentrations in Prawn Tissues

The prawn tissues also contained all ten investigated metals, although concentrations were generally lower than those observed in crabs Table 2. Iron ranged from 19.62 ± 1.02 mg/kg at Ntawogba Creek to 27.41 ± 1.39 mg/kg at Okujagu/Okuruama, while Zn ranged from 11.53 ± 0.49 to 15.82 ± 0.69 mg/kg. Manganese and copper ranged from 3.68 ± 0.21 to 5.02 ± 0.29 mg/kg and from 2.56 ± 0.14 to 3.67 ± 0.20 mg/kg, respectively. Lead concentrations ranged from 0.48 ± 0.04 to 0.71 ± 0.06 mg/kg, while Cd ranged from 0.09 ± 0.01 to 0.16 ± 0.02 mg/kg. Mercury remained the least concentrated metal, with values between 0.011 ± 0.002 and 0.022 ± 0.004 mg/kg. The highest concentrations occurred predominantly at Okujagu/Okuruama, whereas Ntawogba Creek recorded the lowest values for most metals, as shown in Table 2.

Table 2: Heavy metal concentrations in prawn tissues from the five selected creek systems

Heavy metal	Amadi Creek	Woji Creek	Ntawogba Creek	Elekahia Creek	Okujagu/Okuruama
Pb	0.56 ± 0.04	0.63 ± 0.05	0.48 ± 0.04	0.54 ± 0.04	0.71 ± 0.06
Cd	0.11 ± 0.01	0.14 ± 0.01	0.09 ± 0.01	0.12 ± 0.01	0.16 ± 0.02
Cr	0.28 ± 0.02	0.33 ± 0.03	0.24 ± 0.02	0.29 ± 0.02	0.38 ± 0.03
Ni	0.48 ± 0.04	0.54 ± 0.04	0.42 ± 0.03	0.46 ± 0.04	0.61 ± 0.05
Cu	2.87 ± 0.16	3.21 ± 0.17	2.56 ± 0.14	2.91 ± 0.15	3.67 ± 0.20
Zn	12.64 ± 0.56	14.28 ± 0.61	11.53 ± 0.49	13.17 ± 0.57	15.82 ± 0.69
Fe	21.74 ± 1.13	24.35 ± 1.26	19.62 ± 1.02	22.18 ± 1.17	27.41 ± 1.39
Mn	4.13 ± 0.24	4.61 ± 0.26	3.68 ± 0.21	4.25 ± 0.24	5.02 ± 0.29
Co	0.21 ± 0.02	0.24 ± 0.02	0.18 ± 0.02	0.20 ± 0.02	0.28 ± 0.03
Hg	0.014 ± 0.003	0.018 ± 0.003	0.011 ± 0.002	0.015 ± 0.003	0.022 ± 0.004

3.3. Comparative Heavy Metal Accumulation in Crabs and Prawns

Comparison of the overall mean concentrations revealed consistently greater accumulation of the investigated metals in crab tissues than in prawn tissues Table 3. Mean Pb concentration was 0.83 ± 0.12 mg/kg in crabs compared with 0.58 ± 0.09 mg/kg in prawns, while Cd concentrations were 0.19 ± 0.04 and 0.12 ± 0.03 mg/kg, respectively. Similarly, mean Cu and Zn concentrations were 4.41 ± 0.43 and 19.34 ± 1.92 mg/kg in crabs compared with 3.04 ± 0.39 and 13.49 ± 1.65 mg/kg in prawns. Iron also showed a marked difference, with mean concentrations of 33.72 ± 4.02 mg/kg in crabs and 23.06 ± 3.14 mg/kg in prawns. The crab-to-prawn concentration ratios ranged from 1.38 for Mn to 1.58 for Cd, indicating consistently higher accumulation in crab tissues, as shown in Table 3.

Table 3: Overall mean concentrations of heavy metals in crabs and prawns

Metal	Crab (mg/kg)	Prawn (mg/kg)	Crab/Prawn ratio
Pb	0.83 ± 0.12	0.58 ± 0.09	1.43
Cd	0.19 ± 0.04	0.12 ± 0.03	1.58
Cr	0.44 ± 0.06	0.30 ± 0.05	1.47
Ni	0.73 ± 0.08	0.50 ± 0.07	1.46
Cu	4.41 ± 0.43	3.04 ± 0.39	1.45
Zn	19.34 ± 1.92	13.49 ± 1.65	1.43
Fe	33.72 ± 4.02	23.06 ± 3.14	1.46
Mn	6.00 ± 0.64	4.34 ± 0.51	1.38
Co	0.32 ± 0.05	0.22 ± 0.04	1.45
Hg	0.023 ± 0.006	0.016 ± 0.004	1.44

3.4. Bioaccumulation Factors

Bioaccumulation factors exceeded unity for all ten metals in both organisms Table 4. In crabs, BAF values ranged from 1.38 for Fe to 2.43 for Zn, whereas prawn BAF values ranged from 1.12 for Fe to 1.82 for Zn. Zinc therefore recorded the highest BAF in both crabs and prawns, followed by Cd and Cu in crabs. The consistently greater BAF values observed in crabs indicate stronger accumulation relative to the corresponding environmental concentrations, as shown in Table 4.

Table 4: Bioaccumulation factors of heavy metals in crabs and prawns

Metal	Crab BAF	Prawn BAF
Pb	1.64	1.26
Cd	2.31	1.71
Cr	1.48	1.17
Ni	1.56	1.21
Cu	2.18	1.67
Zn	2.43	1.82
Fe	1.38	1.12
Mn	1.72	1.31
Co	1.47	1.16
Hg	1.91	1.43

3.5. Human Health Risk Assessment

The estimated daily intake and hazard quotient varied among the investigated metals and between adult and child consumers Table 5. For adult crab consumers, the highest EDI was recorded for Zn at 0.02763 mg/kg/day, followed by Cu at 0.00630 mg/kg/day, while Hg had the lowest value at 0.000033 mg/kg/day. The corresponding prawn EDI values were 0.01927, 0.00434 and 0.000023 mg/kg/day, respectively. Among the individual HQ values, Cd produced the highest estimates, with HQ values of 0.54 for adult crab consumers and 0.34 for adult prawn consumers. Child HQ values were higher, reaching 1.62 for Cd through crab consumption and 1.02 through prawn consumption. Pb and Ni also contributed appreciably to the estimated non-carcinogenic risk, as shown in Table 5.

Table 5: Estimated non-carcinogenic health risk associated with consumption of crab and prawn tissues

Metal	Crab EDI adult	Crab HQ adult	Prawn EDI adult	Prawn HQ adult	Crab HQ child	Prawn HQ child
Pb	0.00118	0.39	0.00083	0.28	1.17	0.83
Cd	0.00027	0.54	0.00017	0.34	1.62	1.02
Cr	0.00063	0.21	0.00043	0.14	0.63	0.43
Ni	0.00104	0.35	0.00071	0.24	1.04	0.71
Cu	0.00630	0.21	0.00434	0.14	0.63	0.43
Zn	0.02763	0.09	0.01927	0.06	0.27	0.19
Hg	0.000033	0.11	0.000023	0.08	0.33	0.23

3.6. Hazard Index for Crab and Prawn Consumption

The combined hazard index was 1.91 for adult consumption of crab and 1.28 for adult consumption of prawns Table 6. For children, the corresponding HI values increased to 5.69 for crabs and 3.84 for prawns. Thus, all four exposure scenarios produced HI values greater than unity, with crab consumption producing higher values than prawn consumption. The difference was particularly pronounced under the child exposure scenario, as shown in Table 6.

Table 6: Combined hazard index for consumers of crab and prawn tissues

Organism	Adult HI	Child HI	Interpretation
Crab	1.91	5.69	HI > 1
Prawn	1.28	3.84	HI > 1

3.7. Carcinogenic Risk

The estimated carcinogenic risks differed among the investigated metals and exposure groups Table 7. For adult crab consumers, the individual risks were 2.8×10^{-5} for Pb, 1.6×10^{-5} for Cd, 3.2×10^{-5} for Cr and 1.4×10^{-5} for Ni, giving a combined value of 9.0×10^{-5} . Adult prawn consumers had a combined carcinogenic risk of 6.2×10^{-5} . Under the child exposure scenario, the total risks increased to 2.70×10^{-4} for crab consumption and 1.86×10^{-4} for prawn consumption. Chromium and Pb contributed substantially to the calculated totals, as shown in Table 7.

Table 7: Estimated carcinogenic risk from consumption of crab and prawn tissues

Metal	Crab adult	Prawn adult	Crab child	Prawn child
Pb	2.8×10^{-5}	2.0×10^{-5}	8.4×10^{-5}	6.0×10^{-5}
Cd	1.6×10^{-5}	1.0×10^{-5}	4.8×10^{-5}	3.1×10^{-5}
Cr	3.2×10^{-5}	2.2×10^{-5}	9.6×10^{-5}	6.6×10^{-5}
Ni	1.4×10^{-5}	9.7×10^{-6}	4.2×10^{-5}	2.9×10^{-5}
Total	9.0×10^{-5}	6.2×10^{-5}	2.70×10^{-4}	1.86×10^{-4}

3.8. Ecological Risk Assessment

The contamination factors and ecological risk factors demonstrated considerable differences among the investigated metals Table 8. The highest contamination factor was recorded for Cd (1.61), followed by Pb (1.38) and Hg (1.29), while Fe had the lowest contamination factor of 0.84. When the toxic-response coefficients were incorporated, Hg produced an ecological risk factor of 51.60 and Cd produced 48.30. The calculated contributions to the potential ecological risk were therefore greatest for Hg and Cd, accounting for 61.4% and 57.5%, respectively, according to the values presented in Table 8.

Table 8: Contamination and ecological risk factors of heavy metals

Metal	CF	Toxic-response factor	Er	Contribution to PERI (%)
Pb	1.38	5	6.90	8.2
Cd	1.61	30	48.30	57.5
Cr	0.91	2	1.82	2.2
Ni	1.22	5	6.10	7.3
Cu	1.17	5	5.85	7.0
Zn	1.03	1	1.03	1.2
Fe	0.84	1	0.84	1.0
Mn	0.96	1	0.96	1.1
Co	0.88	5	4.40	5.2
Hg	1.29	40	51.60	61.4

3.9. Potential Ecological Risk Index across the Five Creek Systems

The PERI values varied among the five sampling locations Table 9. Okujagu/Okuruama recorded the highest PERI of 146.3, followed by Woji Creek with 132.9. Amadi Creek and Elekahia Creek recorded PERI values of 113.0 and 109.3, respectively, whereas Ntawogba Creek recorded the lowest value of 96.9. Across the individual ecological risk components, Hg and Cd accounted for substantial portions of the PERI at each location. The spatial distribution of PERI therefore indicates differences in the potential ecological pressure associated with heavy-metal contamination among the investigated creek systems, as shown in Table 9.

Table 9: Potential ecological risk index across the selected creek systems

Creek	Pb Er	Cd Er	Cr Er	Ni Er	Cu Er	Zn Er	Fe Er	Mn Er	Co Er	Hg Er	PERI
Amadi Creek	6.2	42.1	1.7	5.6	5.4	1.0	0.8	0.9	4.1	45.2	113.0
Woji Creek	7.1	50.3	2.0	6.4	6.1	1.1	0.9	1.0	4.6	53.4	132.9
Ntawogba Creek	5.4	35.8	1.5	5.1	4.8	0.9	0.7	0.8	3.8	38.1	96.9
Elekahia Creek	6.0	40.6	1.6	5.5	5.2	1.0	0.8	0.9	4.0	43.7	109.3
Okujagu/Okuruama	7.8	54.6	2.2	6.9	6.7	1.2	1.0	1.1	5.0	59.8	146.3

4. Discussion

The present study demonstrated that crabs and prawns collected from the five investigated Trans-Amadi creek systems contained measurable concentrations of all ten assessed metals. The concentrations varied among locations and between the two organisms, indicating that metal accumulation was influenced by both spatial and biological factors. The occurrence of multiple metals in aquatic organisms from an urban-industrial environment is consistent with previous investigations within the Niger Delta, where heavy metals have been reported in surface waters, sediments, fish and other aquatic resources [1, 2, 4–6]. The present findings therefore reinforce the importance of considering aquatic organisms as an important component of environmental monitoring programmes.

A notable feature of the results was the predominance of Fe and Zn in both crab and prawn tissues. In crabs, Fe ranged from 28.74 to 39.17 mg/kg, while Zn ranged from 16.85 to 22.14 mg/kg. The corresponding ranges in prawns were 19.62–27.41 mg/kg for Fe and 11.53–15.82 mg/kg for Zn. The relatively high concentrations of these elements may partly reflect their greater environmental abundance and their physiological roles in aquatic organisms. However, their occurrence at measurable concentrations should still be interpreted within the context of environmental exposure because essential elements can also become problematic when accumulation is excessive. Similar emphasis on the occurrence and ecological significance of multiple heavy metals has been reported in Niger Delta sediment and aquatic-environment investigations [1, 11].

The concentrations of Pb, Cd, Cr, Ni, Cu, Co and Hg were comparatively lower than those of Fe and Zn, but their presence remains environmentally significant. Of particular interest were Cd, Pb and Hg because of their toxicological importance. Previous studies in the Niger Delta have identified these metals among contaminants of concern in aquatic environments and biological tissues [2, 8, 10]. The detection of Pb and Cd in both crabs and prawns in the present investigation suggests that the creek systems are receiving or retaining sources of potentially toxic metals that can become incorporated into aquatic food webs.

The spatial distribution of metals showed a consistent pattern in which Okujagu/Okuruama generally recorded the highest tissue concentrations, whereas Ntawogba Creek tended to have the lowest values. For example, crab Fe increased from 28.74 mg/kg at Ntawogba Creek to 39.17 mg/kg at Okujagu/Okuruama, while Zn increased from 16.85 to 22.14 mg/kg. A similar spatial pattern occurred in prawns, with Fe increasing from 19.62 to 27.41 mg/kg and Zn from 11.53 to 15.82 mg/kg. This spatial variability suggests that metal exposure was not uniform across the creek network. Such heterogeneity is consistent with the broader understanding that contaminant distributions in Niger Delta aquatic systems are affected by local environmental and anthropogenic conditions [1, 3, 15].

The relatively elevated concentrations observed at Okujagu/Okuruama may reflect greater contaminant loading, differences in sediment interaction, hydrodynamic conditions or the intensity of nearby anthropogenic activities. However, the present study did not directly quantify individual contaminant sources; therefore, the spatial pattern should be interpreted as an indication of differential exposure rather than proof of a specific pollution source. This interpretation is consistent with the need for integrated environmental investigations that consider hydrological and sedimentary controls when assessing aquatic contamination [15].

The consistently higher concentrations observed in crabs compared with prawns constitute one of the major findings of the study. Mean concentrations of Pb, Cd, Cr, Ni, Cu, Zn, Fe, Mn, Co and Hg were all higher in crabs, with crab-to-prawn ratios ranging from 1.38 for Mn to 1.58 for Cd. The difference was particularly apparent for Cd, where the mean crab concentration was 0.19 mg/kg compared with 0.12 mg/kg in prawns. Similar organism-dependent differences in metal accumulation have been recognised in studies of aquatic organisms, including edible crabs and fish from Niger Delta environments [2, 9, 10, 12].

The greater accumulation observed in crabs may be associated with differences in feeding behaviour, habitat utilisation and contact with contaminated environmental matrices. Crabs can maintain close contact with bottom sediments and particulate materials, potentially increasing their opportunity for exposure to sediment-associated metals. Prawns may also accumulate metals, but their patterns of environmental interaction and physiological regulation may differ. The present results therefore suggest that the two crustacean groups should not necessarily be treated as interchangeable bioindicators of metal contamination.

The bioaccumulation-factor results provide further evidence of this species-related difference. All ten metals had BAF values greater than unity in both organisms, indicating that the organisms accumulated metals at concentrations exceeding the corresponding environmental concentrations used in the calculation. In crabs, BAF values ranged from 1.38 for Fe to 2.43 for Zn, whereas prawn values ranged from 1.12 to 1.82. Zinc therefore had the highest BAF in both organisms, while Cd and Cu also showed relatively high accumulation in crabs. These results agree with the broader observation from Niger Delta studies that aquatic organisms can act as effective repositories of potentially toxic elements [2, 6, 9].

The relatively high BAF for Zn should nevertheless be interpreted differently from that of toxic metals such as Cd, Pb and Hg because Zn is an essential element. High accumulation of an essential metal does not automatically imply equivalent toxicological significance. Conversely, the lower concentration of a toxic metal does not necessarily indicate negligible concern. The ecological-risk analysis in this study illustrates this distinction clearly because Cd and Hg contributed substantially to ecological risk despite their lower tissue concentrations compared with Fe and Zn.

The human-health risk assessment showed that dietary exposure to the investigated metals was more pronounced under the child-consumer scenario than under the adult scenario. For adults, the calculated HI was 1.91 for crab consumption and 1.28 for prawn consumption, while the corresponding values for children were 5.69 and 3.84. Since the study used an HI greater than unity as an indication of potential non-carcinogenic concern, these results indicate that the combined exposure scenario warrants attention, particularly for children. The higher values in children are consistent with the influence of body weight and exposure assumptions on estimated dietary risk. Similar incorporation of child and adult exposure scenarios has been applied in recent assessments of contaminated water and aquatic food resources in Nigeria [6, 13, 16].

Among the individual metals, Cd produced the highest HQ values in both organisms. The adult crab and prawn HQ values for Cd were 0.54 and 0.34, respectively, whereas the corresponding child values were 1.62 and 1.02. Pb and Ni also contributed appreciably to the overall non-carcinogenic risk. This pattern is important because the overall risk was not simply determined by the metals with the highest concentrations. Rather, it reflected the interaction between tissue concentration, exposure assumptions and the toxicological reference dose. This principle is also relevant to previous Niger Delta studies in which heavy-metal contamination was evaluated using health-risk indices rather than concentration alone [8–10].

The carcinogenic-risk estimates followed a similar pattern, with higher calculated values associated with children and with crab

consumption. The combined carcinogenic risk was reported as 9.0×10^{-5} for adult crab consumers and 6.2×10^{-5} for adult prawn consumers, increasing to 2.70×10^{-4} and 1.86×10^{-4} , respectively, under the child exposure scenario. Pb and Cr made substantial contributions to the calculated totals. These findings should be interpreted as modelled exposure estimates rather than direct evidence of cancer occurrence in the exposed population. Nevertheless, the results provide useful information for identifying exposure pathways that may require closer monitoring, particularly where seafood consumption is frequent.

The ecological-risk assessment further demonstrated that concentration alone did not determine the overall ecological significance of contamination. Cd had a contamination factor of 1.61, while Hg had a contamination factor of 1.29; however, their high toxic-response coefficients resulted in ecological risk factors of 48.30 and 51.60, respectively. Thus, Hg and Cd made the largest contributions to the calculated potential ecological risk. This observation is consistent with established ecological-risk assessment approaches in which metals are weighted according to their relative toxicological significance [1, 11].

Spatial differences in PERI provided additional evidence of heterogeneous ecological pressure across the creek systems. Okujagu/Okuruama had the highest PERI of 146.3, followed by Woji Creek at 132.9, whereas Ntawogba Creek recorded the lowest value of 96.9. The same general spatial pattern was observed in the organism-tissue concentrations. This correspondence strengthens the interpretation that the ecological-risk estimates reflect real spatial differences in the degree of metal contamination represented by the investigated samples. Similar spatial approaches have been used in assessments of heavy-metal contamination and ecological risk in Niger Delta rivers and sediments [1, 11, 15].

The results also have implications for the interpretation of seafood safety in Trans-Amadi. Crabs and prawns are not merely environmental indicators; they are potential dietary exposure pathways where they are harvested and consumed. Previous research on seafood from Rivers State has similarly emphasised the importance of determining both essential and toxic metals and evaluating their implications for human health [14]. The present study extends this concern to creek-associated crustaceans and demonstrates that differences between species can materially influence the estimated exposure.

5. Conclusion

This study demonstrates that crabs and prawns from the investigated creek systems within the Trans-Amadi area accumulated measurable concentrations of the ten assessed heavy metals. Crabs generally contained higher metal concentrations than prawns, indicating differences in metal uptake and retention between the two organisms. Iron and zinc were the most abundant metals in the tissues, whereas mercury and cadmium occurred at comparatively lower concentrations.

The spatial variation in metal concentrations also showed that contamination was not uniform across the sampling locations. Okujagu/Okuruama and Woji Creek generally recorded higher concentrations, while Ntawogba Creek recorded comparatively lower levels. The bioaccumulation factors greater than unity for all investigated metals further indicate that both organisms were capable of accumulating metals from their surrounding environment.

The health-risk assessment showed that the combined hazard indices exceeded unity for both adult and child consumers, with higher values observed among children. The carcinogenic-risk estimates were also higher for children and for crab consumption. From the ecological assessment, cadmium and mercury made substantial contributions to the potential ecological risk, while the highest overall PERI was recorded at Okujagu/Okuruama.

These findings highlight the importance of continued monitoring of heavy-metal contamination in the Trans-Amadi creek system and in commonly consumed aquatic organisms. Regular assessment of water, sediment and biota, together with appropriate control of anthropogenic discharges, would help to reduce potential risks to aquatic ecosystems and communities that depend on these resources for food.

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