Noncarcinogenic risk assessment of ten heavy metals in nine freshwater species sourced from market-ready landing sites

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Abstract

The public health risks associated with consumption of freshwater species potentially contaminated with metals at Otuo-cha, Ose and Atani landing sites in Anambra State, Nigeria were assessed. Species comprising seven fishes (*Malapterurus electricus*, *Clarias gariepinus*, *Tilapia zillii*, *Gnathonemus tamandua*, *Citharinus citharus*, *Oreochromis niloticus* and *Auchenoglanis occidentalis*) and two edible snails (*Bulinus globosus* and *Bulinus africanus*) were analysed for ten heavy metals with known varying degrees of toxicities: arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), manganese (Mn), nickel (Ni), lead (Pb), iron (Fe), copper (Cu) and zinc (Zn). Results showed that concentrations of As (4.76 mg kg^{-1}), Cr ($1.54 - 6.60 \text{ mg kg}^{-1}$) and Hg ($1.07 - 2.66 \text{ mg kg}^{-1}$) were higher than the FAO/WHO safe limits. The calculated target hazard quotient and hazard index values, representing quantitative estimates of noncarcinogenic risk of dietary exposure from freshwater species consumption, were below 1 for all metals, which indicate that freshwater species pose no noncancer risk from oral exposure under the environmental conditions of the study. Further studies across spatiotemporal scale are recommended to understand impact of season–location variables on metal concentrations in those freshwater species examined.

Keywords Exposure · Freshwater species · Metals · Noncancer · Landing sites

1 Introduction

There has been a growing community concern among residents within riverine areas of Anambra State Nigeria about the potential contamination of freshwater ecosystems that hold critical livelihood economics of the community through fish trade. A body of empirical research in River Niger and Anambra River, the largest freshwater ecosystems in the state, has shown the degree to which the systems are contaminated with appreciable metal concentrations that potentially pose public health risks to freshwater food consumers [1–5]. The river sites studied represent zones of unregulated waste disposal and human

activities that threaten ecology of those freshwater systems. What is lacking, however, is that the environmental health risk assessment associated with freshwater food consumption in a significant number of these studies is highly limited in scope and fails to include a crucial step in freshwater food value chain—landing sites. A lack of consideration of roles landing sites play in risk profiling often leads to hasty conclusions founded on less data-informed accurate risk assessment.

Fish and freshwater species landing sites are a critical component of the local freshwater food value chain and characterise the pattern associated with catches of edible water species landed in domestic anchorages for trade and

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transport to market [6]. Accurate risk profiling of freshwater species on landing sites is a significant public health control point and provides first-hand information on toxicological status of the collected fish and contamination trails along the value chain. The information at this stage integrates risk with demand–supply data and provides further understanding of how contaminants transfer and transport from freshwater to terrestrial food chains, which prompts an early warning for a proactive food risk management response.

Freshwater animals constitute an affordable source of food rich in animal protein that is vital to a local population that depend on freshwater resources and fishing activities for livelihoods [3, 7]. Being bioactive species with diverse reactive biotic ligands, freshwater fish and snails accumulate environment-derived metals in their tissues at higher concentration than inhabiting media with adverse effects sometimes to potential feeders along the food chain or web [5, 7–9]. However, essential metals such as copper (Cu), chromium (Cr), iron (Fe), nickel (Ni), manganese (Mn) and zinc (Zn) play important roles in biological systems, but when in excess, produce toxic effects [10]. Nonessential metals such as arsenic (As), lead (Pb), cadmium (Cd) and mercury (Hg) on the other hand are toxic even in trace amounts [10]. Assessment of metals in edible freshwater species-based food not only shows the extent of its safety for consumers, but also gives an insight on the degree of contamination of water bodies.

Given that important information on metal concentrations in freshwater species collected from landing sites is relatively scarce in Nigeria, this study aimed to analyse As, Cd, Cr, Hg, Mn, Ni, Pb, Fe, Cu and Zn concentrations in tissues of widely consumed seven fishes and two snails sourced from three market-ready fish landing sites in Anambra State. In order to understand the public health implications of consuming those freshwater species, quantitative risk estimation basis on hazard and exposure non-carcinogenic valuation was determined.

2 Materials and methods

2.1 Location description

Three market-ready fish landing sites, Otuocho, Ose and Atani, were selected for the study. These sites are largely located along Anambra River and sparsely distributed tributaries of River Niger in Anambra state where ~97% of the freshwater species distributed to markets for sale in the state (and other parts of Nigeria) are sourced and collected. Anambra River is the largest river in Anambra State, with a spatial location between latitude 6°10' and 7°20' N and longitude 6°35' and 7°40' E (Fig. 1). With a

large basin of 14,010 km², the river is the largest tributary of River Niger flowing 210 km below Lokoja [11]. The climate is tropical with annual rainfall exceeding 1500 mm per annum, temperature between 23 and 35 °C, and seasonal flooding makes it productive in terms of biodiversity and agricultural purposes. River Niger is the largest river in Nigeria with major tributaries traversing various states and locations of the country. The Lower Niger River, which cuts across Anambra and Niger Delta, is significant and has been the subject of a recent review that has characterised the river ecology, spatial geography and biogeochemistry [11].

Several tributaries of River Niger and Anambra River flow through agricultural and industrialised areas reported to be contributing to contamination of its resources [5, 11]. Both rivers are predominantly exposed to persistent problems of drought, deforestation, erosion, flooding, farming, fishing, marketing activities, waste disposal, sand mining and excavation and sewage disposal. Significant flanks of tributaries of both rivers are in spatial proximity to Onitsha metropolis that has a range of urban and industrial activities generating and dispersing effluents and municipal wastes to the environment [5, 11].

2.2 Sampling, preparation and analysis

About five samples each of the nine freshwater species, which represent preponderant fishes and snails (e.g. *Bulinus globosus* and *Bulinus africanus*) sold on markets and popularly consumed by people were collected from landing sites in Otuocho (*Malapterurus electricus*, *Clarias gariepinus*, *Tilapia zillii* and *Snail*, *Bulinus globosus*), Ose (*Tilapia zillii*, *Gnathonemus tamandua*, *Citharinus citharus* and *Snail*, *Bulinus africanus*) and Atani (*Clarias gariepinus*, *Oreochromis niloticus*, *Auchenoglanis occidentalis* and *Snail*, *Bulinus africanus*). We further provide in Table 1 the habitat preference and feeding trophic ecology of the selected samples to underpin understanding of species differential metal bio-uptake relative to environmental inclination and dietary requirements and plasticity. Both the habitat preference and feeding habits of the samples were determined following various trophic ecological attributes that may affect environment predilection and feeding biology including season, milieu changes and plasticity, prey availability and biometric and morphometric characteristics [12–16].

Collected samples of the freshwater species were washed and transported to laboratory after preservation in not less 2 °C icebox. On arrival at the laboratory, samples were identified and dissected with a clean knife. Edible fillet tissue of each species was collected and stored at –20 °C prior to metals analysis [7, 17].

Fig. 1 Map of Anambra State showing the three fish landing sites studied

Individual frozen samples were weighed and dried in Gallenkamp® oven at 105 °C and pulverised with a pre-cleaned pestle and porcelain mortar into fine powder. 1 g each of the ground fillet samples was dissolved and digested in a 70% mix of concentrated sulphuric acid, concentrated nitric acid and perchloric acid at a ratio of 1:5:1, respectively, at 80 °C, until a colourless solution was

observed. Digested solutions were allowed to cool and filtered through Whatman No. 41 filter paper, which were thereafter, filled up to 20 ml volume with distilled water. Metal concentrations in each of the prepared solutions were determined using atomic absorption spectrophotometer (Varian Techtron Spectra B®) with the recorder staged at 10 mV and aspiration rate at 6 ml min⁻¹. Quality

Table 1 Habitat-feeding characteristics of freshwater species sourced from market-ready landing sites in Anambra State

S/N	Freshwater species	Habitat preference	Feeding habit
1	<i>Bulinus globosus</i>	Benthic	Omnivorous, detritivorous
2	<i>Bulinus africanus</i>	Benthic	Omnivorous, detritivorous
3	<i>Malapterurus electricus</i>	Benthic	Carnivorous
4	<i>Clarias gariepinus</i>	Benthic	Omnivorous
5	<i>Tilapia zillii</i>	Pelagic	Omnivorous
6	<i>Gnathonemus tamandua</i>	Demersal	Carnivorous, detritivorous
7	<i>Citharinus citharus</i>	Demersal	Omnivorous, detritivorous
8	<i>Oreochromis niloticus</i>	Benthopelagic	Omnivorous
9	<i>Auchenoglanis occidentalis</i>	Pelagic	Omnivorous

assurance and control methods were carefully practised ensuring accurate procedures. Distilled water was used to wash freshwater samples to remove surface contaminants before dissection. During heavy metal analysis, precautions were followed to prevent cross-contamination. Each analytical batch of ten runs was accompanied by an acid blank and three certified reference materials (CRM). Mean recoveries were in an acceptable range (90–99.5%) compared to the CRM theoretical or certified values for the metals [17]. Results were expressed in mg kg^{-1} dry weight with instrumental detection limit of 0.001 mg kg^{-1} dry weight and compared with FAO/WHO Codex Alimentarius (or Food Code). The Codex has worked since 1963 to create harmonised international food standards to protect the health of consumers and ensure fair trade practices [18, 19].

Data normality was checked using the Shapiro–Wilk test, while Levene's test was used to analyse homogeneity of variance. For normally distributed data, a parametric one sample Student's *t* test was used to compare metal concentrations with FAO/WHO standards. For data that could not be normalised, a nonparametric Mann–Whitney *U* test was applied for comparison.

2.3 Exposure and noncarcinogenic risk assessment

Target hazard quotient (THQ) used to characterise oral metal exposure and chronic noncarcinogenic risk was conducted following established methods and assumptions [2, 7, 20–25]:

$$\text{THQ} = \frac{\text{ADI}}{\text{RfD}} \quad \text{where ADI} = \frac{\text{MC} \times \text{IR} \times \text{EF} \times \text{ED} \times \text{CF}}{\text{BW} \times \text{ATn}} \text{ is the average daily intake}$$

MC = metal mean concentration (mg kg^{-1}), IR = the daily ingestion rate (adult) (0.04 kg), EF = the exposure frequency (365 days/year), ED = the exposure duration for noncarcinogens (30 years), CF = the conversion factor (0.21) at 79% of moisture content, BW = average adult

body weight (70 kg), ATn = average exposure time for non-carcinogens (10,950 days), and RfD = reference dose of individual metals, including As, Hg, Cu, Cr, Cd, Fe, Ni, Zn, Pb and Mn at $3.00\text{E}-04$, $1.60\text{E}-04$, $4.00\text{E}-01$, $3.00\text{E}-03$, $1.00\text{E}-03$, $7.00\text{E}-01$, $2.00\text{E}-02$, $3.00\text{E}-01$, $3.5\text{E}-03$ and $1.40\text{E}-01 \text{ mg kg}^{-1} \text{ day}^{-1}$, respectively) [22]. The hazard index (HI) was further calculated from THQ values as follows:

$$\text{HI} = \text{THQ (As)} + \text{THQ (Pb)} + \text{THQ (Cr)} + \text{THQ (Cd)} + \text{THQ (Mn)} \\ + \text{THQ (Hg)} + \text{THQ (Ni)} + \text{THQ (Cu)} + \text{THQ (Zn)} + \text{THQ (Fe)}.$$

3 Results and discussion

Concentrations of metals in the species collected from the landing sites and their comparisons with the FAO/WHO standards are shown in Table 2. Generally, there were observed differential patterns in accumulation of examined metals, which may be linked to species variation, life stages, environmental factors, biometric characteristics, feeding biology and trophic ecology (Table 1). A body of evidence has shown that factors including habitat preference and feeding-dietary requirements of aquatic freshwater species play a crucial role in contaminant exposure, uptake and toxicity [26–30], and these may be the case in our study with individual species accumulation in response to the river metal-load exposure.

The mean concentration values of inorganic As ranged between not detected (ND) and 4.76 mg kg^{-1} , which were lower than values ($12.33 - 20.94 \text{ mg kg}^{-1}$) found in species from Sanmen Bay, China [31]. However, the maximum

concentration exceeded FAO/WHO recommended limit for public health of consumers. Persistent exposure to high levels of inorganic As has severe health risk implications, including anaemia, diarrhoea, liver damage, hypertension and skin disease [17, 32].

Table 2 Metal concentrations (mg kg^{-1}) in nine freshwater species collected from three landing sites in Anambra State

Landing site	Freshwater species	As	Pb	Cr	Cd	Mn	Hg	Ni	Cu	Zn	Fe
Otuocho	<i>Bulinus globosus</i>	ND	0.94 ± 0.09	0.03 ± 0.05	0.04 ± 0.01	0.06 ± 0.01	2.41 ± 0.03	0.21 ± 0.03	0.48 ± 0.02	1.33 ± 0.05	ND
	<i>Clarias gariepinus</i>	ND	2.18 ± 0.42	0.36 ± 0.11	0.06 ± 0.01	0.09 ± 0.04	2.66 ± 0.13	0.23 ± 0.09	0.16 ± 0.05	0.92 ± 0.01	14.49 ± 0.33
	<i>Malapterurus electricus</i>	ND	4.97 ± 1.71	1.54 ± 0.43	0.19 ± 0.04	0.34 ± 0.11	1.55 ± 0.07	0.32 ± 0.14	0.40 ± 0.07	1.02 ± 0.06	0.18 ± 0.19
	<i>Tilapia zillii</i>	2.75 ± 0.00	0.92 ± 0.05	0.11 ± 0.01	0.06 ± 0.02	0.04 ± 0.06	2.83 ± 0.09	0.16 ± 0.23	0.13 ± 0.01	0.70 ± 0.01	10.70 ± 1.29
Ose	<i>Bulinus africanus</i>	0.01 ± 0.00	0.17 ± 0.01	6.60 ± 0.07	0.16 ± 0.01	0.44 ± 0.02	0.47 ± 0.01	0.26 ± 0.00	0.27 ± 0.03	10.65 ± 0.06	2.38 ± 0.01
	<i>Citharus citharus</i>	0.23 ± 0.01	0.29 ± 0.01	0.05 ± 0.06	0.02 ± 0.02	0.34 ± 0.06	0.96 ± 0.01	0.17 ± 0.00	0.13 ± 0.00	2.28 ± 0.09	2.31 ± 0.02
	<i>Gnathonemus tamandua</i>	2.27 ± 0.07	0.14 ± 0.00	0.54 ± 0.03	0.05 ± 0.02	0.67 ± 0.05	0.93 ± 0.01	0.15 ± 0.00	0.21 ± 0.10	4.57 ± 2.10	1.79 ± 0.02
	<i>Tilapia zillii</i>	ND	0.51 ± 0.00	13.14 ± 0.58	0.11 ± 0.01	0.11 ± 0.01	0.16 ± 0.04	0.14 ± 0.00	0.50 ± 0.00	4.08 ± 0.16	0.62 ± 0.01
Atani	<i>Bulinus africanus</i>	4.76 ± 0.29	0.13 ± 0.01	0.26 ± 0.01	0.03 ± 0.00	3.18 ± 0.23	1.07 ± 0.05	0.09 ± 0.00	0.86 ± 0.01	5.61 ± 0.21	13.25 ± 0.28
	<i>Auchenoglanis occidentalis</i>	1.43 ± 0.18	0.21 ± 0.01	0.09 ± 0.04	0.06 ± 0.07	0.52 ± 0.01	1.07 ± 0.06	0.65 ± 0.71	0.23 ± 0.04	2.11 ± 0.12	1.62 ± 0.86
	<i>Clarias gariepinus</i>	1.82 ± 1.89	0.13 ± 0.06	0.27 ± 0.26	0.05 ± 0.02	1.22 ± 1.21	1.37 ± 0.52	0.35 ± 0.40	0.42 ± 0.27	2.89 ± 1.74	5.40 ± 4.97
	<i>Oreochromis niloticus</i>	0.79 ± 0.12	0.13 ± 0.02	0.22 ± 0.02	0.03 ± 0.02	0.65 ± 0.05	1.13 ± 0.00	0.17 ± 0.03	0.25 ± 0.01	2.52 ± 0.08	4.32 ± 0.03
	FAO/WHO limit	1–3.5	1–6	1.0	2.0	–	1.0	–	30	30	–

Values are mean ± standard deviation of ten replicates

ND not detected, FAO/WHO Food and Agriculture Organization and World Health Organization, As arsenic, Pb lead, Cr chromium, Cd cadmium, Mn manganese, Hg mercury, Ni nickel, Cu copper, Zn zinc, Fe iron

Lead (Pb) is a known hazardous metal to human health [1]. The range of Pb concentration in examined species was 0.14 – 4.97 mg kg^{-1} . The maximum Pb concentration value was ~ 7.0 orders of magnitude lower than concentration (34.04 mg kg^{-1}) in fish collected from the neighbouring Benin River [20]. Biological effects of Pb have been widely documented in the environmental health and biomedical literature, as it induces oxidative damage in vital organs and triggers histopathological decomposition of tissues in human body [33, 34].

Elevated values of Cr concentration found in *Malapterurus electricus* (1.54 mg kg^{-1}), *Bulinus africanus* (6.60 mg kg^{-1}) and *Tilapia Zillii* (13.14 mg kg^{-1}) exceeded 1 mg kg^{-1} FAO/WHO recommended limit and were higher than 1 mg kg^{-1} Cr in fish species around Challawa area in Kano State Nigeria [35]. An array of factors may contribute to the mechanistic uptake of the metal in these fish species [29, 30]. While the three fish species are all omnivorous—feeding on a variety of food of both plant and animal matter, only *Malapterurus electricus* and *Bulinus africanus* and *Tilapia Zillii* are known benthic and pelagic dwellers, respectively (Table 1). Such habitat preference and feeding biology may play a part in uptake of Cr and, potentially, other metals, by fish and ultimately may account for the elevated concentration observed in our study. Extant studies have demonstrated that benthic and omnivorous freshwater fish species tend to bioaccumulate high concentration of contaminants, including metals, from exposure environments in Nigeria [1, 27] and other countries [28–30]. Although continuous discharge of agricultural and industrial wastes can increase Cr concentration in environmental surface waters and in effect contaminate freshwater organisms, studies have shown the nutritional importance of low Cr level as an essential metal for human consumption [36].

The values of Cd concentration in species from this survey (0.02 – 0.19 mg kg^{-1}) were lower than FAO/WHO limit of 2 mg kg^{-1} for fishery resources. This is consistent with studies in Nigeria where Cd levels in freshwater ranged 0.01 – 1 mg kg^{-1} [7, 20], but ~ 74 to 152 orders of magnitude lower than concentration (3.03–14 mg kg^{-1}) found in Bangladesh water [37]. High level of Cd in the environment is risky and with exposure can induce tissue injury, chronic kidney failure and death by altering the regulation of calcium and phosphorus in humans and freshwater organisms [38, 39].

While manganese co-functions with crucial enzymes needed for maintenance of human physiology, it can become toxic upon overexposure, as well as lead to poor reproductive performance, growth retardation and abnormal function of bone and cartilage when deficient [40]. The range of Mn concentration (0.06 – 1.22 mg kg^{-1}) in freshwater species at the landing sites was relatively low

and may not be of public health concerns, though no WHO/FAO limit exists for Mn. Increased concentrations of Mn in tissues of humans and freshwater organisms are as a result of accumulative exposure to water bodies, but health impact is not widely reported [41].

The amount of inorganic Hg ($0.16 - 2.83 \text{ mg kg}^{-1}$) observed, while variable in species examined, comparison across studies shows that the values were 4 – 6 factors higher than $0.04 - 0.5 \text{ mg kg}^{-1}$ in seafoods collected from Xiangshan Bay, China [42]. Notably, Hg occurs naturally as a contaminant and elevated concentration is often accelerated by industrial activities and emission, with attendant public health issues including neurobehavioral and developmental disorders [43, 44].

Across Otuocha, Ose and Atani landing sites, values of Ni concentration in freshwater species were $0.09 - 0.65 \text{ mg kg}^{-1}$ and found to be lower than concentration ($33.03 - 53.57 \text{ mg kg}^{-1}$) measured in Benin River [20]. Nickel is an essential element for both animal and human health; although it causes allergic reactions, with some compounds capable of inducing adverse reproductive, renal, cardiovascular and immunological effects [45].

Copper plays an important role in human health by triggering the release of iron to form haemoglobin and production of blood cells [46]. We reported $0.13 - 0.86 \text{ mg kg}^{-1}$ Cu in freshwater species collected from the landing sites, which were below FAO/WHO recommended limit of 30 mg kg^{-1} and consistent with previous findings in a study elsewhere [7]. However, one study conducted in a more contaminated river stream report a copper concentration value (60.83 mg kg^{-1}) that was significantly higher than those found in Anambra landing sites survey [20].

Concentrations of Zn in the examined species ranging $0.70 - 10.65 \text{ mg kg}^{-1}$ were significantly lower than 55.14 mg kg^{-1} Zn found in fish collected from Palk Bay, Southeastern India [46]. It is notable that concentration of Zn higher than 30 mg kg^{-1} recommended by FAO/WHO is potentially detrimental to human health and can cause diseases such as hepatolenticular degeneration, diarrhoea, fever and nausea [18]. Nevertheless, this is not the case for present finding with Zn, which was relatively lower than the limit. Zinc is an essential micronutrient required to maintain certain biological processes in animals and humans [47].

Iron (Fe) can be toxic and can result in organ failure, convulsion, coma and possibly death in humans, and gill clogging in aquatic organisms when it occurs in high concentration; therefore, exposure needs to be minimised and controlled [48]. Analysis showed that freshwater species from the landing sites accumulated maximum concentration of 14.49 mg kg^{-1} . This concentration is close to, but an order of magnitude lower than, maximum 15.58 mg kg^{-1}

Table 3 Target hazard quotient (THQ) and hazard index (HI)

Landing site	Freshwater species	As	Pb	Cr	Cd	Mn	Hg	Ni	Cu	Zn	Fe	HI
Otuocha	<i>Bulinus globosus</i>	NC	3.2E-02	1.2E-03	4.7E-03	5.0E-05	1.8E-01	1.3E-03	1.4E-03	5.3E-04	NC	2.2E-01
	<i>Clarias gariepinus</i>	NC	7.4E-02	1.4E-02	7.1E-03	7.6E-05	1.9E-01	1.4E-03	4.7E-04	2.7E-03	2.5E-03	2.9E-01
	<i>Malapterurus electricus</i>	NC	1.6E-01	6.1E-02	2.3E-02	2.9E-04	1.2E-01	1.9E-03	1.2E-03	4.0E-04	3.0E-05	3.6E-01
	<i>Tilapia zillii</i>	1.0E-01	3.1E-02	4.4E-03	7.1E-03	3.4E-05	2.1E-01	9.5E-04	3.8E-04	2.8E-04	1.8E-03	3.5E-01
Ose	<i>Bulinus africanus</i>	3.9E-03	5.7E-03	2.6E-01	1.9E-02	3.7E-04	3.4E-01	1.5E-03	8.0E-04	4.2E-03	4.0E-04	6.3E-01
	<i>Citharus citharus</i>	9.1E-02	9.8E-03	2.0E-03	2.3E-03	2.9E-04	7.1E-01	1.0E-03	3.8E-04	9.0E-04	3.9E-04	8.1E-01
	<i>Gnathonemus tamandua</i>	1.0E-02	4.7E-03	2.1E-02	5.9E-03	5.7E-04	6.9E-01	8.9E-04	6.2E-04	1.8E-03	3.0E-04	7.3E-01
	<i>Tilapia zillii</i>	NC	1.7E-02	5.2E-01	1.3E-02	9.3E-05	1.2E-01	8.3E-04	1.5E-03	1.6E-03	1.0E-04	6.7E-01
Atani	<i>Bulinus africanus</i>	1.8E-01	4.4E-03	1.0E-02	3.5E-03	2.7E-03	7.9E-01	5.3E-04	1.0E-04	2.2E-03	2.2E-03	9.9E-01
	<i>Auchenoglanis occidentalis</i>	5.6E-01	7.1E-03	3.5E-03	7.1E-03	4.4E-04	7.9E-01	3.8E-03	6.8E-04	8.3E-04	2.8E-04	9.3E-01
	<i>Clarias gariepinus</i>	7.2E-01	4.4E-03	1.0E-02	5.9E-03	1.0E-03	1.0E-01	2.0E-03	1.2E-03	1.1E-03	9.2E-04	8.4E-01
	<i>Oreochromis niloticus</i>	3.1E-01	4.4E-03	8.7E-03	3.5E-03	5.5E-04	8.4E-01	1.0E-03	7.4E-04	9.9E-04	7.3E-04	9.9E-01

NC not calculated as metals were not detected in fish sample, As arsenic, Pb lead, Cr chromium, Cd cadmium, Mn manganese, Hg mercury, Ni nickel, Cu copper, Zn zinc, Fe iron, HI hazard index

found in contaminated Saint Martin Island fish in Bangladesh [37].

Public health risk assessment was conducted based on target hazard quotient (THQ) following the US EPA acceptable value of 1 [22]. The THQs for As, Hg, Cu, Cr, Cd, Fe, Ni, Zn, Pb and Mn estimated based on consumption of the nine freshwater species examined in this study are shown in Table 3. The THQ calculations were below 1, ranging ND – 8.4E–01 for all metals. Hazard index (HI), which provides a cumulative chronic noncarcinogenic risk, was below 1 for all metals analysed (2.2E–01 – 9.9E–01), indicative that oral exposure by ingestion to metal contaminated freshwater species-based food was not associated with any potential noncarcinogenic risk to public health.

4 Conclusion

The present study has shown that edible fish and snail species at Otuocha, Ose and Atani landing sites accumulated varying concentrations of As, Cr and Hg higher than the FAO/WHO recommended limits for ingestion. However, while the THQ and HI calculations demonstrated no quantitative estimate of public health risks from consumption of these species, it has provided information on critical point of freshwater food value chain in Anambra State. Since this is the first study that has examined risk profiles of freshwater species landing sites, and given that no metals pose potential dietary health risk to consumers from THQ and HI characterisation, it is recommended that further tiered risk protocol studies examine these species at both spatial and temporal scales to review impact of seasons and locations on cumulative risk evaluation based on location-specific consumption data.

Compliance with ethical standards

Conflict of interest Chigozie Damian Ezeonyejiaku, Maximilian Obinna Obiakor, Charles Obinwanne Okoye declare that they have no conflicts of interest.

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