BIOLOGIJA
2023. Vol. 69. No. 3. P. 217–231
ISSN 1392-0146 eISSN 2029-0578
DOI: https://doi.org/10.6001/biologija.2023.69.3.2

Ecotoxicological risk assessment of metalloid contamination in the sediment and benthic fauna of a tropical lotic freshwater ecosystem in Southern Nigeria

Peter Osaretin Uwaifo[1],

Nkonyeasua Kingsley Egun[2*],
iD https://orcid.org/ 0000-0001-5612-4166

Timothy Imuetinya Agho[3]

[1] *Benin-Owena River Basin Development Authority/University of Benin Joint Analytical Research Laboratory, University of Benin, Edo State, Nigeria*

[2] *Department of Animal and Environmental Biology, University of Benin, Benin City, Nigeria*

[3] *Department of Science Laboratory Technology, University of Benin, Benin City, Nigeria*

The increasing exposure of freshwater bodies to pollutants and the bioaccumulation of heavy metals in body parts of aquatic organisms has raised concerns on the ecotoxicological and human health risk. This study evaluated the potential ecological and human health risk of heavy metal pollution in sediment and benthic fauna (*Caridina africana*) of the Osse River, Edo State, Nigeria. Using requisite equipment, samples of water sediment and *C. africana* were collected at designated stations from September 2015 to February 2017. Heavy metal concentrations in samples were determined using atomic absorption spectrophotometer. Result showed heavy metal contamination with concentration profiles of Fe > Zn > Mn > Cu > Ni > Pb > Cr > Cd > V in sediments and Fe > Zn > Mn > Cu > Ni > Cr > Pb > Cd > V in *C. africana*. The potential ecological risk index (PERI) values classified stations 1, 2 and 4 as of low ecological risk (PERI ≤ 150), while station 3 (PERI ≤ 300) was classified as of moderate ecological risk. Human health risk assessment for heavy metals in *C. africana* indicated significant non-carcinogenic health risk (HI > 1), and high carcinogenic risk to human health. The consumption of the contaminated *C. africana*, which is harvested in commercial quantities, portends health risk to the general public. There is need for urgent action in the abatement and regulation of identified anthropogenic activities responsible for the release of these heavy metals into the Osse River.

Keywords: heavy metals, human health risk assessment, ecological risk, sediment, *Caridina africana*, Osse River

* Corresponding author. Email: kenegun@yahoo.com

INTRODUCTION

Increasing anthropogenic activities within the watershed of inland freshwater bodies and its attendant increasing deposits of pollutants into the water bodies have become a global concern to sustainable development as these water bodies, which are mainly relied upon by rural communities in underdeveloped and developing nations as sources of potable water for domestic usage and fishery resources, have been polluted. Pollution of aquatic ecosystems has led to a cascade of outcomes commencing from deterioration of water quality, sediment toxicity, loss of biodiversity, and bioaccumulation of contaminants in aquatic fauna and culminating with potential health risk to humans through food transfer and dermal contact. In Nigeria, several studies have raised public concern on the increasing levels of aquatic pollution of inland freshwater bodies, particularly with heavy metals and organochloride phosphates (Omoigberale, Ogbeibu, 2007; Enuneku et al., 2018; Egun, Oboh, 2021; Egun, Oboh, 2023). Therefore, there is the need for continuous environmental monitoring and development of abatement strategies and practices to curtail further pollution.

Sediments are the bedrock of aquatic ecosystems as they are fundamental in the formation, development, and setting up of aquatic flora and fauna. The combination of sediment biogeochemical constituents and aquatic hydrodynamics enables it to function as a sink for pollutants, which makes them useful markers for aquatic ecosystem pollution (Massaquoi et al., 2015). Several methods have been developed for sediment quality assessment for the purpose of ascertaining the level of contamination, the degree of adverse effects of a particular contaminant on the sediment quality, and its implication on the aquatic ecosystem. These methods or approaches include Sediment Quality Guidelines (SQGs) (Harikumar et al., 2009; Luo et al., 2010), the contamination factor (CF), the contamination degree (CD), the pollution load index (PLI), and the potential ecological risk index (PERI). These methods were utilised in this study to evaluate the influence of identified anthropogenic activities on the quality of sediment and the sensitivity of the biota to heavy metal toxicity.

The ability of benthic organisms to concentrate aquatic contaminants in their body tissues has led to them been utilised as bio-indicators in environmental studies for the monitoring of bioaccumulation and biomagnification of contaminants such as heavy metals across the food web (Olomukoro, Dirisu, 2014). Also, benthic organisms such as water snails and shrimps, which are harvested in commercial quantities, are assessed to ascertain the human health risk associated with their consumption. Shrimps are benthic invertebrates of economic importance, which serve as a relatively cheap source of animal protein to rural households and a priced delicacy in urban centres in Nigeria. Shrimps are considered important in aquatic ecosystem monitoring as they have low mobility and reveal the accumulative effects of the present and previous conditions of the ecosystem.

The Osse River, which provides diverse ecosystem services to several communities along its course, is been exposed to pollution from natural and anthropogenic sources within the watershed. In recent times, increasing anthropogenic activities ranging from domestic effluent discharge to petroleum exploration and processing have seen the concomitant increase in the quantity of pollutants released into the Osse River. Existing literatures on the Osse River have focused on assessing the suitability of water quality for consumption and domestic use (Omoigberale, Ogbeibu, 2007; Ekhator et al., 2015; Uwaifo et al., 2018). The need for an ecological risk assessment of the water body and the health risk associated with the consumption of the benthic fauna (*Caridina africana*), which is harvested in large quantities and sold in several open markets in the region, has necessitated this study.

MATERIALS AND METHODS

Description of the study area. The Osse River is one of the rivers in the Benin-Owena River Basin in Nigeria. It is a freshwater ecosystem that is located within the tropical rainforest belt in Southern Nigeria and transverses through several communities in Edo State, Nigeria. Human settlements along the river course are mostly rural communities, with the river providing ecosystem services that include a source of water for domestic use, a route for transportation of humans and logs of timber wood, and provision of aquatic animals – fishes, snails, and shrimps for food and commercial gains. Also situated within the watershed is a petroleum exploration and processing company, with runoffs containing heavy metals discharging into the river.

Sampling sites. For this study, sampling locations were selected along the river course based on their propinquity to the areas of intense anthropogenic activities. Station 1 (006°15.236´ N, 05°33.625´ E) is located upstream of the river, with the bottom sediment comprised of brownish fine sand particles. Station 2 (006°15.511´ N, 05°34.355´ E) is located at the entry point of the Gelegele community and receives other domestic waste because of its proximity to the settlers. Station 3 (006°16.033' N, 05°34.960´ E) is located close to the petroleum processing company facilities and is exposed to constant gas flaring. Station 4 (006°16.458' N, 05° 34.942´ E) is located downstream at the lziedema community, with logging activities close to the station (Fig. 1).

Sample collection. Water sediment samples were collected from designated stations using an Ekman grab. Field sampling was carried out from September 2015 to February 2017 taking into cognizance the dry and rainy seasons. After collection, samples were wrapped in an

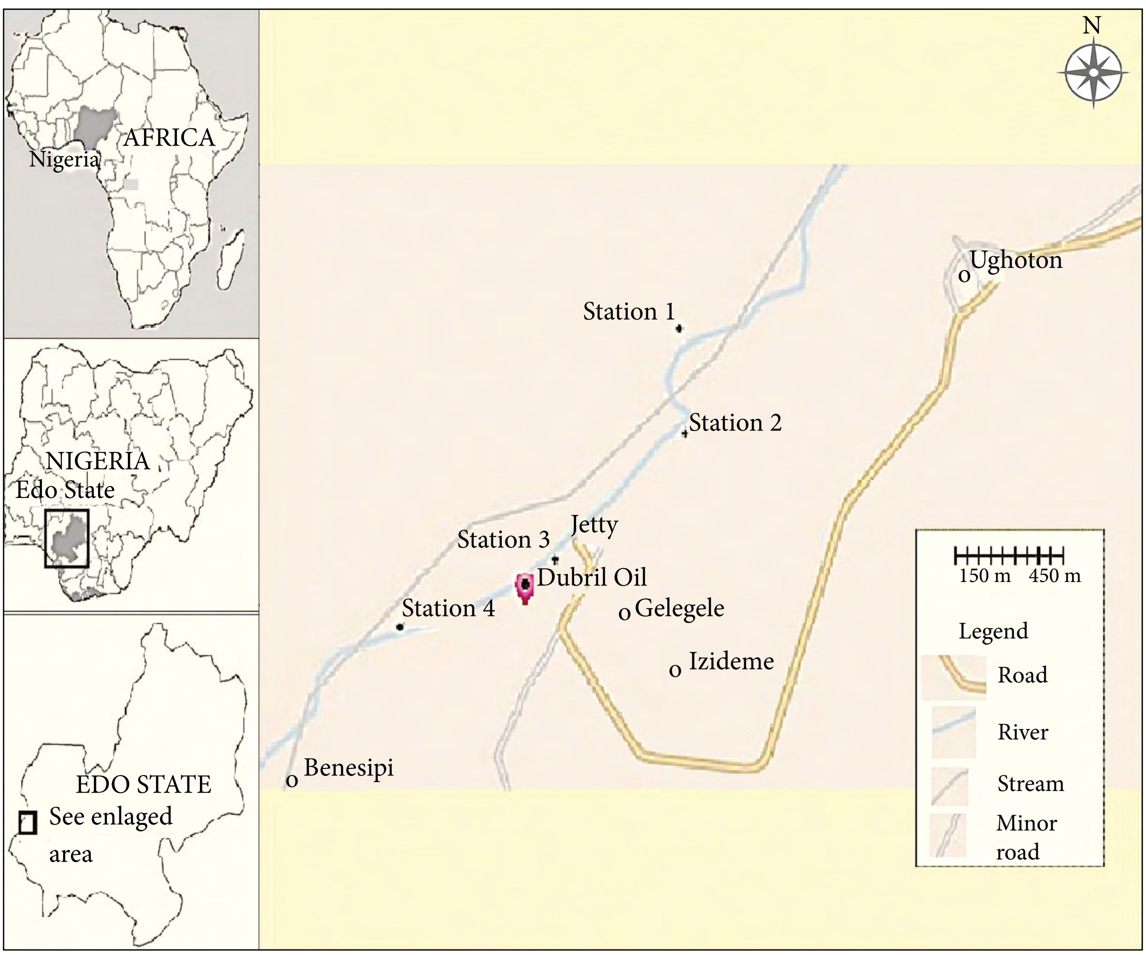

Fig. 1. Map of the Osse River, Edo State, Nigeria, showing the locations of sampling stations. Inset maps: (A) Nigeria (B) Edo State

aluminium foil and transported in ice chests to the Benin Owena River Basin Authority/ University of Benin Analytical Laboratory, Benin City, Edo State. Sediment samples were freeze dried and sieved using a 2-mm mesh sieve to remove debris (Guy, 1969). Samples of *C. africana* were collected at designated stations along the stretch of the river with the assistance of artisanal fishermen using local traps. *C. africana* samples were preserved in an icebox and taken to the laboratory for identification and preserved in the refrigerator until analysis.

Sample analysis

Sediment samples were digested following procedures described by APHA (2012). Sediment samples were thawed and then dried at 100°C for 24 h. One (1) g of a finely ground, homogenised sediment sample was weighed into a 100 ml Erlenmeyer flask to which 20 mL concentrated nitric acid (HNO_3) and 10 mL perchloric acid ($HClO_4$) were added (GFS Chemicals, USA). The samples were heated at 70°C for 1 h, and each sample was then made up to 50 ml with deionised water. The beakers were removed from the hot plate, allowed to cool, and then filtered using the Whatman filter paper (Sigma-Aldrich, Germany). Heavy metal concentrations in sample filtrates were determined using the Atomic Absorption Spectrophotometer (Model 210 VGP, Buck Scientific, USA).

Caridina africana samples were weighed and oven dried at 105°C. Using a ceramic mortar and pestle, dried samples were homogenised into fine powder. Samples were digested using a tri-acid mixture (HNO_3:$HClO_4$:H_2SO_4 = 10:4:1) at a rate of 5 ml per 0.5 g homogenised sample and were placed on a heater at 100°C. Heating continued until a clear liquid was obtained. The digested liquid was allowed to cool, filtered through Whatman No. 42 filter paper, and diluted to 25 ml with distilled water. Solutions were stored in vials and analysed for heavy metal content using an atomic absorption spectrophotometer (Model 210 VGP, Buck Scientific).

Ecological risk assessment of heavy metals in sediment

Pollution load index (PLI). Pollution load index (PLI) denotes the extent by which the levels of heavy metals in the sediment surpass the background concentration. It offers an all-inclusive information about the metal toxicity in a specific sample (Yang et al., 2011).

The PLI is calculated as described by Tomilson et al. (1980):

$$\mathrm{PLI} = (\mathrm{CF}_1 \times \mathrm{CF}_s \times \mathrm{CF}_3 \ldots \ldots .. \times \mathrm{CF}_n)^{1/n},$$

where n is the number of heavy metals i.e., $n = 9$ in this study CF is the contamination factor.

$$\mathrm{CF} = \frac{\text{Metal concentration in sediment}}{\text{Background value of metal}}.$$

According to Håkanson (1980), CF < 1 signifies low or small degree of contamination, 1 < CF < 3 signifies a moderate degree, 3 < CF < 6 signifies a considerable or significant degree, and CF > 6 indicates a very high degree of contamination. The PLI value of >1 indicates pollution, whereas <1 indicates no pollution (Barakat et al., 2012).

Contamination degree (CD). This parameter refers to the totality of all contamination factors. It provides an insight into the extent of the overall contamination of sediments from a particular location. It is expressed as:

$$\mathrm{CD} = \sum_{i=1}^{n} \mathrm{CF}_i .$$

The CD value of <6 denotes a low degree of contamination, 6 ≤ Cd < 12 indicates a moderate degree, 12 ≤ Cd < 24 indicates a considerable degree, and Cd ≥ 24 represents a very high degree of contamination (Håkanson, 1980).

Potential ecological risk index (PERI). PERI is utilised in evaluating the ecological risk of heavy metals in sediments by taking into consideration heavy metal toxicity and comparing the concentration of the metal with its background value. In this study, PERI was used to measure the potential ecological hazard of contaminated sediment to biota.

According to Håkanson's (1980) formula for estimating PERI,

$$E^i_r = T^i_r \times \mathrm{CF}_i,$$

where E^i_r is the individual metal potential risks, T^i_r is the toxic response factor for a given substance, and CF is the contamination factor.

The toxic response factor designated to the heavy metals Zn, Cr, Cd, Pb, Mn, Cu, and Ni used in the estimation of PERI are 1, 2, 30, 5, 1, 5 and 5, respectively (Jiao et al., 2015; Soliman et al., 2015).

PERI is the summation of the individual potential risks (E^i_r). It is presented as:

$$\mathrm{PERI} = \sum_{i=1}^{n} E^i_r.$$

For the categorisation of individual potential risks (E^i_r) in the sediments, $E^i_r \leq 40$ indicates a low ecological risk; $40 < E^i_r \leq 80$ indicates a moderate ecological risk; $80 < E^i_r \leq 160$ indicates *a* considerable ecological risk, $160 < E^i_r \leq 320$ indicates a high ecological risk, and $E^i > 320$ indicates a very high ecological risk. Furthermore, PERI values are categorized as: PERI ≤ 150 denotes a low ecological risk; 150 < PERI ≤ 300 denotes a moderate ecological risk; 300 < PERI ≤ 600 denotes a considerable ecological risk, and PERI >600 is reflective of a very high ecological risk.

Sediment-to-benthic transfer assessment. Sediment-to-benthic fauna metal transfer was calculated as transfer factor (TF). This is defined by the equation:

$$\mathrm{TF} = \frac{C_{\mathrm{fauna}}}{C_{\mathrm{sediment}}},$$

where C_{fauna} is the concentration of heavy metals in *C. africana* and C_{sediment} is the concentration of heavy metals in sediment (Abdallah, Abdallah, 2008).

Human health risk assessment

Exposure assessment. One of the identified primary exposure pathways of heavy metals to humans is through the dietary intake of contaminated foods. The estimated daily intake (EDI) of each heavy metal from the ingestion of *C. africana* was determined by the equation (USEPA, 2012):

$$\mathrm{EXP}_{\mathrm{diet}} = \frac{C_m \times \mathrm{IR} \times \mathrm{ED} \times \mathrm{EF}}{\mathrm{BW} \times \mathrm{AT}},$$

where, C_m is the mean content of heavy metal in *C. africana* (mg/Kg).

IR is the ingestion rate of *C. africana* (0.114 Kg/day).

ED is Exposure duration (Conventional life expectancy of 70 years for adults).

EF is Exposure frequency (days/year i.e. 365 days/year).

BW is the body weight (approximate average of 70 kg for adults).

AT is Averaging time; for non-carcinogenic risk, AT is equal to ED × 365 days. While for carcinogenic risk, AT is the average life expectancy of people × 365 days (USEPA, 2004). Average life expectancy is 55 years for adults in Nigeria (United Nations, 2019).

Non-carcinogenic risk assessment. The potential non-carcinogenic risk of heavy metal concentrations in *C. africana* was characterised using the target hazard quotient (THQ) and the hazard index (HI) (USEPA, 2012)

For THQ estimations, the assumptions of no effect of cooking on the toxicity of heavy metals and that ingested dose of heavy metal is equal to the absorbed pollutant dose were considered (Cooper et al., 1991).

Target Hazard quotient (THQ):

$$\mathrm{THQ}_{\mathrm{diet}} = \frac{\mathrm{EXP}_{\mathrm{diet}}}{\mathrm{RfD}_{\mathrm{diet}}},$$

where RfD (mg/kg/day): the reference dose level of a particular metal through oral exposure (USEPA, 2021).

Since benthic organisms are able to accumulate more than one heavy metal, which may result in interactive effects, the HI is the arithmetic sum of the THQ of the individual heavy metals in a particular fish sample (Chien et al., 2002; Zheng et al., 2007).

The hazard index (HI):

$$HI = \sum THQ_{diet}.$$

The population exposed to heavy metals is considered safe from health risk where HI < 1.0; and when HI > 1.0 there could be a concern for a potential non-cancer health effect (Tripathee et al., 2016; Saha, Paul, 2018).

Carcinogenic risk assessment. The potential carcinogenic risk of heavy metals in *C. africana* were estimated using the incremental or excess individual lifetime cancer risk. The carcinogenic risk (CR) is the product of the daily exposure dose (EXP_{diet}) and the cancer slope factor (CSF).

$$CR_i = EXO_{diet} \times CSF_i,$$

where CR_i is the carcinogenic risk of heavy metals through oral route,

EXP_{diet} is the daily exposure dose of carcinogenic pollutants, and

CSF_i is the cancer slope factor of carcinogenic pollutants.

The integrated carcinogenic risk (ICR) can also be acknowledged as the summation of exposure of carcinogenic risks by various pollutants, with the postulation that there is no antagonism and synergism between individual pollutants.

$$ICR = \sum_{i=1}^{n} CR_i.$$

USEPA (2005) believes that the carcinogenic risk value for humans is acceptable within 1×10^{-4}, while the maximum acceptable risk value recommended by International Commission on Radiological Protection (ICRP) is 5×10^{-5} (Zeng et al., 1998). For the clarity of risk evaluation results, risk classification based on the Delphi method, assessment criteria of USEPA and ICRP was carried out in this study as shown in Table 1 (Yuan et al., 2011; Liu et al., 2015; Li et al., 2017).

Data analysis. The Microsoft Excel 2016 and Statistical Package for Social Sciences (SPSS) v.21 software were used for data analysis. Analysis of variance (ANOVA) was used to determine differences among means of heavy metal content in fish tissues.

RESULTS

The mean variations of heavy metals in sediments and *C. africana* from different study stations are presented in Tables 2 and 3 and illustrated in Fig. 2. Iron (Fe) showed the highest concentration in sediment and *C. africana* in all the sampled stations, while vanadium (V) had the least content. Heavy metal concentration profile in sediment was Fe > Zn > Mn > Cu > Ni > Pb > Cr > Cd > V; and Fe > Zn > Mn > Cu > Ni > Cr > Pb > Cd > V in *C. africana*. The average CD and the PLI values for heavy metals in sediment samples from the Osse River are presented in Table 4. The CF value for Fe and Cd exceeded the benchmark value of 1, with higher values recorded for Fe (CF > 20). Using the CD and PLI values, pollution levels were in the sequence of station 3 > station 2 > station 4 > station

Table 1. **Carcinogenic levels and values of assessment standards**

Risk grades		Range of risk value	Acceptability
Grade I	Extremely low risk	<10–6	Completely accept
Grade II	Low risk	(10–6, 10–5)	Not willing to care about the risk
Grade III	Low-medium risk	(10–5, 5 × 10–5)	Do not mind about the risk
Grade IV	Medium risk	(5 × 10–5, 10–4)	Care about the risk
Grade V	Medium-high risk	(10–4, 5 × 10–4)	Care about the risk and willing to invest
Grade VI	High risk	(5 × 10–4, 10–3)	Pay attention to the risk and take action to solve it
Grade VII	Extremely high risk	>10–3	Reject the risk and must solve it

Table 2. **Mean values of heavy metal concentration in the sediment samples from the Osse River**

Metal (mg/Kg)	Station 1			Station 2			Station 3			Station 4			*SQG*
	Mean ± SE	Min.	Max.	Mean ± SE	Min.	Max.	Mean ± SE	Min.	Max.	Mean ± SE	Min.	Max.	
Fe	109.3 ± 13.2	33.80	183.20	216.2 ± 24.5	27.10	291.30	313.5 ± 1.8	98.30	445	112.4 ± 15.8	55.80	192.90	4.72
Zn	74.1 ± 19.9	11.50	167.00	30.0 ± 7.40	10.70	78.30	68.8 ± 7.0	27.10	99	51.9 ± 11.4	13.20	112	90
Cr	0.86 ± 0.21	0.00	1.90	1.77 ± 0.63	0.00	4.80	4.95 ± 1.15	0.00	12.10	1.13 ± 0.35	0.00	3.10	100
Cd	0.37 ± 0.14	0.00	1.10	1.01 ± 0.44	0.00	3.30	2.23 ± 0.86	0.00	6.23	0.34 ± 0.15	0.00	1.24	0.3
Pb	1.59 ± 0.63	0.00	4.70	3.30 ± 1.33	0.00	9.70	3.21 ± 0.61	0.00	5.50	2.23 ± 0.95	0.00	8.30	20
Mn	21.0 ± 4.96	0.29	41.70	27.1 ± 7.22	0.21	60.60	21.7 ± 3.38	3.59	35.50	8.72 ± 1.82	0.68	19.20	850
Cu	5.73 ± 2.30	0.20	18.00	3.63 ± 1.29	0.20	11.00	9.21 ± 2.13	1.10	21.00	8.33 ± 3.59	0.70	26.90	45
Ni	2.99 ± 1.11	0.00	8.10	4.70 ± 1.98	0.00	14.10	7.61 ± 2.53	0.00	19.10	8.66 ± 4.09	0.00	0.80	68
V	0.30 ± 0.13	0.00	0.85	0.41 ± 0.17	0.00	1.55	1.35 ± 0.56	0.00	4.10	0.33 ± 0.11	0.00	0.81	130

SQG – Geochemical background value taken is that given by Turekian and Wedepohl (1961).

Table 3. **Mean values of heavy metals concentration in *C. africana* samples from the Osse River**

Metal (mg/Kg)	Station 1			Station 2			Station 3			Station 4			Overall mean values
	Mean ± SE	Min.	Max.	Mean ± SE	Min.	Max.	Mean ± SE	Min.	Max.	Mean ± SE	Min.	Max.	
Fe	99.9 ± 13.30	68.30	186.30	100.4 ± 23.90	30.10	277.70	160.4 ± 30.30	85.00	361.40	156.4 ± 27.9	57.10	330.20	129.28
Zn	38.4 ± 7.50	9.00	71.40	47.0 ± 9.60	10	91.20	56.7 ± 12.20	8.00	99.50	39.6 ± 6.70	9.00	67.30	45.43
Cr	0.48 ± 0.16	0.00	1.35	1.06 ± 0.35	0.00	2.90	2.10 ± 0.78	0.00	6.92	0.47 ± 0.16	0.00	1.30	1.03
Cd	0.15 ± 0.10	0.00	0.84	0.15 ± 0.11	0.00	1.08	1.84 ± 0.60	0.00	4.50	0.18 ± 0.12	0.00	0.99	0.58
Pb	0.45 ± 0.14	0.00	0.99	0.59 ± 0.18	0.00	1.40	0.71 ± 0.21	0.00	1.67	0.59 ± 0.19	0.00	1.32	0.59
Mn	4.88 ± 1.87	0.00	18.40	7.97 ± 2.26	0.70	21.40	10.47 ± 2.37	4.30	28.3	8.06 ± 2.45	0.50	19	7.85
Cu	0.78 ± 0.23	0.12	1.80	1.47 ± 0.37	0.33	3.50	8.88 ± 4.81	1.22	52.00	4.55 ± 1.91	0.20	15.20	3.92
Ni	2.11 ± 0.88	0.00	6.50	1.85 ± 0.76	0.00	5.80	2.07 ± 0.79	0.00	5.80	2.43 ± 1.01	0.00	7.20	2.12
V	0.06 ± 0.04	0.00	0.37	0.12 ± 0.09	0.00	0.90	0.34 ± 0.23	0.00	1.91	0.20 ± 013	0.00	1.09	0.18

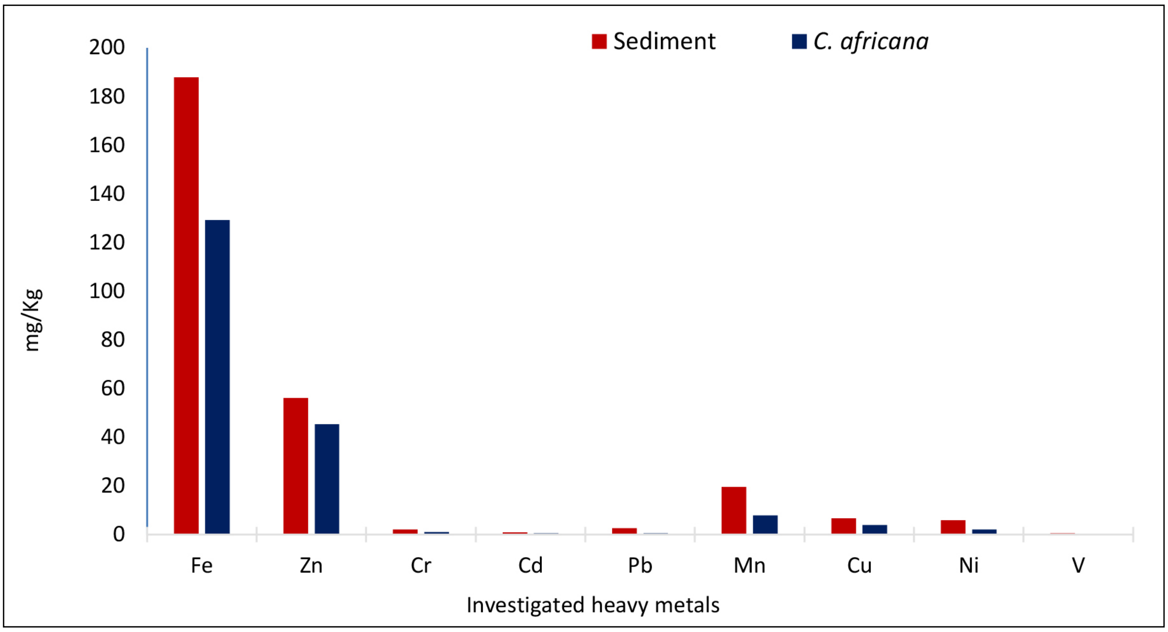

Fig. 2. Mean concentrations of heavy metals in the sediment and *C. africana*

Table 4. **Calculated contamination degree (CD) and the pollution load index (PLI) of sediment samples from the Osse River**

	Station 1	Station 2	Station 3	Station 4	All samples
Fe	23.16	45.81	66.42	23.81	39.80
Zn	0.82	0.33	0.76	0.58	0.62
Cr	0.009	0.02	0.05	0.01	0.02
Cd	1.22	3.37	7.43	1.13	3.29
Pb	0.08	0.17	0.16	0.11	0.13
Mn	0.03	0.03	0.03	0.01	0.02
Cu	0.13	0.08	0.21	0.19	0.15
Ni	0.04	0.07	0.11	0.13	0.09
V	0.002	0.003	0.010	0.003	0.005
CD	25.48	49.87	75.18	25.97	44.13
PLI	0.12	0.16	0.30	0.13	0.19

1, as CD values ranged from 25.48 (station 1) to 75.18 (station 3), while PLI values varied from 0.12 (station 1) to 0.30 (station 3). The individual potential risk of the heavy metals are summarised in Table 5. PERI values of the sediments ranged from 38.62 (station 1) to 226.27 (station 3). Similar to CD and PLI values, the order of PERI values was the following: station 3 > station 2 > station 4 > station 1. The calculated benthic to fauna TF values for heavy metals in the study varied from 0.23 to 0.81 (TF < 1) as shown in Table 6 and Fig. 3. The results of non-carcinogenic risk assessment of *C. africana* indicate a HI value of 2.83 (HI > 1), indicating a significant health risk to consumers. Carcinogenic risk estimation of heavy metals in *C. africana* gives a value of 7.06×10^{-3}, which classifies *C. africana* meat as high risk (Grade VI) to consumers (Table 7).

Table 5. **Individual potential risks (E^i_r) and the potential ecological risk index (PERI)**

	Station 1	Station 2	Station 3	Station 4	All samples
Zn	0.82	0.33	0.76	0.58	0.62
Cr	0.02	0.04	0.10	0.02	0.04
Cd	36.50	101.00	223.00	34.00	98.63
Pb	0.40	0.83	0.80	0.56	0.65
Mn	0.03	0.03	0.03	0.01	0.02
Cu	0.64	0.40	1.02	0.93	0.75
Ni	0.22	0.35	0.56	0.64	0.44
PERI	38.62	102.98	226.27	36.73	101.15

Table 6. **Calculated sediment-to-benthic TF of heavy metals**

	Sediment	*C. africana*	Calculated TF
Fe	187.85	129.275	0.69
Zn	56.20	45.425	0.81
Cr	2.18	1.0275	0.47
Cd	0.99	0.58	0.59
Pb	2.58	0.585	0.23
Mn	19.63	7.845	0.40
Cu	6.73	3.92	0.58
Ni	5.99	2.115	0.35
V	0.60	0.18	0.30

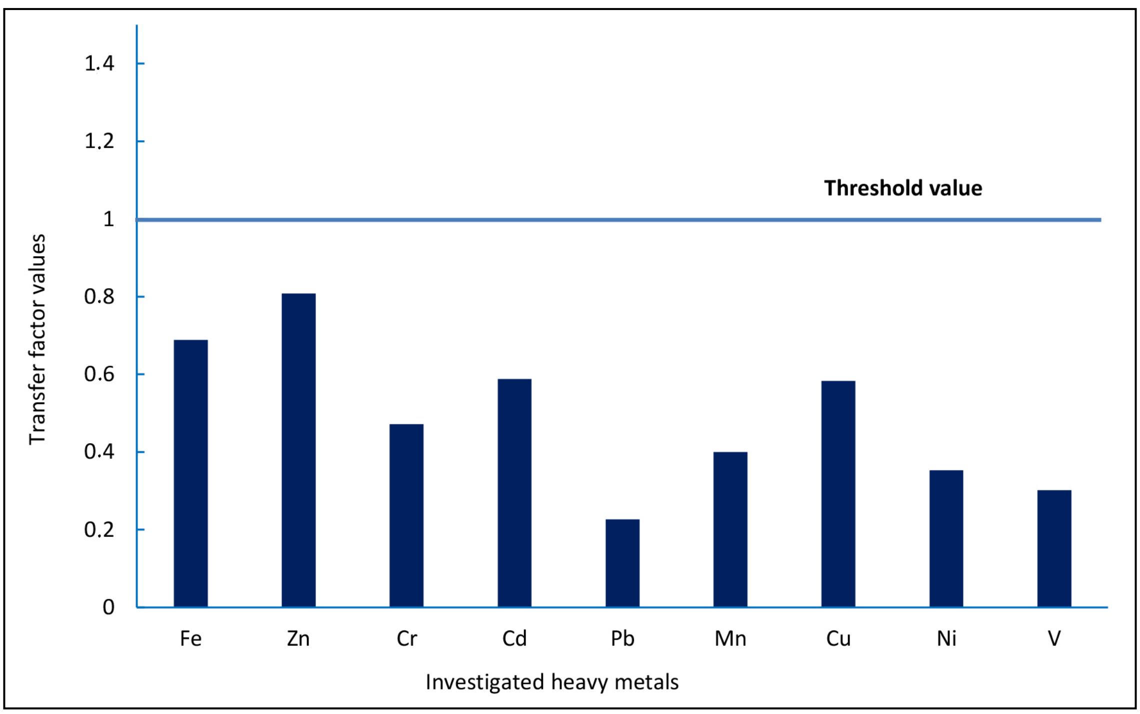

Fig. 3. TF of heavy metals in *C. africana*

Table 7. **Carcinogenic risk assessment of *C. africana***

Metals	C_m (mg/Kg)	EXP_{diet}	CSF_i	CRi
Cr	1.0275	0.001673	0.50	8.37 E-04
Cd	0.58	0.000945	0.38	3.59 E-04
Pb	0.585	0.000953	0.0085	8.10 E-06
Ni	2.115	0.003444	1.70	5.86 E-03
ICR				**7.06 E-03**

C_m is the overall average concentration of metal in *C. africana*,
EXP_{diet} is the average daily carcinogenic exposure dose,
CSF_i is the cancer slope factor for the reference metal through oral ingestion,
CR_i is the cancer risk value for the reference metal, and
ICR is the integrated carcinogenic risk value for *C. africana*

DISCUSSION

Variation of heavy metal concentrations in sediment

The distribution of heavy metals – Zn, Cr, Pb, Mn, Cu, Ni, and V – in the sediment of the Osse River indicated that Fe was the highest and V was the lowest in all four sampling stations. Station 3 recorded the highest mean content for – Cr, Pb, Cu and V, while stations 1, 2, and 4 had the highest mean concentrations for Zn, Mn, and Ni, respectively. Elevated levels of heavy metals at station 3 was attributed to the sediment ability to trap chemical contaminants released from the nearby petroleum processing facilities. The ability of mangrove forest sediments to act as entrapment for chemical contaminants, due to their high percentage content of silt and clay which causes an increase in the adsorption of heavy metals, was reported (Ranjan et al., 2008; Vallejuelo et al., 2010; Enuneku et al., 2018). In comparison with the USEPA Sediment Quality Guidelines (SQGs), the mean content of Fe and Cd in the sediment from all the stations in the Osse River exceeded their respective geochemical background levels, which is indicative of increased enrichment of sediments with heavy metals.

The CD and the PLI

The estimation of the magnitude of contamination of the individual heavy metals in reference to their geochemical background values showed that Zn, Cr, Pb, Mn, Cu, Ni, and V were of a low degree of contamination (CF < 1), Cd was of a substantial degree of contamination (CF < 6), and Fe was of a very high degree of contamination (CF > 6). The contamination degree (CD) of the heavy metals in the sediment samples from the Osse River, indicate a very high degree of sediment contamination from heavy metals (CD> 24), with the contamination factor (CF) for Fe contributing about 90% to CD in all the study stations.

The PLI values for sediment from the study stations were less than 1 (PLI < 1) indicating no sediment pollution. However, the highest PLI value of 0.30 recorded in sediments from station 3 is indicative of the substantial amount of anthropogenic activity involving the discharge of heavy metals within the surrounding areas. High PLI values (PLI > 1) in sediments is indicative of significant impacts of anthropogenic activities on sediment quality, while lower PLI values (PLI < 1) implies no substantial influence of anthropogenic activities on sediment quality.

Ecological risk assessment

The estimation of the ecological risk of heavy metals in the sediments using PERI showed that the individual potential risk of Zn, Cr, Pb, Mn, Cu, and Ni in all the sampling stations were below 40 ($E^i_r \leq 40$), which is indicative of low ecological risk, while Cd values were ≤40 in stations 1 and 4, ≤160 in station 2 (considerable ecological risk), and ≤320 in station 3 (indicating high ecological risk). The individual potential risk value of Cd accounted for over 90% of the PERI values in all the study locations. This emphasises the adverse effect Cd poses to benthic fauna and aquatic ecosystem of the Osse River. Furthermore, PERI values classified stations 1, 2, and 4 as of low ecological risk (PERI ≤ 150), while station 3 (PERI ≤ 300) was classified as moderate ecological risk. A similar study by Enuneku et al. (2018) reported that Cd had the highest individual potential risk value in the sediments of studied stations along the Benin River, as Cd concentrations were above its geochemical background value.

The CD, the PLI, and PERI values with the order station 3 > station 2 > station 4 > station 1 in this study has buttressed the fact that station 3 is seriously impacted by the ongoing petroleum exploration and processing activities within the surrounding area, while station 1, which is located upstream of the river, is least impacted.

Heavy metals in benthic fauna

The observed heavy metal concentration in *C. africana* collected from the various study stations in the Osse River showed that *C. africana* collected from station 3 recorded the highest content of investigated heavy metals. This is in cognizance with sediment estimations for CD, PLI and PERI, which recorded highest values at station 3. In comparison with the WHO/FAO (2011) recommended maximum levels of heavy metals in shell fish, mean Cu values in *C. africana* were below the 3.0 mg/Kg permissible limit; mean Pb values exceeded the 0.5 mg/Kg permissible, while mean content of Cd in *C. africana* samples from station 3 (1.84 mg/Kg) exceeded the tolerable value of 0.5 mg/Kg for human consumption. Enuneku et al (2018) reported similar elevated levels of heavy metals in shell fish (*T. fuscatus*) obtained from Benin River.

Transfer factor

The biotic transfer of heavy metals from sediment to benthic fauna has been seen as a major route in the biomagnification of heavy metals along the food web and route to exposure of humans to heavy metals. The estimation of the TF has developed as an important tool for investigating of human health risk index (Cui et al., 2004). The sediment to *C. africana* transfer values of heavy metals in this study indicate that there was bioaccumulation of heavy metals in *C. africana* but the heavy metals were not bio-magnified (TF < 1). According to Ibhadon et al. (2014), a TF of 1 and above (TF ≥ 1) for a particular metal is indicative that the metal is biomagnified. Although the TF values were low, bioaccumulation of metals with high toxicity and carcinogenic properties at low levels is a risk to the integrity of the aquatic ecosystem and public health.

Health risk assessment

In recent times, the assessment of health risk of human exposure to heavy metals through various identified routes has become of necessity due to increasing heavy metal pollution of the ecosystem. In this study, the non-carcinogenic risk evaluation of *C. africana* indicates that its consumption poses an obvious health risk (HI > 1) to the consumers, with Cd and Cr contributing 33.56% and 19.97% of the non-cancer effect of heavy metals to the HI of *C. africana*.

The carcinogenic risk estimation of heavy metals – Cr, Cd, Pb, and Ni – in *C. africana* indicated that cancer risk values for the metals did not exceed the USEPA (2005) permissible carcinogenic risk value of 1×10^{-4} for humans, except for Ni (5.86×10^{-3}). The content level of Ni in *C. africana* accounted for about 83% of the integrated carcinogenic risk (ICR) associated with the consumption of *C. africana* from the study location. In reference to the standards of carcinogenic values (Table 1), in this study the ICR value of 7.06×10^{-3} for *C. africana* categorises it as high carcinogenic risk to human health. This is a serious concern for public health, as *C. africana* harvested from the study locations is not only consumed locally but sold commercially in urban centres across the state. Therefore, there is need for urgent action to be taken in the abatement and regulation of the identified anthropogenic activities responsible for the release of these heavy metals into the Osse River.

CONCLUSIONS

The concern on the deterioration of the aquatic ecosystem caused by the increasing deposit of pollutants in the aquatic milieu has necessitated this investigation to ascertain the content of heavy metals in the sediment and *C. africana* of the Osse River and to evaluate the ecological risk of the contaminated sediments as well as the human health risk as an outcome of the ingestion of *C. africana.* The results show heavy metal contamination of both sediment and *C. africana* from the study stations, with variations in heavy metal concentrations largely influenced by anthropogenic activities within the vicinity of the respective stations. Although Fe contributed significantly to the contamination degree of the sediments, Cd was considered to be of higher ecological risk as its concentration accounted for over 90% of the PERI values in all the study locations. Bioaccumulation of heavy metals in *C. africana* was observed, but the heavy metals were not bio-magnified as the calculated TF were below 1. Human health risk assessment associated with the consumption of *C. africana* showed that the HI values for heavy metals were >1, which implies significant non-carcinogenic health risk to consumers. Also, the carcinogenic risk estimation for *C. africana* categorises it as of high carcinogenic risk to human health. The consumption of the contaminated *C. africana*, which is harvested in commercial quantities from the Osse River, portends health risk to the general public. There is the need for urgent action to be taken in the abatement and regulation of the identified anthropogenic activities responsible for the release of these heavy metals into the Osse River.

Acknowledgements

The authors are grateful to all the laboratory technicians at Benin Owena River Basin/University of Benin Joint Analytical Laboratory, University of Benin, Nigeria, who contributed to producing high-quality analytical data.

Declarations

The authors have no financial or non-financial interests to disclose.

The authors have no competing interests to declare that are relevant to the content of this article.

Received 14 July 2023
Accepted 3 August 2023

References

1. Abdallah MAM, Abdallah AMA. Biomonitoring study of heavy metals in biota and sediments in the south eastern coast of Mediterranean Sea, Egypt. Environ Monit Assess. 2008; 146: 139–45.
2. APHA/AWWA/WEF. Standard methods for the examination of water and wastewater. American Public Health Association, Washington, DC, 2012.
3. Barakat A, El Baghdadi M, Rais J, Nadem S. Assessment of heavy metal in surface sediments of day river at Beni-Mellal-Region, Morocco. Res J Environ Earth Sci. 2012; 4: 797–806.
4. Chien LC, Hung TC, Choang KY, Yeh CY, Meng PJ, Shieh MJ, Ha BC. Daily intake of TBT, Cu, Zn, Cd and As for fishermen in Taiwan. Sci Total Environ. 2002; 285: 177–85.
5. Cooper CB, Doyle ME, Kipp K. Risk of consumption of contaminated seafood, the Quincy Bay case study. Environ Health Perspect. 1991; 90: 133–40.
6. Cui YJ, Zhu YG, Zhai RH, Chen DY, Huang YZ, Qui Y, Liang JZ. Transfer of metals from near a smelter in Nanning, China. Environ Int. 2004; 30 :785–91.
7. Egun NK, Oboh IP. Surface water quality evaluation of Ikpoba reservoir, Edo State, Nigeria. Int J Energ Water Res. 2021; 6: 509–19.

8. Egun NK, Oboh IP. Assessment of water quality for suitability and human health risk: a study of the Owan River, Edo State, Nigeria. Afr J Aquat Sci. 2023; 48: 19–27.
9. Ekhator O, Izegaegde JI, Osadebamwen OS. Assessment of water quality index (WQI) for Osse River in Edo State, Southern Nigeria. Niger Ann Nat Sci. 2015; 15: 031–041.
10. Enuneku A, Omoruyi O, Tongo I, Ogbomida E, Ogbeide O, Ezemonye L. Evaluating the potential health risks of heavy metal pollution in sediment and selected benthic fauna of Benin River, Southern Nigeria. Appl Water Sci. 2018; 8: 224.
11. Zeng GM, Li XM, Zhuo L, Zhong ZL, Zhang PY. Assessment models for water environmental health risk analysis. Adv Water Sci. 1998; 9: 212–7.
12. Guy HP. Laboratory theory and methods for sediment analysis. Techniques for water resources investigations 05-C1. USGS Publications Warehouse, 1969. https://doi.org/10.3133/twri05C1
13. Håkanson L. An ecological risk index for aquatic pollution control–a sedimentological approach. Water Res. 1980; 14:9 75–1001.
14. Harikumar PS, Nasir UP, Rahman MPM. Distribution of heavy metals in the core sediments of a tropical wetland system. Int J Environ Sci Technol. 2009; 6: 225–32.
15. Ibhadon S, Emere MC, Abdulsalami MS, Yilwa V. Bioaccumulation of some trace metals in wild and farm-raised African Catfish *Clarias gariepinus* in Kaduna, Nigeria. Pak J Nutri. 2014; 13: 686–91.
16. Jiao X, Teng Y, Zhan Y, Wu J, Lin X. Soil heavy metal pollution and risk assessment in Shenyang industrial district, Northeast China. PLoS ONE. 2015; 10: e0127736.
17. Li F, Qiu Z, Zhang J, Liu C, Cai Y, Xiao M. Spatial Distribution and Fuzzy Health Risk Assessment of Trace Elements in Surface Water from Honghu Lake. IJERPH. 2017; 14: 1011.
18. Liu YJ, Liang J, Yuan XZ, Zeng GM, Yuan YJ, Wu HP, Li F, Li X. An integrated risk model for assessing heavy metal exposure to migratory birds in wetland ecosystem: A case study in Dongting Lake wetland, China. Chemosphere. 2015; 525: 450–6.
19. Luo W, Lu Y, Wang T, Hu W, Jiao W, Naile JE, Khim JS, Giesy JP. Ecological risk assessment of arsenic and elements in sediments of coastal areas of Northern Bohai and Yellow Seas, China. Ambio. 2010; 39: 367–75.
20. Massaquoi LD, Ma H, Liu XH, Han PY, Zuo SM, Hua ZX, Liu DW. Heavy metal accumulation in soils, plants, and hair samples: an assessment of heavy metal exposure risks from the consumption of vegetables grown on soils previously irrigated with wastewater. Environ Sci Pollut Res Int. 2015; 22: 18456–68.
21. Olomukoro JO, Abdul-Rahman D. Macroinvertebrate community and pollution tolerance index in Edion and Omodo rivers in derived savannah wetlands in Southern Nigeria. Jordan J Biol Sci. 2014; 7: 19–24.
22. Omoigberale MO, Ogbeibu AE. Assessing the environmental impacts of oil exploration and production on the water quality of Osse River, southern Nigeria. Glob J Environ Sci. 2007; 6: 1–13.
23. Ranjan RK, Ramanathan A, Singh G, Chidambaram S. Assessment of metal enrichments in tsunamigenic sediments of Pichavaram mangroves, southeast coast of India. Environ Monit Assess. 2008; 147: 389–411.
24. Saha P, Paul B. Suitability assessment of surface water quality with reference to drinking, irrigation and fish culture: a human health risk perspective. Bull Environ Contam Toxicol. 2018; 101: 262–71.
25. Soliman NF, Nasr SM, Okbah MA. Potential ecological risk of heavy metals in sediments from the Mediterranean coast, Egypt. J Environ Health Sci Eng. 2015; 13: 70–81.
26. Tomilson DC, Wilson JG, Harris CR, Jeffrey DW. Problems in assessment of heavy

metals in estuaries and the formation of pollution index. Helgol Meeresunlters. 1980; 33: 566–75.

27. Tripathee L, Kang S, Sharma CM, Rupakheti D, Paudyal R, Huang J, Sillanpää M. Preliminary health risk assessment of potentially toxic metals in surface water of the Himalayan Rivers, Nepal. Bull Environ Contam Toxicol. 2016; 97: 855–62.
28. United Nations, Department of Economic and Social Affairs, Population Division. 2019. World Population Prospects 2019: Data Booklet (ST/ESA/SER.A/424).
29. USEPA. 2004. Risk assessment guidance for superfund: Vol. I: Human health evaluation manual (Part E, supplemental guidance for dermal risk assessment) final. EPA/540/R/99/005 OSWER 9285.7-02EP PB99-963312 July 2004. Office of Superfund Remediation and Technology Innovation, Washington, DC.
30. USEPA. 2012. Risk assessment guidance for superfund: Vol. III Part A. Process for conducting probalistic risk assessment EPA, 540-R-02-002 OSWER 9285745PB2002 963302. USEPA, Human health risk assessment. Available at http://www.epa.gov/riskk/health-risk.html (cited 2017 June 6)
31. USEPA. 2021. Regional screening levels (RSLs) – generic tables. Tables as of May 2021. https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables (cited 2021 September 24).
32. USEPA. 2005. Guidelines for carcinogen risk assessment [Internet]. Washington, D.C.: United States Environmental Protection Agency; 2005 Mar [cited 2015 Nov 13]. 166 p. Available from: http://www3.epa.gov/airtoxics/cancer_ guidelines_final_3-25-05.pdf
33. Uwaifo OP, Omogbeme MI, Olomukoro JO. Water quality assessment of Osse River, Gelegele: a tributary of Benin River, southern Nigeria. J Appl Sci Environ Manag. 2018; 22: 1349–54.
34. Vallejuelo SF, Arana G, Diege AD, Madariaga JM. Risk assessment of trace elements in sediments: the case of the estuary of the Nerbioi-Ibaizabal River (Basque Country). J Hazard Mater. 2010; 181: 565–73.
35. WHO/FAO. 2011. Recommended maximum levels of heavy metals in shell fish.
36. Yang Z, Lu W, Long Y, Bao X, Yang Q. Assessment of heavy metals contamination in urban topsoil from Changchun City, China. J Geochem Explor. 2011; 108: 27–38.
37. Yuan XH, Wang FF, Zhang JS. Integrated fuzzy model based on interval number for the assessment of environmental health risk of drinking water resources. J Saf Environ. 2011; 11: 129–33 (In Chinese).
38. Zheng N, Wang Q, Zhang X, Zheng D, Zhang Z, Zhang S. Population health risk due to dietary intake of heavy metals in the industrial area of Huludao City, China. Sci. Total Environ. 2007; 387: 96–104.

Peter Osaretin Uwaifo, Nkonyeasua Kingsley Egun, Timothy Imuetinya Agho

TROPINIO LOTIKO GĖLAVANDENĖS EKOSISTEMOS NUOSĖDŲ IR BENTOSO FAUNOS UŽTERŠTUMO METALOIDAIS EKOTOKSIKOLOGINĖS RIZIKOS VERTINIMAS PIETŲ NIGERIJOJE

Santrauka

Gausėjantys teršalai gėlo vandens telkiniuose ir sunkiųjų metalų bioakumuliacija vandens organizmuose kelia ekotoksikologinį pavojų ir didina riziką žmonių sveikatai. Šiame tyrime buvo įvertintas galimas sunkiųjų metalų taršos Osse upės (Edo valstija, Nigerija) nuosėdose ir bentoso faunoje (*Caridina africana*) ekologinis ir žmonių sveikatai keliamas pavojus. Vandens nuosėdų ir *C. africana* mėginiai buvo paimti stotyse nuo 2015 m. rugsėjo iki 2017 m. vasario mėnesio. Sunkiųjų metalų koncentracijos mėginiuose nustatytos atominės absorbcijos spektrofotometru. Tyrimo duomenys atskleidė nuosėdų ir *C. africana* užterštumą sunkiaisiais metalais (atitinkamai Fe > Zn > Mn > Cu > Ni > Pb > Cr > Cd > V ir Fe > Zn > Mn > Cu > Ni > Cr > Pb > Cd > V). Potencialios ekologinės rizikos indekso (PERI) vertės 1, 2 ir 4 stotis priskyrė mažos ekologinės rizikos (PERI ≤ 150), o 3 stotį (PERI ≤ 300) – vidutinės ekologinės rizikos kategorijai. Sunkiųjų metalų kiekiai bentoso faunoje (*C. africana*) rodo reikšmingą nekancerogeninę (HI > 1) ir didelę kancerogeninę riziką žmonių sveikatai. Užterštos *C. africana*, kuri surenkama komerciniais kiekiais, vartojimas kelia pavojų visuomenės sveikatai. Būtina skubiai mažinti ir reguliuoti šių sunkiųjų metalų išmetimą į Osse upę.

Raktažodžiai: sunkieji metalai, rizikos žmogaus sveikatai vertinimas, ekologinė rizika, nuosėdos, *Caridina africana*, Osse upė