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Hazard Identification and Potential Risk Analysis of Toxic Metals in Redbelly Tilapia (*Coptodon zillii*) Consumed and Surface Water from the Niger Delta Estuary

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Abstract

Anthropogenic activities have led to the escalation of toxic metals, polluting rivers and accumulating in water, sediments, and fish. This damages aquatic ecosystems and has lasting effects on humans and aquatic life. The study aimed to determine the accumulation of heavy metals (Pb, Cr, Cu, Fe, Ni, Cd, and Zn) in Redbelly tilapia (*Coptodon zillii*) and water from three sampling stations along Atuka Creek in southern Nigeria, an oil-filled creek. The investigation also assessed potential health risks associated with consuming C. zillii, as well as the pollution and productivity levels of the aquatic ecosystem. Results indicated significant variations in heavy metal concentrations among stations, with Station 1 showing the highest contamination levels due to its proximity to pollution sources. Fish from Station 1 exhibited elevated contamination levels, exceeding WHO's recommended limits for Pb, Fe, Ni, and Zn. Calculations of chronic daily intake (CDI) values suggested potential health risks for both adults and children, especially at Stations 1 and 2. Hazard quotient (HQ) and hazard index (HI) values surpassed safe levels at these stations, indicating risks unrelated to cancer from consuming fish and swimming. Furthermore, assessments of lifetime cancer risk (ILCR and TLCR) revealed an increased cancer risk, particularly at Stations 1 and 2. These results underscore the necessity for stringent pollution control measures, regulations, and remediation strategies to address heavy metal contamination, maintain water quality, and protect public health in southern Nigerian communities.

Keywords: Toxic Metals, Tilapia, Estuary, Health Risks, Pollution.

Introduction

The aquatic ecosystems in the Niger Delta region of Nigeria are notorious for significant environmental pollution, primarily stemming from industrial activities, population growth, and other human impacts as noted by Bashir et al. (2020). The legal and illegal exploration and exploitation of crude oil in the Niger Delta have degraded the aquatic ecosystem prevalent in the southern part of Nigeria. Oil spills have tainted numerous creeks and rivers in the region, as highlighted by Chijioke et al. (2018) and Akpotor (2019). As per Chris et al. (2023a), native edible fishes, crucial protein sources for many local communities, are now threatened by trace metals pollution from crude oil and other contaminants. The disposal of waste and energy by civilization has exceeded the water resources' carrying capacity in Nigeria, leading to the persistence of environmental pollutants in aquatic ecosystems, as discussed by Davies and Ekperusi (2021).

In many countries that are developing, the depletion of rivers and lakes by crude oil and other pollutants is an important environmental issue (Fayiga et al., 2018; Chris and Oghenetekevwe 2023; Çavuş, et al., 2023). Ukhurebor et al. (2021) report that Nigeria, which is one of the world's highest oil producers, has had several oil spills and other cases of environmental damage, which have caused significant degradation of aquatic ecosystems. Because it may result in adverse effects on both aquatic life and people who ingest it, crude oil pollution of creeks and rivers is a severe problem (Landrigan et al., 2020; Aa et al., 2022). Contamination of aquatic ecosystems with various pollutants, including heavy metals, has been a matter of concern in developing countries for many years (Ali et al., 2019). The increased industrial activities and growing population in these countries have led to exposing the environment to multiple (Chris and Anyanwu, 2023). According to Sonone et al. (2020), heavy metals are major environmental pollutants due to their toxicity, soil, water, and biota persistence, and ability to amplify through the food chain.

Pollution from heavy metals in river systems not only endangers aquatic life but also puts humans who come in contact with such water bodies at risk (Emenike et al., 2021; Fida et al., 2023). In aquatic food chains, the trophic transfer of metals has been a subject of concern for decades, and locations adjacent to agricultural areas and industrial layouts are at high risk of pollution due to significant runoff and industrial discharges (Sibanda et al., 2015; Akankali et al., 2020). Various studies have revealed elevated levels of metals such as Pb, Cr, Cu, Fe, Ni, Cd, Zn, and V in various rivers in southern Nigeria (Okere et al., 2020; Obasi et al., 2022). Native peoples in such areas are known to consume the edible fish species

C. zillii (Ibim and Gogo, 2019). Nevertheless, there is significant concern about the likelihood of trace metal in the tissues of fish as a consequence of crude oil pollution. Although heavy metals such as lead, cadmium, mercury, and arsenic are considered carcinogens to humans, their accumulation in the tissue of fish can have severe adverse effects on consumers' well-being (Isangedighi and David, 2019; Davies and Anyanwu, 2023).

One area significantly affected by heavy metal contamination due to artisanal petroleum extraction is Atuka Creek in Rivers State, Nigeria. Obasi et al. (2020) highlighted that mining activities near areas with high concentrations of harmful substances such as lead and arsenic pose risks to both the environment and human health. These toxic inorganic pollutants are known to be carcinogenic to humans and have been linked to various health issues, including anaemia, neurological impacts, developmental delays, and an increased likelihood of developing different types of cancer (Davies and Anyanwu, 2023). Odekina et al. (2021) emphasized the importance of conducting a comprehensive evaluation of the health hazards associated with consuming trace metals found in fish from crude oil-contaminated creeks in southern Nigerian cities to tackle this issue effectively. This assessment would help in shaping policies that ensure the protection of aquatic resources and the well-being of those dependent on them for sustenance, underscoring the necessity of assessing these trace metals. The current study seeks to assess the concentrations of specific toxic metals in Redbelly tilapia (*C. zillii*) from crude oil-affected creeks in southern Nigeria, ascertain the potential adverse health impacts linked to their consumption, and evaluate the pollution levels and ecological health of the aquatic ecosystem to safeguard the local population's well-being when consuming native edible fish from communities in the region.

Materials and methods

This section provides information about the materials and methodology (research model, sample, data collection, data collection tools, and data analysis) of this study, which is to identify and analyze toxic metals present in Redbelly Tilapia (*Coptodon zillii*) consumed and surface water from the Niger Delta Estuary.

Description of the Study Area

Atuka Creek, located along the Buguma axis in Rivers State, Nigeria, is a fishing settlement within the Asari Toru Local Government Area. It is positioned in the southeastern part of the Niger Delta region, near the Oproama channel, a tributary of the Sombrero estuary. The area's waterways connect various communities along the riverbanks. Abandoned artisanal crude oil sites pose a pollution risk. The local population consists mainly of fishermen who depend on activities such as collecting periwinkle and harvesting seafood like *C. zillii*, Nile tilapia, Madron sardines, and black gobies. These resources are essential for the local economy. The diverse mangrove ecosystem includes red, white, and black mangroves, along with mangrove ferns and sedges. Racemose mangroves dominate, providing habitats for marine life. Sediments in this area consist of spongy and highly fibrous peat mud. However, the area is threatened by human activities such as illegal refineries and refueling, sand dredging, and the deliberate destruction of young mangroves. The study was conducted at three sites along the river between 004' 78' 96''N and 006 85' 60.72"E (Figure 1).

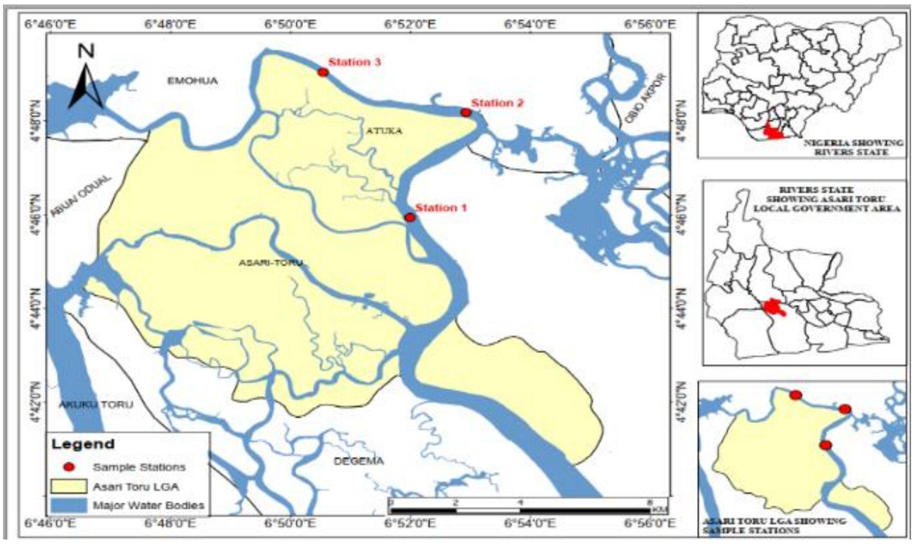

Fig. 1. Showing a map of the three sampled locations at Atuka Creek.

Sample collection

C. zillii samples were gathered from each station between July and December 2022. The fish specimens were promptly taken to the lab in an ice chest for examination. The soft tissues from 5 to 10 individuals were dissected, dried, and kept in clean, clearly labeled plastic containers. Monthly, water samples were taken from the creek using a one-liter sampler and transferred to a clean 250 ml plastic bottle. These samples were acidified to pH 2 with nitric acid (HNO3) as per Sharma and Tyagi (2013). The digestion process utilized concentrated Analar nitric acid following Zhang et al. (2014), and heavy metal analysis was conducted using a UNICAMSolaar 969 atomic absorption spectrometer (AAS) with an acetylene-air flame.

Sample preparation and digestion

Red-bellied tilapia (C. zillii) muscle samples weighing 0.95 ± 0.12 g were directly weighed into acid-washed Teflon digestion vessels. 10 mL of high-purity nitric acid was added to each vessel, then heated to 100°C using an XT-9800 pretreatment heater until most of the nitrogen dioxide was expelled. Before microwave digestion, add a 4 mL aliquot of concentrated HNO3: HF acid mixture (1:1 v/v). Each digestion batch includes a reagent blank, a reference standard, and typically a replicate sample to ensure homogeneity and process efficiency. Microwave digestion involves three steps: 1.5 MPa for 1 minute, 1.0 MPa for 2 minutes, and 1.5 MPa for 3 minutes. After cooling for at least an hour, the digested samples were moved to graduated plastic tubes and diluted to 100 ml with Milli-Q water (Yi et al., 2011; Kpee et al., 2019).

Quality Assurance and Control

After microwave digestion, Atomic Absorption Spectroscopy (AAS) was conducted on Redbelly tilapia samples using Sigma-Aldrich Certified Reference Materials (CRMs) to analyze cadmium (Cd), lead (Pb), zinc (Zn), iron (Fe), nickel (Ni), and copper (Cu). Each metal was analyzed in triplicate. The instrument was calibrated with Buck-certified atomic absorption standards for hazardous metals to generate analytical curves. To ensure equipment stability, the reagent blank value was initially measured for each of the 10 identified samples. Metal recoveries (%R) were as follows: Cd 100%, Cu 97.6%, Ni 99.6%, Fe 89.0%, Pb 98.7%, and Zn 84.5%. Metal contents in Redbelly tilapia samples were determined using Atomic Absorption Spectrophotometry (Model 210 VGP, Buck Scientific). Average results for each sample were calculated and cross-validated.

Human Health Risk Assessment

Levels of heavy metals in both the Red-bellied tilapia (*C. zillii*) and water have surpassed regulatory limits. Consequently, a health risk assessment was carried out for the water (dermal) due to residents swimming in the highly saline water or potentially ingesting it unintentionally while swimming and consuming Red-bellied tilapia (*C. zillii*) as a local delicacy in this fishing community.

Chronic Daily Intake (CDI)

The number of heavy metals consumed daily (CDI) from the water in the Atuka Creek mangrove swamp through skin contact or may accidentally be ingested during the swim and consumption of Red-bellied tilapia (*C. zillii*) (ingestion) using equation 1 (Anyanwu et al., 2023).

$$\mathrm{CDI} = \frac{\mathrm{CwxSAxK_pxETxEFxEDxCF}}{\mathrm{BWxAT}} \quad (1)$$

$$\mathrm{CDI_{ing}} = \frac{\mathrm{C_I \; x \; IR_{ing} \; x \; EF \; x \; ED}}{\mathrm{BW \; x \; AT}} \quad (2)$$

Where CDI is the daily dose of heavy metals in µg/kg/day, users are prone to dermal contact; Cw is the heavy metal concentration (µg/l); IRing (L/day) represents the ingestion rate depending on the target sample's age; CF is the conversion factor (0.001 l/cm3); SA is the skin surface area - 18000 cm2 (adult) and 6600 cm2 (children); Kp denotes the absorbency coefficient as per Moldovan et al. (2020), with values of 0.0001 cm/h for Pb and 0.0006 cm/h for Zn, and 0.001 cm/h for Cd, Cu, and Ni. The exposure parameters for health risk assessment via the ingestion pathway are detailed in Table 1.

Table 1. Input parameters used in the health risk assessment (USEPA 2012; Anyanwu et al., 2023)

Parameter	Unit	Children	Adult
Exposure time (ET)	H/event	1	0.58
Average time (AT) (ED x 365)	Days	2190	10950
Body weight (BW)	Kg	15	70
Exposure frequency (EF)	Days/ years	350	350
Exposure duration (ED)	Years	6	30
Ingestion rate (IR)	L/day	1.00	2.00

Hazard Quotients (HQ)

The hazard quotient (HQ) is a ratio that is used to assess the level of risk associated with a particular hazard. It is commonly used to evaluate the potential impact of a risk, especially in risk characterization (Sharif *et al*., 2016). The Hazard Quotient (HQ) is often used to assess the non-carcinogenic risk associated with exposure via the skin, and this is determined using equation 3 from USEPA (2012):

$$\mathrm{HQ} = \frac{CDI}{RfD} \quad (3)$$

To determine the daily dose of heavy metals that a consumer may be exposed to, we use Chronic Daily Intake (CDI) in micrograms/kg/day. We also consider the dermal reference dose (RfD) in micrograms for each of the metals being analyzed. The RfD is the daily dosage that allows the individual to maintain this level of exposure for an extended period without any harmful effects. If the hazard quotient (HQ) is greater than 1 (HQ > 1), it suggests non-carcinogenic adverse effects that need attention. On the other hand, an HQ less than 1 (HQ < 1) is considered acceptable.

Health Risk Assessment for Red-bellied Tilapia (*C. zillii*)

The target hazard quotient (THQ) for each heavy metal was calculated according to Biswas et al. (2021). It was calculated using Equation 4:

$$\mathrm{THQ} = \frac{\mathrm{ED \; x \; IR \; x \; EF \; x \; CW}}{\mathrm{RfD \; x \; BW \; x \; AT}} \; \mathrm{x} \; 10^{-3} \quad (4)$$

Where ED is the Exposure duration of 30 years (adults) and 6 years (children); IR is the ingestion rate (Litre/day) - 0.3 gm/kg/person/day (adults) and 0.15 gm/kg/person/day (children) (Markmanuel *et al*., 2022); EF is the exposure frequency (365 days/year); CW is the concentration of respective heavy metal (mg/kg) in the *C. zillii*; RFD is the reference oral dose in mg/kg/day (0.001 for Cd, 0.004 for Pb, 0.3 for Zn, 0.02 for Ni, 0.04 for Cu, 1.5 for Cr and 0.007 for Fe mg/kg/day, respectively. BW is the body weight of 70 kg (adults) and 15 kg (children) and AT (ED x EF) is the average time of exposure of 25550 days (adults) and 3650 days (children) (USEPA, 2001, 2004).

Hazard Index (HI)

Hazard index (HI) is the cumulative potential for non-carcinogenic effects from more than one heavy metal through dermal or ingestion (*C. zillii*) pathways and can be Chronic from equation 5 (Sharma, 2020).

$$\text{HI} = \sum_{i=1}^{n} \text{THQ} \quad (5)$$

Where HI is the hazard index for the overall toxic risk and n equals the total number of metals under consideration. If HI for non-carcinogenic adverse effects due to ingestion exposures is lower than one (HI < 1.0), then no chronic risks are expected to occur but if HI is greater than one (HI > 1.0), possible chronic risk arising from the ingestion exposures could manifest (Anyanwu et al., 2023).

Carcinogenic Risk

CR is the lifelong risk of developing cancer as a result of consuming swimming Redbelly tilapia (*C. zillii*) that has been exposed to Cd, Pb, Cr, and Ni. Target Cancer Risk (TR) was used to determine the carcinogenic risk (Noman et al., 2022). Target cancer risk (TR) posed by the assessed heavy metals was determined with Equation 6 (Bonsignore et al., 2018):

$$\text{TR} = \frac{\text{ED x IR x EF x CW x } C_{SF}}{\text{BW x AT}} \text{ x } 10^{-3} \quad (6)$$

Where CSF is the Cancer Slope Factor while other input parameters have been previously defined in Equation 1. The acceptable range for carcinogenic risks is between 10^{-4} and 10^{-6} and values > 10^{-4} will likely result in cancer (Noman et al., 2022). The cancer slope factor (CSF) of heavy metals used is 6.3 mg/kg/day for Cd, 0.0085 mg/kg/day for Pb, 0.91 mg/kg/day and 05 mg/kg/day for Ni and Cr, respectively (USEPA 2012; Anyanwu et al. 2023).

The total lifetime cancer risk (TLCR)

An important method to assess the health risk resulting from human exposure to carcinogenic metals is the total lifetime cancer risk (TLCR). The expression will be utilized for estimating the study's total lifetime cancer risk. The TLCR was calculated using the following equation 7:

$$\text{TLCR} = \text{CLRIng} + \text{CLRDerm} \quad (7)$$

Where CR indicates the chance calculated in percentage (of the populations) in mg/kg/day, CADD represents chronic average daily doses, and CSF for the cancer slope factor (mg/kg/day). When the cancer risk (CR) ranges are greater than 10^{-6} or 10^{-4}, according to USEPA (2012), the amounts of the above metals can be regarded as hazardous to human health (Rahman et al., 2019).

Total cancer risk (TCR)

Total Cancer Risk indicates the lifetime cancer risk. According to the USEPA (2012), the values for TCR are calculated using the following equation 8:

$$\text{TCR} = \frac{\text{Cf x EFr x ED x FIR x CSF}}{\text{Bw x AT}} \; X \; 10^{-3} \quad (8)$$

where AT is the average time for carcinogens (days/year × ED), EFr is the exposure frequency (days/year), ED is the exposure duration (years), FIR is the food ingestion rate (g/day), Bw is the average body weight (kg), AT is the average exposure time for non-carcinogens (days/year × ED), and CSF is the oral carcinogenic slope factor derived from the Integrated Risk Information System by the USEPA (2012). The calculated TCR value $<10^{-6}$ is negligible, and values within 10^{-6} and 10^{-4} are acceptable values whereas values $>10^{-4}$ are unacceptable (Rahman *et al.*, 2019). The parameters used for the calculation of the TCR are highlighted in Tables 2 and 4. The exposure factors used for target carcinogenic risk (TCR) estimation were according to (USEPA 2012; Anyanwu et al. 2023).

Statistical Analysis

The data into Microsoft Excel and then a statistical analysis was performed using one-way ANOVA to identify any significant differences. Tukey Pairwise test was used to determine the source of these differences between means. To perform these statistical analyses, The PAST software package (Version 3.24) was used according to Hammer et al. (2001).

Discussion and Conclusion

The summary of the heavy metal in *C. zillii* from the Atuka Creek

Table 2 shows the concentrations of Pb, Cr, Cu, Fe, Ni, Cd and Zn in Fish (*C. zillii*) from the Atuka Creek following the sequence: Fe > Zn > Cu > Pb > Cr > Ni > Cd with Fe recording the highest value of 7.06±0.05 mg/kg, followed by Zn (6.25±0.1 mg/kg), while the least value was recorded in Cd (0.001±0.01 mg/kg) for Station1, Fe > Zn > Cu > Pb > Cr > Ni > Cd with Fe recording the highest value of 7.12±0.01 mg/L, followed by Zn (6.02±0.3 mg/kg) and the least value of 0.001±0.01 mg/kg was reported by Cd. However, the sequence was: Fe > Zn > Cu > Ni > Pb > Cr > Cd in station 3 with Fe recording the highest value of 7.05±0.02 mg/kg, followed by 5.81±0.3 mg/kg in Zn while the lowest value was reported in Cd (0.001±0.01 mg/kg). Nevertheless, the mean values Pb, Cr, Cu, Fe, Ni and Zn in Station1, 2 and 3 exceeded the respective permissible limits of 0.05 mg/kg, 0.01 mg/kg, 0.4 mg/kg, 0.3 mg/kg, 0.1 mg/kg, and 0.02 mg/L set by the World Health Organization guideline for fisheries cultivation (WHO 2011) except Cd (0.001±0.01) which was observed to be with the WHO 2011) guidelines. No significant difference ($p < 0.05$) was observed in Fe, Ni, Cd and Zn in concentrations across the three sample stations. However, Pb, Cr and Cu varied Significantly ($p > 0.05$) among the three stations.

Table 2. Mean heavy metals values in *C. zillii* from the Atuka Creek

	Heavy metals (Mg/kg)						
Stations	**Pb**	**Cr**	**Cu**	**Fe**	**Ni**	**Cd**	**Zn**
Station1	0.21±0.15*	0.15± 0.29**	0.82±0.64**	7.06±0.05*	0.9± 0.10*	0.001±0.01*	6.25±0.1*
Station2	0.18±0.15**	0.11±0.09*	0.69±0.09*	7.12±0.01*	0.8±0.01*	0.001±0.01*	6.02±0.3*
Station3	0.19±0.23*	0.12± 0.32*	0.72±0.03**	7.05±0.02*	0.7± 0.25*	0.001±0.01*	5.81±0.3*
WHO (2011)	0.01	0.05	2.0	0.3	0.02	0.003	0.1

* *Not significantly different* (*p < 0.05*)
** *Significantly different* (*p > 0.05*)

The mean heavy metal values in water from Atuka Creek are detailed in Table 3. Station 1 exhibited the highest Pb values of 0.86±0.01 mg/L, followed by Station 2 (0.56±0.02 mg/L), with the lowest reported in Station 3 (0.29±0.04 mg/L). Station 1 significantly differed (p > 0.05) from stations 2 and 3. The highest Cr concentration (0.75±0.03 mg/L) in the water from Atuka Creek was found in station 1 (0.98±0.0 mg/L), while the lowest was observed in station 3 (0.66±0.03 mg/L). A significant difference (p > 0.05) existed between Station 1 and the other two stations. Cu levels were higher in station 1 (0.75±0.03 mg/L), followed by station 2 (0.62±0.07 mg/L), and the lowest was in station 3 (0.58±0.01 mg/L). However, Fe, Ni, Cd, and Zn exhibited higher values of 6.45±0.02 mg/L, 0.68±0.01 mg/L, 0.46±0.01 mg/L, and 0.98±0.01 mg/L, respectively, in Station 1, and the lowest values of 0.29±0.04 mg/L, 0.66±0.03 mg/L, 0.58±0.01 mg/L, 5.74±0.37 mg/L, 0.17±0.01 mg/L, 0.22±0.03 mg/L, and 0.23±0.03 mg/L, respectively, in Station 3. No significant difference (p < 0.05) was noted in Fe, Ni, and Cd concentrations across the stations. However, the concentrations of Pb, Cr, Cu, and Zn significantly varied (p > 0.05) between station 1 and the other two stations. The metal concentrations in the water followed this order: Fe > Cr = Zn > Pb > Cu > Ni > Cd in station 1, Fe > Cr > Zn > Cu > Pb > Ni > Cd in station 2, and in station 3, the sequence was Fe > Cr > Cu > Pb > Zn > Cd > Ni.

Table 3. Mean heavy metal values in Water from the Atuka Creek

	Metals Concentrations (mg/L)						
Stations	**Pb**	**Cr**	**Cu**	**Fe**	**Ni**	**Cd**	**Zn**
Station1	0.86±0.01**	0.98±0.0**	0.75±0.03**	6.45±0.02*	0.68±0.01*	0.46±0.01*	0.98±0.01**
Station2	0.56±0.02*	0.75±0.04*	0.62±0.07*	5.46±0.91*	0.45±0.02*	0.42±0.04*	0.67±0.11*
Station3	0.29±0.04*	0.66±0.03*	0.58±0.01*	5.74±0.37*	0.17±0.01*	0.22±0.03*	0.23±0.03*
WHO (2011)	0.01	0.05	2.0	0.3	0.02	0.003	0.1

* *Not significantly different* (*p < 0.05*)
*** Significantly different (p > 0.05)*

Chronic Daily Intake (CDI) of Redbelly tilapia (*C. zillii*)

The results in Table 4 show the chronic daily intake (CDI) of heavy metals in Redbelly tilapia (*C. zillii*) from Atuka Creek for both adults and children group, in addition to the health risk assessment based on non-carcinogenic risk. The CDI values for the different heavy metals and stations show significant variations (p > 0.05). Station 1 recorded higher CDI values when compared to Station 2 and Station 3 for all the heavy metals assessed.

Hazard quotient (HQ) and Hazard index (HI) of the contaminated Redbelly *tilapia (C. zillii)*

Table 5 shows the hazard quotient (HQ) and hazard index (HI) of heavy metals in Redbelly tilapia *(C. zillii*) from Atuka Creek for both adults and children. The HQ values for all the heavy metals were greater than one, indicating a potential non-carcinogenic risk to human health associated with their exposure. The HI values for Station 1 and Station 2 exceeded the safe limit of one for both adults and children.

Chronic Daily Intake of Water Via Ingestion (CDI_{Ing}) and Dermal Contact (CDI_{Derm})

Table 6 shows the Chronic daily intake of water via ingestion (CDI_{ing}) and dermal contact (CDI_{derm}) for heavy metals in Water from Atuka Creek for both adults and children. The CDI_{ing} and CDI_{derm} values for all the heavy metals are observed to be higher at Station 1 and Station 2 and the least reported in Station 3

Table 4. Chronic Daily Intake (CDI) of Redbelly *tilapia (C. zillii*)

	Adult		
Heavy Metal	**Station 1**	**Station 2**	**Station 3**
Zn	0.763209	0.735123	0.709479
Pb	0.025644	0.02198	0.023202
Cd	0.000285	0.000285	0.000285
Cr	0.04274	0.031342	0.034192
Cu	0.100133	0.084258	0.087922
Fe	2.011616	2.028712	2.008767
Ni	0.256438	0.227945	0.199452
Children			
Heavy Metal	**Station 1**	**Station 2**	**Station 3**
Zn	0.712329	0.686115	0.662181
Pb	0.023934	0.020515	0.021655
Cd	0.00133	0.00133	0.00133
Cr	0.199452	0.146265	0.159562
Cu	0.093458	0.078641	0.08206
Fe	9.387543	9.467324	9.374247
Ni	1.196712	1.063744	0.930776

Table 5. Hazard quotient (HQ) and Hazard index (HI) of the contaminated Redbelly *tilapia* (*C. zillii*)

		Adult	
Heavy Metal	**Station 1**	**Station 2**	**Station 3**
Zn	0.393076923	0.408094812	0.422845227
Pb	0.136485043	0.15923255	0.150851889
Cd	3.509615385	3.509615385	3.509615385
Cr	0.467948718	0.638111888	0.584935897
Cu	0.399468418	0.474730583	0.454950142
Fe	0.004971127	0.004929235	0.004978178
Ni	4.911565613	5.194714453	5.128176719
HI	**9.430054302**	**9.981334094**	**9.83350821**
		Children	
Heavy Metal	**Station 1**	**Station 2**	**Station 3**
Zn	0.421153846	0.437244442	0.453048458
Pb	0.146233974	0.170606303	0.161627024
Cd	0.75206044	0.75206044	0.75206044
Cr	0.100274725	0.136738262	0.125343407
Cu	0.428001876	0.508639911	0.487446581
Fe	0.001065241	0.001056265	0.001066752
Ni	0.016712454	0.018801511	0.021487441
HI	**1.444348711**	**1.587902691**	**1.549031645**

Hazard quotient of Ingestion (HQ_{Ing}) and Dermal contact (HQ_{Derma}) with the Water

Table 7 shows the hazard quotient of ingestion (HQ_{Ing}) and dermal contact (HQ_{Derma}) with the water for heavy metals from Atuka Creek in Rivers State, Nigeria. The hazard quotient values are higher at Stations 1 and 2 compared to Station 3, indicating a potential non-carcinogenic health risk associated with the consumption of Redbelly tilapia from these locations.

Table 6. Chronic Daily Intake of Water Via Ingestion (CDI_{Ing}) and Dermal Contact (CDI_{Derm})

	CDI_{Ing}			CDI_{Derm}		
Adult						
Heavy Metal	**Station 1**	**Station 2**	**Station 3**	**Station 1**	**Station 2**	**Station 3**
Zn	0.011506849	0.007866928	0.002700587	0.001001096	0.000684423	0.000234951
Pb	0.010097847	0.006575342	0.003405088	0.000878513	0.000572055	0.000296243
Cd	0.01260274	0.011506849	0.006027397	0.001096438	0.001001096	0.000524384
Cr	0.026849315	0.020547945	0.018082192	0.00233589	0.001787671	0.001573151
Cu	0.008806262	0.007279843	0.006810176	0.000766145	0.000633346	0.000592485
Fe	0.176712329	0.149589041	0.157260274	0.006588845	0.005577534	0.005863562
Ni	0.018630137	0.012328767	0.004657534	0.001620822	0.001072603	0.000405205
Children						
Heavy Metal	**Station 1**	**Station 2**	**Station 3**	**Station 1**	**Station 2**	**Station 3**
Zn	0.005369863	0.003671233	0.001260274	3.38301E-05	2.31288E-05	7.93973E-06
Pb	0.004712329	0.003068493	0.001589041	2.96877E-05	1.93315E-05	1.0011E-05
Cd	0.029406393	0.026849315	0.014063927	0.00018526	0.000169151	8.86027E-05
Cr	0.062648402	0.047945205	0.042191781	0.000394685	0.000302055	0.000265808
Cu	0.004109589	0.00339726	0.003178082	2.58904E-05	2.14027E-05	2.00219E-05
Fe	0.412328767	0.349041096	0.366940639	0.000222658	0.000188482	0.000198148
Ni	0.04347032	0.028767123	0.01086758	0.000273863	0.000181233	6.84658E-05

Table 7. Hazard quotient of Ingestion (H_{QIng}) and Dermal contact (HQ_{Derma}) with the Water

	HQ_{Ing}			HQ_{Derma}		
Adult						
Heavy Metal	**Station 1**	**Station 2**	**Station 3**	**Station 1**	**Station 2**	**Station 3**
Zn	26.07142857	38.13432836	111.0869565	59.93431856	87.66512266	255.3723138
Pb	0.346608527	0.532291667	1.027873563	0.597600909	0.917744253	1.772195799
Cd	0.079347826	0.086904762	0.165909091	0.00912044	0.009989053	0.01907001
Cr	0.744897959	0.973333333	1.106060606	0.321076707	0.41954023	0.476750261
Cu	4.542222222	5.494623656	5.873563218	15.66283525	18.94697812	20.25366627
Fe	0.056589147	0.066849817	0.06358885	106.2401616	125.5034876	119.3813662
Ni	1.073529412	1.622222222	4.294117647	24.67883705	37.29246488	98.71534821
HI	**32.9146236**	**46.9105538**	**123.618069**	**207.443950**	**270.7553268**	**495.9907106**
Children						
	HQ_{Ing}			HQ_{Derma}		
Heavy Metal	**Station 1**	**Station 2**	**Station 3**	**Station 1**	**Station 2**	**Station 3**
Zn	55.86734694	81.71641791	238.0434783	1773.566569	2594.171997	7556.935818
Pb	0.742732558	1.140625	2.202586207	17.68410853	27.1577381	52.44252874
Cd	0.034006211	0.037244898	0.071103896	0.053978113	0.059118886	0.112863327
Cr	0.319241983	0.417142857	0.474025974	1.900249896	2.482993197	2.821583179
Cu	9.733333333	11.77419355	12.5862069	463.4920635	560.6758833	599.3431856
Fe	0.024252492	0.028649922	0.027252364	3143.841516	3713.878714	3532.713899
Ni	0.460084034	0.695238095	1.840336134	146.0584234	220.7105064	584.2336935
HI	**67.18099755**	**95.80951223**	**255.2449898**	**5546.596908**	**7119.136951**	**12328.60357**

Total Life Carcinogenic risk (TLCR) to both age groups arising from Water intake via exposure

Figures 2a and 2b depict the Total Life Carcinogenic Risk (TLCR) for adults and children who consume water from Atuka Creek in Rivers State, Nigeria. The analysis focused on heavy metals like Pb, Cd, Cr, and Ni to evaluate the possible cancer risks linked to water consumption in this region. TLCR serves as an indicator of the lifelong cancer risk from exposure to these heavy metals through fish consumption. Findings reveal that individuals, both adults, and children, who consume fish from Stations 1 and 2 face a higher TLCR compared to those consuming fish from Station 3.

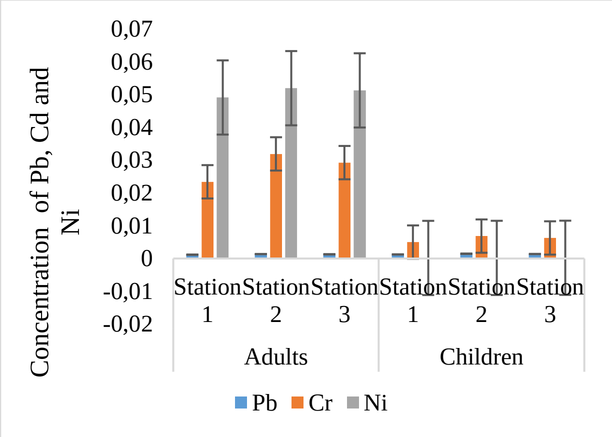

Fig. 2a. Showing the Individual lifetime cancer risk (ILCR) to both age groups from Water intake.

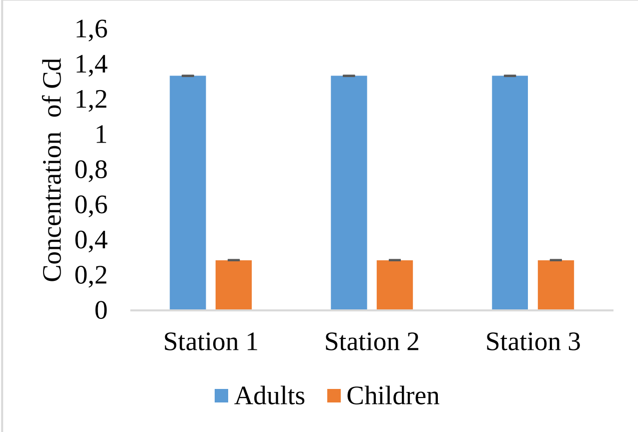

Fig. 2b. Showing the Individual lifetime cancer risk (ILCR) to both age groups from Water intake.

Total Life Carcinogenic risk (TLCR) to both age groups arising from Water intake via exposure

Figures 3a and 3b depict the Total Life Carcinogenic Risk (TLCR) for adults and children who drink water from Atuka Creek in Rivers State, Nigeria. Heavy metals like Pb, Cd, Cr, and Ni were studied to evaluate the possible cancer risks linked to water consumption in this region. The TLCR represents the lifetime cancer risk from exposure to these heavy metals through fish consumption. The findings reveal that individuals, both adults and children, who consume fish from Stations 1 and 2 face a greater TLCR compared to those consuming fish from Station 3.

Discussion

The considerable variation in heavy metal concentrations among different metals in fish (*C. zillii*) at the three stations may be due to the proximity of the creek to pollution sources (Ustaoğlu et al., 2020). Station 1 is near the main artisanal refining discharge site where illegal mining activities take place, leading to higher levels of heavy metals in the water. This could lead to bioaccumulation of these metals in fish (*C. zillii*) at Station 1 (Chris and Oghenetekevwe, 2022). However, Jafarabadi et al. (2020) noted that sediment composition and characteristics at different stations could also impact the availability and bioavailability of heavy metals in fish. Station 1 might have sediment with elevated heavy metal concentrations, contributing to higher accumulation levels in fish (Takarina and Pin, 2017). According to Davies and Ekperusi (2021), heavy metal concentrations in fish can be influenced by water flow and dilution rate at each station. Station 1, however, could have reduced water flow or inadequate dilution, leading to increased heavy metal buildup in the water, affecting *C. zillii* as observed by Javed and Usmani in 2019. It is crucial to highlight that heavy metal concentrations at all three stations exceed the World Health Organization (WHO) safety guidelines. This indicates a significant health risk to *C. zillii*, and the heavy metal levels in *C. zillii* from Atuka Creek could potentially pose risks to human and environmental health

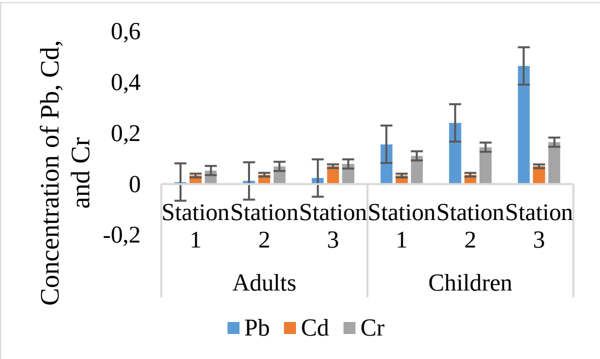

Fig. 3a. Total Life Carcinogenic risk (TLCR) to both age groups arising from Water intake via exposure

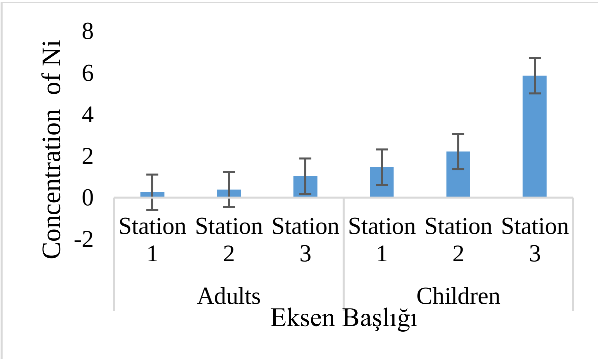

Fig. 3b. Total Life Carcinogenic risk (TLCR) to both age groups arising from Water intake via exposure.

The highest concentrations of all the heavy metals were observed in Station 1, followed by Station 2 and then Station 3. These variations in the metal content in the different stations could be attributed to the fact that Station 1 was closer to the main pollution sources where direct discharges and runoff were observed than the other two stations, which may have led to the higher concentrations of heavy metals reported in the water. Similar results were reported by John and Nnadozie (2021) in an artisanal crude oil refining impact estuarine ecosystem in the Niger Delta. However, Zhang et al. (2014) reported that the differences in the chemistry of the water and the sediments might affect the availability and bioavailability of heavy metals. Therefore, station 1 may have more acidic or polluted water, leading to higher levels of heavy metal contamination. This agrees with Atangana and Oberholster (2021) who reported highly acidic water in heavy metal contamination groundwater on catchment levels. Human activities like illegal crude oil mining runoff, or other waste from domestic disposal in Station 1 may contribute to the higher concentrations of heavy metals in the water compared to the other stations. The findings reported by Chris et al. (2023b) align with the results obtained from studying heavy metals contamination in water, sediment, and shellfish in conventional artisanal oil mining zones in Nigeria. According to Amanullah et al. (2020), changes in weather patterns such as rainfall can affect the runoff of pollutants into the water, leading to variations in heavy metal concentrations. Furthermore, Nassiri et al. (2021) stated that varying concentrations of heavy metals in the water may be attributed to the alterations in the natural concentrations of these elements in the sediment and the distance of the station from potential pollution sources. These variations could be attributed to the closeness of Station 1 to the pollution sources and the higher concentrations of heavy metals observed in both the water and the fish from this station (Obasohan and Eguavoen, 2021). Brilliance and Davies (2023) reported similar results on the hazard implications of higher concentrations of heavy metals concentration in swimming crab (*Callinectes amnicola)* consumed from polluted creeks in the Niger Delta.

Chronic daily intake values indicate that consuming Redbelly tilapia from Atuka Creek may pose a significant health risk, especially for children who are more vulnerable to heavy metal toxicity. The levels of heavy metals in the fish exceed the safe limits set by the World Health Organization (WHO). This suggests that both adults and children consuming this fish could face health issues like organ damage, growth retardation, anaemia, and impaired cognitive development (Vaishaly et al., 2015; Sankhla et al., 2017). Studies by Okereafor et al. (2020) and Rakib et al. (2022) show high heavy metal levels in fish and aquatic organisms in the Niger Delta region, indicating widespread pollution in water bodies (Amadi et al., 2020). Pollution sources in the area include oil spills, gas flaring, industrial discharge, and artisanal mining (Fayiga et al., 2018; Raimi et al., 2022). These findings suggest that consuming fish and aquatic organisms from Niger Delta water bodies could pose significant health risks, especially for those who depend on fish as a primary protein source.

The variations in the HQ and HI values observed across the three stations could be attributed to differences in the concentrations of heavy metals in the water and fish samples collected (Enuneku et al., 2018). However, Station 1 recorded higher concentrations of heavy metals, which could result in higher HQ and HI values. The high HI values observed in Redbelly tilapia from Atuka Creek could have severe health implications for both adults and children (Safiur Rahman et al., 2021). However, Engwa et al., 2019) stated that long-term exposure to heavy metals can lead to adverse health effects such as neurotoxicity, kidney damage, gastrointestinal disorders, and an increased risk of cancer. Children are more susceptible to the toxic effects of heavy metals due to their developmental stage and lower body weight (Davies and Anyanwu, 2023). In other research findings in the Niger Delta region of Nigeria, similar levels of heavy metals have been reported in different fish species and other aquatic organisms (Okoye et al. 2021; Abarshi et al., 2017; Ehiemere et al., 2022). These findings indicate widespread pollution of the water bodies in the region and suggest the need for urgent action to regulate and control pollution sources to protect human health and ensure the safety of the food resources in the region. The HQ and HI values in the table for both adults and children are generally greater than one, indicating a potential non-carcinogenic health risk associated with consuming Redbelly tilapia from Atuka Creek. The HI values for Station 1 and Station 2 exceed the safe limit of one for both adults and children, indicating a higher potential for chronic health effects. Comparing the HI values to the postulation by Chris et al. (2023), the values obtained in this study suggest a potential chronic risk for both dermal (water) and ingestion (Redbelly tilapia) exposures. The HI values for Station 1 and Station 2 are particularly of great concern and suggest that the populations relying on fish as a major source of protein in these areas could experience chronic health effects.

The CDIing and CDIderm values obtained in this study show great concerns for both adults and children who consume Redbelly tilapia from Atuka Creek. According to Ihunwo et al. (2022), long-term exposure to heavy metals can lead to adverse health effects such as neurotoxicity, kidney damage, gastrointestinal disorders, and an increased risk of cancer. Children are more susceptible to the toxic effects of heavy metals due to their developmental stage and lower body weight (Abdel-Kader and Mourad, 2022). Similar CDIing and CDIderm values have been reported in different fish species and other aquatic organisms for heavy metals such as Pb and Cd in the Niger Delta region of Nigeria (Emoyan et al., 2021; Iwegbue et al., 2021). These findings highlight the potential widespread pollution of water bodies in the region, which may pose a significant risk to human health.

The Chronic daily intake of water via ingestion (CDIing) and dermal contact (CDIderm) values for heavy metals in Redbelly tilapia from the Atuka Creek in Rivers State, Nigeria suggests a potential non-carcinogenic health risk for both adults and children. The values obtained in this study are comparable to other research findings in the Niger Delta region of Nigeria, which reported similar CDIing and CDIderm values for heavy metals such as Pb and Cd in different fish and aquatic organisms. These findings have significant health implications for populations living in the Niger Delta region who rely on fish as a major source of protein. Long-term exposure to heavy metals like Pb, Cd, and Cr can lead to adverse health effects such as neurotoxicity, kidney damage, gastrointestinal disorders, and an increased risk of cancer (Ihunwo et al., 2022). Children are more susceptible to the toxic effects of heavy metals due to their lower body weight and developmental stage (Anyanwu and Chris 2023). However, several studies have reported similar health risks associated with metal contamination in the Niger Delta region (Abarshi et al., 2017; Dirisu et al., 2019; Nnaemeka, 2020). According to Akankali and Davies (2021), heavy metals such as Pb, Cd, and Zn in fish from the Bonny estuary in the Niger Delta region exceeded the safe limits recommended by the World Health Organization (WHO). Another study by Joseph et al. (2017) found that fish from the Atlantic Ocean and Qua Iboe River in the Niger Delta region contained high levels of heavy metals such as Pb, Cd, Cr, and Fe.

The Hazard quotients for ingestion (HQ_{Ing}) values for heavy metals such as Zn, Cu and Fe exceed the safe limit of 1 for both adults and children in Station 1 and Station 2. This indicates that exposure to such heavy metals can have adverse effects on human health, leading to gastrointestinal disorders and other health issues (Rehman et al., 2018; Fu and Xi, 2020). For Cu, the HQDerma values also exceed the safe limit in both adult and child categories, indicating a potential risk of skin irritation from dermal contact with water (Liu, 2019; Egbueri et al., 2023).

Comparing the findings to other research results in the Niger Delta region of Nigeria, there are significant health risks associated with the consumption of fish contaminated with heavy metals. A study by Ogamba et al. (2021) reported that the surface water of Taylor Creek, Bayelsa State, Nigeria contained high levels of heavy metals such as Pb, Cd, Cu, and Zn, exceeding the safe limits of the Codex Alimentarius Commission (CAC). These heavy metals can accumulate in fish tissues and pose a potential health risk for consumers. According to Obasi and Akudinobi (2020), long-term exposure to heavy metals like Pb, Cd, and Cu can have serious health consequences. These may include neurotoxicity, kidney damage, gastrointestinal disorders, and an elevated risk of cancer (Manwani et al., 2022). Children are more susceptible to the toxic effects of these heavy metals due to their lower body weight and developmental stage. The contamination of aquatic resources with heavy metals also has far-reaching ecological implications, affecting aquatic biodiversity and ecosystem functioning (Yarkwan, 2023). These findings are consistent with other research results in the Niger Delta region, emphasizing the urgent need for increased water resource management and stricter regulations to control pollution sources in the region (Loucks and Van Beek, 2017; Chen et al., 2021).

The higher TLCR in Stations 1 and 2 may be attributed to anthropogenic activities such as illegal oil exploration, industrial activities and other practices around the study areas. According to Chris et al. (2023a), long-term exposure to heavy metals through water intake can result in an increased lifetime cancer risk for both adults and children. Children are more vulnerable to the toxic effects of these heavy metals due to their lower body weight and developmental stage Onojake et al. (2017). Abarshi, et al. (2017) reported that the consumption of contaminated water can pose significant public health concerns in the Niger Delta region. There is a significant chance of cancer-related to exposure to heavy metals through fish diet, according to findings of this study and prior research in the Niger Delta region. High amounts of heavy metals, such as Pb, Cd, and Zn, were discovered in fish from the Bonny River in research by Onojake et al. (2017), above the safe limits advised by the World Health Organization (WHO). The accumulation of these heavy metals in fish tissues poses a serious threat to human health (Abarshi, et al. (2017).

The higher TLCR in Stations 1 and 2 may be attributed to anthropogenic activities such as illegal oil exploration, industrial activities and other practices around the study areas. According to Akankali et al. (2022), long-term exposure to heavy metals through water intake can result in an increased lifetime cancer risk for both adults and children. Children are more vulnerable to the toxic effects of these heavy metals due to their lower body weight and developmental stage (Zeng et al., 2019). Anyanwu and Chris (2023) reported that the consumption of contaminated water can pose significant public health concerns in the Niger Delta region.

High concentrations of heavy metals which include Pb, Cd, and Cu have been detected in water samples in the Niger Delta, following Chinedu and Chukwuemeka (2018), which exceeded the permissible threshold established by the World Health Organization (WHO). Alengebawy et al. (2021) agree that the accumulation of these heavy metals in human tissues poses a serious threat to human wellness. Exposure to contaminated water in Atuka Creek can lead to severe health consequences, including long-term risks of cancer in both adults and children. To minimize these risks, it is crucial to implement stricter regulations and remediation measures that can reduce the concentration of heavy metals in aquatic resources in the Niger Delta region. Increased water resource management is also necessary to address this issue effectively.

Conclusion

Metal concentrations varied at different stations, with Station 1 showing the highest levels likely due to its proximity to pollution sources. Fish from Station 1 had the highest contamination levels, posing health risks, while Stations 2 and 3 had lower but still above recommended levels. Chronic daily intake (CDI) values for heavy metals indicated potential risks for both adults and children, with Station 1 having the highest values. Hazard quotients (HQ) and hazard index (HI) values exceeded safe limits in Stations 1 and 2, suggesting potential non-carcinogenic health risks from fish consumption. Lifetime cancer risk (ILCR and TLCR) assessments showed an increased cancer risk from heavy metal exposure through fish consumption, especially at Stations 1 and 2 in Atuka Creek. Therefore, raising awareness about the dangers of consuming fish and water from Stations 1 and 2, particularly for vulnerable groups like children, is crucial. These findings highlight the importance of regulating and managing pollution sources in the Niger Delta region of Nigeria.

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