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HEAVY METAL EVALUATION: POTENTIAL RISK FOR HUMAN HEALTH AND IMPACT ON TISSUES OF TILAPIA FISH (*OREOCHROMIS NILOTICUS*) FROM A NATURAL URBAN RIVER

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ABSTRACT
This research study sought to determine the effect of some heavy metals on non-carcinogenic health risk for humans and tissues of Tilapia (*Oreochromis niloticus*) harvested from Dandaru River (a natural urban river) located South-West of Nigeria. Concentration of magnesium, nickel, manganese, cadmium, iron, zinc, copper, lead, and cobalt in water sample, gill, liver, intestine, and muscle of fish was quantified spectrophotometrically. Bioaccumulation factor (BAF) and hazard quotient (HQ) were estimated. Histopathological lesions in fish tissue were assessed. Heavy metals in water sample were mostly within permissible limits set by water quality regulatory agencies but, considerably high across target tissues. An appreciable number of the metals were bioaccumulative (BAF=1000-5000) or extremely bioaccumulative (BAF>5000) across all tissues. Hazard quotient were above the acceptable limit (>1.00) for most of the metals. The gills showed curling of secondary lamella, hyperplasia as well as oedema. Dilated sinusoids and congestive melanomacrophages were seen in the liver. Degeneration of intestinal mucosal surface was evident. Atrophy, inflammation and degeneration of smooth and skeletal muscle fibers were obvious. Conclusively, the combination of high hazard quotient and histological deformations seen in fish tissue confirms possible health risk to humans and adverse impact of heavy metals on fish.

Keywords: Marine ecosystem, Bioaccumulation, Hazard quotient, Pathologic, Nigeria.

INTRODUCTION

The crisis of water pollution has become one of great apprehension for the global community; hence, the importance attached to adequate supply of good quality water for use in agro-industrial practices as well as domestic purposes, cannot be over flogged (Sdiri *et al*., 2018; Gill *et al*., 2019; Konapala *et al*., 2020; Tortajada, 2020; UN-WATER, 2020). Heavy metals constitute one of the critical causes of water pollution (Chen *et al*., 2015; Masindi and Muedi, 2018; Bansal, 2020). These metals are naturally occurring and quite a number of them are essential to life in minute quantities (Bhattacharya *et al*., 2016; Chen *et al*., 2019; Kieliszek, 2019; Sharma *et al*., 2021; Agbugui and Abe, 2022; Njinga *et al*., 2023). They are known to have high densities, atomic weights, and atomic numbers with potential to bioaccumulate in tissues of aquatic organisms consequently forming bonds with enzymes, and ultimately disrupting the function of the enzymes (Onyegbula and Okesola, 2016; Ahmed *et al*., 2019; Maurya *et al*., 2019; Onyegbula *et al*., 2021; Sharma *et al*., 2021; Agbugui and Abe, 2022; Njinga *et al*., 2023). Indirectly, humans may be exposed to heavy metal poisoning through fish consumption resulting in acute and chronic health complications (Gerenfes and Teju, 2018). Some of the health effects connected with heavy metal poisoning in humans include cardiac arrest, pneumonia, brain haemorrhage, dermatitis, asthma, spontaneous abortion, congenital structural malformations, chromosomal aberrations, liver damage, neurotoxicity, chronic respiratory tract inflammation, birth defects, cancer, kidney lesions, and hypertension (Deng and Wang, 2019; Cheng, 2020; Kannan *et al*., 2021). This study was conducted to establish the concentration of nine heavy metals; magnesium (Mg), nickel (Ni), manganese (Mn), cadmium (Cd), iron (Fe), zinc (Zn), copper (Cu), lead (Pb), and cobalt (Co) in water sample as well as tissues (gill, liver, intestine, and muscle) of Tilapia fish (*Oreochromis niloticus*) harvested from Dandaru River during the rainy season months of May and June. Pattern of metal bioaccumulation in the target tissues as well as, the hazard quotient in humans were estimated in order to evaluate the health risk linked with consumption of the fish. In addition, the morphologic alterations in the organs investigated were identified. The heavy metals considered in this study have been established to impart toxic effects on various human organs and systems. Hypermagnessaemia (Mg toxicity) has been reported to affect the cardiovascular system where it manifests in different symptoms (nervous breakdown, muscle weakness, hypotension, irregular heartbeat, and respiratory distress) and ultimately cardiac arrest (Jaiswal *et al*., 2020; Qazi *et al*., 2021; Demissie *et al*., 2024). Mustapha *et al*., (2023) had reported: respiratory failure, birth defects, allergies, and heart failure as a consequence of Ni toxicity; Manganism (Mn toxicity) characterized by neuro-degenerative disorders and Parkinsonism-like symptoms; damage to the lungs, kidneys, bones, as well as cardiovascular diseases; iron overload disorders (haemochromatosis), coma, shock, methanolic acidosis, liver failure, coagulopathy, respiratory distress syndrome, long-term organ damage, and death from Fe toxicity. It has been reported that Pb is toxic to the pulmonary, neurologic, and hepatorenal systems, in addition to being harmful to the bones as well as affecting cognition and behavior in humans (Satarug *et al*., 2020; Shvachiy *et al*., 2020; Wei *et al*., 2020; Eiro *et al*., 2021; Boskabady *et al*., 2022; Laoye *et al*., 2025). It is also reported to have caused anaemia, arthritis and chronic kidney disease in humans (Balali-Mood *et al*., 2021; Wang *et al*., 2021; Fang *et al*., 2023; Laoye *et al*.,. 2025). Other metals such as Cd, Zn, Cu, and Co are also known to be toxic in humans when they are in excess (Mustapha *et al*., 2023; Owonikoko *et al*., 2023; Farh *et al*., 2024; Laoye *et al*., 2025). The study site (Dandaru River) is located in Ibadan which is, reputed for being the largest city in West Africa. The city lies within the coordinates: 7º23´47´´N - 3º55´0´´E -/-

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7.39639^{o}N 3.916667^{o}E in Nigeria with area coverage of about 828km^2 and a population of approximately 2.6 million (Akinyemi *et al*., 2014; Onyegbula and Okesola, 2016). Human activities carried out around the neighborhood of the river include car washing, laundry, bathing, swimming and fishing to mention a few. The river shares boundaries with the defunct Agodi zoological gardens and the University College Hospital (UCH) from where it receives effluents.

MATERIALS AND METHODS

Sample Collection

Polyethylene plastic sampling bottles of 1 liter capacity were pre-conditioned by washing with metal-free detergent solution, and subsequently rinsed with distilled water, as well as water from the sampling site. Water samples from the upstream and downstream points of the river were then collected and preserved by acidifying with 5 ml of 6N HNO3 (pH2.0) for assessment of heavy metal concentration (Javed and Usmani, 2003; Onyegbula and Okesola, 2016). Several live samples of Tilapia (*Oreochromis niloticus*) of different sizes, weights and maturity were collected with the support of trained fishermen and transferred into sterile buckets containing water from the river and transported immediately to the laboratory. Fishes were dissected and target tissues harvested for analysis of heavy metal concentration and histology.

Assessment of Heavy Metal Concentration in Harvested Fish Tissues and Dandaru River Water

With strict adherence to standard protocols set by the American Public Health Association (2005), the concentration of Mg, Ni, Mn, Cd, Fe, Zn, Cu, Pb, and Co were estimated in fish tissues and river water samples using Atomic Absorption Spectrophotometer (AAS) (Perkin Elmer, Analyst A 800).

Estimation of Heavy Metal Bioaccumulation in Fish Tissues

The bioaccumulation factor of each heavy metal in fish tissues was estimated by applying a previously used mathematical equation (Onyegbula and Okesola, 2016).

$$\text{Bioaccumulation factor (BAF)} = \frac{\text{Heavy metal concentration in fish tissue (mg/kg)}}{\text{Heavy metal concentration in water sample (mg/l)}}$$

Bioaccumulation factor is interpreted as follows: BAF<1000 (No probability of accumulation); BAF=1000–5000 (Bioaccumulative); BAF>5000 (Extremely bioaccumulative) (Ahmed *et al*., 2019).

Assessment of Health Risk for Human Consumers of Fish

Estimated daily intake of heavy metal

The risk for human health as a result of consuming Tilapia from Dandaru river, South-West, Nigeria was assessed by calculating the estimated daily intake (EDI) using the following equation (Onsaint *et al*., 2010; Onyegbula and Okesola, 2016).

$$\text{EDI} = \frac{\text{C (fish)X D (fish)}}{\text{BW}}$$

Where C (fish) is the mean concentration of metal in fish muscle (ppm dry weight), D (fish) is the global mean daily consumption (g/day) which is 6.5 g/person for Nigerians (Williams and Unyimadu, 2013; Onyegbula and Okesola, 2016), and BW is the average body weight (kg) considering an adult average body weight to be 70 kg (USEPA, 2000).

Hazard quotient (non-carcinogenic)

The hazard quotient (HQ) was then calculated by dividing the estimated daily intake (EDI) by the established reference dose (RfD) of heavy metal for an adult average body weight of 70kg to assess the health risk associated with fish consumption. There would be no obvious risk if the HQ for each metal investigated were less than 1.00 (Onsaint, *et al*., 2010; Onyegbula and Okesola, 2016).

$$\text{HQ} = \frac{\text{EDI}}{\text{RfD}}$$

Data Analysis

The results are presented as mean of duplicate determinations.

Tissue Preparation for Histologic Examination

Fishes were dissected and tissues of interest (gill, liver, intestine, and muscle) were harvested and held overnight in Davidson's fluid. They were then thoroughly rinsed in running tap water and fixed in 10% formol-saline overnight and subsequently dehydrated through 70%, 80%, 90%, and two changes of absolute ethanol for 1 hour each. Tissues were then embedded in two changes of molten paraffin wax for 1 hour each prior to blocking out for sectioning (Humason,1979; Onyegbula and Okesola, 2016). All sections in triplicates were examined and photographed using SONY cybershot DSCW800 digital camera attached to a Leitz binocular microscope.

RESULTS

Concentration of Heavy Metals in Tissues of Tilapia fish (*Oreochromis niloticus*) and Dandaru River Water

The mean concentration of heavy metals in selected tissues of fish and river water examined in this study relative to local and international water quality standard concentrations are shown in Table 1.The mean concentrations of these metals in the river water compared to the standard concentrations are: Mg (11.60ppm/50.00ppm), Ni (0.01ppm/0.50ppm), Mn (0.35/0.20), Cd (0.01ppm/0.20ppm), Fe (1.07ppm/0.50ppm), Zn (0.23ppm/5.00ppm), Cu (0.02ppm/3.00ppm), Pb (0.07ppm/5.00ppm), and Co (0.07ppm/0.01ppm). The mean concentrations of the metals in the tissues of fish relative to their concentration in river water are: Mg ranged between 210.00ppm (liver) and 2400.00ppm (muscle) compared to 11.60ppm (water sample); Ni was between 10.00ppm (gill and intestine, respectively) and 20.00ppm (liver and muscle, respectively) compared to 0.01ppm (water sample); Mn ranged between 10.00ppm (liver) and 6200.00ppm (intestine) as against 0.35ppm (water sample); Cd varied from 10.00ppm (liver, intestine as well as muscle, respectively) to 30.00ppm (gill) compared to 0.01ppm (water sample); Fe ranged from 1100.00ppm (gill) to 18400.00ppm (intestine) compared to 1.07ppm (water sample). The concentration of Zn ranged from 380.00ppm (gill) to 2690.00ppm (muscle) in contrast with 0.23ppm (water sample); Cu ranged between 110.00ppm (gill) and 410.00ppm (liver) in comparison to 0.02ppm (water sample). The value of Pb ranged from 10.00ppm (intestine) to 60.00ppm (liver and muscle, respectively) compared to 0.07ppm (water sample) while, the concentration of Co ranged from 30.00ppm (liver) to 100.00ppm (intestine) compared to 0.07ppm (water sample).

Table 1: Mean concentration of heavy metals in tissues of Tilapia (*Oreochromis niloticus*), and Dandaru River water compared with water quality standards in ppm

Fish Tissue / River Water/ Water Quality Standards	Mg	Ni	Mn	Cd	Fe	Zn	Cu	Pb	Co
Gill	440.00	10.00	20.00	30.00	1100.00	380.00	110.00	40.00	40.00
Liver	210.00	20.00	10.00	10.00	11200.00	590.00	410.00	60.00	30.00
Intestine	1290.00	10.00	6200.00	10.00	18400.00	610.00	160.00	10.00	100.00
Muscle	2400.00	20.00	50.00	10.00	8300.00	2690.00	120.00	60.00	40.00
River Water	11.60	0.01	0.35	0.01	1.07	0.23	0.02	0.07	0.07
SON	20.00	0.02	0.20	0.003	0.30	3.00	1.00	0.01	NA
NAFDAC	30.00	NA	NA	0.00	NA	5.00	NA	0.00	NA
WPCL	NA	0.02	NA	0.003	0.45	4.25	NA	0.01	NA
CCME	NA	0.20	0.05	0.002	NA	NA	NA	5.00	NA
WHO	50.00	0.02	0.10	0.003	0.30	5.00	NA	0.01	NA
USEPA	NA	0.50	0.05	0.005	0.50	5.00	1.00	0.10	NA
EUC	NA	0.02	0.05	0.20	NA	5.00	3.00	0.50	NA
NYSDEC	NA	NA	NA	NA	NA	NA	NA	NA	0.01

Key: SON (Standards Organization of Nigeria, 2015); NAFDAC (National Agency for Food and Drug Administration & Control); WPCL (Water Pollution Control Legislation, 2004); CCME (Canadian Council of Ministers of The Environment, 1999); WHO (World Health Organization, 2003); USEPA (United States Environmental Protection Agency, 2002); EUC (European Union Commission, 1998); NYSDEC (New York State Department of Conservation, 1986); NA (Not Available); ppm (Parts Per Million)

Bioaccumulation of Heavy Metals in Tissues of Tilapia (*Oreochromis niloticus*) from Dandaru River

The BAF for each metal in the examined organs is shown in Table 2. The bioaccumulation pattern for each metal in the different tissues are as follows: Cu (BAF>5000) while, Cd, Zn, Fe, and Ni (BAF=1000-5000) in the gill; Cu and Fe (BAF>5000) while, Zn, Ni, and Cd (BAF=1000-5000) in the liver; Mn, Fe, and Cu (BAF>5000) while, Zn, Co Ni, and Cd (BAF=1000-5000) in the intestine; Zn, Fe, and Cu (BAF>5000) while, Ni and Cd (BAF=1000-5000) in the muscle. There was no probability of Mg bioaccumulation in the gill (37.93), liver (18.10), intestine (111.21) and muscle (206.89). Similarly, there was no likelihood of bioaccumulation of Mn in the gill (57.14), liver (28.57) and muscle (142.86). In addition, there was no chance of Pb bioaccumulation in the gill (571.43), liver (857.14), intestine (142.86) and muscle (857.14). Finally, the possibility of bioaccumulation of Co in the gill (571.43), liver (428.57), and muscle (571.43) was remote.

Table 2: Bioaccumulation factor (BAF) of heavy metals in selected tissues of Tilapia (*Oreochromis niloticus*) from Dandaru River

Metal	Gill	Liver	Intestine	Muscle
Mg	37.93	18.10	111.21	206.89
Ni	1000.00	2000.00	1000.00	2000.00
Mn	57.14	28.57	17714.29	142.86
Cd	3000.00	1000.00	1000.00	1000.00
Fe	1028.04	10467.29	17196.26	7757.01
Zn	1652.17	2565.22	2652.17	11695.65
Cu	5500.00	20500.00	8000.00	6000.00
Pb	571.43	857.14	142.86	857.14
Co	571.43	428.57	1428.57	571.43

Health Risk Associated with Consumption of Tilapia (*Oreochromis niloticus*) from Dandaru River by Humans

In Table 3, health risk to human consumers of Tilapia fish harvested from Dandaru River was estimated by using the mathematical equation for calculating hazard quotient earlier used by Onsaint *et al*., (2010) as well as Onyegbula and Okesola (2016) in their publications. With the exception of Pb which had the least HQ of 0.52 which is less than the threshold of 1.00, all other metals assessed in this study had HQ values which exceeded the threshold. The respective value for each metal is Mg (222.86), Ni (1.33), Mn (4.73), Cd (13.29), Fe (1572.88), Zn (11.89), Cu (3.98), Pb (0.52), and Co (185.50)

Table 3: Health risk associated with consumption of Tilapia (*Oreochromis niloticus*) from Dandaru River

Metal	Concentration in Fish Muscle (ppm)	Permissible Limits (mg/kg dry weight)	EDI (mg/kg b.w/day)	RfD (mg/70kg b.w/day)	Hazard Quotient (EDI/RfD)
Mg	2400.00	NA	222.86	1.00	222.86*
Ni	20.00	10 (FAO, 1983)	1.86	1.40	1.33*
Mn	50.00	0.5–1.2 (WHO, 1982)	4.64	0.98	4.73*
Cd	10.00	0.5 (FAO, 1983)	0.93	0.07	13.29*
Fe	8300.00	1.0–4.5 (WHO, 1982)	770.71	0.49	1572.88*
Zn	2690.00	50 (FAO, 1983)	249.79	21.00	11.89*
Cu	120.00	30 (FAO, 1983)	11.14	2.80	3.98*
Pb	60.00	0.5 (FAO, 1983)	0.13	0.25	0.52
Co	40.00	0.01 (USFDA, 1993)	3.71	0.02	185.50*

Key: ppm (parts per million); EDI (Estimated Daily Intake); RfD (Reference Dose); USEPA (United States Environmental Protection Agency); NA (Not Available); FAO (Food and Agricultural Organization); WHO (World Health Organization); USFDA (United States Food & Drug Administration; *Obvious Risk to Human Health).

Histological Alterations in Tissues of Tilapia (*Oreochromis niloticus*) from Dandaru River

As shown in Plate 1 (A-E), several histopathological lesions were observed in the examined tissues (gill, liver, intestine, and muscle) of Tilapia (*Oreochromis niloticus*) fish harvested from Dandaru River. The gill exhibited notable histopathological lesions such as curling of the tip of the secondary lamella as well as hyperplasia and oedema. Degeneration of the intestinal mucosal surface was also demonstrated. Other alterations observed are: degeneration, atrophy and presence of inflammatory cells in the skeletal muscle fibers; atrophy and inflammatory cell presence in the smooth muscle fibers as well as dilated sinusoids and occurrence of congestive melanomacrophages in the liver.

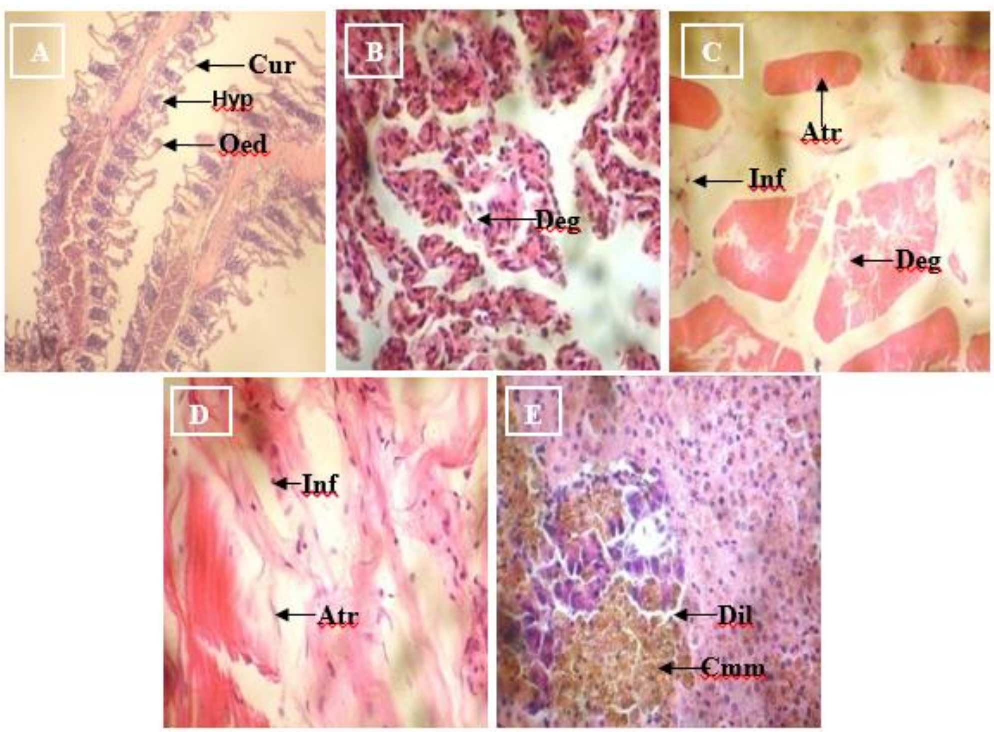

Plate 1: Selected photomicrographs of dissected organs of Tilapia (*Oreochromis niloticus*) from Dandaru River stained with Haematoxylin and eosin (H&E).
(A) Section of gills showing curling (Cur) of secondary lamella, hyperplasia (Hyp) and oedema (Oed) (x200); **(B)** Section of intestinal tract showing degeneration (Deg) of mucosal surface (x200); **(C)** Section of skeletal muscle fibers showing degeneration (Deg), atrophy (Atr) and inflammatory (Inf) cells (x200); **(D)**Section of smooth muscle fibers showing inflammatory (Inf) cells and atrophy (Atr**)** (x200); **(E)** Section of liver showing dilated sinusoids **(**Dil**)** and congestive melanomacrophages (Cmm**)** (x200)

DISCUSSION

Heavy Metals in Tissues of Tilapia Fish (*Oreochromis niloticus*) and Dandaru River Water

In this study, levels of heavy metals (Mg, Ni, Mn, Cd, Fe, Zn, Cu, Pb and Co) were quantified in selected tissues of fish as well as in the water sample from the river. As observed, for most of these metals, their concentrations in the river water were within the confines specified by the national and international water quality regulatory agencies referenced in this study and they occurred sequentially as Mg>Fe>Mn>Zn>Pb/Co>Cu>Ni/Cd. In spite of this, their presence in the river water is suggestive of pollution which may be from natural events such as chemical weathering or soil leaching as well as anthropogenic activities like effluent discharge from residential homes, small scale industries, hospitals, hotels, and zoological garden (Aminiebor, 2016; Ayeloja and Adeoye, 2018; Njinga *et al*., 2023; Laoye *et al*., 2025). It is often reported that the low concentration of heavy metals in river water relative to their concentration in river sediments and tissues of aquatic organisms may be ascribed to certain factors among which are the high flow rate of the river culminating in dilution and reduction in the concentration of metals in the river water (Liu *et al*., 2024). Another possible cause is the accumulation of heavy metal in river sediments which renders the sediments more concentrated than the surface water (Okon *et al*., 2022). In addition, heavy metals have been known to be compartmentalized in the different organs of aquatic organisms leading to lower concentrations in the water column (Ukamaka *et al*., 2024). Sampling and analytical errors have also been shown to be likely contributory factors (Shakirat and Akinpelu, (2013). The levels of some of these heavy metals in Dandaru River from previous studies have been inconsistent. As reported by Aminiebor (2016), the sequence of occurrence was Zn>Cu>Mn>Fe>Pb. That of Aiyeloja and Adeoye (2018) was Zn>Mn>Pb>Cu>Fe/Ni>Cd. While, Adesiyan *et al*., (2018) reported the order as Mn>Cd>Pb, Ayoade and Nathaniel (2018) reported it as Mn>Fe>Pb>Ni>Zn>Cu>Co>Cd. These variations in the sequence of occurrence of metals in water samples from this river compared to the order of occurrence observed in this present study could for the most part be attributed to seasonal differences at time of sampling. Furthermore, it could be linked to errors related with sampling technique and laboratory analysis to a less extent.

The heavy metals investigated in this study were all exceedingly higher in the target tissues of fish than in the river water. The tissue-specific orders of occurrence of the metals are gill (Fe>Mg>Zn>Cu>Pb/Co>Cd>Mn>Ni); liver (Fe>Zn>Cu>Mg>Pb>Co>Ni>Mn/Cd; intestine (Fe>Mn>Mg>Zn>Cu>Co>Ni/Cd/Pb); and muscle (Fe>Zn>Mg>Cu>Pb>Mn>Co>Ni>Cd). These observations show that the concentration of Fe was the highest in all the tissues (gill, liver, intestine, and muscle) examined. Aiyeloja and Adeoye (2018) also observed a comparable trend (Fe>Zn>Ni>Pb/Cd/Cu/Mn) in Tilapia fish from the same river although, their report was not tissue or organ specific. The preponderance of Fe in all the tissues examined in this study may not be unconnected with the fact that it is the most commonly occurring metal component on earth by mass and the fourth most common element found in the earth's crust as well as being the most extensively used element (>90%) in the metal production industries (Mustapha *et al*., 2023). In addition, the nutritional behavior of different species of fish has been reported to contribute to the quantity of different metals found in their tissues (Aiyeloja and Adeoye, 2018). A large portion of Dandaru River is covered by luxuriant green vegetation from which the fish possibly derived its large Fe concentration because of its herbivorous feeding habit.

Bioaccumulation of Heavy metals in Tissues of Tilapia Fish (*Oreochromis niloticus*) from Dandaru River

In this study, heavy metal bioaccumulation in some tissues (gill, liver, intestine and muscle) was estimated. While some of the metals were observed to be extremely bioaccumulative others were noted to be either bioaccumalative or non-bioaccumulative. In the tissues examined, the sequence of bioaccumulation was Cu>Cd>Zn>Fe>Ni (gill), Cu>Fe>Zn>Ni>Cd (liver), Mn>Fe>Cu>Zn>Co>Ni/Cd (intestine), and Zn>Fe>Cu>Ni>Cd (muscle). Studies on tissue specific heavy metal bioaccumulation in fish in this river are scanty thus; reports for comparison were not readily available. Nevertheless, in a non-tissue specific study, it was reported that the sequence of occurrence of heavy metal bioaccumulation in Tilapia (*Oreochromis niloticus*) harvested from this river was Fe>Zn>Cd/Ni>Pb>Cu>Mn (Ayeloja and Adeoye, 2018). The order of heavy metal bioaccumulation in Tilapia (*Orechromis niloticus*) obtained from Eleyele River in Nigeria was given as Pb>Cu>Ni (Hammed *et al*., 2023). From other geographical locations, a tissue-specific study conducted by Abass (2024) puts the chronological occurrence of heavy metal bioaccumulation in *Tilapia zillii* harvested from a polluted drainage in the Abiece region of Alexandria, Egypt as Pb>Zn>Cd>Cu>Fe>Ni>Cr>Mn (muscle), Cd>Pb>Zn>Cu>Fe>Ni>Cr>Mn (gill), and Cd>Zn>Pb>Cu>Fe>Cr>Ni>Mn (liver).In the same report, the recorded sequential order of occurrence of heavy metal bioaccumulation in *Tilapia zillii* from a commercial fish farm from the same location was recorded as Zn>Pb>Ni>Cr>Cd>Mn>Fe (muscle), Zn>Pb>Cr>Ni>Mn>Fe (gill), and Zn>Ni>Cd>Fe>Cr>Pb>Mn (liver).In a non-tissue specific study conducted on Tilapia (*Oreochromis niloticus)* harvested from three different sites on the Nile River in Egypt, the order of heavy metal bioaccumulation was given as Cu>Fe>Mn>Pb>Zn>Cd(El Rahawy village), Cu>Zn>Pb>Fe>Mn>Cd (El Rahawy drain discharge site), and Cu>Cd>Zn>Fe>Pb>Mn (Al Qatta village) (Dawood *et al*., 2023). In another study carried out on freshwater and marine water Tilapia fish by Pattipeiluhu and Fendjalang (2024) in the Ambon Bay area in Indonesia, the sequence of heavy metal bioaccumulation was given as Zn>Pb>Cd>Cu (freshwater Tilapia), and Zn>Cu>Pb>Cd (marine water Tilapia). From these reports, it appears that the pattern of heavy metal bioaccumulation in different tissues or species of fish is unpredictable. This irregularity has been related to a number of factors including prolonged anthropogenic activities as well as some physical and chemical parameters (pH, temperature, and hardness) of the water together with, the nutritional behavior of the different species of aquatic organisms (Ahmed *et al*., 2019; Gupta and Arunachalam, 2024). Other factors are the age of the fish, lipid content in the tissues, and ability or inability of the fish to break down the metals (Eneji *et al*., 2014; Mustapha *et al*., 2023).

Health Risk Associated with Consumption of Tilapia Fish (*Oreochromis niloticus*) from Dandaru River

The non-carcinogenic health risk for human consumers of Tilapia fish harvested from heavy metal contaminated Dandaru River was assessed by estimation of HQ. The outcome from this study indicate that, the HQ of all the target metals exceeded safe levels

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(HQ>1) with the exception of Pb which had a value less than the threshold (HQ<1). In addition, the chronological order for the HQ of each metal is Fe>Mg>Co>Cd>Zn>Mn>Cu>Ni>Pb. The implication of this result is that consumption of Tilapia fish from Dandaru River might not be safe for humans because of its potential non-carcinogenic health risk. Quite a number of studies have been conducted on the health hazards connected with consumption of diverse species of fish harvested from various heavy metal polluted aquatic habitats. While reporting their findings on the health hazard linked to Pb, Cu, and Zn pollution; Ajibare and Loto (2023) found the HQ of these metals to be lower than the threshold value (HQ<1) in *Tilapia guineensis* harvested from the Lagos Lagoon in Nigeria with the chronological order observed to be Pb>Cu>Zn. Thus, they concluded that this species of fish obtained from the Lagos Lagoon may be safe for human consumption. Yahaya *et al*., (2022), reported their findings on *Tilapia zilli* as well as *Chrysichthys nigrodigitatus* harvested from the Epe Lagoon in Lagos, Nigeria with respect to Pb, Cd, Ni, Zn, and Cu contamination. They observed that for *Tilapia zilli*, the HQ for Cd, Pb, Ni, and Zn was above the level regarded as being safe (HQ>1) while, Cu was at a safe level (HQ<1). The sequential order was observed to be Pb>Cd>Ni>Zn>Cu. On *Chrysichthys nigrodigitatus*, the HQ for all the metals was above safe limit (HQ>1). The chronological order was given as Cd>Pb>Ni>Zn>Cu. The inference being that these fishes may be unsafe for human consumption. The report of Ekpeyong (2019) on Tilapia (*Oreochromis niloticus*) harvested from the Ibaka River located in Akwa-Ibom state, Nigeria shows that the HQ for Pb and Fe was within safe limit (HQ<1) however, the HQ for Cd was above the acceptable level (HQ>1). For this reason, they recommended that caution should be exercised in the consumption of this fish as it may not be safe for edible purposes. Outside of Nigeria, El-Sayed *et al*., (2023) while reporting the outcome of their research on the health implications attached to consumption of Tilapia fish (*Oreochromis niloticus)* harvested from the Ismaila Canal in Egypt, they observed that the estimated HQ for Fe, Mn, Ni, Zn, Cd, and Pb was within safe bracket (HQ<1) with the order given as Pb>Zn>Ni>Fe>Cd>Mn. Their findings suggest that this fish was safe for human consumption. In Lake Mariut also located in Egypt, Hasanein *et al*., (2022) reported their findings on the health consequences of consuming various species of fish (*Chrysanthus gariepinus*, *Oreochromis aureus*, *Oreochromis niloticus*, and *Tilapia zilli*) harvested from the lake. Their findings revealed that the HQ associated with Cd and Pb was within safe level (HQ<1) with the order given as Cd>Pb. This shows that consumption of these species of fish from this lake was quite safe for humans. Shaalan (2024), reported on the health hazards that may be linked with consumption of the Nile Tilapia fish obtained from the Damietta branch as well as the El-Rayan El-Tawfeeky Canal of River Nile in Egypt, respectively. Their results from the Damietta branch showed that, HQ levels estimated for Mg, Ni, and Pb was above the acceptable limit (HQ>1) while, the values for Cd, Cu, and Zn was within acceptable limit (HQ<1). The order was given as Ni>Mg>Pb>Zn>Cu>Cd. The results from the El-Rayan El-Tawfeeky Canal showed that, the HQ levels for Mg, Cd, Ni, Pb, and Zn were above the limit considered as being acceptable (HQ>1) while, the HQ value for Cu was within acceptable limit (HQ<1). The sequential order is Cd>Ni>Pb>Mg>Zn>Cu. Fish from both sites are considered unwholesome for human consumption. Gupta and Arunachalam (2024) reported the tissue-specific potential health hazards inherent in the consumption of Tilapia fish (*Oreochromis niloticus*) harvested from the Cauvery River in India. The HQ reported for Cd, Fe, Zn, Ni, Pb, and Cu was within the confines of the set standard (HQ<1) in the muscle while, that of Co was above the satisfactory limit (HQ>1). The sequential order was Co>Cd>Pb>Ni>Fe>Cu>Zn. In the gill, the reported HQ for Cd, Fe, Zn, Ni, Pb, and Cu was within the acceptable limit (HQ<1) while, that of Co was outside of the acceptable limit (HQ>1). The sequential order observed is Co>Cd>Pb>Fe>Ni>Cu>Zn. The HQ estimated for Fe, Zn, Ni, and Cu in the liver was within tolerable limit (HQ<1) while, that of Cd, Pb, and Co was above tolerable limit (HQ>1). The observed sequence is Co>Cd>Pb>Ni>Fe>Cu>Zn. With these results, it is apparent that Tilapia fish from the Cauvery River in India is unhealthy for human consumption. Reporting on the heavy metal (Pb, Cd, and Cu) health risk linked to human consumption of several species of fish (*Apocryptes bato*, *Pampus chinensis*, *Liza parsia*, *Mugil cephalus*, *Hyporhampus limbatus*, and *Tenualosa toil*) harvested from the Karnaphuli River estuary in Bangladesh, it was observed that the HQ estimated for each metal in each species of fish was at safe level (HQ<1) and their sequential order was Pb>Cd>Cu. These fishes may therefore be considered safe for human consumption. Generally, it appears that hazard quotients in fishes due to heavy metal pollution in aquatic habitats are inconsistent. These inconsistencies may be attributed to an intricate interface of factors among which are: the source of the pollution which may be determined by the type of industrial discharge, mining activities, agricultural runoff, improper waste disposal, and natural processes peculiar to the environment (Anyanwu and Chris, 2023; Abubakar *et al*., 2024). Other determinants include the process of biomagnification, varying degrees of toxicity associated with different metals, water pH and dissolved oxygen which affects the solubility and mobility of heavy metals in the aquatic habitats as well as heavy metal accumulation in sediments (Hameed *et al*., 2020; Sanyaolu *et al*., 2022; Toghavi *et al*., 2024; Quahb *et al*., 2025).

Histological Alterations in Tissues of Tilapia Fish (*Oreochromis niloticus*) from Dandaru River

Results of this study shows the range of histopathological lesions (curling of the tip of secondary lamella, hyperplastic proliferation, oedema, degeneration, atrophy, inflammatory cell infiltration, sinusoidal dilation, and congestive melanomacrophages) elicited in selected tissues (gill, liver, intestine, and muscle) of Tilapia (*Oreochromis niloticus*) fish collected from heavy metal (Mg, Ni, Mn, Cd, Fe, Zn, Cu, Pb, and Co) contaminated Dandaru River. Similar reports on heavy metal induced histopathological alterations in tissues of several species of fish harvested from various aquatic habitats exist in literature. Hyperplastic proliferation and lymphocytic infiltration was reported by Olayinka-Olagunju (2022), in the gill and liver, respectively of two species of fish (*Mormyrus rume* and *Clarias gariepinus*) harvested from Ose River in Ondo state, Nigeria discovered to be contaminated by some metals (Fe, Pb, Cd, and Zn). In the coastal water of Poka village, Ambon Bay in Indonesia, Pattipeiluhu and Fendjalang (2024), reported the induction of secondary lamella hyperplasia in Tilapia fish (*Oreochromis niloticus*) exposed to heavy metals (Zn, Pb, Cd, and Cu). The reports of Tayel *et al*., (2018) and Shaalan (2024) shows that the gill of Tilapia fish (*Oreochromis niloticus*) exposed to heavy metal (Fe, Mn, Mg, Cd, Cu, Ni, Pb, and Zn) contaminated water from the Damietta branch of the Nile River exhibited curling of secondary lamella and proliferation of inflammatory cells. In addition, they reported the presence of melanomacrophages in the liver as well as damage (degeneration and oedema) to muscle fibers. From the El-Rahawy branch of the Nile River, heavy metal (Cd, Pb, Cu, Zn, Mn, and Fe) pollution was reported to have inflicted atrophic and degenerative changes on the smooth and skeletal muscle fibers of Tilapia (*Oreochromis niloticus*) harvested from the river (*Dawood et al*., 2023). Acute toxicity test on Tilapia fish (*Oreochromis niloticus*) exposed to heavy metals (Ni and Pb) under laboratory conditions was reported to have induced histopathological lesions such as lamellar atrophy and eosinophilic infiltration in the liver (Rehman *et al*., 2020). Finally, Mahboob *et al*., (2020) reported the induction of sinusoidal dilation in the liver of Tilapia fish (*Oreochromis niloticus*) collected from heavy metal (Pb, Cu, and Ni) contaminated freshwater reservoir Wadi Namar Riyadh in Saudi Arabia. Several mechanistic processes may have been responsible for initiating the histopathologic changes observed in this study as well as in the other studies mentioned in this discussion. Contact with heavy metals in aquatic habitats catalyzes chemical reactions which in turn produce reactive oxygen species that overruns the antioxidant defense system of the fish thereby damaging important cell components and interfere with various cellular processes such as mitochondrial function (Koyama *et al*., 2024: Kumar *et al*., 2024; Mustafa *et al*., 2024). Degree of tissue damage is influenced by several factors including: the type and concentration of metal which determines the toxicity level as well as the rate of metal bioaccumulation; duration of exposure, age and species of fish as well as environmental factors (water pH, and temperature) (Mustafa *et al*., 2024; Ray and Vashishth, 2024; Zahran *et al*., 2025).

Conclusion

This study established the presence of heavy metals (Mg, Ni, Mn, Cd, Fe, Zn, Cu, Pb, and Co) in water and Tilapia fish (*Oreochromis niloticus*) collected from Dandaru River which is suggestive of contamination. Furthermore, a good number of the metals were biomagnified in the fish tissues (gill, liver, intestine, and muscle) and had unacceptable HQ suggesting that the fish may be unsafe for human consumption. In addition, several histopathological lesions indicative of tissue damaging effect were elicited in the fish.

Conflict of interest

The authors declare no conflict of interest in the study.

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