OPEN ACCESS

Orapuh Journal

ORIGINAL ARTICLE

Journal of Oral & Public Health

Human Health Risk Assessment of Trace Metals in *Pseudotolithus senegalensis* and *Penaeus notialis* From Moanda, DRC

Waku, M. A.[1,2], Kasogo, B. P.[1,3], Maria, N. T.[1,2,5], Kusonika, N. A.[1,2], Gizanga, V. R.[1,2], Ngwanza, M. M.[4], & Biey, M. E.[1,3]

[1]*Laboratory of Ecotoxicology and Ecosystem Health, Department of Environmental Sciences and Management, Faculty of Science and Technology, University of Kinshasa (UNIKIN), Kinshasa, Democratic Republic of the Congo* [2]*Department of Environmental Sciences and Management, Faculty of Science and Technology, University of Kinshasa (UNIKIN), Kinshasa, Democratic Republic of the Congo* [3]*Laboratory of Microbiology and Environmental Biotechnology, Department of Environmental Sciences and Management, Faculty of Science and Technology, University of Kinshasa (UNIKIN), Kinshasa, Democratic Republic of the Congo* [4]*Chemistry Laboratory, SOCIR S.A. (Société Congolaise des Industries de Raffinage), Moanda, Democratic Republic of the Congo* [5]*Chemical, Biological, Radiological and Nuclear Centre of Excellence (CoE-CBRN/DRC), Kinshasa, Democratic Republic of the Congo*

ARTICLE INFO

Received: *06 June 2026*
Accepted: *07 August 2026*
Published: *21 November 2026*

Keywords:
Trace metals, human health risk, *Pseudotolithus senegalensis*, *Penaeus notialis*, estimated daily intake, hazard quotient, Moanda, Democratic Republic of the Congo

Peer-Review: *Externally peer-reviewed*

© 2026 The Authors.

Re-use permitted under CC BY-NC 4.0
No commercial re-use or duplication.

Correspondence to:
Aristote WAKU MALONDA
aristote.waku@unikin.ac.cd

To cite:
Waku, M. A., Kasogo, B. P., Maria, N. T., Kusonika, N. A., Gizanga, V. R., Ngwanza, M. M., & Biey, M. E. (2026). Human health risk assessment of trace metals in *Pseudotolithus senegalensis* and *Penaeus notialis* from Moanda, DRC. *Orapuh Journal, 7*(11), e1505. https://doi.org/10.4314/orapj.v7i11.105

ISSN: *2644-3740*

Published by ***Orapuh, Inc.***, F. Gaye Res., Sukuta-Jamisa, Greater Banjul, The Gambia.

Editor-in-Chief: *Prof. V. E. Adamu (editor@orapuh.org)*

ABSTRACT

Introduction
The Atlantic coast of Moanda, Democratic Republic of the Congo, supports important artisanal fisheries that provide a major source of food and income for local communities. However, trace metal contamination in coastal waters and seafood may represent a potential environmental and public health concern.

Purpose
This study aimed to assess trace metal concentrations in coastal water, *Pseudotolithus senegalensis*, and *Penaeus notialis* from the Banana and Mangrove fishing areas of Moanda and evaluate the potential non-carcinogenic health risks associated with water ingestion and seafood consumption.

Methods
A cross-sectional survey involving 150 participants, including 47 artisanal fishermen and 103 seafood consumers, was conducted using Kobo Collect. Environmental and biological sampling comprised eight water samples, four individual fish specimens, and four composite shrimp samples. Trace metal concentrations (Cd, Pb, As, Hg, Ni, Cr, Cu, Zn, and Sb) were determined using energy-dispersive X-ray fluorescence (ED-XRF). Statistical analyses included descriptive statistics and one-way analysis of variance (ANOVA) for comparisons of water samples between the two fishing areas. Health risk indicators included estimated daily intake (EDI), hazard quotient (HQ), contamination factor (CF), and organism-to-water concentration ratios.

Results
The survey identified *P. senegalensis* (44.68%) and *P. notialis* (29.79%) as the most frequently consumed aquatic species. No statistically significant differences in water trace metal concentrations were observed between the Banana and Mangrove areas ($p > 0.05$). Arsenic and mercury were detected in water but not in the analyzed organisms. Shrimp generally presented higher concentrations of cadmium, lead, zinc, and antimony than fish, whereas fish showed higher nickel and copper concentrations in some comparisons. EDI values were generally higher in children than in adults. HQ values exceeded 1 for several metals, particularly cadmium, lead, mercury, and antimony through water ingestion, and antimony and cadmium through seafood consumption.

Conclusion
The findings indicate potential non-carcinogenic health concerns associated with trace metal exposure through coastal water and seafood consumption in Moanda. Strengthened environmental monitoring, regular seafood quality assessment, and public health awareness initiatives are recommended to protect aquatic resources and vulnerable populations.

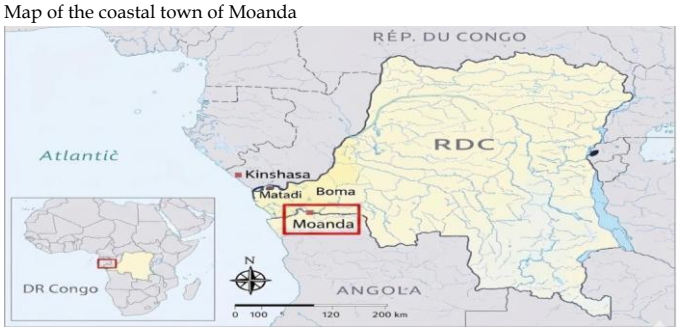
INTRODUCTION

Coastal areas are strategic environments characterized by a high concentration of human activities, including industrial development, fisheries, maritime transport, trade, and tourism. The increasing intensity of these activities exerts considerable anthropogenic pressure on coastal ecosystems, resulting in significant environmental degradation and growing public health concerns (UNEP, 2006). As transitional zones between terrestrial and marine ecosystems, coastal environments are highly productive and ecologically valuable but remain particularly vulnerable to physical, chemical, and biological pollution (Clark, 2001).

Coastal pollution originates from both marine- and land-based sources. However, numerous studies have shown that land-based activities, including industrial effluents, agricultural runoff, domestic wastewater, and riverine discharges, constitute the principal sources of contamination affecting coastal ecosystems (Islam & Tanaka, 2004; UNEP/GPA, 2006). These inputs introduce a wide range of contaminants, particularly trace metals (TMs), hydrocarbons, and persistent organic pollutants, which may accumulate in aquatic environments and living organisms. Fish and crustaceans are recognized as effective bioindicators because of their capacity to accumulate contaminants in their tissues, thereby reflecting the quality of their surrounding environment (Storelli et al., 2005). Consequently, the bioaccumulation and trophic transfer of trace metals may increase human exposure through the regular consumption of contaminated seafood (Burger & Gochfeld, 2005).

The Moanda region **(Map 1)**, located on the Atlantic coast of the Democratic Republic of the Congo, is characterized by intensive petroleum activities and a strong dependence of local communities on fisheries for food and livelihoods. These conditions increase the likelihood of chemical contamination of coastal waters through industrial discharges, urban runoff, and other anthropogenic activities. Despite the importance of seafood in the local diet, limited information is available on trace metal contamination and the associated health risks for consumers in the Democratic Republic of the Congo. Therefore, this study aimed to assess the potential non-carcinogenic human health risks associated with the consumption of *Pseudotolithus senegalensis* and *Penaeus notialis* from the Atlantic coast of Moanda, Democratic Republic of the Congo. Specifically, the study sought to determine trace metal concentrations in water and edible aquatic organisms, characterize differences in metal concentrations between the Banana and Mangrove fishing areas and between the two species, and estimate dietary exposure and potential non-carcinogenic health risks through the calculation of estimated daily intake (EDI) and hazard quotients (HQ). Organism-to-water concentration ratios were also examined to provide complementary information on the distribution of trace metals between the aquatic organisms and their surrounding environment.

Map 1:
Map of the coastal town of Moanda



METHODS

The study focused on two aquatic species, *Pseudotolithus senegalensis* and *Penaeus notialis*, selected because they are among the most frequently consumed seafood species by local populations in Moanda. Biological samples were obtained directly from artisanal fishermen immediately after landing. The sampling design comprised 16 environmental and biological samples, including eight water samples (four collected from the Banana fishing area and four from the Mangrove fishing area), four *Pseudotolithus senegalensis* specimens (two collected from each fishing area), and four composite samples of *Penaeus notialis* (two collected from each fishing area), with each composite sample consisting of approximately 20 individuals.

The study was conducted in two fishing areas along the Atlantic coast of Moanda **(Map 2)**: Zone A, corresponding to the Banana coastal area (Atlantic Ocean), and Zone B, corresponding to the Mangrove area located at the mouth of the Congo River.

https://doi.org/10.4314/orapj.v7i11.105

A non-probabilistic purposive sampling approach combined with convenience sampling was adopted because no reliable sampling frame was available for fishermen and seafood consumers. Participants were therefore selected according to their presence at the fishing sites, their availability, and their willingness to participate in the survey. A total of 150 respondents, including 47 fishermen and 103 consumers, were interviewed using a structured questionnaire administered through Kobo Collect. The survey collected information on seafood consumption habits, preservation methods, and perceptions of water and fish quality.

The analyses focused on the following trace metals: Cd, Pb, As, Hg, Ni, Cr, Cu, Zn, and Sb.

Map 2:
Map of fishing areas in Moanda [replace figure with verified Moanda Zone A and Zone B map].

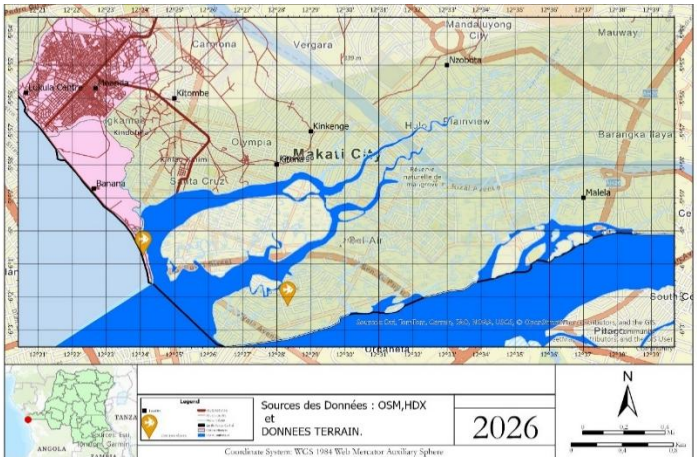


Table 1:
Distribution of environmental and biological samples collected during the study

Sample type	Fishing area	Number of biological/ environmental samples	Analytical replicates	Sample description
Water	Banana	4	4	Environmental water samples collected at the monitoring points
Water	Mangrove	4	4	Environmental water samples collected at the monitoring points
Pseudotolithus senegalensis	Banana	2 specimens	4	Individual fish analyzed separately
Pseudotolithus senegalensis	Mangrove	2 specimens	4	Individual fish analyzed separately
Penaeus notialis	Banana	2 composite samples	4	Each composite sample consisted of approximately 20 shrimp
Penaeus notialis	Mangrove	2 composite samples	4	Each composite sample consisted of approximately 20 shrimp

Total environmental and biological samples = 16. *Note*: Four analytical determinations were performed for each collected sample. These determinations represent technical replicates and do not constitute additional independent environmental or biological samples.

After field collection, water and biological samples were stored under appropriate conditions and transported in insulated coolers to the respective laboratories for analysis. Laboratory analyses were carried out at the laboratory of the Societe Congolaise des Industries de Raffinage (SOCIR S.A.), the Soil Science Laboratory of the University of Kinshasa, and the Central Analysis Laboratory of the CGEA/CREN-K. A representative 5.00 g subsample was then prepared from each biological sample for trace metal analysis.

Laboratory Analysis

Prior to elemental analysis, fish and shrimp samples were thoroughly rinsed with distilled water, oven-dried at 105 deg C for 24 h, and subsequently calcined in a muffle furnace at 500-550 deg C for 24-48 h to obtain mineral ash. Trace metal concentrations (Cd, Pb, As, Hg, Ni, Cr, Cu, Zn, and Sb) were determined using an energy-dispersive X-ray fluorescence spectrometer (ED-XRF XEPOS III; SPECTRO Analytical Instruments, Germany). This analytical technique is based on the detection of characteristic X-ray fluorescence emitted by chemical elements following excitation with an X-ray beam. The measured concentrations were expressed on an ash-weight basis (mg/kg ash).

The analytical procedures followed the routine quality assurance and quality control (QA/QC) protocols of the participating laboratories. However, detailed information regarding the limits of detection (LOD), limits of quantification (LOQ), certified reference materials (CRM), and analytical recovery rates was not available because the analyses were performed as part of routine laboratory services. This limitation should be considered when interpreting the analytical results.

Statistical Analysis

Statistical analyses were performed using R software (version 4.3). Trace metal concentrations were summarized using descriptive statistics (mean +- standard deviation) and presented in tables and figures. For water samples, separate one-way analyses of variance (ANOVAs) were conducted to compare trace metal concentrations between the Banana and Mangrove fishing areas, using the four independent environmental samples recorded for each area. Statistical significance was set at $p < 0.05$. For fish and shrimp, concentrations were summarized descriptively because the available analytical data did not allow the laboratory determinations to be assigned to the individual biological samples. Therefore, no biological-sample-level ANOVA was performed for the aquatic organisms.

Health Risk Assessment

Human exposure and potential health risks associated with water ingestion and seafood consumption were assessed using the estimated daily intake (EDI), hazard quotient (HQ), contamination factor (CF), and organism-to-water concentration ratio. For fish and shrimp, trace metal concentrations measured on an ash-weight basis were converted to a fresh-weight basis before the calculation of exposure and contamination indicators. The assessment followed the methodological approaches and reference values adopted from the World Health Organization (WHO), the Food and Agriculture Organization (FAO), and the United States Environmental Protection Agency (U.S. EPA).

Before calculating the exposure and contamination indicators for fish and shrimp, trace metal concentrations measured on an ash-weight basis were converted to a fresh-weight basis using the following equation:

$$C_{fresh} = C_{ash} \times (m_{ash} / m_{initial})$$

where C_{fresh} is the trace metal concentration expressed on a fresh-weight basis (mg/kg FW), C_ash is the concentration measured on an ash-weight basis (mg/kg ash), m_ash is the mass of ash obtained after calcination, and $m_{initial}$ is the initial mass of the biological sample (5.00 g). This conversion was performed separately for each analytical replicate before calculating the mean concentrations used in subsequent assessments.

The estimated daily intake (EDI) was calculated using the following equation:

$$EDI = (C \times Q \times F) / P$$

where C is the trace metal concentration in water (mg/L) or seafood (mg/kg fresh weight), Q is the daily ingestion rate (L/day for water or kg/day for seafood), F is the exposure frequency factor, and P is the average body weight (kg). Body weights of 28 kg for children and 70 kg for adults were used. Daily fish and shrimp ingestion rates were set at 0.031 kg/day for children and 0.062 kg/day for adults, while daily water ingestion rates were 1.7 L/day and 2.5 L/day, respectively. The seafood ingestion rates used in this study were adopted as study-specific exposure assumptions. Exposure frequency factors of 3 for children and 2 for adults were adopted as local study assumptions, based on the local exposure context, the studies consulted, and the professional judgement of ecotoxicology researchers at the University of Kinshasa. These factors are study-specific assumptions and are not presented as universal international constants.

The non-carcinogenic health risk was assessed using the hazard quotient (HQ):

$$HQ = EDI / RfD$$

where RfD is the oral reference dose for each trace metal, expressed in mg/kg body weight/day. The hazard quotient (HQ) is a dimensionless indicator used to assess potential non-carcinogenic health risks. An HQ value below 1 indicates that the estimated exposure is below the reference dose, whereas an HQ value equal to or greater than 1 suggests a potential non-carcinogenic health concern.

The contamination factor (CF) was calculated using the following equation:

$$CF = C_{sample} / C_{reference}$$

where C_{sample} is the measured trace metal concentration in the sample and $C_{reference}$ is the corresponding reference or guideline value. Comparisons were performed separately for each sample matrix using compatible concentration units and mass bases. Water concentrations were expressed in mg/L, whereas fish and shrimp concentrations were expressed on a fresh-weight basis (mg/kg FW). The

reference values used for the contamination factor calculations were obtained from the World Health Organization guidelines for food contaminants and drinking-water quality (WHO, 2022), according to the sample matrix.

The organism-to-water concentration ratio was calculated using the following equation:

Organism-to-water concentration ratio = $C_{organism}$, FW / C_{water}

where $C_{organism}$, FW is the trace metal concentration in fish or shrimp expressed on a fresh-weight basis (mg/kg FW), and C_{water} is the corresponding concentration in water (mg/L). The resulting ratio is expressed in L/kg. This ratio was used to compare trace metal concentrations in aquatic organisms with those measured in the surrounding water and was not interpreted as a direct measure of bioconcentration.

Ethical Considerations

This study was conducted within the framework of a Master's research project at the University of Kinshasa. Prior to the commencement of fieldwork, an official research authorization was issued by the University of Kinshasa in 2024. Before the field survey began in 2025, the Territorial Administrator of Moanda officially acknowledged receipt of the research authorization and authorized the field activities within the study area.

Because part of the Mangrove fishing area is located within the private concession of SOCIR S.A., permission to access the site and to conduct part of the laboratory analyses was formally requested and granted by the company. In addition, the local management authority of Mangrove acknowledged receipt of the research request and authorized the implementation of the study. Before each interview, the objectives of the study were clearly explained to all participants. Only individuals who were available at the time of the survey and who voluntarily agreed to participate were included in the study, in accordance with the convenience sampling approach adopted. Verbal informed consent was obtained from all participants prior to data collection, and the anonymity and confidentiality of the information collected were strictly respected. The fish (*Pseudotolithus senegalensis*) and shrimp (*Penaeus notialis*) analyzed in this study were purchased directly from artisanal fishermen after capture during their routine commercial fishing activities. No animals were captured, handled, or euthanized specifically for research purposes.

RESULTS

Seafood Consumption Survey

A questionnaire survey was conducted among 150 respondents, including 47 artisanal fishermen and 103 seafood consumers. While some questions were addressed to all respondents (n = 150), others specifically concerned fishing activities and fishery resources and were therefore answered only by artisanal fishermen (n = 47). The following results summarize the most relevant findings related to seafood consumption and fishery resources.

Seafood Consumption Patterns Among the Surveyed Population (n = 150)

Table 2:
Seafood consumption characteristics among the surveyed population (n = 150)

Variable	Category	n	%
Main source of seafood	Local fishermen	66	44.00
	Local market	44	29.33
	Fish retailers	40	26.67
	Total	**150**	**100.00**
Most frequently consumed form	Fresh	94	62.67
	Smoked	28	18.67
	Dried/Salted	28	18.67
	Total	**150**	**100.00**
Origin of consumed seafood	Local fisheries	109	72.67
	Other cities	41	27.33
	Total	**150**	**100.00**

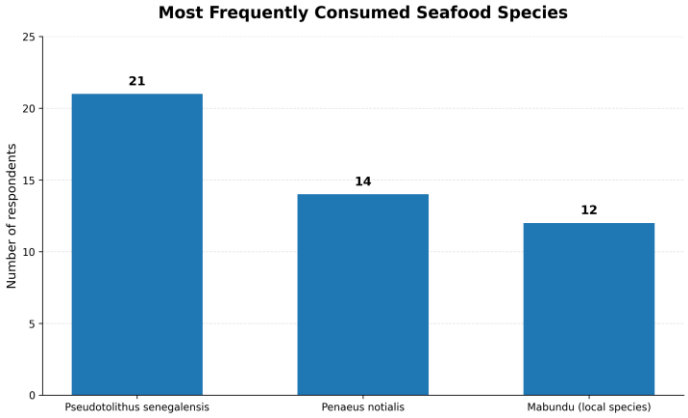
Table 2 summarizes the seafood consumption characteristics of the surveyed population. Most respondents obtained seafood directly from artisanal fishermen (44.00%), followed by local markets (29.33%) and fish retailers (26.67%). Fresh seafood was the most frequently consumed form (62.67%), whereas smoked and dried/salted products each represented 18.67% of consumption. Furthermore, most respondents (72.67%) reported that the seafood they consumed originated from local fisheries in Moanda, highlighting the dependence of local communities on fishery resources from the study area and supporting the relevance of assessing potential health risks associated with trace metal contamination.

Most Frequently Consumed Seafood Species Among Artisanal Fishermen (n = 47)

The following results are based exclusively on responses provided by the 47 artisanal fishermen, as these questions specifically addressed fishing activities and fishery resources.

Figure 1 shows the seafood species most frequently consumed according to the surveyed artisanal fishermen. *Pseudotolithus senegalensis* was identified as the most frequently consumed species (44.68%), followed by *Penaeus notialis* (29.79%) and *Mabundu* (25.53%). These findings justify the selection of *Pseudotolithus senegalensis* and *Penaeus notialis* for trace metal analysis and health risk assessment because they represent the main seafood species consumed by the local population.

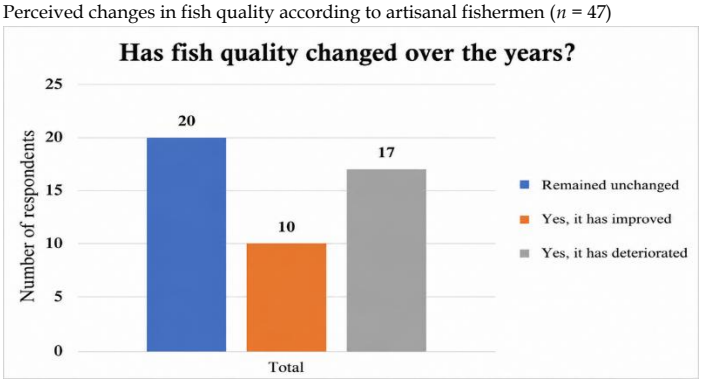
Figure 1:
Most frequently consumed seafood species reported by artisanal fishermen (*n* = 47)



Perceived Changes in Fish Quality Among Artisanal Fishermen (n = 47)

Figure 2 illustrates artisanal fishermen's perceptions of changes in fish quality over recent years. Most respondents (42.55%) considered that fish quality had remained unchanged, whereas 36.17% perceived a deterioration and 21.28% reported an improvement. These findings provide useful contextual information on local perceptions of fishery resources and complement the analytical assessment of trace metal contamination and the associated health risks presented in the subsequent sections.

Figure 2:
Perceived changes in fish quality according to artisanal fishermen (*n* = 47)



Trace Metal Concentrations in Water and Aquatic Organisms

Trace Metal Concentrations in Water, *Pseudotolithus senegalensis*, and *Penaeus notialis.*

Table 3:
Mean concentrations (+- *SD*) of trace metals in water and aquatic organisms collected from the Banana (Zone A) and Mangrove (Zone B) fishing areas

No.	Element	Zone A / Banana: Water (mg/L)	Zone A / Banana: *P. senegalensis* (mg/kg FW)	Zone A / Banana: *P. notialis* (mg/kg FW)	Zone B / Mangroves: Water (mg/L)	Zone B / Mangroves: *P. senegalensis* (mg/kg FW)	Zone B / Mangroves: *P. notialis* (mg/kg FW)	RfD, FAO 2018 (mg/kg bw/day)
1	Cadmium	0.2995 +- 0.060913	0.038145 +- 0.0076119	0.58083 +- 0.095986	0.24375 +- 0.041884	0.079175 +- 0.01363	0.64062 +- 0.10406	0.001
2	Lead	0.0703 +- 0.012499	0.021935 +- 0.0032041	0.27254 +- 0.018113	0.0795 +- 0.0079373	0.01407 +- 0.0057313	0.21788 +- 0.035065	0.0035
3	Arsenic	0.00381 +- 0.0026391	ND	ND	0.19234 +- 0.37911	ND	ND	0.0003
4	Mercury	0.00875 +- 0.0040311	ND	ND	0.0085 +- 0.0036968	ND	ND	0.0003
5	Nickel	0.0006375 +- 0.00015903	0.08423 +- 0.0078304	0.3722 +- 0.012815	0.000505 +- 0.00015927	0.2802 +- 0.027272	0.29069 +- 0.01953	0.02
6	Chromium	0.00026275 +- 0.000074213	0.001521 +- 0.00090868	0.0088465 +- 0.0021686	0.00026325 +- 0.000061878	0.001128 +- 0.00044028	0.0042135 +- 0.00084647	0.003
7	Copper	0.00042725 +- 0.000518	0.12515 +- 0.0090339	0.53753 +- 0.045872	0.00095 +- 0.00028868	0.6128 +- 0.029078	0.41717 +- 0.046878	0.04
8	Zinc	0.00041925 +- 0.00027252	1.5333 +- 0.081969	3.317 +- 0.33835	0.00064 +- 0.00048049	0.85769 +- 0.041671	2.7058 +- 0.36323	0.30
9	Antimony	0.20742 +- 0.043148	0.5327 +- 0.020829	3.2255 +- 0.27957	0.13828 +- 0.086173	0.37293 +- 0.015478	2.6784 +- 0.34283	0.0004

Abbreviations: RfD, reference dose; *SD*, standard deviation; ND, not detected; FW, fresh weight; *P. senegalensis*, *Pseudotolithus senegalensis*; *P. notialis*, *Penaeus notialis*.

Table 3 presents the mean concentrations (+- *SD*) of trace metals measured in water and in the tissues of *Pseudotolithus senegalensis* and *Penaeus notialis* collected from the Banana (Zone A) and Mangrove (Zone B) fishing areas. Concentrations in fish and shrimp are expressed on a fresh-weight basis. The results show differences in trace metal concentrations between sampling areas and biological matrices. Shrimp generally exhibited higher concentrations of cadmium (Cd), lead (Pb), nickel (Ni), chromium (Cr), zinc (Zn), and antimony (Sb) than fish,

whereas copper (Cu) concentrations were higher in fish from the Mangrove area than in shrimp from the Mangrove area, and higher in shrimp from the Banana area than in fish from the Banana area. Arsenic (As) and mercury (Hg) were detected in water samples but were not detected (ND) in the analyzed aquatic organisms. These findings provide the basis for the subsequent assessment of estimated daily intake and potential human health risks.

Table 4:
Estimated daily intake (EDI) of trace metals for children and adults through water and seafood consumption (mg/kg body weight/day)

No.	Metal	Banana (Zone A): Water Child	Banana (Zone A): Water Adult	Banana (Zone A): *P. senegalensis* Child	Banana (Zone A): *P. senegalensis* Adult	Banana (Zone A): *P. notialis* Child	Banana (Zone A): *P. notialis* Adult	Mangrove (Zone B): Water Child	Mangrove (Zone B): Water Adult	Mangrove (Zone B): *P. senegalensis* Child	Mangrove (Zone B): *P. senegalensis* Adult	Mangrove (Zone B): *P. notialis* Child	Mangrove (Zone B): *P. notialis* Adult
1	Cadmium	0.054552	0.021393	0.0001267	0.000067571	0.0019292	0.0010289	0.044397	0.017411	0.00026297	0.00014025	0.0021278	0.0011348
2	Lead	0.012805	0.0050214	0.000072856	0.000038856	0.00090521	0.00048278	0.01448	0.0056786	0.000046733	0.000024924	0.00072366	0.00038595
3	Arsenic	0.00069396	0.00027214	ND	ND	ND	ND	0.035032	0.013738	ND	ND	ND	ND
4	Mercury	0.0015937	0.000625	ND	ND	ND	ND	0.0015482	0.00060714	ND	ND	ND	ND
5	Nickel	0.00011612	0.000045536	0.00027976	0.00014921	0.0012362	0.00065933	0.000091982	0.000036071	0.00093066	0.00049635	0.00096552	0.00051495
6	Chromium	0.000047858	0.000018768	0.0000050519	0.0000026943	0.000029383	0.000015671	0.000047949	0.000018804	0.0000037466	0.0000019982	0.000013995	0.0000074639
7	Copper	0.000077821	0.000030518	0.00041568	0.00022169	0.0017854	0.00095219	0.00017304	0.000067857	0.0020354	0.0010855	0.0013856	0.00073898
8	Zinc	0.000076363	0.000029946	0.0050928	0.0027161	0.011017	0.0058758	0.00011657	0.000045714	0.0028487	0.0015193	0.008987	0.0047931
9	Antimony	0.037781	0.014816	0.0017693	0.00094363	0.010713	0.0057137	0.025186	0.0098768	0.0012386	0.00066061	0.0088962	0.0047446

Abbreviations: EDI, estimated daily intake; ND, not detected; *P. senegalensis*, *Pseudotolithus senegalensis*; *P. notialis*, *Penaeus notialis*.

Table 4 presents the estimated daily intake (EDI) of trace metals for children and adults through water ingestion and the consumption of *Pseudotolithus senegalensis* and *Penaeus notialis* in the Banana (Zone A) and Mangrove (Zone B) fishing areas. EDI values were generally higher in children than in adults across the assessed exposure pathways. Among the trace metals, cadmium and antimony contributed comparatively high estimated intakes through water ingestion, while zinc and antimony were prominent contributors through seafood consumption. The relative contribution of each metal varied between the two fishing areas and between fish and shrimp. No EDI values were calculated for arsenic and mercury through seafood consumption because these metals were not detected in the analyzed organisms.

Table 5:
Hazard quotient (HQ) values for children and adults exposed to trace metals through water and seafood consumption

No.	Metal	Banana (Zone A): Water Child	Banana (Zone A): Water Adult	Banana (Zone A): *P. senegalensis* Child	Banana (Zone A): *P. senegalensis* Adult	Banana (Zone A): *P. notialis* Child	Banana (Zone A): *P. notialis* Adult	Mangrove (Zone B): Water Child	Mangrove (Zone B): Water Adult	Mangrove (Zone B): *P. senegalensis* Child	Mangrove (Zone B): *P. senegalensis* Adult	Mangrove (Zone B): *P. notialis* Child	Mangrove (Zone B): *P. notialis* Adult
1	Cadmium	54.552	21.393	0.1267	0.067571	1.9292	1.0289	44.397	17.411	0.26297	0.14025	2.1278	1.1348
2	Lead	3.6585	1.4347	0.020816	0.011102	0.25863	0.13794	4.1372	1.6224	0.013352	0.0071211	0.20676	0.11027
3	Arsenic	2.3132	0.90714	ND	ND	ND	ND	116.77	45.794	ND	ND	ND	ND
4	Mercury	5.3125	2.0833	ND	ND	ND	ND	5.1607	2.0238	ND	ND	ND	ND
5	Nickel	0.0058058	0.0022768	0.013988	0.0074604	0.061812	0.032966	0.0045991	0.0018036	0.046533	0.024818	0.048276	0.025747
6	Chromium	0.015953	0.006256	0.001684	0.00089811	0.0097943	0.0052236	0.015983	0.0062679	0.0012489	0.00066606	0.0046649	0.002488
7	Copper	0.0019455	0.00076295	0.010392	0.0055424	0.044634	0.023805	0.0043259	0.0016964	0.050884	0.027138	0.03464	0.018474
8	Zinc	0.00025454	0.000099821	0.016976	0.0090538	0.036724	0.019586	0.00038857	0.00015238	0.0094958	0.0050644	0.029957	0.015977
9	Antimony	94.452	37.04	4.4233	2.3591	26.783	14.284	62.965	24.692	3.0966	1.6515	22.24	11.862

Abbreviations: HQ, hazard quotient; ND, not detected; *P. senegalensis*, *Pseudotolithus senegalensis*; *P. notialis*, *Penaeus notialis*.

Table 5 presents the hazard quotient (HQ) values estimated for children and adults exposed to trace metals through water ingestion and seafood consumption in the Banana (Zone A) and Mangrove (Zone B) fishing areas. HQ values were generally higher in children than in adults. For water ingestion, cadmium (Cd), lead (Pb), mercury (Hg), and antimony (Sb) exceeded the reference threshold (HQ >= 1) in both areas for both age groups, whereas arsenic (As) exceeded 1 for children in both areas and for adults in the Mangrove area. Through seafood consumption, antimony (Sb) showed HQ values above 1 in both fish and shrimp from both areas and for both age groups. Cadmium (Cd) also exceeded 1 through shrimp consumption in both areas for children and adults. The remaining detected

metals generally had HQ values below 1 for seafood consumption. These results identify the exposure pathways and trace metals contributing most to the estimated non-carcinogenic risk.

Table 6:
Organism-to-water concentration ratios of trace metals in *Pseudotolithus senegalensis* and *Penaeus notialis* collected from the Banana (Zone A) and Mangrove (Zone B) fishing areas

Metal	Water Zone A (mg/L)	Water Zone B (mg/L)	*P. senegalensis* Zone A (mg/kg FW)	*P. senegalensis* Zone B (mg/kg FW)	*P. notialis* Zone A (mg/kg FW)	*P. notialis* Zone B (mg/kg FW)	Fish Zone A (L/kg)	Fish Zone B (L/kg)	Shrimp Zone A (L/kg)	Shrimp Zone B (L/kg)
Cadmium	0.2995	0.24375	0.038145	0.079175	0.58083	0.64062	0.12736	0.32482	1.9393	2.6282
Lead	0.0703	0.0795	0.021935	0.01407	0.27254	0.21788	0.31202	0.17698	3.8767	2.7406
Arsenic	0.00381	0.19234	ND	ND	ND	ND	ND	ND	ND	ND
Mercury	0.00875	0.0085	ND	ND	ND	ND	ND	ND	ND	ND
Nickel	0.0006375	0.000505	0.08423	0.2802	0.3722	0.29069	132.13	554.85	583.84	575.63
Chromium	0.00026275	0.00026325	0.001521	0.001128	0.0088465	0.0042135	5.7888	4.2849	33.669	16.006
Copper	0.00042725	0.00095	0.12515	0.6128	0.53753	0.41717	292.92	645.05	1258.1	439.12
Zinc	0.00041925	0.00064	1.5333	0.85769	3.317	2.7058	3657.3	1340.1	7911.7	4227.8
Antimony	0.20742	0.13828	0.5327	0.37293	3.2255	2.6784	2.5681	2.697	15.55	19.37

Abbreviations: FW, fresh weight; ND, not detected; *P. senegalensis*, *Pseudotolithus senegalensis*; *P. notialis*, *Penaeus notialis*.

Table 6 presents the organism-to-water concentration ratios of trace metals in *Pseudotolithus senegalensis* and *Penaeus notialis* from the Banana and Mangrove fishing areas. The ratios were calculated by dividing the fresh-weight concentration in each organism by the corresponding concentration measured in water and are expressed in L/kg. The highest ratios were generally observed for zinc (Zn), copper (Cu), and nickel (Ni), with particularly high values for zinc in both fish and shrimp. Chromium (Cr) and cadmium (Cd) showed intermediate or comparatively lower ratios, while lead (Pb) and antimony (Sb) showed lower ratios in relation to the other detected metals. Ratios were not calculated for arsenic (As) and mercury (Hg) because these metals were not detected in the analyzed organisms. These ratios provide a comparison between concentrations in aquatic organisms and water and are not interpreted as direct measurements of bioconcentration.

Table 7:
Contamination factors (CF) of trace metals in *Pseudotolithus senegalensis* and *Penaeus notialis* from the Banana (Zone A) and Mangrove (Zone B) fishing areas

Metal	Fish Banana (mg/kg FW)	Fish Mangrove (mg/kg FW)	Shrimp Banana (mg/kg FW)	Shrimp Mangrove (mg/kg FW)	Reference (mg/kg FW)	CF Fish Banana	CF Fish Mangrove	CF Shrimp Banana	CF Shrimp Mangrove
Cadmium	0.038145	0.079175	0.58083	0.64062	0.05	0.7629	1.5835	11.617	12.812
Lead	0.021935	0.01407	0.27254	0.21788	0.3	0.073117	0.0469	0.90845	0.72625
Arsenic	ND	ND	ND	ND	0.1	ND	ND	ND	ND
Mercury	ND	ND	ND	ND	0.5	ND	ND	ND	ND
Nickel	0.08423	0.2802	0.3722	0.29069	0.5	0.16846	0.5604	0.7444	0.58139
Chromium	0.001521	0.001128	0.0088465	0.0042135	0.1	0.01521	0.01128	0.088465	0.042135
Copper	0.12515	0.6128	0.53753	0.41717	30	0.0041717	0.020427	0.017917	0.013905
Zinc	1.5333	0.85769	3.317	2.7058	40	0.038333	0.021442	0.082924	0.067644
Antimony	0.5327	0.37293	3.2255	2.6784	0.3	1.7756	1.2431	10.752	8.9281

Abbreviations: CF, contamination factor; FW, fresh weight; ND, not detected.

Table 7 presents the contamination factors (CF) of trace metals in fish and shrimp from the Banana and Mangrove fishing areas. Cadmium (Cd) and antimony (Sb) showed the highest CF values, particularly in shrimp. Cadmium CF values in shrimp were 11.617 in Banana and 12.812 in Mangrove, while antimony CF values were 10.752 and 8.9281, respectively. Antimony also exceeded a CF of 1 in fish from both areas, and cadmium exceeded 1 in fish from Mangrove (1.5835). CF values for lead, nickel, chromium, copper, and zinc were below 1 across all organism-area combinations. Arsenic and mercury CF values were not calculated because these metals were not detected in the analyzed organisms.

Table 8:
Contamination factors (CF) of trace metals in water collected from the Banana (Zone A) and Mangrove (Zone B) fishing areas.

Metal	Water Banana (mg/L)	Water Mangrove (mg/L)	Reference (mg/L)	CF Banana	CF Mangrove
Cadmium	0.2995	0.24375	0.003	99.833	81.25
Lead	0.0703	0.0795	0.01	7.03	7.95
Arsenic	0.00381	0.19234	0.01	0.381	19.233
Mercury	0.00875	0.0085	0.001	8.75	8.5
Nickel	0.0006375	0.000505	0.02	0.031875	0.02525
Chromium	0.00026275	0.00026325	0.05	0.005255	0.005265
Copper	0.00042725	0.00095	2	0.00021363	0.000475
Zinc	0.00041925	0.00064	4	0.00010481	0.00016
Antimony	0.20742	0.13828	0.02	10.371	6.9138

Abbreviations: CF, contamination factor.

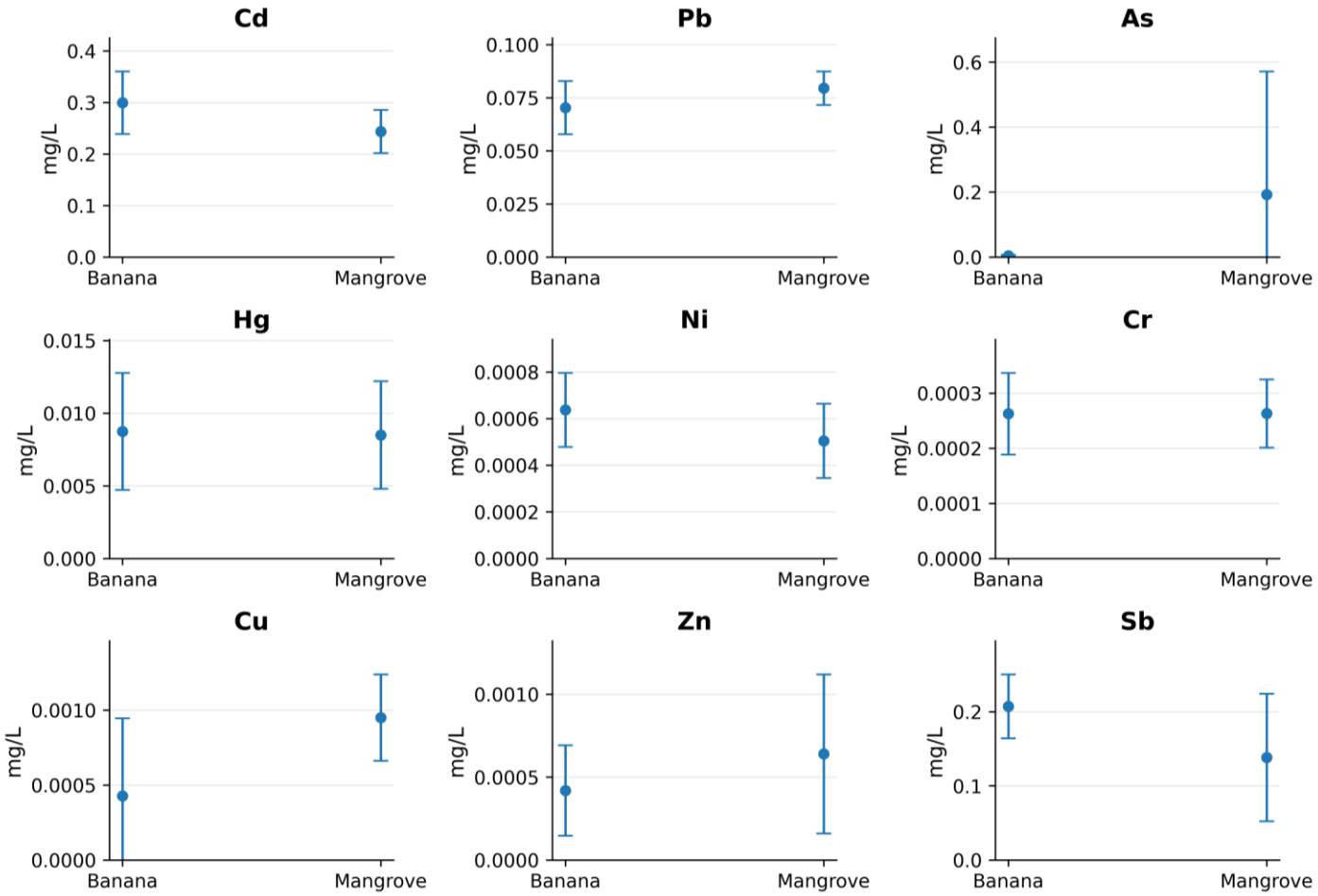
Table 8 presents the contamination factors (CF) of trace metals in water from the Banana and Mangrove fishing areas. Cadmium (Cd), lead (Pb), mercury (Hg), and antimony (Sb) showed CF values greater than 1 in both areas. Arsenic (As) showed a CF below 1 in Banana (0.381) and a substantially higher value in Mangrove (19.233). In contrast, nickel (Ni), chromium (Cr), copper (Cu), and zinc (Zn) had CF values below 1 in both areas.

Comparison of Metal Concentrations by Site (Mangrove and Banana)

Figure 3 presents the mean concentrations of trace metals measured in water samples collected from the Banana (Zone A) and Mangrove (Zone B) fishing areas. Differences in mean concentrations were observed between the two areas, particularly for arsenic, cadmium, and antimony. Higher arsenic concentrations were recorded in the Mangrove area, whereas cadmium and antimony showed higher mean concentrations in the Banana area.

One-way analysis of variance (ANOVA) indicated that none of the analyzed trace metals showed statistically significant differences between the two sampling areas at the 0.05 significance level. Specifically, cadmium ($F = 2.275$; $p = 0.1822$), lead ($F = 1.544$; $p = 0.2603$), arsenic ($F = 0.989$; $p = 0.3584$), mercury ($F = 0.008$; $p = 0.9301$), nickel ($F = 1.386$; $p = 0.2836$), chromium ($F = 0.000$; $p = 0.9921$), copper ($F = 3.108$; $p = 0.1284$), zinc ($F = 0.639$; $p = 0.4546$), and antimony ($F = 2.059$; $p = 0.2013$) showed no statistically significant differences between the Banana and Mangrove fishing areas.

Figure 3:
Mean (+- *SD*) concentrations of trace metals in water collected from the Banana (Zone A) and Mangrove (Zone B) fishing areas

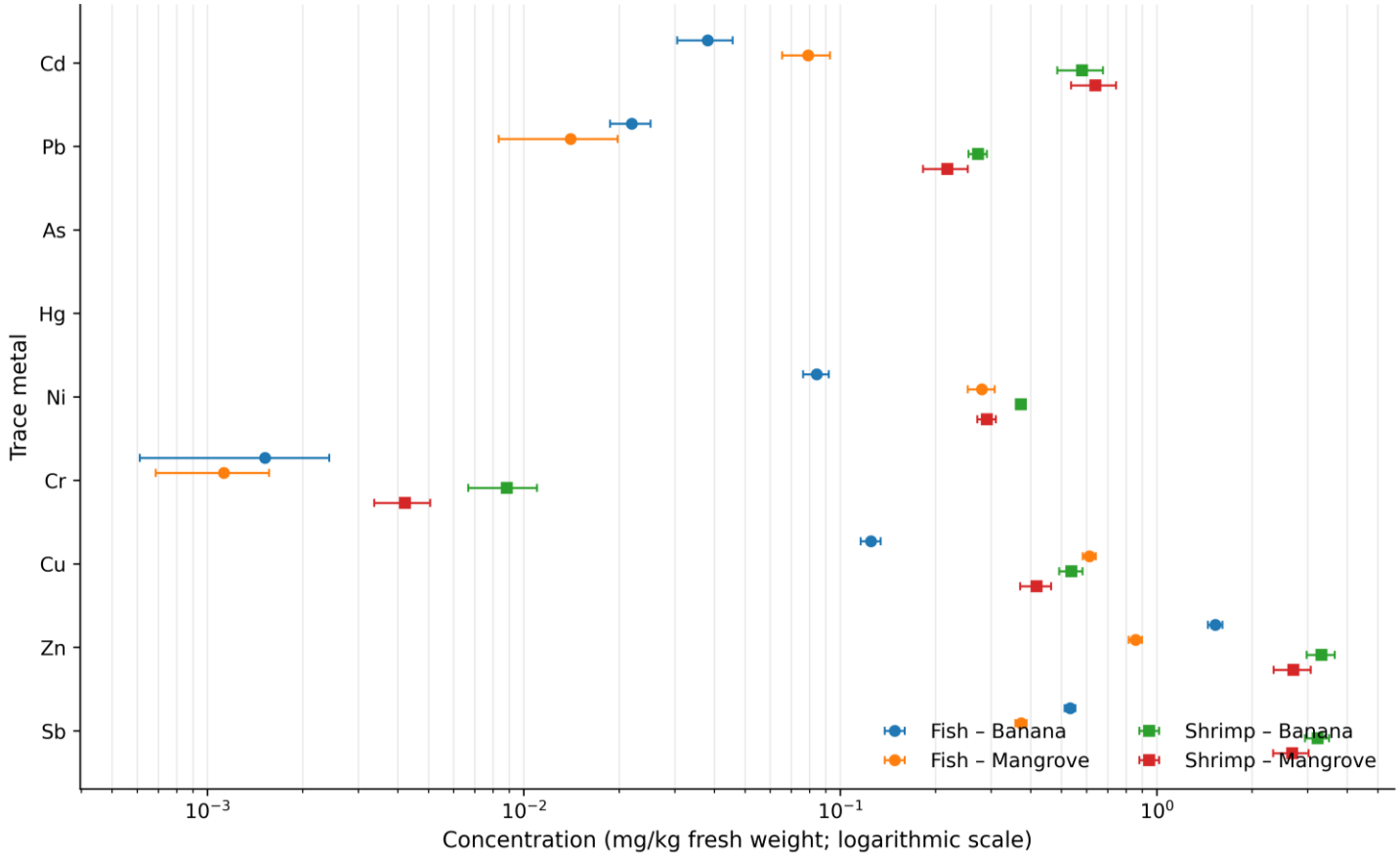


Comparison of Concentrations Among Species by Site

Figure 4 presents the mean concentrations of trace metals measured in *Pseudotolithus senegalensis* and *Penaeus notialis* collected from the Banana (Zone A) and Mangrove (Zone B) fishing areas. The concentrations are expressed on a fresh-weight basis following conversion from the ash-weight measurements. Trace metal concentrations varied between the two species and sampling areas. Zinc (Zn) was among the predominant metals in both species, followed by antimony (Sb). Shrimp generally showed higher concentrations of cadmium, lead, zinc, and antimony than fish, whereas fish showed higher nickel and copper concentrations in the Mangrove area.

The concentrations in fish and shrimp were summarized descriptively. No inferential statistical comparisons were performed between the two sampling areas because the available laboratory determinations could not be assigned to the individual biological samples. The observed variability therefore represents analytical-replicate variability rather than biological variability.

Figure 4:
Mean (+- *SD*) concentrations of trace metals in *Pseudotolithus senegalensis* and *Penaeus notialis* collected from the Banana (Zone A) and Mangrove (Zone B) fishing areas

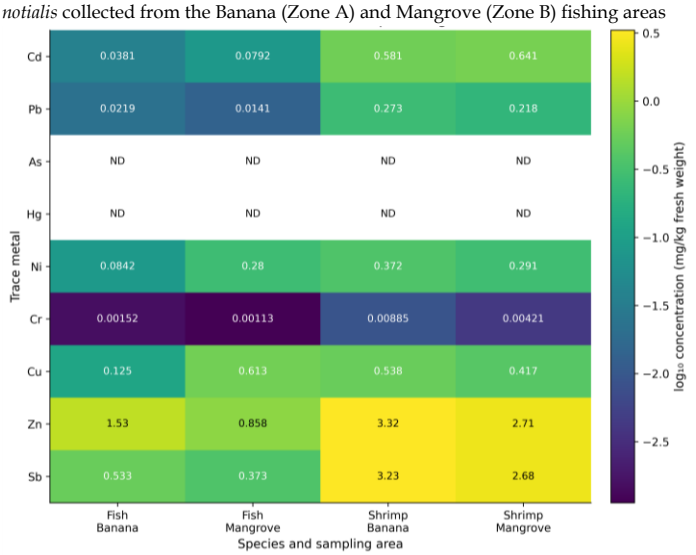


Metal Distribution Between Pseudotolithus senegalensis and Penaeus notialis

Figure 5 illustrates the distribution of trace metal concentrations in *Pseudotolithus senegalensis* and *Penaeus notialis* collected from the Banana (Zone A) and Mangrove (Zone B) fishing areas. The concentrations are expressed on a fresh-weight basis (mg/kg FW). The distribution pattern shows variations among metals, species, and sampling areas. Zinc (Zn) and antimony (Sb) were among the most concentrated metals in both organisms. Shrimp generally exhibited higher concentrations of cadmium, lead, zinc, and antimony, whereas fish showed higher nickel and copper concentrations in the Mangrove area.

These observations describe the distribution of trace metals in the analyzed organisms and do not imply statistically significant differences between species or sampling areas.

Figure 5:
Distribution of trace metal concentrations in *Pseudotolithus senegalensis* and *Penaeus notialis* collected from the Banana (Zone A) and Mangrove (Zone B) fishing areas



DISCUSSION

Seafood Consumption Patterns and Risk Perception

The survey identified *Pseudotolithus senegalensis* (44.68%) and *Penaeus notialis* (29.79%) as the most frequently consumed aquatic species among respondents. Most participants relied on local fisheries (72.67%), while 62.67% reported consuming seafood mainly in its fresh form. Although 58.00% recognized that pollution could affect seafood quality, only 26.00% perceived frequent seafood consumption as a potential health risk. These findings highlight the importance of local fisheries for food supply and the need to strengthen public awareness of environmental contaminants. Similar dependence on locally harvested seafood has been reported in coastal communities of West and Central Africa (Burger & Gochfeld, 2005; FAO, 2018). Studies conducted along the Atlantic coast of the Democratic Republic of the Congo have also identified seafood as a potential pathway of human exposure to trace metals (Storelli et al., 2005; Suami et al., 2018).

Water Contamination and Estuarine Dynamics

The results revealed differences in trace metal concentrations between the Banana and Mangrove areas. Cadmium and antimony showed higher mean concentrations in Banana, whereas arsenic was more concentrated in Mangrove. However, the ANOVA results indicated that none of these differences was statistically significant ($p > 0.05$). These variations may reflect differences in local environmental conditions and contaminant inputs, although the available data do not allow specific pollution sources to be established. Previous studies along the Atlantic coast of the Democratic Republic of the Congo have reported trace metal contamination associated with petroleum-related activities, riverine inputs, and other anthropogenic pressures (Nsiala et al., 2026; Suami et al., 2020). Similar influences of natural processes and human activities on metal distribution have been described in tropical coastal ecosystems (Islam & Tanaka, 2004).

Interspecies Bioaccumulation of Trace Metals

The corrected concentrations, expressed on a fresh-weight basis, revealed differences in metal distribution between *Pseudotolithus senegalensis* and *Penaeus notialis*. Shrimp generally presented higher concentrations of cadmium, lead, zinc, and antimony than fish, whereas fish showed higher nickel and copper concentrations in the Mangrove area. Zinc and antimony were among the predominant metals in both organisms. These patterns may be related to differences in feeding habits, habitat use, and physiological characteristics between species (Luoma & Rainbow, 2008). Similar species-related variations have been reported in edible marine fish from the Congolese Atlantic coast (Suami et al., 2018). Nevertheless, these observations are descriptive and do not establish statistically significant differences between the species or sampling areas.

Human Exposure and Estimated Daily Intake (EDI)

The estimated daily intake (EDI) values were generally higher in children than in adults across the assessed exposure pathways. This difference is mainly related to the lower body weight used for children in the exposure calculations. Water ingestion and seafood consumption both contributed to estimated exposure, although the relative contribution varied according to the metal, sampling area, and food matrix. Considering the high reliance on local fisheries reported by survey participants, seafood consumption represents a relevant pathway to consider in the assessment of potential human exposure in Moanda.

Hazard Quotient (HQ) and Health Risk

The hazard quotient assessment identified potential non-carcinogenic health concerns associated with several exposure pathways. For water ingestion, HQ values exceeded 1 for cadmium, lead, mercury, and antimony in both areas and age groups. Arsenic also exceeded this threshold in Mangrove, while the value for children in Banana was above 1. Through seafood consumption, antimony presented HQ values above 1 in both fish and shrimp, whereas cadmium exceeded this threshold in shrimp from both areas. In general, children presented higher HQ values than adults. An HQ greater than 1 indicates that potential non-carcinogenic health effects cannot be excluded, although it does not establish that adverse effects will necessarily occur. These results support the need for continued monitoring of water quality and seafood safety, particularly for populations that frequently consume locally harvested aquatic products.

Organism-to-Water Concentration Ratios

The organism-to-water concentration ratios showed substantial differences among metals and aquatic species. Zinc presented the highest ratios in both fish and shrimp, followed by copper and nickel, although the relative ranking varied between the two sampling areas and organisms. These differences suggest that metal concentrations in aquatic organisms are not determined solely by their concentrations in the surrounding water. Species-specific physiological characteristics and environmental exposure conditions may also influence metal accumulation. However, these ratios should be interpreted as comparisons between organism and water concentrations rather than direct measurements of bioconcentration or trophic transfer.

Contamination Factor (CF)

The contamination factor results showed contrasting patterns among the analyzed metals and sample matrices. In water, cadmium, lead, mercury, and antimony presented CF values above 1 in both sampling areas, while arsenic exceeded 1 only in Mangrove. In fish, antimony and cadmium exceeded 1 in Mangrove, whereas antimony exceeded 1 in Banana. In shrimp, cadmium and antimony presented CF values above 1 in both areas. These findings indicate that the degree of deviation from the selected reference concentrations varied according to the metal and sample matrix. Similar trace metal contamination patterns have been documented in aquatic environments along the Atlantic coast of the Democratic Republic of the Congo (Atibu et al., 2018; Suami et al., 2020). The results underline the importance of continued monitoring of coastal waters and commercially important seafood species to support environmental management and food safety measures.

CONCLUSION

This study investigated trace metal contamination in coastal water, *Pseudotolithus senegalensis*, and *Penaeus notialis* from the Atlantic coast of Moanda, Democratic Republic of the Congo, and assessed the potential human health risks associated with seafood consumption. The findings revealed the presence of several trace metals in the studied matrices. Cadmium, lead, mercury, and antimony were among the main elements of concern in water, while cadmium and antimony were particularly relevant in seafood samples. Arsenic was detected in water but was not detected in the analyzed fish and shrimp samples.

No statistically significant differences in water metal concentrations were found between the Banana and Mangrove areas. However, descriptive comparisons showed variations in metal concentrations between the two aquatic species, with shrimp generally presenting higher concentrations of cadmium, lead, zinc, and antimony, while fish showed higher nickel and copper concentrations in some comparisons.

The health risk assessment indicated potential non-carcinogenic concerns, particularly in relation to water exposure and the consumption of certain seafood samples. Hazard quotient values exceeded 1 for several metals, including cadmium and antimony in shrimp, and antimony in fish. Children generally presented higher estimated exposure and risk values than adults, highlighting their potential vulnerability.

These findings underline the importance of strengthening environmental monitoring and regularly assessing the quality of coastal waters and commercially consumed seafood in Moanda. Future investigations should extend monitoring to additional environmental compartments, including sediments, and cover a wider range of sampling locations and periods. Public awareness initiatives and appropriate pollution prevention and control measures are

also needed to reduce potential exposure and protect both aquatic resources and public health.

Use of Artificial Intelligence (AI) Declaration: During the preparation of the manuscript, the authors used ChatGPT solely as an assistance tool for language editing, grammar correction, stylistic improvement, and formatting. It was not used to generate, alter, or manipulate primary research data or scientific results. After using this tool, the authors thoroughly reviewed and edited the content as needed and take full responsibility for the accuracy, integrity, and publication of the final manuscript.

Authors' Contributions:

i. **Waku, M.A.:** Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Visualization, and Writing – original draft.

ii. **Kasogo, B.P.:** Data curation and Visualization.

iii. **Maria, N.T.:** Writing – review & editing.

iv. **Kusonika, N.A.:** Conceptualization, Validation, and Writing – review & editing.

v. **Gizanga, V.R.:** Conceptualization, Validation, and Writing – review & editing.

vi. **Ngwanza, M.M.:** Investigation (laboratory analysis).

vii. **Biey, M.E.:** Conceptualization, Validation, and Writing – review & editing

Data Availability Statement: The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Ethical Approval: This study was conducted in accordance with institutional and local administrative requirements. Formal research authorization was granted by the University of Kinshasa (2024), and permission for field activities was duly acknowledged by the Territorial Administrator of Moanda (2025). Additional site access, operational, and laboratory permissions were obtained from SOCIR S.A. and the local Mangrove management authority.

Informed Consent: Prior to participation, all individuals were informed of the study objectives and procedures, and verbal informed consent was obtained from all participants.

Funding: This study was self-funded by the lead author. No external funding was received for this research.

Conflicts of Interest: The authors declare that they have no conflicts of interest.

ORCID iDs:

Waku, M. A.[1,2]: https://orcid.org/0009-0002-4009-952X
Kasogo, B. P.[1,3]: https://orcid.org/0009-0007-4975-1699
Maria, N. T.[1,2]: https://orcid.org/0009-0009-3882-5431
Kusonika, N. A.[1,2]: https://orcid.org/0009-0008-1258-6578
Gizanga, V. R.[1,2]: Nil identified.
Ngwanza, M. M.[4]: Nil identified.
Biey, M. E.[1,3]: Nil identified.

Open Access: This original article is distributed under the Creative Commons Attribution Non-Commercial (CC BY-NC 4.0) license. This license permits people to distribute, remix, adapt, and build upon this work non-commercially and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made are indicated, and the use is non-commercial. See: https://creativecommons.org/licenses/by-nc/4.0/.

REFERENCES

Atibu, E. K., Lacroix, P., Sivalingam, P., Ray, N., Giuliani, G., Mulaji, C. K., Otamonga, J.-P., Mpiana, P. T., Slaveykova, V. I., & Pote, J. (2018). High contamination in the areas surrounding abandoned mines and mining activities: An impact assessment of the Dilala, Luilu, and Mpingiri Rivers, Democratic Republic of the Congo. *Chemosphere*, 191, 1008-1020.

Burger, J., & Gochfeld, M. (2005). Heavy metals in commercially caught fish in New Jersey. *Environmental Research*, 99(3), 403-412.

Clark, R. B. (2001). *Marine pollution* (5th ed.). Oxford University Press.

Food and Agriculture Organization. (2018). *The state of world fisheries and aquaculture 2018: Meeting the sustainable development goals*. Food and Agriculture Organization.

Islam, M. S., & Tanaka, M. (2004). Impacts of pollution on coastal and marine ecosystems including coastal and marine fisheries and approach for management: A review and synthesis. *Marine Pollution Bulletin*, 48(7-8), 624-649.

Luoma, S. N., & Rainbow, P. S. (2008). *Metal contamination in aquatic environments: Science and lateral management*. Cambridge University Press.

Nsiala, G. O., Mulaji, C. K., Carvalho, F. P., Biey, E. M., Pote, J., & Atibu, E. K. (2026). Trace metals and rare earth elements in sediments along the Muanda River estuary and coastal ocean continuum in an oil exploitation area. *Discover Sustainability*, 7, 140.

Storelli, M. M., Storelli, A., D'Addabbo, R., Marano, C., Bruno, R., & Marcotrigiano, G. O. (2005). Trace elements in loggerhead turtles (*Caretta caretta*) from the eastern Mediterranean Sea: Overview and evaluation. *Environmental Pollution*, 135(1), 163-170.

Suami, R. B., Sivalingam, P., Al Salah, D. M., Grandjean, D., Mulaji, C. K., Mpiana, P. T., Breider, F., Otamonga, J.-P., & Pote, J. (2020). Heavy metals and persistent organic pollutants contamination in river, estuary, and marine sediments from the Atlantic coast of the Democratic Republic of the Congo. *Environmental Science and Pollution Research*, 27(16),

20000-20013. https://doi.org/10.1007/s11356-020-08179-4

Suami, R. B., Sivalingam, P., Kabala, C. D., Otamonga, J.-P., Mulaji, C. K., Mpiana, P. T., & Pote, J. (2018). Concentration of heavy metals in edible fishes from the Atlantic coast of Muanda, Democratic Republic of the Congo. *Journal of Food Composition and Analysis*, 73, 1-9.

United Nations Environment Programme. (2006). *Marine and coastal ecosystems and human well-being: A synthesis report*. United Nations Environment Programme.

United Nations Environment Programme / Global Programme of Action for the Protection of the Marine Environment from Land-based Activities. (2006). *The state of the marine environment: Trends and processes*. UNEP/GPA Coordination Office.

U.S. Environmental Protection Agency. (1989). *Risk assessment guidance for superfund (RAGS), Volume I: Human health evaluation manual (Part A)* (EPA/540/1-89/002). U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. (2011). *Exposure factors handbook: 2011 edition* (EPA/600/R-09/052F). U.S. Environmental Protection Agency.

World Health Organization. (2007). *Evaluation of certain food additives and contaminants*. World Health Organization.

World Health Organization. (2022). *Guidelines for drinking-water quality* (4th ed., incorporating the 2nd addendum). World Health Organization.