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Safety Assessment of Heavy metals in *Tilapia zilli* (Tilapia fish) and *Chrysichthys nigrodigitatus* (catfish) obtained from Epe Lagoon, Lagos, Nigeria

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ABSTRACT

Epe Lagoon in Lagos State, Nigeria, is a notable lagoon in the country that provides important ecosystem and economic services such as fishing, agriculture, transportation, and water for domestic use, among others. However, the lagoon regularly receives municipal, agricultural, and industrial waste, which may compromise the suitability of aquatic organisms in the lagoon for consumption. This study determined the safety of the lagoon's fish for consumption with the aim of providing information for effective pollution control and management. Samples of *Tilapia zilli* (tilapia fish) and *Chrysichthys nigrodigitatus* (catfish) from the lagoon were treated and analysed for copper, chromium, cadmium, lead, and nickel using atomic absorption spectroscopy. The estimated daily intake (*EDI*), hazard quotient (*HQ*), target hazard quotient (*THQ*), and carcinogenic risks (*CR*) of the heavy metals were also calculated. On average, the levels of lead, nickel, chromium, and copper in the various tissues of the two fish species exceeded permissible limits recommended by the World Health Organization (WHO), with the intestine being the most contaminated, followed by the trunk, head, and tail, respectively. The *EDI*, *HQ*, *THQ*, and *CR* of the majority of the heavy metals in the two fish species exceeded the threshold limits. The *Tilapia zilli* samples were more contaminated than *Chrysichthys nigrodigitatus*, suggesting that the former poses more risk. From these results, it can be inferred that the two fish species may not be ideal for consumption. Heavy metal remediation and periodic monitoring need to be implemented in the lagoon.

Keywords: Hazard quotient, Heavy metals, Lead, Pollution, *Tilapia zilli*

INTRODUCTION

Fish is consumed worldwide because it is a good source of proteins, vitamins, omega-3 fatty acids, and minerals, all of which have been associated with health benefits, especially its cardio-protective effects (Tørris *et al.*, 2018; Yahaya *et al.*, 2022a). Moreover, fish are consumed as food, used as by-products, and they are also used in controlling diseases such as malaria, yellow fever, and other diseases (Lynch *et al.*, 2016; Balami *et al.*, 2019). On account of this, fishing contributes greatly to the economy in many countries, providing income to fishermen, middlemen, and government revenue (Shamsuzzaman *et al.*, 2020). Unfortunately, heavy metal contamination is devaluing the benefits of fish (Yahaya *et al.*, 2022b). Heavy metals from natural and anthropogenic sources pollute water bodies, endangering aquatic life and the environment and ultimately affecting the health of humans that depend on them (Haïfa *et al.*, 2017).

Heavy metals are natural elements with a high atomic weight and at least five times the density of water (Oboh and Okpara, 2019). Heavy metals' multipurpose industrial, domestic, agricultural, medical, and technological use has led to environmental contamination, and their impact on human health and the environment has been a source of concern (Tchounwou *et al.*, 2012). The toxicity of heavy metals depends on the heavy metal type, concentrations, and exposure route, as well as the exposed person's age, gender, genetic constitution, and nutritional profile (Jaishankar *et al.*, 2014; Arora and Chauhan, 2021). Heavy metals have been linked to several acute and chronic health hazards, of which consumption of aquatic organisms is a major exposure route (Bhat *et al.*, 2019; Jyothi *et al.*, 2020). Thus, there is a need to determine the heavy metal levels and safety for consumption of aquatic organisms from every body of water.

Epe Lagoon in Lagos State, Nigeria, is a notable lagoon in the country. Aside from being a source of water for domestic, agricultural, and industrial use, a lot of fishing activities take place in the lagoon. The fish caught from the lagoon are sold locally and to nearby towns, especially in Lagos metropolis. Unfortunately, the lagoon receives enormous waste from different sources, which could potentially pollute the water and compromise fish quality. Although literature shows that few studies have been conducted on the lagoon, the aquatic environment is dynamic and susceptible to ever-changing anthropogenic activities. Thus, periodic heavy metal assessment of fish in the lagoon is imperative to prevent health hazards. Therefore, this study was conceptualized to determine the safety of *Tilapia zilli* (red-belly tilapia) and *Chrysichthys nigrodigitatus* (bagrid catfish) obtained in Epe Lagoon with regards to heavy metal contamination. The two fish species are the most abundant fish in the lagoon and, coincidentally, the most consumed fish species in the area. *Tilapia zilli* are palatable, nutritious, tolerate a wide range of environmental factors, and have high reproductive and growth rates, all of which could explain their abundance in the lagoon (Ahmad *et al*., 2015). *Chrysichthys nigrodigitatus* is very popular because it tastes good, is nutritious, and is fleshy (Ouro-Sama *et al*., 2020).

MATERIALS AND METHODS

Description of the study area

This study was carried out at Epe Lagoon in Epe Town, Lagos State, Southwest Nigeria (Figure 1). The Epe Lagoon can be located between latitudes 03°50’–04°10’N and longitudes 005°30’–005°40’E (Cimate-Data.org, 2022).The lagoon has a surface area of approximately 243 km^2 and lies between the freshwater Lekki Lagoon to the east and the brackish Lagos Lagoon to the west (Toyosi *et al*., 2018).The city of Epe is the headquarters of Epe Local Government Area, located on the north side of the Lekki Lagoon. It is a Yoruba town with many rural and semi-urban communities. Epe's climate is classified as tropical with a long wet season and a short dry season (Cimate-Data.org, 2022). The town has an average temperature of 26.3 °C and a precipitation of about 1990 mm (Cimate-Data.org, 2022).

Epe town is known for intensive fishing, which provides livelihood to a significant part of the town’s populace. Both men and women in the town engage in fishing, and it is tagged as the largest home of fish in Lagos and one of the largest in Nigeria. The fish are sold to the locals and other towns in southwest Nigeria, especially Lagos, the most populated city in Nigeria. Unfortunately, the lagoon regularly receives potentially toxic domestic, municipal, agricultural, and industrial waste. This necessitates constant monitoring of the water resources to safeguard human health and protect the aquatic environment.

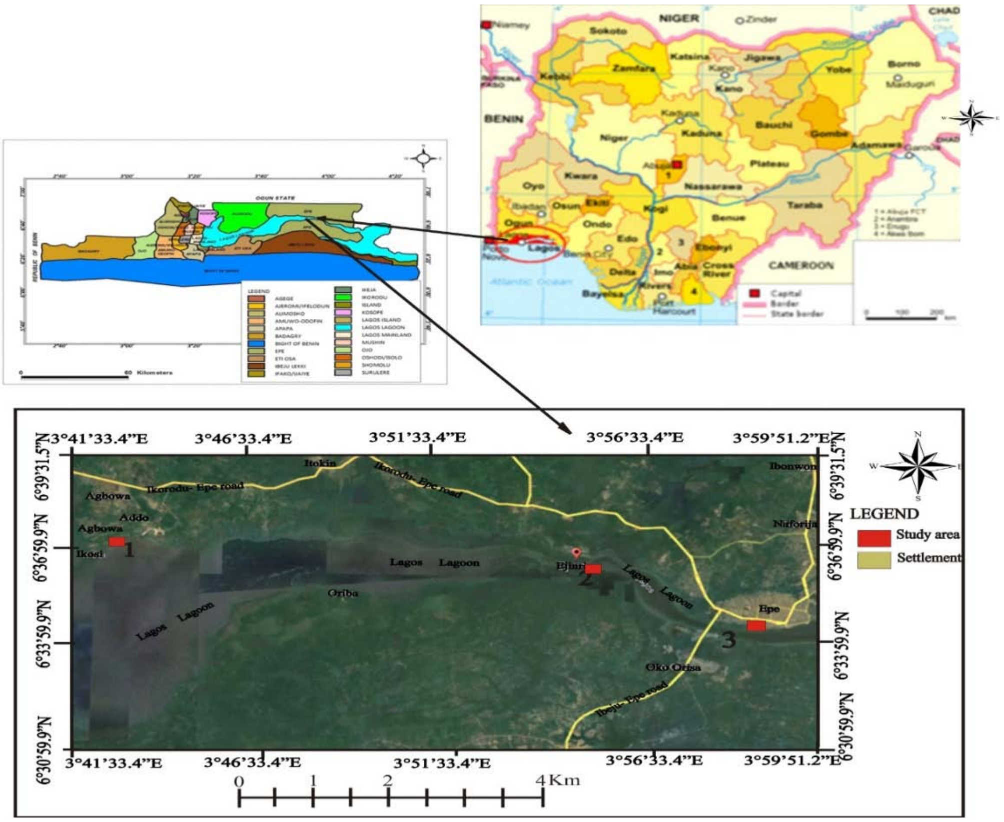

Figure 1: Locations of the study area, showing sampling points (drawn using ArcGIS 10.3 software)

Fish sample collection and preparation

Triplicate samples of *Tilapia zilli* (red-belly tilapia) and *Chrysichthys nigrodigitatus* (bagrid catfish) were caught monthly in Epe Lagoon between February 2022 and May 2022. The sampling resulted in the collection of a total of 30 fish samples (15 of each species). The fish were put in an ice box containing water from the lagoon and then taken to the laboratory. The fish were rinsed with distilled water in the laboratory to remove impurities, after which the scales were removed and each fish was cut into a head, trunk, tail, and intestines. The fish parts were oven-dried at 80 °C to a constant weight, ground into powder, and kept in a dessicator prior to further analysis.

Heavy metal analysis

Exactly 0.3g of powder from each fish part was transferred into a digestion flask containing a mixture of concentrated sulphuric and nitric acids prepared in a ratio of 3:1 and heated over a water bath. The solution was heated while also continuously adding three-quarter drops of hydrogen peroxide until it turned clear. The added hydrogen peroxide was meant to decrease nitrous oxide vapours and hasten digestion by elevating the temperature. The digestion was completed at 150 °C and was left to cool to room temperature. The digest was diluted with distilled water to the meniscus in a 50-mL volumetric flask and filtered with a 0.45 mm pore size acid-resistant filter paper into a clean glass vial. The levels of copper (Cu), chromium (Cr), cadmium (Cd), lead (Pb), and nickel (Ni) in the solution were measured with a PG atomic absorption spectrophotometer (model AA990).

Quality assurance and control

Analytical-grade reagents were used throughout. Glass wares were immersed in 10% nitric acid for 24 hours and rinsed with ultrapure water, followed by a 0.5% (w/v) $KMNO_4$ solution, and ultrapure water again. Blank samples were analysed alongside the test samples to check for background contamination. Each sample was analysed three times, and the reproducibility of the same values was ensured at 95% accuracy. Accuracy and precision were verified by using reference materials. The blank samples analysed indicated that the analyses were performed within the certified range of 96–100% recovery for the heavy metals that were studied.

Health risk assessment of heavy metals

Non-carcinogenic health risk

The non-carcinogenic health risk of daily consumption of the fish was calculated from the estimated daily intake (*EDI*), hazard quotient (*HQ*), and target hazard quotient of the heavy metals as shown in equations 1, 2, and 3 (USEPA, 2004).

$$EDI = \frac{Cn \text{ x } EF \text{ x } ED \text{ x } FIR}{WAB \text{ x } AT} \quad (1)$$

$$HQ = EDI/RFD \quad (2)$$

$$THQ = \sum HQ \text{ of individual heavy metals} \quad (3)$$

Where *Cn* is the heavy metal concentration in fish (mg kg^{-1}); *EF* denotes exposure frequency (365 days $year^{-1}$); *ED* stands for exposure duration (55 years, the average life span of a resident of Nigeria); *FIR* represents fish ingestion rate in kg per person day^{-1}, which is 19.5 g per person day^{-1}; *WAB* indicates average body weight (65 kg); *AT* is the average exposure time for non-carcinogenic health risk (365 days $year^{-1}$ × *ED*); and *RfD* means oral reference dose (mg kg^{-1} day^{-1}). Note that *RfD* for Pb is 0.004, Ni = 0.05, Cd = 0.001, Cr = 0.003, Cu = 0.04.

Carcinogenic health risk

The carcinogenic health risk (CR) of daily consumption of the fish was estimated using equation 4 (USEPA, 2004).

$$CR = EDI \text{ x } CSF \quad (4)$$

Where *EDI* stands for estimated daily intake and *CSF* means cancer slope factor (mg/kg/day). The *CSF* for Pb is 0.009, Ni is 1.70 and Cd 0.6. The cancer risk values and their grades are presented in Table 1.

Table 1: Cancer risk values and grades (Li *et al*., 2017)

Risk grades	Range of risk value	Acceptability
Grade I (Very low risk)	$<10^{-6}$	Acceptable
Grade II (Low risk)	$10^{-6}, 10^{-5}$	Unconcerned 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)	$10^{-4}, 5 \times 10^{-4}$	Concerned about the risk and ready to spend
Grade VI (High risk)	$5 \times 10^{-4}, 10^{-3}$	Take action on the risk
Grade VII (Very high risk)	$>10^{-3}$	Resolve the risk at all cost

Data analysis

The levels of heavy metals in the fish samples were presented as mean ± standard deviation (SD) using the Microsoft Excel software (version 2021). The *EDI* and *HQ* were also calculated using the software. The graphs were drawn using Minitab software, version 7.0.

RESULTS AND DISCUSSION

Levels of heavy metals in the fish samples

Tables 2 and 3 reveal the concentrations of Pb, Zn, Ni, Cu, Cd, and Cr in the samples of the two fish species obtained in Epe Lagoon. The tissues of *Tilapia zilli* had more Pb, Ni, and Cr than the permissible limits of the World Health Organization (2022), but Zn, Cu, and Cd were within the safe limits (Table 2).

The *Chrysichthys nigrodigitatus* contained non-permissible levels of Pb and Ni in all the tissues analysed. Meanwhile, Zn, Cu, Cd, and Cr were within the permissible limits, except for intestine (Cu and Cr only) (Table 3).

Figure 2 compares the overall levels of heavy metal contamination in the two fish species, and Figure 3 reveals the level of heavy metals in various tissues of the fish. On average, *Tilapia zilli* was more contaminated than *Chrysichthys nigrodigitatus*, and the intestine was the most contaminated, followed by the trunk, head, and tail.

Table 2: Mean levels of heavy metals (mg/kg) in *Tilapia zilli* obtained in Epe Lagoon, Lagos

Tissues	Pb	Zn	Ni	Cu	Cd	Cr
Head	0.763±0.02	0.571±0.07	2.350±0.11	0.03±0.001	0.045±0.008	0.819±0.05
Trunk	0.812±0.05	0.736±0.07	2.694±0.43	0.04±0.002	0.12±0.005	1.12±0.04
Tail	0.865±0.05	0.437±0.04	2.03±0.77	0.03±0.008	0.13±0.051	1.16±0.05
Intestine	1.921±0.12	2.14±0.046	4.03±0.53	0.09±0.003	0.15±0.001	2.34±0.05
∑	4.361±0.56	3.884±0.79	11.104±0.89	0.19±0.03	0.445±0.05	5.439±0.67
(FAO/WH, 2022)	0.40	5.0	0.6	0.50	2.0	0.15

Table 3: Mean levels of heavy metals (mg/kg) in *Chrysichthys nigrodigitatus* obtained in Epe Lagoon, Lagos

Tissues	Pb	Zn	Ni	Cu	Cd	Cr
Head	1.082±0.02	2.371±0.15	1.000±0.55	0.093±0.07	0.250±0.04	0.055±0.003
Trunk	0.681±0.05	1.115±0.55	0.941±0.11	0.048±0.01	0.215±0.01	0.050±0.004
Tail	0.625±0.11	0.941±0.02	1.050±0.22	0.099±0.01	0.890±0.20	0.040±0.001
Intestine	1.238±0.55	2.049±0.06	1.170±0.42	1.042±0.05	1.537±0.00	0.734±0.010
∑	3.626±0.30	6.476±0.69	4.161±0.10	1.282±0.48	2.892±0.625	0.879±0.343
(FAO/WHO, 2022)	0.40	5.0	0.6	0.50	2.0	0.15

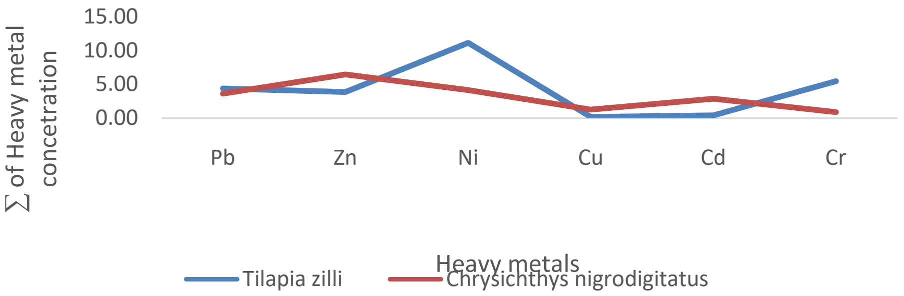

Figure 2: Cumulative levels of each heavy metal in all the tissues of *Tilapia zilli* and *Chrysichthys nigrodigitatus* obtained in Epe Lagoon

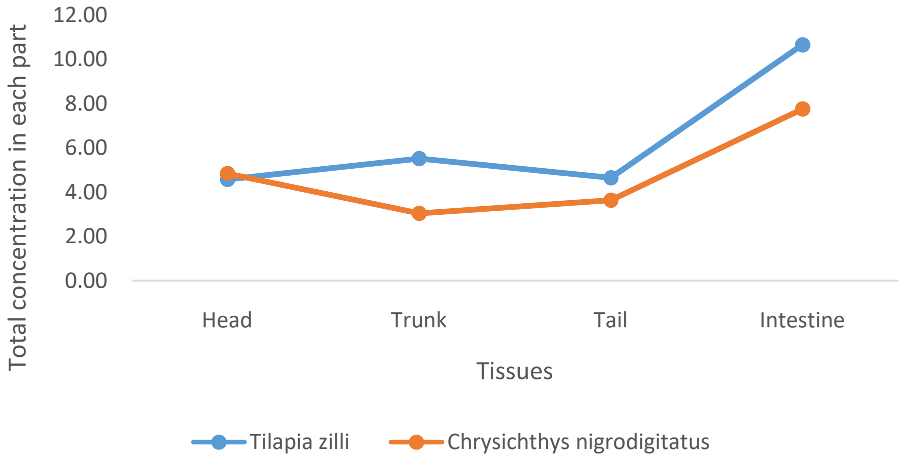

Figure 3: Cumulative levels of heavy metals in each tissue of *Tilapia zilli* and *Chrysichthys nigrodigitatus* obtained in Epe Lagoon

Health risk of the heavy metals in the fish samples

Table 4 reveals that Pb and Cr were above the recommended estimated daily intake (*EDI*) in all the tissues of *Tilapia zilli*; Ni was above the limit only in the intestines of the fish; and the remaining heavy metals (Zn, Cd, and Cu) were within recommended limits. In the *Chrysichthys nigrodigitatus* samples, only Cd was above the recommended limits in all the tissues (Table 5).

Furthermore, Tables 6 and 7 reveal that the hazard quotient (*HQ*) and target hazard quotient (*THQ*) of the majority of the heavy metals were greater than the threshold of 1.

Table 4: Estimated human daily intake (*EDI*) of heavy metals from *Tilapia zilli* obtained in Epe lagoon, Lagos

Tissues	Pb	Zn	Ni	Cu	Cd	Cr
Head	0.239	0.171	0.705	0.009	0.014	0.246
Trunk	0.284	0.221	0.801	0.012	0.036	0.336
Tail	0.259	0.131	0.609	0.009	0.039	0.348
Intestine	0.576	0.642	1.209	0.027	0.045	0.702
RDI	0.24	18.0	0.50	0.90	0.06	0.05

RDI: recommended daily intake (Yahaya *et al.*, 2022a)

Table 5: Estimated human daily intake (*EDI*) of heavy metals from *Chrysichthys nigrodigatatus* obtained in Epe Lagoon, Lagos

Tissues	Pb	Zn	Ni	Cu	Cd	Cr
Head	0.224	0.711	0.300	0.028	0.075	0.017
Trunk	0.204	0.335	0.282	0.014	0.075	0.015
Tail	0.188	0.282	0.315	0.030	0.067	0.012
Intestine	0.171	0.615	0.351	0.313	0.061	0.020
RDI	0.24	18.0	0.50	0.90	0.06	0.05

RDI: recommended daily intake (Yahaya *et al.*, 2022a)

Table 6: Hazard quotient (*HQ*) of heavy metals in *Tilapia zilli* obtained in Epe Lagoon, Lagos

Tissues	Pb	Zn	Ni	Cu	Cd	Cr	*THQ*
Head	59.75	0.57	14.10	0.23	14.00	82.00	170.65
Trunk	71.00	0.74	16.02	0.30	36.00	112.0	236.06
Tail	64.75	0.44	12.18	0.23	39.00	116.0	232.60
Intestine	144.00	2.14	24.18	0.68	45.00	234.0	450.0

Table 7: Hazard quotient (*HQ*) of heavy metals in *Chrysichthys nigrodigitatus* obtained in Epe Lagoon, Lagos

Tissues	Pb	Zn	Ni	Cu	Cd	Cr	*THQ*
Head	56.00	2.37	3.75	0.70	75.00	5.67	143.49
Trunk	51.00	1.12	5.64	0.35	75.00	5.00	138.11
Tail	47.00	0.94	6.30	0.75	67.00	4.00	125.90
Intestine	42.75	2.05	7.02	7.83	61.00	6.67	127.32

Table 8: Cancer risk of heavy metals in *Tilapia zilli* obtained in Epe Lagoon, Lagos

Tissues	Pb	Ni	Cd	Cr
Head	0.002	1.199	0.0084	0.123
Trunk	0.003	1.360	0.046	0.168
Tail	0.002	1.035	0.023	0.174
Intestine	0.005	2.055	0.027	0.351
Risk grades	**VI**	**VII**	**VII**	**VII**

Table 9: Cancer risk of heavy metals in *Chrysichthys nigrodigitatus* obtained in Epe Lagoon, Lagos

Tissues	Pb	Ni	Cd	Cr
Head	0.002	0.510	0.045	0.009
Trunk	0.0018	0.479	0.045	0.008
Tail	0.0017	0.536	0.040	0.006
Intestine	0.0015	0.597	0.037	0.010
Risk grades	**VI**	**VII**	**VII**	**VI**

The current study determined the suitability for consumption of fish species in Epe Lagoon in Lagos State, Nigeria. Table 1 shows that samples of *Tilapia zilli* and *Chrysichthys nigrodigitatus* obtained from the lagoon contained non-permissible levels of Pb, Ni, Cr, and Cu, suggesting that the fish species might not be suitable for consumption in their present state. Heavy metals are non-bio-degradable and so may persist in the fish tissues for a long time and bioaccumulate in human systems upon consumption of the fish. While some heavy metals, including Pb, As, Hg, and Cd, are toxic at any dose, some heavy metals such as Fe, Zn, Cu, and Mn at minute quantities perform biological functions and become toxic at certain levels (Uddin *et al*., 2021). Pb accumulates in the brain, liver, kidney, bones, and teeth and, over time, causes organ damage (WHO, 2021). Acute ingestion of Ni compounds can cause nausea, vomiting, diarrhea, and headaches, while chronic ingestion may cause reproductive anomalies and cancers (Das *et al*., 2019). Both trivalent and hexavalent Cr have been demonstrated to cause DNA damage and cancer (Wang *et al*., 2017). Excessive Cu ingestion can cause loss of weight, vacuolation, inflammation, and disruption of gut microbial diversity (Huang *et al*., 2021). The results of the current study are consistent with those of Olowu *et al.* (2010) and Mustapha *et al.* (2021), who detected non-permissible levels of some heavy metals in fish caught in Epe Lagoon. Furthermore, Yahaya *et al.* (2021) detected non-tolerable levels of Pb, Ni, Cd, and Cr in fish samples obtained in the Bariga section of a lagoon in Lagos metropolis. Both Aderinola *et al.* (2009) and Don-Pedro *et al.* (2004) also found non-permissible levels of heavy metals in lagoons in the Lagos metropolis. This overwhelmingly consistent results show that lagoons in Lagos State are grossly contaminated.

As shown in Figure 2, *Tilapia zilli* had overall higher concentrations of heavy metals in their tissues than in the tissues of *Chrysichthys nigrodigitatus*. This suggests that *Tilapia zilli* samples were more contaminated and thus posed a greater risk to consumers. This result is consistent with that of Mustapha *et al.* (2021), who detected higher concentrations of heavy metals in *Tilapia guineensis* than in *Chrysichthys nigrodigitatus* obtained in Epe lagoon. Similarly, Nwude *et al.* (2020) detected higher levels of heavy metals in *Tilapia species* than in *Clarias species* obtained from Ogun River in Ogun State, Nigeria. However, the result contradicts that of Mapenzi *et al.* (2020), who found higher concentrations of heavy metals in *Clarias gariepinus* than tilapia species obtained in Lake Rukwa in Tanzania. Abidemi-Iromini *et al.* (2022) also detected higher levels of heavy metals in *Chrysichthys nigrodigitatus* than in *Oreochromis niloticus* caught in Asejire River in Osun State and a lagoon in Lagos. According to Nwude *et al.* (2020), the accumulation of heavy metals in a fish depends on the extent to which the species scavenges matter from the sediment and water, its ecological needs and feeding habits, food metabolism, and time spent on the bottom of rivers. Sex, age, size, reproductive cycle, swimming pattern, and geographical location may also influence the accumulation of metals in fish (Zhao *et al*., 2012). Tilapia species, including *Tilapia zilli,* scavenge both the water columns and sediments and are thus expected to encounter a variety of pollutants. Furthermore, tilapia species are both herbivorous and omnivorous, both of which are feeding habits that promote the accumulation of heavy metals from phytoplankton compared to *Chrysichthys nigrodigitatus,* which is carnivorous (Khalid, 2004). Overall, this suggests that herbivorous fish species in the lagoon may pose a greater risk than carnivorous ones.

Furthermore, Figure 3 revealed that the intestines of the two fish species had the highest accumulation of heavy metals, followed by the trunk, head, and tail. In a study by Rajeshkumar *et al.* (2018), heavy metals accumulated more in the intestines than in the liver and muscles of fish. Zhang *et al.* (2007) also detected more heavy metals in the intestines than in the muscles of some fish species obtained in three gorges in China. Similarly, Yahaya *et al.* (2022a) detected higher concentrations of heavy metals in the intestines of some fish species caught in Ogun River in Lagos than in other tissues. Helminth parasite infestation may be responsible for the high concentrations of heavy metals in the intestines of the two fish species, though parasite infestation was not tested in the current study. According to Sure (2003), intestinal helminths such as cestodes and acanthocephalans have a high heavy metal accumulation capacity and can accumulate heavy metals several times higher than in host tissues. Zhang *et al.* (2007) reported that fish intestines usually accumulate more heavy metals than other parts and so might be good bio-monitors of metals in the aquatic environment. This suggests that the lagoon water (though not evaluated in the current study) is seriously contaminated. Regarding the trunk, heavy metals were more accumulated in the tissue than in the head and tail because it housed metabolically active organs such as the kidneys, liver, and stomach. Ali *et al.* (2019) reported that tissues and organs with a lot of metabolic activity, like the brain and liver, store more heavy metals than tissues with less metabolic activity, like muscles and skin.

In the non-carcinogenic health risk assessment of the heavy metals, the non-permissible estimated daily intake (*EDI*) of Pb, Cr, and Ni (intestines only) via the tissues of *Tilapia zilli* confirmed the risk posed by daily consumption of the fish species. On the other hand, the tolerable *EDI* of most of the heavy metals via the tissues of the *Chrysichthys nigrodigitatus* further proved that the fish species is less contaminated and its daily consumption might pose a lesser risk. However, as mentioned earlier, there are no safe limits for some heavy metals, so the mere detection of them in food or drinks portends danger for consumers. Furthermore, the health risk was assessed based on the average life span of a resident in Nigeria (55 years), so people who consume the two fish species beyond 55 years of age may experience a greater risk. The first assertion made above is confirmed by the non-tolerable (greater than the threshold of 1) hazard quotient (*HQ*) of the heavy metals in the two fish species. Moreover, the target hazard quotient (*THQ*) of the heavy metals in the two fish species was greater than 1, suggesting that the heavy metals may combine additively to increase health hazards for consumers. Generally, heavy metals do not act alone; they interact to increase the toxicity of substances. For instance, the combinations of any two of the following: Ag, Cd, Cu, Ni, Pb, and Zn or the whole mixture at low concentrations may produce chronic effects compared to individual heavy metals (Cremazy *et al*., 2018). Additive combinations of either Cd + Zn, Cu + Zn, or Cu + Cd at low concentrations also have synergetic effects on organisms (Cedergreen, 2014).

The carcinogenic risk assessment of the heavy metals in the various organs of the fish also proved that daily consumption of the two fish species can pose health risks. While Pb concentrations can induce cancer risk grade V (mild risk), Ni, Cd, and Cr can induce grade VII cancer risk (extremely high risk). Mechanistically, Pb on its own may not induce carcinogenesis but can boost cellular and molecular events that lead to cancer, such as DNA damage, DNA repair, and repression of tumor suppressor and promoter genes (Silbergeld, 2003). Ni has weak mutagenic activity and so induces carcinogenesis through non-genotoxic pathways such as epigenetic changes, activation of hypoxia signaling pathways, and the generation of reactive oxygen species (Son, 2020). Cd is also a weak mutagen and so exerts tumorigenic effects through non-genotoxic events such as epigenetic dysregulation (Lin, 2021). Hexavalent chromium is a known carcinogen (group 1) that causes oxidative stress, chromosome breaks, and DNA-adduct formation (DesMarais and Costa, 2019). Although trivalent chromium cannot penetrate the cell membranes easily, it can accumulate around the cell membrane and, with time, compromise its lipid structure and damage the DNA (Wang *et al*., 2017).

Although source identification of pollutants in the fish is not the primary aim of this study, the heavy metals detected can point to possible sources of heavy metals in the fish through the lagoon water. The presence of Pb in the fish suggests waste from lead–acid storage batteries, lead-laden petrol, non-ferrous metal smelting and refining, natural deposits, and sewage sludge (Odjer-Bio *et al*., 2015). Cd occurs naturally, but excessive concentration could suggest deposition of manures, phosphate fertilizer from farming activities, and sewage sludge into the lagoon (Odjer-Bio *et al*., 2015). Ni also occurs naturally, but it may also come from anthropogenic sources such as smelting, metal mining, vehicle emissions, fossil fuel burning, household, municipal, and industrial waste, fertilizer, and organic manure

(Algül and Beyhan, 2020). Aside from natural deposits, the main sources of Cr are domestic wastewater and industrial wastewater, mainly industrial leather wastewater (Algül and Beyhan, 2020).

CONCLUSION

The results show that the samples of *Tilapia zilli* and *Chrysichthys nigrodigitatus* obtained in Epe lagoon contained non-permissible levels of Pb, Ni, and Cr. The health risk assessment of these heavy metals revealed that their estimated daily intake (*EDI*) exceeded the tolerable limits, but their hazard quotient (*HQ*) was within the threshold of 1. *Tilapia zilli* samples were more contaminated than *Chrysichthys nigrodigatatus*, suggesting that the former poses more risk. Overall, the results suggest that consumption of the two fish species may predispose humans to health hazards.

Based on the above, there is a need for heavy metal remediation of the lagoon water. Dumping of waste into the lagoon should be prevented. The fish should be washed thoroughly before consumption. Similar studies, like the current one, should be carried out on the lagoon periodically.

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