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Original Article

Toxicological Assessment of Captured Fish Species from a Lotic Freshwater Ecosystem in Nigeria

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Abstract

Consumption of safe aquatic foods is critical to the sustainable development goal of good health and wellbeing. This study assessed the content of metals in *Clarias gariepinus* and *Tilapia zillii* from Owan River in Nigeria and evaluated the plausible human health risk associated with their consumption. The results showed that mean concentrations of iron (25.03 – 74.98 mg kg^{-1}), zinc (8.21 - 38.97 mg kg^{-1}) and copper (4.48 – 12.08 mg kg^{-1}) exceeded their respective WHO permissible guideline values, while concentrations of lead (0.019 – 0.065 mg kg^{-1}) and cadmium (0.013 – 0.041 mg kg^{-1}) were below their respective WHO guideline value for fish food in both fish species. The order of heavy metal accumulation in the fillets, gills and liver was Fe > Zn > Cu > Pb > Cd. The human health risk assessment indicated that the THQ values for the metals were < 1, calculated HI values (0.146 – 0.214) did not exceed the threshold value of 1 (HI < 1) which implies that the consumers are not predisposed to non-carcinogenic health risk. Estimated carcinogenic risk values and integrated carcinogenic risk (ICR) values associated with the consumption of the fish species classified the consumption of *C. gariepinus* and *T. zillii* as extremely low risk (Grade I). Concerted efforts in the periodic monitoring of anthropogenic activities within the watershed to prevent the deterioration of the water quality of Owan River in order to guarantee the sustainable availability of safe aquatic foods for human consumption is recommended.

Keywords: Metal toxicity, Health risk, *Clarias gariepinus*, *Tilapia zillii*, Owan River.

INTRODUCTION

Increasing anthropogenic activities due to socioeconomic development and the uncontrolled discharge of pollutants into the environment is a serious threat to the sustainability of freshwater ecosystems. These pollutants which are transported from their sources to rivers, contain metals which are persistent in the water bodies and are taken up by resident organisms like fishes and stored in their various tissues. The high susceptibility of fishes to metal contamination among the aquatic fauna, has made them good indicators for investigating heavy metal pollution in aquatic environment. Also, the high toxicity of these metals to aquatic organisms; their negative impacts on public health and sustainable development has led to several studies on metal contamination of various ecological systems globally and in Nigeria (Isibor, 2016; Choudri *et al*., 2017; Enuneku *et al.,* 2018; Oboh *et al*., 2019; Joan *et al*., 2021; Egun and Oboh, 2022; Uwaifo *et al*., 2023; Egun *et al*., 2023; Biose *et al*., 2024).

Owan River in Edo State Nigeria is an inland freshwater body that is critical to the sustainable development goals agenda of access to clean water (Goal 6) and good health and wellbeing (Goal 3); as it provides diverse aquatic ecosystem services to several communities situated along the watercourse. In recent times, various forms of pollution have been observed at different stretches of the River due to increasing anthropogenic activities arising from the transitioning of some rural communities to peri-urban areas. Recent

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studies on the Owan River has focussed on the water quality (Egun and Oboh, 2023), and the nutritional contribution of fish species to minerals intake of pregnant and lactating women, children and adults in the surrounding rural communities (Egun *et al*., 2022). The reported poor water quality of Owan River and carcinogenic risk associated with the water consumption (Egun and Oboh, 2023), has necessitated the need to evaluate the health risk associated with the consumption of fish species from the River. Therefore, the aim of this study is to determine the levels of metals in selected commercial fish species – Catfish (*Clarias gariepinus*) and Tilapia fish (*Tilapia zillii*) from Owan River and ascertain the plausible health risk associated with their consumption. Selected fish species for the study was based on their cultural acceptability for consumption as food and commercial value in Nigeria.

MATERIALS AND METHODS

Study Location: This study was carried out at Owan River (Latitudes 006° 45’ 36.5” N to 006° 45’ 52.8” N and Longitudes 05° 45' 40.6” E to 05° 46’ 21.8” E) in Edo State, Nigeria. The River lies in the Benin – Owena River basin, and provides various ecosystem services as it transverses several communities in the tropical rain forest belt of Nigeria.

Trophic niche of Selected Fish Species: Apart from the acceptability and commercial value of the selected fish species for the study, their positions in the trophic niche of the aquatic ecosystem make them good bioindicators of metal pollution in a water body. The benthic nature and feeding habit of Catfish (*Clarias gariepinus*) which are both carnivorous and omnivorous predisposes the fish to contaminants in the water column, sediments and those already taken up by aquatic organisms. Also, the feeding habit of Tilapia fish (*Tilapia zillii*) and its intermediate position between primary producers and piscivores in the aquatic trophic niche makes them useful indicators of aquatic pollution and trophic transfer of contaminants.

Sample Collection: Adult sized samples of *Clarias gariepinus* (avg. wt. 810g) and *Tilapia zillii* (avg. wt. 250 grams) were harvested from January 2019 to August 2020 from designated fishing points along the River with the assistance of artisanal fishermen using drag nets. The fish samples were properly identified using taxonomic guides (Idodo-Umeh, 2003), packed in polyethylene bags and preserved in ice box before transported to the laboratory.

Sample Analysis: In the laboratory, the fish samples were dissected and gutted. Fish fillets were collected along the lateral line, the gills and liver tissues were also extracted. The extracted sample tissues were wrapped in aluminium foil paper, labelled and oven – dried at a temperature of 105^0C for 1 hour. The dried samples were ground to powdered form with the aid of a plastic mortar and pestle, sieved to obtain a uniform particle size and stored in labelled containers. Samples were digested following the procedure described by APHA (2012). Two grams (2 g) of the ground samples were weighed and placed in a 125 ml beaker where 100 ml of distilled water and 0.5 ml of Nitric acid (HNO_3) were added, and the addition of 5 ml of concentrated Perchloric acid ($HClO_4$). The mixtures were heated in a well-ventilated hood using a temperature regulated hot plate until volumes were reduced to 20 ml with the appearance of white fumes. The beakers were removed from the hot plate, allowed to cool and then filtered using the Whatman filter paper. Metal concentrations in sample filtrates were determined using the Atomic Absorption Spectrophotometer (Model 210 VGP, Buck Scientific). The equipment was calibrated using buck-certified atomic absorption standards for the several metals to obtain a calibration curve. Reagent blank was first run at intervals of every 10 samples analysis to eliminate equipment drift.

Quality Assurance and Control: Fish samples were packed in polyethylene bags and preserved in ice box to guarantee the biological integrity of the tissues of interest prior to analysis. Laboratory analysis were carried out at a national reference laboratory - the Benin Owena River Basin Authority/ University of Benin Analytical laboratory, University of Benin, Nigeria. All samples were analyzed in triplicates and the mean values were reported. Information on certified reference materials, detection limits, quantification limits and percentage material recovery on each metal is presented in Table 1.

Table 1. Certified Values for Elements in SRM 3233 Detection limit (DL), Quantification limit (QL), % of Relative Standard Deviation (RSD) and Recovery.

Metals	Detection limits (DL) (µg mL^{-1})	Quantification limit (QL) (µg mL^{-1})	Relative Standard Deviation (%RSD)	% Recovery
Cu	0.1 – 1.0	0.01 – 1.0	1 – 5	90
Zn	0.1 – 1.0	0.01 – 1.0	1 – 5	99
Fe	0.1 – 1.0	0.01 – 1.0	1 – 5	99
Pb	0.1 – 1.0	0.01 – 1.0	1 – 5	99
Cd	0.1 – 1.0	0.01 – 1.0	1 – 5	99

Note: Standard Reference Material (SRM) 3233 (2020)

Data Analysis: All statistical analysis was computed using Microsoft Excel and Statistical Package for Social Sciences (SPSS) version 21. At every sampling visitation, three (3) specimen of each species were collected from fish catches at Owan River. In this study, a total of one hundred and eight (108) fish specimens comprising of fifty-four (54) specimens of *C. gariepinus* and fifty-four (54) specimens of *T. zillii* were collected and and analysed. Analytical results are presented as the pooled means ± SD per 100 g of each fish specimen analysed. Analysis of Variance (ANOVA) was used to determine variation ($p < 0.05$) in metal content among the organs in each fish species.

Human Health Risk Assessment:

Exposure Assessment: The estimated daily intake (EDI) of each metal from the consumption of *C. gariepinus* and *T. zillii* was determined by the equation (USEPA, 2012):

$$EXP_{diet} = \frac{C_m \times IR \times ED \times EF}{BW \times AT}$$

Cm: mean concentration of metal in fish (mg kg^{-1})
IR: ingestion rate of medium (Fish g/day). According to the Food and Agriculture Organization (FAO) of the United Nations, in year 2021 the per capita consumption of fish in Nigeria was 8.39 kg, which is equivalent to 23g (0.023 kg) portion per day (FAOSTAT, 2023).
ED: Exposure duration (Conventional life expectancy of 9 years for children and 70 years for adults)
EF: Exposure frequency (days/year i.e. 365 days/year)
BW is the body weight (approximate average of 70 kg for adults and 16 kg for children)
AT: 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 x 365 days (USEPA, 2004). Average life expectancy is 63.4 years for adults in Nigeria

Note: Mean concentration of metals in the fish fillets was used for estimating health risk. However, for *C. gariepinus*, the combined concentrations of gills and muscles was used. As the consumption of the gills of *C. gariepinus* along with the head portion of the fish is a priced delicacy among the indigenous people in the Southern Nigeria.

Non – carcinogenic Risk Assessment: The potential non – cancer risk of metal concentrations in *C. gariepinus* and *T. zilli* was characterized using the target hazard quotient (THQ) and hazard index (HI) (USEPA, 2012).

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

Target Hazard quotient (THQ):

$$THQ_{diet} = \frac{EXP_{diet}}{RfD_{diet}}$$

RfD (mg kg^{-1}/day): reference dose level of a particular metal through oral exposure (USEPA, 2021).

Table 2. Oral Reference Dose (R_fDo) for metals

Metals	**R_fDo (mg kg^{-1}/day)**
Lead	3.0×10^{-3} (USEPA, 2012)
Copper	4.0×10^{-2} (USEPA, 2012)
Cadmium	1.0×10^{-3} (USEPA, 2012)
Iron	7.0×10^{-1} (USEPA, 2012)
Zinc	3.0×10^{-1} (USEPA, 2012)

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

Hazard Index (HI):

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

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

Carcinogenic Risk Assessment: The potential carcinogenic risk of metals in *C. gariepinus* and *T. zillii* were estimated using the incremental or excess individual lifetime cancer risk. Carcinogenic risk (CR) is the product of daily exposure dose (CDI) and cancer slope factor (CSF).

$$CR_i = CDI_i \times CSF_i$$

CRi : carcinogenic risk of metals through oral route
CDIi : daily exposure dose of carcinogenic pollutants;
CSFi : cancer slope factor of carcinogenic pollutants

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

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

USEPA (2005) believes that carcinogenic risk value for humans is acceptable within 1 × 10^{-4}, while the maximum acceptable risk value recommended by International Commission on Radiological Protection (ICRP) is 5 × 10^{-5} (Zeng *et al*., 1998). For 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 3 (Yuan *et al*., 2011; Liu *et al*, 2015; Li *et al*, 2017).

RESULTS

Metal concentrations in Fishes

Mean concentrations of metals in gills, liver and fillets of *C. gariepinus* and *T. zillii* from Owan River are presented in Table 4. The results showed that *C. gariepinus* had higher mean concentration of metals than *T. zillii* in all the organs, except for copper concentrations in the fillets and liver. The order of accumulation of metals in all the tissues of *C. gariepinus* and *T. zillii* was Fe > Zn > Cu > Pb > Cd. In all the fish specimen analyzed iron had the highest concentration while cadmium had the least.

Health Risk Assessment

The results of the exposure intake (EXP), target hazard quotient (THQ) and hazard index (HI) in adults and children for non – cancerous risk assessment of the *C. gariepinus* and *T. zillii* from Owan River are summarized in Table 5. The calculated HI values (0.146 – 0.214) did not exceed the threshold value of 1 (HI < 1). For cancerous risk assessment (Table 6), calculated integrated cancerous risk (ICR) values of 2.38 x 10^{-7} to 4.32 x 10^{-6} were recorded, with *T. zillii* (fillets only) in children having lowest ICR values; while *C. gariepinus* (gills + fillets) in adults had the highest ICR values. The ICR values were within the USEPA acceptable carcinogenic risk value for humans (1 × 10^{-6}).

DISCUSSION

Metal Concentrations in Fishes

Fish consumption has been acknowledged as one of the healthiest and readily available source of animal protein and minerals especially in coastal communities and among socioeconomic challenged households (Egun *et al*., 2024). Global efforts towards achieving sustainable development goals of live below water (Goal 14) and good health and wellbeing for all ages (Goal 3), has raised concerns on the pollution of water bodies and its implication on the sustainability of fishery resources. Also, the innate ability of fish to bioaccumulate metals in its edible body parts – muscles (fillets) and gills, has seen the exposure of consumers to metal toxicity and its attendant health issues (Oboh *et al*., 2019; Egun *et al*., 2023).

Several factors such as feeding habits, fish size, species variation, position in the trophic structure and type of pollutants present in their aquatic environment have been identified to influence the uptake and accumulation of metals in fishes (Egun, 2021; Santhana *et al*., 2022). In this study, analytical results indicated the uptake and accumulation of metals in the examined organs of the fish species. Iron content was highest when compared with other metals in the organs of both fish species. This emphasizes the importance of iron for both cellular supply of oxygen and antioxidant defense in fishes (Zhe *et al*., 2023). Zinc content in the examined organs recorded the second highest metal content in both fish species, as zinc is an essential trace element which is associated with several structural, catalytic and regulatory functions in fish physiology (Dawood *et al*., 2022). Similar high iron and zinc contents was reported for *C. gariepinus* and *T. zillii* in Ikpoba Reservoir, and was attributed to the increased levels of these metals in the habitat water (Egun *et al*., 2023). Acute and chronic zinc toxicity in fish with elevated zinc concentrations in habitat water has been reported, the high zinc content observed especially in the gills is an indication that the fishes are subject to induced physiological stress which can result in mortality, growth retardation and reproductive impairment (Akan *et al*., 2012). However, the high iron and zinc contents in the examined organs of *C. gariepinus* and *T. zillii* did not exceed their respective FAO/WHO permissible limits of 100 mg kg^{-1} for iron and 50 mg kg^{-1} for zinc in food fish (Hossain *et al*., 2022).

Copper is an essential trace metal necessary for growth and metabolism of aquatic organisms, but toxic to aquatic life at high concentrations resulting in impairment of sensory functions and disruption of growth (Malhotra *et al*., 2020; Wei *et al*., 2023). Mean copper content in the organs of *C. gariepinus* and *T. zillii* was very high in comparison with the 0.5 mg kg^{-1} permissible for fish food. This implies that the organs of the fishes are predisposed to copper toxicity due to reported elevated levels of copper (0.17 mg L^{-1} – 0.63 mg L^{-1}) in the water body (Egun and Oboh, 2023). In a similar study, Monteiro *et al* (2008) reported a dose-response relationship with water copper levels on fish gill histopathology, with alteration of gill function in *Oreochromis niloticus* at waterborne copper levels of 0.04 mg L^{-1}. Also, elevated levels of copper in the fillets of the *C. gariepinus* and *T. zillii* predisposes the consumers to elevated copper intake and associated health risk.

Table 3. Levels and values of assessment standards.

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

Table 4. Summary of heavy metal content in the organs of *Clarias gariepinus* and *Tilapia zillii* from Owan River

Metals (mg kg^{-1})		Gills	Liver	Fillets	P value
		Mean ± SD	Mean ± SD	Mean ± SD	
Iron (mg kg^{-1})	*C. gariepinus*	73.98 ± 11.48^{c}	36.72 ± 2.05^{a}	50.93 ± 2.80^{b}	$p< 0.05$
	T. zillii	50.58 ± 11.96^{b}	25.03 ± 5.07^{a}	74.98 ± 6.37^{c}	$p< 0.05$
Zinc (mg kg^{-1})	*C. gariepinus*	38.97 ± 4.69^{b}	29.08 ± 2.14^{a}	20.64 ± 3.22^{a}	$p< 0.05$
	T. zillii	15.42 ± 1.74^{b}	8.21 ± 1.67^{a}	13.21 ± 3.05^{b}	$p< 0.05$
Copper (mg kg^{-1})	*C. gariepinus*	10.32 ± 0.81^{b}	8.78 ± 0.75^{b}	4.48 ± 0.50^{a}	$p< 0.05$
	T. zillii	8.76 ± 1.81^{b}	12.08 ± 1.58^{b}	4.62 ± 0.43^{a}	$p< 0.05$
Lead (mg kg^{-1})	*C. gariepinus*	0.047 ± 0.006^{a}	0.050 ± 0.019^{a}	0.030 ± 0.005^{a}	$p> 0.05$
	T. zillii	0.065 ± 0.028^{a}	0.047 ± 0.060^{a}	0.019 ± 0.002^{a}	$p> 0.05$
Cadmium (mg kg^{-1})	*C. gariepinus*	0.041 ± 0.005^{a}	0.023 ± 0.004^{a}	0.020 ± 0.003^{a}	$p> 0.05$
	T. zillii	0.029 ± 0.007^{a}	0.022 ± 0.010^{a}	0.013 ± 0.006^{a}	$p> 0.05$

Note: Values are presented as pooled means ± standard deviations (SD) of metal content in the organs of fish species throughout the study duration. Across each row, similar superscript indicates no significant difference ($p > 0.05$), while dissimilar superscript indicates significant difference ($p < 0.05$).

Table 5. Non – carcinogenic Risk Assessment

Metals	Adults					
	EXP$_1$	THQ$_1$	EXP$_2$	THQ$_2$	EXP$_3$	THQ$_3$
Iron	3.21E-02	0.05	2.62E-02	0.04	3.86E-02	0.06
Zinc	1.53E-02	0.05	1.06E-02	0.04	6.80E-03	0.02
Copper	3.80E-03	0.10	2.30E-03	0.06	2.38E-03	0.06
Lead	1.98E-05	0.01	1.54E-05	0.01	9.77E-06	0.003
Cadmium	1.57E-05	0.02	1.03E-05	0.01	6.69E-06	0.01
HI		0.21		0.15		0.15

Metals	Children					
	EXP$_1$	THQ$_1$	EXP$_2$	THQ$_2$	EXP$_3$	THQ$_3$
Iron	1.67E-02	0.02	2.05E-02	0.03	2.46E-02	0.04
Zinc	6.78E-02	0.02	9.79E-03	0.03	4.34E-03	0.02
Copper	1.47E-03	0.04	2.43E-03	0.06	1.53E-03	0.04
Lead	9.86E-06	0.003	1.27E-05	0.004	6.24E-06	0.002
Cadmium	6.57E-06	0.01	1.00E-05	0.01	4.27E-06	0.004
HI		**0.09**		**0.14**		**0.09**

Note: EXP$_1$ – Exposure intake of metals from *C. gariepinus* (fillets only); EXP$_2$ – Exposure intake of metals from *C. gariepinus* (gills + fillets); EXP$_3$ – Exposure intake of metals from *T. zillii* (fillets only); THQ$_1$ – Target hazard quotient of metals from *C. gariepinus* (fillets only); THQ$_2$ – Target hazard quotient of metals from *C. gariepinus* (gills + fillets); THQ$_3$ – Target hazard quotient of metals from *T. zillii* (fillets only); HI – Hazard index.

Table 6. Carcinogenic Risk Assessment

Metals	Adults					
	EXP$_1$	CR$_1$	EXP$_2$	CR$_2$	EXP$_3$	CR$_3$
Lead	1.09E-05	9.25E-08	1.40E-05	1.19E-07	6.89E-06	5.86E-08
Cadmium	7.26E-06	2.76E-06	1.11E-05	4.20E-06	4.72E-06	1.79E-06
ICR		2.85E-06		4.32E-06		1.85E-06

Metals	Children					
	EXP$_1$	CR$_1$	EXP$_2$	CR$_2$	EXP3	CR3
Lead	1.80E-06	1.53E-08	1.80E-06	1.53E-08	8.86E-07	7.53E-09
Cadmium	1.42E-06	5.41E-07	1.42E-06	5.41E-07	6.06E-07	2.30E-07
ICR		5.56E-07		5.56E-07		2.38E-07

Note: EXP$_1$ – Exposure intake of metals from *C. gariepinus* (fillets only); EXP$_2$ – Exposure intake of metals from *C. gariepinus* (gills + fillets); EXP$_3$ – Exposure intake of metals from *T. zillii* (fillets only); CR$_1$ – Carcinogenic risk of metals from *C. gariepinus* (fillets only); CR$_2$ – Carcinogenic risk of metals from *C. gariepinus* (gills + fillets); CR$_3$ – Carcinogenic risk of metals from *T. zillii* (fillets only); ICR – Integrated carcinogenic risk.

Lead and cadmium are highly toxic in aquatic environments, and fishes are susceptible to their toxic effects due to their position in the aquatic food chain (Ju-Wook *et al*., 2019). The exposure of fishes to elevated lead and cadmium levels have been reported to cause various types physiological damage to fish organs and inhibit the synthesis of essential trace elements (Li *et al*., 2018; Xu *et al*., 2021; Liu *et al*., 2022). In this study, the mean contents of lead and cadmium in the organs of *C. gariepinus* and *T. zillii* were low when compared to their respective WHO (2003) permissible limit of 0.5 mg kg^{-1} (lead) and 0.15 mg kg^{-1} (cadmium) for fish food. The observed low concentrations of lead and cadmium in the fishes could be attributed to the low levels of these metals in Owan River (Egun and Oboh, 2023). Similar low levels of lead and cadmium were reported in the organs of *C. gariepinus* and *T. zillii* from Ikpoba reservoir (Egun *et al*., 2023). While elevated levels of lead and cadmium in the liver of *C. gariepinus* and *T. zillii* from Ikpoba River were reported by Ogbeide and Okoduwa (2024).

In this study, the observed variation patterns in the accumulation of metals in different organs of a fishes can primarily be attributed to the differences in the surface area exposure to water, physiological role of each organ, species variation. The large surface area exposure of gills to the water which fastens diffusion of metals rapidly and the physiological role of gills as pathways of metal ion exchange (Dhaneesh *et al*., 2012) influenced the elevated levels of metals in the gills as compared to other organs. Also, the observed higher levels of metal contents in the organs of *C. gariepinus* as compared to *T. zillii* could be attributed to species variation in their positions in the aquatic trophic level which influenced their feeding habits and uptake of these metals from the water body. The display lateral migration towards surrounding marshes for spawning by the fish species did not influence the uptake of metals by the fishes as the Owan River is exposed to influx of pollutants from diverse natural and anthropogenic activities especially from the various commercial agricultural farms situated along the watercourse where pesticides and herbicides are applied. These activities have resulted in increased levels of iron, zinc, copper, lead and cadmium in the river (Egun and Oboh, 2023). This study corroborates the assertions of Khawar *et al*., (2024) that the levels of metal concentration in fishes are mostly associated with sediment composition, changes in water quality, or the amount of contaminated water or food ingested.

Human Health Risk Assessment

The consumption of contaminated fish food has been identified as one the sources of human exposure to metal toxicity. The probability of non – carcinogenic health risk from the exposure to a metal is high when the target hazard quotient (THQ) value for that metal is greater than 1 (USEPA, 2012). In this study, the estimated THQ values for metals in *C. gariepinus* and *T. zillii* from Owan River were below 1.0, which indicate that both the adult and children populations are not predisposed to non-carcinogenic health risk from ingesting of any metals through the consumption of the fishes. Also, the estimated non-carcinogenic hazard index (HI) values indicate that the consumers are safe to health risk (HI < 1); as an exposed population is considered safe to health risk where HI < 1.0 (Tripathee *et al.* 2016; Saha and Paul, 2018). The safe levels of the consumption of the fishes can be attributed to the overall low level of pollution of Owan river (Egun and Oboh, 2023). In similar studies, Oboh *et al.* (2019) reported lower hazard index values (HI < 1) in adults for consumption of *C. gariepinus* and *P. obscura* from Ikpoba River, Edo State, Nigeria. While Egun *et al* (2023) reported higher index values (HI > 1) in children for *C. gariepinus* and *T. zillii* from Ikpoba reservoir in Edo State which is severely polluted**.**

For carcinogenic risk, the estimated integrated carcinogenic risk (ICR) values associated with the consumption of the fish species did not exceed the USEPA acceptable carcinogenic risk value for humans (1×10^{-4}). As the ICR values associated with the consumption of the fish species classified the consumption of *C. gariepinus* and *T. zillii* as extremely low risk (Grade I). Egun *et al* (2023) reported higher ICR values for *C. gariepinus* and *T. zillii* from Ikpoba Reservoir which classified the consumption of the fishes as low – medium risk (Grade III) to consumers.

Taking into cognizance that the consumption of the head portion of *C. gariepinus* along with gills in culinary delicacies in Nigeria, this study showed that consumers were exposed to higher non – carcinogenic risk with the consumption of the gills along with the fillets when compared with the consumption if the fillets only. However, there is no adverse associated non-carcinogenic and carcinogenic risk health risk to consumers. In a similar study, the consumption of gills of *C. gariepinus* from Ikpoba reservoir was highly discouraged as consumers were exposed to higher non – carcinogenic risk and carcinogenic risk (Egun *et al.*, 2023). This study also raises concerns on the water quality of freshwater bodies where capture fisheries activities are carried out and its implication on public health.

CONCLUSION

Concerns on public health and sustainable development has necessitated this study to determine heavy metal contents in *C. gariepinus* and *T. zillii* from Owan River and ascertain the plausible health risk associated with their consumption. Results from this study showed heavy metal contamination of the *C. gariepinus* and *T. zillii*, with the order of accumulation of Fe > Zn > Cu > Pb > Cd in all the examined organs. Mean concentrations of iron, zinc and copper exceeded their permissible guideline values, while concentrations of lead and cadmium were below their respective WHO guideline value for fish food. The human health risk assessment indicated that the THQ values for the metals were < 1, calculated HI values (0.146 – 0.214) did not exceed the threshold value of 1 (HI < 1) which implies that the consumers are not predisposed to non-carcinogenic health risk. Estimated carcinogenic risk values and integrated carcinogenic risk (ICR) values associated with the consumption of the fish species classified the consumption of *C. gariepinus* and *T. zillii* as extremely low risk (Grade I). It is recommended that concerted efforts be made to prevent the deterioration of the water quality of Owan River in order to guarantee the sustainable availability of safe aquatic foods for human consumption.

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CREDIT AUTHOR STATEMENT

NK and **IP**: Conceptualization and Methodology. **NK**, **UC** and **H**: Data curation and Investigation. **NK**: Writing-Original draft preparation. **IP**: Supervision. All authors reviewed the manuscript.

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