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

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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

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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 Iziedema 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](image)
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 (HNO₃) and 10 mL perchloric acid (HClO₄) 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 triacid mixture (HNO₃:HClO₄:H₂SO₄ = 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):

\[
PLI = (C_{F1} \times C_{F2} \times C_{F3} \ldots \ldots \times C_{Fn})^{1/n},
\]

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

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:

\[
CD = \sum_{i=1}^{n} C_{Fi}.
\]

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,

\[ E_i^r = T_i^r \times CF_i \]

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; Solomon et al., 2015).

PERI is the summation of the individual potential risks \( (E_i^r) \). It is presented as:

\[ \text{PERI} = \sum_{i=1}^{n} E_i^r. \]

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 \( E_i^r > 320 \) 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:

\[ TF = \frac{C_{\text{fauna}}}{C_{\text{sediment}}}, \]

where \( C_{\text{fauna}} \) is the concentration of heavy metals in \( C. \text{africana} \) and \( C_{\text{sediment}} \) 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 \( C. \text{africana} \) was determined by the equation (USEPA, 2012):

\[ \text{EXP}_{\text{diet}} = \frac{C_m \times \text{IR} \times \text{ED} \times \text{EF}}{\text{BW} \times \text{AT}}, \]

where, \( C_m \) is the mean content of heavy metal in \( C. \text{africana} \) (mg/Kg). IR is the ingestion rate of \( C. \text{africana} \) (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 \( C. \text{africana} \) 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):

\[ \text{THQ}_{\text{diet}} = \frac{\text{EXP}_{\text{diet}}}{\text{RID}_{\text{diet}}}, \]

where \( \text{RID} \) (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 \text{THQ}_{\text{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$_{\text{diet}}$) and the cancer slope factor (CSF).

\[
\text{CR}_i = \text{EXP}_{\text{diet}} \times \text{CSF}_i,
\]

where CR$_i$ is the carcinogenic risk of heavy metals through oral route,

- EXP$_{\text{diet}}$ 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.

\[
\text{ICR} = \sum_{i=1}^{n} \text{CR}_i.
\]

USEPA (2005) believes that the carcinogenic risk value for humans is acceptable within $1 \times 10^{-4}$, while the maximum acceptable risk value recommended by International Commission on Radiological Protection (ICRP) is $5 \times 10^{-5}$ (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 5.

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

<table>
<thead>
<tr>
<th>Risk grades</th>
<th>Range of risk value</th>
<th>Acceptability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade I</td>
<td>Extremely low risk</td>
<td>&lt;10–6</td>
</tr>
<tr>
<td>Grade II</td>
<td>Low risk</td>
<td>(10–6, 10–5)</td>
</tr>
<tr>
<td>Grade III</td>
<td>Low-medium risk</td>
<td>(10–5, 5 $\times$ 10–5)</td>
</tr>
<tr>
<td>Grade IV</td>
<td>Medium risk</td>
<td>(5 $\times$ 10–5, 10–4)</td>
</tr>
<tr>
<td>Grade V</td>
<td>Medium-high risk</td>
<td>(10–4, 5 $\times$ 10–4)</td>
</tr>
<tr>
<td>Grade VI</td>
<td>High risk</td>
<td>(5 $\times$ 10–4, 10–3)</td>
</tr>
<tr>
<td>Grade VII</td>
<td>Extremely high risk</td>
<td>&gt;10–3</td>
</tr>
</tbody>
</table>

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*Note:* CD, concentration factor; PLI, pollution load index.
Table 2. Mean values of heavy metal concentration in the sediment samples from the Osse River

<table>
<thead>
<tr>
<th>Metal (mg/Kg)</th>
<th>Station 1</th>
<th>Station 2</th>
<th>Station 3</th>
<th>Station 4</th>
<th>SQG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>109.3 ± 13.2</td>
<td>33.80</td>
<td>183.20</td>
<td>216.2 ± 24.5</td>
<td>27.10</td>
</tr>
<tr>
<td>Zn</td>
<td>74.1 ± 19.9</td>
<td>11.50</td>
<td>167.00</td>
<td>30.0 ± 7.40</td>
<td>10.70</td>
</tr>
<tr>
<td>Cr</td>
<td>0.86 ± 0.21</td>
<td>0.00</td>
<td>1.90</td>
<td>1.77 ± 0.63</td>
<td>0.00</td>
</tr>
<tr>
<td>Cd</td>
<td>0.37 ± 0.14</td>
<td>0.00</td>
<td>1.10</td>
<td>1.01 ± 0.44</td>
<td>0.00</td>
</tr>
<tr>
<td>Pb</td>
<td>1.59 ± 0.63</td>
<td>0.00</td>
<td>4.70</td>
<td>3.30 ± 1.33</td>
<td>0.00</td>
</tr>
<tr>
<td>Mn</td>
<td>21.0 ± 4.96</td>
<td>0.29</td>
<td>41.70</td>
<td>27.1 ± 7.22</td>
<td>0.21</td>
</tr>
<tr>
<td>Cu</td>
<td>5.73 ± 2.30</td>
<td>0.20</td>
<td>18.00</td>
<td>3.63 ± 1.29</td>
<td>0.20</td>
</tr>
<tr>
<td>Ni</td>
<td>2.99 ± 1.11</td>
<td>0.00</td>
<td>8.10</td>
<td>4.70 ± 1.98</td>
<td>0.00</td>
</tr>
<tr>
<td>V</td>
<td>0.30 ± 0.13</td>
<td>0.00</td>
<td>0.85</td>
<td>0.41 ± 0.17</td>
<td>0.00</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Metal (mg/Kg)</th>
<th>Station 1</th>
<th>Station 2</th>
<th>Station 3</th>
<th>Station 4</th>
<th>Overall mean values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>99.9 ± 13.3</td>
<td>68.30</td>
<td>186.30</td>
<td>100.4 ± 23.9</td>
<td>30.10</td>
</tr>
<tr>
<td>Zn</td>
<td>38.4 ± 7.50</td>
<td>9.00</td>
<td>71.40</td>
<td>47.0 ± 9.60</td>
<td>10.00</td>
</tr>
<tr>
<td>Cr</td>
<td>0.48 ± 0.16</td>
<td>0.00</td>
<td>1.35</td>
<td>1.06 ± 0.35</td>
<td>0.00</td>
</tr>
<tr>
<td>Cd</td>
<td>0.15 ± 0.10</td>
<td>0.00</td>
<td>0.84</td>
<td>0.15 ± 0.11</td>
<td>0.00</td>
</tr>
<tr>
<td>Pb</td>
<td>0.45 ± 0.14</td>
<td>0.00</td>
<td>0.99</td>
<td>0.59 ± 0.18</td>
<td>0.00</td>
</tr>
<tr>
<td>Mn</td>
<td>4.88 ± 1.87</td>
<td>0.00</td>
<td>18.40</td>
<td>7.97 ± 2.26</td>
<td>0.70</td>
</tr>
<tr>
<td>Cu</td>
<td>0.78 ± 0.23</td>
<td>0.12</td>
<td>1.80</td>
<td>1.47 ± 0.37</td>
<td>0.33</td>
</tr>
<tr>
<td>Ni</td>
<td>2.11 ± 0.88</td>
<td>0.00</td>
<td>6.50</td>
<td>1.85 ± 0.76</td>
<td>0.00</td>
</tr>
<tr>
<td>V</td>
<td>0.06 ± 0.04</td>
<td>0.00</td>
<td>0.37</td>
<td>0.12 ± 0.09</td>
<td>0.00</td>
</tr>
</tbody>
</table>
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

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

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 $7.06 \times 10^{-3}$, which classifies *C. africana* meat as high risk (Grade VI) to consumers (Table 7).
Table 5. Individual potential risks ($E_i$) and the potential ecological risk index (PERI)

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

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

<table>
<thead>
<tr>
<th></th>
<th>Sediment</th>
<th>$C.\text{africana}$</th>
<th>Calculated TF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>187.85</td>
<td>129.275</td>
<td>0.69</td>
</tr>
<tr>
<td>Zn</td>
<td>56.20</td>
<td>45.425</td>
<td>0.81</td>
</tr>
<tr>
<td>Cr</td>
<td>2.18</td>
<td>1.0275</td>
<td>0.47</td>
</tr>
<tr>
<td>Cd</td>
<td>0.99</td>
<td>0.58</td>
<td>0.59</td>
</tr>
<tr>
<td>Pb</td>
<td>2.58</td>
<td>0.585</td>
<td>0.23</td>
</tr>
<tr>
<td>Mn</td>
<td>19.63</td>
<td>7.845</td>
<td>0.40</td>
</tr>
<tr>
<td>Cu</td>
<td>6.73</td>
<td>3.92</td>
<td>0.58</td>
</tr>
<tr>
<td>Ni</td>
<td>5.99</td>
<td>2.115</td>
<td>0.35</td>
</tr>
<tr>
<td>V</td>
<td>0.60</td>
<td>0.18</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Fig. 3. TF of heavy metals in $C.\text{africana}$
Table 7. Carcinogenic risk assessment of *C. africana*

<table>
<thead>
<tr>
<th>Metals</th>
<th>(C_m) (mg/Kg)</th>
<th>EXP\textsubscript{diet}</th>
<th>CSFi</th>
<th>CRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr</td>
<td>1.0275</td>
<td>0.001673</td>
<td>0.50</td>
<td>8.37 E-04</td>
</tr>
<tr>
<td>Cd</td>
<td>0.58</td>
<td>0.000945</td>
<td>0.38</td>
<td>3.59 E-04</td>
</tr>
<tr>
<td>Pb</td>
<td>0.585</td>
<td>0.000953</td>
<td>0.0085</td>
<td>8.10 E-06</td>
</tr>
<tr>
<td>Ni</td>
<td>2.115</td>
<td>0.003444</td>
<td>1.70</td>
<td>5.86 E-03</td>
</tr>
</tbody>
</table>

\(C_m\) is the overall average concentration of metal in *C. africana*,

EXP\textsubscript{diet} is the average daily carcinogenic exposure dose,

CSFi is the cancer slope factor for the reference metal through oral ingestion,

CRi 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 $1 \times 10^{-4}$ for humans, except for Ni ($5.86 \times 10^{-3}$). 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 $7.06 \times 10^{-3}$ 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 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.

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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.

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

Santrauka
Gausėjantys teršalai gėlo vandens telkiniuose ir sunkiujų metalų bioakumuliacija vandens organizmų kelia ekotoksikologinį pavojų ir didina riziką žmonių sveikatai. Šiame tyrime buvo įvertintas galimas sunkiujų metalų taršos Osse upės (Edo valstija, Nigerija) nuosėdose ir bentoso faunos (Caridina africana) ekologinis ir žmonių sveikatai keliamas pavojus. Vandens nuosėdų ir C. africana mėginiui buvo paimti stotyse nuo 2015 m. rugpjūčio iki 2017 m. vasario mėnėsio. Sunkiujų metalų koncentracijos mėginiuose nustatytos atominės absorbcijos spek trofotometru. 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