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Health Risk Assessment of Potentially Toxic Metals in Edible Parts of Commonly Consumed Fish Species from the Makoko Fish Market, Lagos, Nigeria

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ABSTRACT

Fish is an important component of the Nigerian diet due to it nutritional value and cost in comparison with other protein sources but may contain potentially toxic metals (PTMs) associated with adverse health effects. There are many fish species sold in the market but yet is dearth of information about PTMs load and their associated risks. The aim of this study was to determine the concentration of PTMs (lead (Pb), zinc (Zn), copper (Cu), cadmium (Cd), and chromium (Cr)) in eight commonly sold fish species from the Makoko market, Lagos, Nigeria and to evaluate the possible consumption risk associated. The eight fish species (*Pomadasys jubelini, Pseudotolithus typus*, *Mugil cephalus*, *Oreochromis niloticus*, *Chrysichthys nigrodigitatus*, *Sphyraena barracuda* and *Lutjanus agennes)* were ccollected on 6th of May, 2019. PTMs were determined using a Buck Scientific model 210VGP atomic absorption spectrophotometer after digestion. The concentration of Pb, Zn, Cu, Cd and Cr ranged between s 0.745 ± 0.525 and 2.050 ± 0.247, 0.533 ± 0.448 and 1.233 ± 0.548, < 0.001 ± 0.000 and 0.250 ± 0.100, <0.001±0.000 and 0.317±0.029 <0.001±0.000 and 0.250±0.177 mg/Kg respectively. Different parts of the different fishes accumulated PTMs to varying levels and were associated with the polluted Lagos Lagoon. The concentration of PTMs determined in the fishes were related to their type of feeding. Carnivores generally accumulated more PTMs than omnivores. . Pb levels exceeded FAO limits. Non-carcinogenic risks (HQ, HI) were below threshold. Carcinogenic risks (CR) though present were generally low but higher for children than adults. Ongoing surveillance and education efforts will be critical to ensuring food safety and public health protection.

Keywords: Cancer risk, estimated daily intake, fish, hazard quotient, Potentially toxic metals

Introduction

Fishes, due to their high nutrition, taste and lower cost when compared with beef, pork and other animal protein sources are important component of many Nigerian diets. Fishes are sourced from artisanal fisheries, industrial trawlers, aquaculture or imported as frozen fishes to meet the demand for fishes in Nigeria. Three of these sources are from the aquatic environments in Nigeria. Many aquatic environments in Nigeria are dumps and sinks to industrial effluents, domestic sewage. They are also associated with wood burning, atmospheric emissions and solid wastes, exposed to heat from thermal plants among others (Sogbamu *et al.,* 2020, Fatunsin, *et al.,* 2023). These activities expose the Nigerian aquatic environments to potentially toxic metals (PTMs) commonly called heavy metals. These metals are widely recognized for their significant involvement in various biological processes and are hazardous even at trace level. PTMs in the

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environment accumulate in the environment and bio magnify along the food chain. Fishes absorb PTMs via food or non-food particles, gills, oral consumption of water and through the skin. The absorbed pollutants (PTMs) are then carried in the blood stream to either a storage organ or to the liver for transformation and/or storage (Bawuro *et al*, 2018; Ojaniyi *et al*,2021). Humans are primarily exposed to contaminants in workplaces but for most people the main PTMs exposure is the diet (food and water) (Adetunde *et al.,* 2018). In the aquatic environment PTMs are a source of concern because of their toxicity/ threat to plants, animal lives and humans that feed on aquatic organisms.

Djedjibegovic *et al.,* (2020) studied metal contaminations in seafoods from Bosnia and Herzegovina. Mwambene *et al.,* (2023), Mukherjee *et al., (*2021), Yi *et al.,* (2017) and Yasmin *et al*., (2016) studied metal concentration of fishes from rivers in Tanzania, India, China and Arabia respectively. Varying concentrations were found. Mwambene *et al.,* (2023) who investigated the accumulation of PTMs in five fish species (namely *O. microlepis, C. gariepinus, O.niloticus, R. moorii,B. meridionalis*) from Lake Nyasa, Tanzania found that the fish species accumulated metals in the following order: iron (Fe) > zinc (Zn) > nickel (Ni) > copper (Cu) > chromium (Cr). The levels of metals detected in the fish samples were within the permitted thresholds and if ingested in accordance with the recommended daily intake, do not present significant health hazards. The study conducted by Mukherjee *et al., (*2021) examined the levels of Pb (lead), Cd (cadmium), Cr, Cu, and Zn in different tissues (muscle, gills, and liver) of five fish species (*Mystus gulio, Notopterus notopterus, Notopterus chitala, Mugil cephalus, and Glossogobius giuris)* in the lower Gangetic area in India. Their study showed that the levels of PTMs in the fish tissues of the selected fish species do not pose a significant risk to human health when consumed at their current concentrations.

Studies in Nigerian waters have reported variable metal levels, with some (such as Bolawa et al., 2012; Okparanta and Daminabo, 2018, Ayoola, 2019) finding exceedances of FAO/WHO limits for Pb, Cu, Cr and Cd, in fishes ands sea foods. This inconsistency highlights the need for updated, multi-species assessments of fishes found in rivers..

Olowu *et al.,* (2015) assessed the level of some PTMs (Zn, Fe, Mn, Cu, Pb and Cd) in the head, gill, and trunk of *Synodontis membrane* (Catfish), *Tilapia Zilli* (Tilapia fish), *Callinectes Amnicola* (Crab) and Macrobrachium macrobachion (Prawn), from Lagos Island and Epe lagoon, Nigeria. The result of their analysis showed the orders of accumulation of PTMs in Catfish were Head>Gill>Trunk while in Tilapia, the accumulation follows the order; Gills >Head >Trunk. Mn and Cu concentrations in the fish samples were found to be above the standard limits. Oshisanya *et al.,* (2011) determined the amount of PTMs in sediment, water and fish (*Oreochromis niloticus* and *Chrysichtys nigrodigitatus*) samples from the University of Lagos, Ikorodu and Iddo area of the Lagoon in Lagos State, Nigeria. Fishes contained a higher concentration of Zn and Cu compared with their water samples which was attributed to bioaccumulation.

Ayanda *et al.* (2018) studied the concentrations of some PTMs tilapia fish from the Makoko River in Lagos. The mean concentration of Cr, Cd and Pd in tilapia fish flesh and liver were 1 ± 0.00 mg/kg, 1±0.00 mg/kg and 31±1.1, mg/kg respectively. Bolawa *et al.,* (2012) who determined Cd, Pb, Manganese (Mn), Cu and Fe in tissues of *Pseudolithus Senegalensis* (Crocker fish) and *Ethmalosa Fimbriata* (Bonga fish) obtained from Carter Bridge River and Makoko River areas of Lagos State, Nigeria. They observed the concentration of Pb, Cd, Cu, Fe and Mn in the tissue of *Ethmalosa Fimbariata* and *Pseudolithus Senegalensis* varied and concentrations of Cd and Pb in the fish tissues exceeded the maximum suitable concentrations for human consumption. Adetutu *et al.,* (2023) determined the concentration PTMs and the potential health risks to consumers *Sarotherodon melanotheron, Chrysichthys nigrodigitatus*, *C. gariepinus,* and *Ethmalosa fimbriata* fishes from the Makoko area of the Lagoon were below the recommended allowance and that the fishes were safe. They used the Estimated Daily Intake (EDI), Target Hazard Quotient (THQ) and Cancer Risk (CR) to estimate the risks. Ayoola (2019) who

also studied the PTMs (Pd, Zn, Mg and Cu) in some fishes of commercial (*Pseudotolithus senegalensis (*croaker fish) and *Ethmalosa fimbriata* (bonga), *Oreochromis mossambicus* (Tilapia fish) and Bagrus bayad (silver catfish)) from the Makoko River of Lagos in comparison with the World Health Organization (WHO) acceptable limits found them highly contaminated. Fishes caught in the Makoko region have been found to contain PTMs. However, most of the studies on PTMs in fishes from Makoko River, market and its environment were limited to few species of fishes. Thus, the need to assess a larger number of species to ascertain the current situation with respect to PTMs. This study addresses this by analyzing eight species and performing a comprehensive, multi-index risk assessment (MPI, EDI, HQ, CR) for both adults and children.

Makoko is located by the 3rd Mainland Bridge in the coastal mainland of Lagos. It is a fishing village in the urban Lagos of over a hundred years old (Uriri. *et al.,* 2019). Today, Makoko is home to many people. Most residents of Makoko depend mainly on fishing and its related business as the main economic activity. The fishing is usually done around Lagos Lagoon to the Atlantic Ocean and these fishes are sold at the Makoko fish market. The fish market is a big market with variety of fishes and its major source of fish for consumption in Lagos (Fajemila *et al*., 2022).

The aim of this study is to access the PTMs and associated health risk of the PTMs in eight species of fishes purchased from the Makoko fish market in Lagos State Nigeria where fishes caught from the surroundings lagoon and nearby Atlantic Ocean are sold.

2.0 Materials and Method

Sampling

Eight (8) species (consisting of 3 per species) of freshly caught fishes (namely: Lesser African threadfin, Grunter fish, Croaker, Grey mullet, Nile tilapia, Silver catfish, Barracuda and Red snapper) from the Lagos Lagoon up to the near end of Atlantic Ocean were randomly purchased from the Makoko fish market on the 6th of May, 2019. Samples were appropriately labelled and preserved in a cooler with ice packs before being transported to the Fishery Department, University of Lagos for proper identification and eventually to laboratory for weighing and analysis.

Analyses of Fish Samples

Sample analyses began immediately on arrival in the laboratory. The Moisture contents and PTMs in the fishes were determined. The fishes were cut into head mass, central bones and edible flesh. Empty crucibles which had been oven dried and cooled in a desiccator were weighed and recorded. Five grams of the fish samples were weighed and transferred directly into the pre-weighed empty crucible. The pre-weighed crucible and the fish sample were taken into the oven at 105 ^{o}C for four hours, after which the sample had attained stable weight. The crucible containing the sample was transferred into a desiccator and allowed to cool. After cooling, the weight of the crucible containing the dried fish sample was weighed and recorded and the moisture content calculated. The remaining fishes were all oven dried at 105 ^{o}C, homogenised and kept for analyses at -4 ^{o}C.

Dried and homogenized fish samples were digested to extract PTMs. Samples were extracted by weighing 2 g of the oven dried and homogenized samples into a digestion flask. To the flask was 20 ml of concentrated nitric acid, hydrochloric acid (3:1) added and the flask heated at 150 °C till digestion was completed. The digests were cooled and filtered into a 50 ml volumetric flask and made to 50 mL mark using deionized water and stored at 4 ^{0}C till analyses. Metals in filtrates from digested fish samples were determined using a calibrated Atomic Absorption Spectrometer-Buck scientific model 210VGP AAS (AOAC, 2000).

Quality Control and Calibration

The dried samples were kept at less than 4 ^{0}C till analyses. All laboratory glass wares were washed and soaked in 1% nitric acid solution overnight before being used for sampling and analyses. Before the value was recorded A four-point calibration was used for quantification of the metals. A range of 0.00 to 3.00 mg/l was used for Pb, Cr, Cu and Zn while 0.00 to 1.00 mg/l was used for cadmium. Cross contamination was prevented by rinsing with distilled water and blotting the probes (the pH and conductivity

meter), while for the aspiration of the AAS, deionised water was used to rinse the tip and aspirated through before the next measurement. Each fish sample was analysed in triplicates. Each fish in this study was analysed (that is three fishes per specie). Blanks were carried out for every batch of analyses using distilled water and blank values were subtracted from values obtained for analyses of field samples.

Potential Health Risk

Comparison with regulatory standards for PTMs in fishes

In 2003, the limits of Pd and Cd in fishes were set as 0.2 mg/Kg and 0.05 mg/Kg respectively by the Food and Agriculture Organization (FAO) of the United Nations (FAO, 2003). It was base on fresh/wet weight for the edible part of the fish which refers to the whole fish after removing the digestive tract. However, in 2023 (FAO, 2023), only the limit of Pd was changed to 0.3 mg/Kg. There are no FAO limit for other metals in this study for fish. Since the concentration of PTMs in this study was calculated in dry weight using the (1) according to Reyes-Márquez *et al.,* (2024) and Udiba *et al.,* (2020) the PTMs concentration in wet weight was obtained.

$$Wet\ weight\ conc\ (mg/Kg) = Dry\ weight\ conc(ppm)\left(1-\left(\frac{\%\ moisture}{100}\right)\right) \quad (1)$$

Metal pollution assessment

Metal pollution is assessed using the metal pollution index (MPi) (Hao *et al.,* 2022). MPI was calculated using (2)

$$MPi = \sqrt[n]{C_1 \times C_2 \times C_3 \times \ldots C_n} \quad \text{(Yap } et\ al.,\ 2003,\ \text{Hao } et\ al.,\ 2022) \text{ ----------2}$$

Where C_n (mg/kg, dry weight) is the concentration of individual metals in this study observed in the flesh, bone and head. Mpi for Flesh, bone and head were generated using their respective concentrations in Table 2 base on dry weight. They are Cd, Pd, Zn, Cr, and Cu. Thus n= 5 (Pinkey *et al.,* 2024).

Estimated daily intake (EDI) **(**Fatunsin *et al.,* 2020) of metals in the fishes were calculated using (3)

$$EDI\ (\mu g/day/Kg) = \frac{MCf \times DCf}{BW} \text{----------(3)}$$

Where MCf is mean concentration of PTMs in fish (µg/g DW), DCf is daily fish consumption, BW is body weight. BW was assumed to be 70 Kg for adult and 16 Kg for children (US-EPA 2018, Hassan *et al*., 2023, Egun *et al.,* 2023), while DCf was assumed to be 20 g fish/day) in Nigeria (Sani *et al.,* 2022).

Hazard quotient (HQ) was used to ascertain the level of non-carcinogenic risk resulting from eating the fishes with pollutants at the concentration found. The hazard quotient was calculated using the (4) (US-EPA 2018, Okogwu *et al.*, 2019, Hassan *et al.,* 2023)

$$HQ = \frac{EDI}{RfD} X 10^{-3} \text{----------(4)}$$

Where RfD is the oral reference dose and the EDI of metals was reported in µg/day/Kg, RfDs of individual metals in foods are 0.3, 0.04 and 0.003 mg/kg/day for Zn, Cu and Cr, respectively as established by US-EPA (2018), 0.004 mg/kg/day for Pb according to Yi *et al*. (2017) and 0.001 mg/kg/day for Cd as in Naseri *et al.,* (2021).

Total hazard quotient (ΣHQ) which is the Hazard index (HI) evaluates the risk associated with exposure to more than one metal tested. It was determined using (5) (Naseri *et al.,* 2021).

$$HI = \Sigma\ THQ = HQ\ Pd + HQ\ Zn + HQ\ Cu + HQ\ Cd + HQ\ Cr \text{----------(5)}$$

Carcinogenic risk (CR) was estimated using (6)

$$CR = CSF \times EDI\ X\ 10^{-3} \text{----------(6)}$$

CSF is the cancer slope factor. EDI in µg/kg/day. The CSF $(mg/kg/day)^{-1}$ is only available for Pd, Cd and Cr. Therefore, the CR in this study was assessed using CSF values of Pb (0.0085) (Norman *et al.,* 2022, Rakib *et al.,* 2021)., Cd (0.38) (Azadeh *et al.,* 2021) and Cr (0.003) (Rakib *et al.,* 2021), The range of acceptable risk value is E^{-4} to E^{-6} (Okogwu *et al.*, 2019) and

Integrated cancer risk (ICR) was estimated using (7)

$$ICR = CR_{pb} + CR_{Cd} + CR_{Cr}. \text{----------(7)}$$

Results

PTMs in Fishes species from the Makoko Fish Market in Lagos, Nigeria

The fishes were confirmed to be Grunter fish (*Pomadasys jubelini*), Croaker (*Pseudototithus typus)*, Grey mullet (*Mugil cephalus)*, Nile tilapia (*Oreochromis niloticus*), Silver catfish (*Chrysichthys nigrodigitatus*), Barracuda (*Sphyraena barracuda*) and Red snapper (*Lutjanus agennes*)) by the fisheries expert at the Department of Marine Sciences, University of Lagos. Weights of the fishes were taken and the results were expressed as mean ± Standard deviation (n= 5) as shown in Table 1. The moisture content ranged from 48.3% to 76.24% with Nile Tilapia especially the head having the highest moisture content (76.24 %), and Barracuda especially the flesh having the lowest moisture content of 48.37%.

This study determined the PTMs in the parts of the fishes usually consumed in Nigerian diets which are flesh, head and bones. Gills and intestines are usually thrown away when making most meals. The concentration of metals (Pb, Zn, Cu, Cd and Cr) in the fishes are as shown in Table 2. The results of the study showed that the concentration of Pb, Zn, Cu, Cd and Cr in fleshes of the fish species were in range of 0.525± 0.134 - 2.40± 0.127 mg/Kg, 0.300 ±0.141-1.150 ±0.071mg/Kg, <0.001-0.250±0.071 mg/Kg, <0.001- 0.200±0.000 mg/Kg and <0.001-0.200±0.000 mg/Kg respectively. In the head, the range was 0.265±0.120 - 2.4± 0.127 mg/Kg, 0.300 ±0.000 - 1.550 ±0.071 mg/Kg, <0.001-0.150±0.071 mg/Kg, <0.001-0.350±0.071 mg/Kg and <0.001 - 0.500±0.000 mg/Kg respectively, while in the bone it was 0.84±0.212-2.18± 0.679 mg/Kg, 0.350±0.071-1.550±0.212 mg/Kg, <0.001-0.350±0.071 mg/Kg, <0.001-0.300±0.000 mg/Kg and <0.001-0.300±0.141 mg/Kg respectively. The mean PTMs concentration for fishes in this study followed the order; *Sphyraena barracuda > Oreochromis niloticus> Galeoides decadactylus> Pomadasys jubelini > Lutjanus agennes> Pseudotolithus typus> Mugil cephalus> Chrysichthys nigrodigitatus.* For the eight species studied, $PTMs_{total}$ in each fish concentrations followed the order bone> flesh> head for *Sphyraena barracuda and Chrysichthys nigrodigitatus,* bone > head >flesh, for *Pseudotolithus typus and Lutjanus agennes*, Head> bone >flesh for *Galeoides decadactylus and Mugil cephalus* while for *Oreochromis niloticus* the order was head > flesh> bone. No common trend was found except that Fish flesh rarely had the higher concentration compared with head and bone.

Results of Risk Analyses of Fishes in this Study

The Mpi values determined for the flesh, head and bone are as shown in Table 3. In this study all the MPi values were less than 2. The values for MPi varied from 0.000±0.499 to 0.434±0.711 for individual parts in the various fishes while the mean Mpi for flesh, head and bone per fish varied from 0.038±0.022 (*Lutjanus agennes* Mean) to 0.760±0.157 (*Sphyraena barracuda* Mean). The total EDI values for adult and children for fishes in this study varied from 0.233 to 1.077 and 1.020 to 4.557 µg/ day/Kg respectively (Tables 3 and 4). The EDI of Metals of fishes in this study were in the order Pb > Zn > Cd > Cu>Cr.

HQ for the individual PTMs in fishes with respect to children and adult were all below 1 and the HI values which sums up individual HQ were all below 1 for both adults and children (Table 4 and 5). CR and ICR values for fishes with respect to children varied from 5.E-07 to 1.E-04, and 6.E-06 to 1.E-04 respectively while for adults CR and ICR values varied from 1.E-07 to 4.E-05 and 1.E-06 to 6.E-05 respectively.

Table1: Fish Samples, Scientific Name, Weight and moisture content of fishes (n=5)

Common Name	Average weight of fish (g)	Parts of fishes analyzed	Moisture content of fish (%)
Croaker (*Pseudotothithus typus*)	17.32±5.00	Flesh	57.13
		Head	69.57
		Bone	51.21
Barracuda (*Sphyraena barracuda*)	23.09± 2.10	Flesh	48.37
		Head	65.4
		Bone	58.4
Lesser African threadfin (*Galeoides decadactylys*)	11.55±4.56	Flesh	61.76
		Head	69.26
		Bone	50.49
Grunter fish (*Pomadasys jubelini)*	11.55± 3.20	Flesh	65.81
		Head	59.38
		Bone	54.2
Nile tilapia (*Oreochromis niloticus*)	40.42± 2.60	Flesh	76.24
		Head	55.89
		Bone	70.34
Red snapper (*Lutjanus agennes*)	34.64±3.50	Flesh	70.34
		Head	69.69
		Bone	62.12
Grey mullet (*Mugil cephalus*)	41.63± 4.20	Flesh	51.24
		Head	66.39
		Bone	56.54
Silver catfish (*Chrysichthys nigrodigitatus*)	23.09± 6.40	Flesh	71.24
		Head	66.1
		Bone	57.98

Table2: PTMs (mg/kg) in fish species from Makoko Market, Lagos showing dry weight (DW) and Wet weight (WW) concentrations

		Pb DW	Zn DW	Cu DW	Cd DW	Cr DW	PTMstotal	Pd WW	Cd WW
Fish species	**Part**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**	**Mean ± SD**
Pseudotolithus typus	Flesh	0.525± 0.134	0.350±0.071	<0.001±0.000	0.200±0.000	<0.001±0.000	1.077±0.227	0.225±0.058	0.086± 0.000
	Head	0.82± 0.057	0.850±0.212	<0.001±0.000	0.350±0.071	0.500±0.000	2.521±0.352	0.276±0.019	0.118± 0.024
	Bone	1.15± 0.099	1.000±0.141	<0.001±0.000	0.200±0.000	0.250±0.071	2.601±0.518	0.500±0.043	0.087± 0.087
	Mean	**0.835±0.320**	**0.733±0.340**	**<0.001± 0.000**	**0.250±0.087**	**0.250±0.177**	**6.199±1.061**	**0.314 ±0.040**	**0.097±0.037**
Sphyraena barracuda	Flesh	2.32± 0.226	1.150±0.071	0.150±0.071	0.150±0.071	<0.001±0.000	3.771±0.988	1.198±0.117	0.077±0.077
	Head	1.83± 0.297	0.900±0.141	0.150±0.072	0.250±0.071	0.250±0.071	3.38±0.711	0.633±0.103	0.087± 0.087
	Bone	1.985± 0.361	1.200±0.141	<0.001±0.000	0.300±0.000	0.300±0.141	3.786±0.821	0.826±0.150	0.125± 0.000
	Mean	**2.050±0.247**	**1.080±0.161**	**0.100±0.00**	**0.230±0.076**	**0.180±0.035**	**10.937±0 .058**	**0.798±0.123**	**0.096±0.055**
Galeoides decadac tylus	Flesh	1.295± 0.021	0.600±0.000	<0.001±0.000	0.300±0.000	<0.001±0.000	2.197±0.539	0.495±0.008	0.115± 0.000
	Head	1.125± 0.007	1.550±0.071	<0.001±0.000	0.350±0.071	<0.001±0.000	3.027±0.700	0.346±0.002	0.108± 0.022
	Bone	1.005± 0.417	1.550±0.212	0.150±0.071	0.300±0.000	<0.001±0.000	3.006±0.655	0.498±0.207	0.149± 0.000
	Mean	**1.142±0.146**	**1.233±0.548**	**0.050±0.00**	**0.317±0.029**	**<0.001± 0.000**	**8.230±1.789**	**0.492±0.072**	**0.124 ±0.007**
Pomadasys jubelini	Flesh	1.815± 0.417	0.550±0.071	0.250±0.071	0.050±0.071	<0.001±0.000	2.666±0.748	0.621±0.143	0.018±0.024
	Head	1.73± 0.438	0.750±0.071	0.100±0.000	<0.001±0.000	<0.001±0.000	2.582±0.747	0.703±0.178	0.000±0.000
	Bone	1.635± 0.205	0.800±0.141	0.300±0.000	0.100±0.00	0.050±0.001	2.786±0.681	0.749±0.094	0.046±0.000
	Mean	**1.297±0.670**	**0.633±0.247**	**0.133±0.153**	**0.050±0.035**	**0.017±0.029**	**8.034±2.166**	**0.721±0.138**	**0.021±0.008**
Oreochromis niloticus	Flesh	1.840± 0.269	0.700±0.000	<0.001±0.000	<0.001±0.000	0.100±0.000	2.642±0.789	0.437±0.064	<0.001±0.000
	Head	2.400± 0.127	0.900±0.000	<0.001±0.000	0.100±0.00	<0.001±0.000	3.303±1.047	1.059±0.056	0.0441±0.000
	Bone	1.615± 0.460	0.900±0.000	0.200±0.000	<0.001±0.000	<0.001±0.000	2.518±0.733	0.479±0.136	<0.001±0.000
	Mean	**1.952±0.404**	**0.833±0.115**	**0.200±0.00**	**0.033±0.000**	**0.030±0.000**	**8.463±2.560**	**0.719±0.085**	**0.015±0.000**
Lutjanus agennes	Flesh	1.13± 0.481	0.500±0.141	<0.001±±0.000	<0.001±0.000	<0.001±0.000	1.632±0.499	0.335±0.143	<0.001±0.000
	Head	1.735± 0.841	0.300±0.000	<0.001±0.000	<0.001±0.000	<0.001±0.000	2.037±0.753	0.526±0.255	<0.001±0.000
	Bone	2.18± 0.679	0.350±0.071	0.100±0.000	<0.001±0.000	<0.001±0.000	2.632±0.935	0.826±0.257	<0.001±0.000
	Mean	**1.682±0.527**	**0.383±0.104**	**0.03±0.000**	**<0.001±0.000**	**<0.001±0.000**	**6.301±2.170**	**0.475±0.214**	**<0.001±0.000**
Mugil cephalus	Flesh	1.03± 0.566	0.450±0.071	0.250±0.071	0.100±0.00	<0.001±0.000	1.732±0.426	0.502±0.276	0.034±0.000
	Head	0.585± 0.177	1.200±0.000	<0.001±0.000	0.150±0.071	<0.001±0.000	1.858±0.524	0.197±0.059	0.065±0.024
	Bone	0.84± 0.212	0.650±0.212	0.250±0.071	0.100±0.00	<0.001±0.000	1.742±0.382	0.365±0.092	0.029±0.000
	Mean	**0.818±0.223**	**0.767±0.388**	**0.167±0.144**	**0.117±0.029**	**<0.001 ±0.000**	**5.332±1.213**	**0.428±0.142**	**0.043 ±0.008**
Chrysichthys nigrodigitatus	Flesh	0.665± 0.191	0.300±0.141	0.250±0.071	0.150±0.071	<0.001±0.000	1.287±0.259	0.191±0.055	0.051±0.020
	Head	0.265± 0.120	0.250±0.212	0.150±0.071	<0.001±0.000	0.150±0.071	0.816±0.106	0.090±0.041	0.000±0.000
	Bone	1.305± 0.163	1.050±0.071	0.350±0.071	0.100±0.000	<0.001±0.000	2.707±0.605	0.548±0.068	0.029±0.000
	Mean	**0.745±0.525**	**0.533±0.448**	**0.250±0.100**	**0.083±0.007**	**0.050±0.000**	**4.810±0.938**	**0.270±0.055**	**0.031±0.007**
FAO (2023) Whole commodity (in general after removing the digestive tract)								0.3	0.05
LoD of, Cd ≤0.001mg/Kg, Cu≤0.001mg/Kg and Cr ≤0.001mg/Kg									

Table 3: Results of MPi, Total EDI (µg/ day/Kg) and EDIs (µg/ day/Kg),,associated with eating the fishes for Adults

Fish	Mpi	Pb EDI	Zn EDI	Cu EDI	Cd EDI	Cr EDI	Total EDI
Pseudotolithus typus Flesh	0.033±0.227	0.1500	0.1000	0.0003	0.0571	0.0003	0.3077
Pseudotolithus typus Head	0.165 ±0.352	0.2343	0.2429	0.0003	0.1000	0.1429	0.7203
Pseudotolithus typus Bone	0.142±0.518	0.3286	0.2857	0.0003	0.0571	0.0714	0.7431
***Pseudotolithus typus* Mean**	**0.340±0.071**	**0.2376**	**0.2095**	**0.0003**	**0.0714**	**0.0715**	**0.5904**
Sphyraena barracuda Flesh	0.143±0.988	0.6629	0.3286	0.0429	0.0429	0.0003	1.0774
Sphyraena barracuda Head	0.434±0.711	0.5229	0.2571	0.0429	0.0714	0.0714	0.9657
Sphyraena barracuda Bone	0.185±0.821	0.5671	0.3429	0.0003	0.0857	0.0857	1.0817
***Sphyraena barracuda* Mean**	**0.760±0.157**	**0.5843**	**0.3095**	**0.0287**	**0.0667**	**0.0525**	**1.0416**
Galeoides decadactylus Flesh	0.047±0.539	0.3700	0.1714	0.0003	0.0857	0.0003	0.6277
Galeoides decadactylus Head	0.057±0.700	0.3214	0.4429	0.0003	0.1000	0.0003	0.8649
Galeoides decadactylus Bone	0.148±0.655	0.2871	0.4429	0.0429	0.0857	0.0003	0.8589
***Galeoides decadactylus* Mean**	**0.252±0.055**	**0.3262**	**0.3524**	**0.0145**	**0.0905**	**0.0003**	**0.7838**
Pomadasys jubelini Flesh	0.105±0.748	0.5186	0.1571	0.0714	0.0143	0.0003	0.7617
Pomadasys jubelini Head	0.042±0.747	0.4943	0.2143	0.0286	0.0003	0.0003	0.7377
Pomadasys jubelini Bone	0.114±0.681	0.4671	0.2286	0.0857	0.0003	0.0143	0.7960
***Pomadasys jubelini* Mean**	**0.261±0.039**	**0.4933**	**0.2000**	**0.0619**	**0.0050**	**0.0050**	**0.7651**
Oreochromis niloticus Flesh	0.042±0.789	0.5257	0.2000	0.0003	0.0003	0.0286	0.7549
Oreochromis niloticus Head	0.018±1.047	0.6857	0.2571	0.0003	0.0003	0.0003	0.9437
Oreochromis niloticus Bone	0.017±0.733	0.4614	0.2571	0.0003	0.0003	0.0003	0.7194
***Oreochromis niloticus* Mean**	**0.077±0.014**	**0.5576**	**0.2381**	**0.0003**	**0.0003**	**0.0097**	**0.8060**
Lutjanus agennes Flesh	0.000±0.499	0.3229	0.1429	0.0000	0.0003	0.0003	0.4663
Lutjanus agennes Head	0.000±0.753	0.4957	0.0857	0.0000	0.0003	0.0003	0.5820
Lutjanus agennes Bone	0.038±0.935	**0.6229**	0.1000	0.0286	0.0003	0.0003	0.7520
***Lutjanus agennes* Mean**	**0.038±0.022**	**0.4805**	**0.1095**	**0.0095**	**0.0003**	**0.0003**	**0.6001**
Mugil cephalus Flesh	0.041±0.426	0.2943	0.1286	0.0714	0.0003	0.0003	0.4949
Mugil cephalus Head	0.035±0.524	0.1671	0.3429	0.0003	0.0203	0.0003	0.5309
Mugil cephalus Bone	0.042±0.382	0.2400	0.1857	0.0714	0.0003	0.0003	0.4977
***Mugil cephalus* Mean**	**0.118±0.004**	**0.2338**	**0.2190**	**0.0477**	**0.0070**	**0.0003**	**0.5078**
Chrysichthys nigrodigitatus Flesh	0.081±0.259	0.1900	0.0857	0.0714	0.0203	0.0003	0.3677
Chrysichthys nigrodigitatus Head	0.068±0.106	0.0757	0.0714	0.0429	0.0003	0.0429	0.2331
Chrysichthys nigrodigitatus Bone	0.055±0.605	0.3729	0.3000	0.1000	0.0003	0.0003	0.7734
***Chrysichthys nigrodigitatus* Mean**	**0.204±0.013**	**0.2129**	**0.1524**	**0.0714**	**0.0070**	**0.0145**	**0.4581**

Table 4: Results of EDIs (µg/kg/day), Total EDI (µgKg/ day), HQs, HI, CRs, and ICRassociated with eating the fishes in this study for children

EDI Chidren	Pb EDI	Zn EDI	CuEDI	Cd EDI	Cr EDI	Total EDI
Pseudotolithus typus Flesh	0.6563	0.4375	0.0013	0.2500	0.00125	1.3463
Sphyraena barracuda Flesh	2.9000	1.4375	0.1875	0.1875	0.00125	4.7138
Sphyraena barracuda Flesh	1.6188	0.7500	0.0013	0.3750	0.00125	2.7463
Pomadasys jubelini Flesh	2.2688	0.6875	0.3125	0.0625	0.00125	3.3325
Oreochromis niloticus Flesh	2.3000	0.8750	0.0013	0.0013	0.12500	3.3025
Lutjanus agennes Flesh	1.4125	0.62500	0.0000	0.0013	0.00125	2.0400
Mugil cephalus Flesh	1.2875	0.5625	0.3125	0.0013	0.00125	2.1650
Chrysichthys nigrodigitatus Flesh	0.8313	0.3750	0.3125	0.08875	0.00125	1.60875
HQ children	**Pb HQ**	**Zn HQ**	**Cu HQ**	**Cd HQ**	**Cr HQ**	**HI**
Pseudotolithus typus Flesh	0.164	0.001	]3.13E-06	0.25000	0.0004	0.41594
Sphyraena barracuda Flesh	0.725	0.005	0.0005	0.18750	0.0004	0.91818
Sphyraena barracuda Flesh	0.405	0.003	3.13E-06	0.37500	0.0004	0.78261
Pomadasys jubelini Flesh	0.567	0.002	0.0008	0.06250	0.0004	0.63318
Oreochromis niloticus Flesh	0.575	0.003	3.13E-06	0.00125	0.04166	0.62084
Lutjanus agennes Flesh	0.353	0.002	0.000	0.00125	0.00041	0.35688
Mugil cephalus Flesh	0.322	0.002	0.0008	0.00125	0.00041	0.32620
Chrysichthys nigrodigitatus Flesh	0.208	0.001	0.0008	0.08875	0.00041	0.29901
CR for Children	**CR_{Pb}**	**CR_{Cd}**	**CR_{Cr}**	**ICR**		
Pseudotolithus typus Flesh	6.E-06	1.E-04	6.E-07	1.E-04		
Sphyraena barracuda Flesh	1.E-05	7.E-05	6.E-07	8.E-05		
Galeoides decadactylus Flesh	6.E-06	1.E-04	6.E-07	1.E-04		
Pomadasys jubelini Flesh	6.E-06	2.E-05	6.E-07	3.E-05		
Oreochromis niloticus Flesh	7.E-06	5.E-07	6.E-05	7.E-05		
Lutjanus agennes Flesh	5.E-06	5.E-07	6.E-07	6.E-06		
Mugil cephalus Flesh	5.E-06	5.E-07	6.E-07	6.E-06		
Chrysichthys nigrodigitatus Flesh	3.E-06	3.E-05	6.E-07	4.E-05		

Table 5: Results of HQs, HI, CRs and ICR associated with eating the fishes in this study for Adults

Fish	Pb HQ	Zn HQ	Cu HQ	Cd HQ	Cr HQ	HI	CR_{Pb}	CR_{Cd}	CR_{Cr}	ICR
Pseudotolithus typus Flesh	0.038	0.000	0.000	0.057	0.000	**0.095**	9.E-07	2.E-05	1.E-07	2.E-05
Pseudotolithus typus Head	**0.059**	0.001	0.000	0.100	0.048	**0.207**	2.E-06	4.E-05	7.E-05	1.E-04
Pseudotolithus typus Bone	0.082	0.001	0.000	0.057	0.024	**0.164**	2.E-06	2.E-05	4.E-05	6.E-05
***Pseudotolithus typus* Mean**	**0.059**	**0.001**	**0.000**	**0.071**	**0.024**	**0.155**	**2.E-06**	**3.E-05**	**4.E-05**	**6.E-05**
Sphyraena barracuda Flesh	0.166	0.001	0.000	0.043	0.000	**0.210**	3.E-06	2.E-05	1.E-07	2.E-05
Sphyraena barracuda Head	0.131	0.001	0.000	0.071	0.024	**0.227**	2.E-06	3.E-05	4.E-05	7.E-05
Sphyraena barracuda Bone	0.142	0.001	0.000	0.086	0.029	**0.257**	3.E-06	3.E-05	4.E-05	8.E-05
***Sphyraena barracuda* Mean**	**0.146**	**0.001**	**0.000**	**0.067**	**0.017**	**0.231**	**3.E-06**	**3.E-05**	**3.E-05**	**5.E-05**
Galeoides decadactylus Flesh	0.093	0.001	0.000	0.086	0.000	**0.179**	1.E-06	3.E-05	1.E-07	3.E-05
Galeoides decadactylus Head	0.080	0.001	0.000	0.100	0.000	**0.182**	4.E-06	4.E-05	1.E-07	4.E-05
Galeoides decadactylus Bone	0.072	0.001	0.000	0.086	0.000	**0.159**	4.E-06	3.E-05	1.E-07	4.E-05
***Galeoides decadactylus* Mean**	**0.082**	**0.001**	**0.000**	**0.090**	**0.000**	**0.173**	**3.E-06**	**3.E-05**	**1.E-07**	**4.E-05**
Pomadasys jubelini Flesh	0.130	0.001	0.000	0.014	0.000	**0.145**	1.E-06	5.E-06	1.E-07	7.E-06
Pomadasys jubelini Head	0.124	0.001	0.000	0.000	0.000	**0.125**	2.E-06	1.E-07	1.E-07	2.E-06
Pomadasys jubelini Bone	0.117	0.001	0.000	0.000	0.005	**0.123**	2.E-06	1.E-07	7.E-06	9.E-06
***Pomadasys jubelini* Mean**	**0.123**	**0.001**	**0.000**	**0.005**	**0.002**	**0.131**	**2.E-06**	**2.E-06**	**2.E-06**	**6.E-06**
Oreochromis niloticus Flesh	0.131	0.001	0.000	0.000	0.010	**0.142**	2.E-06	1.E-07	1.E-05	2.E-05
Oreochromis niloticus Head	0.171	0.001	0.000	0.000	0.000	**0.173**	2.E-06	1.E-07	1.E-07	2.E-06
Oreochromis niloticus Bone	0.115	0.001	0.000	0.000	0.000	**0.117**	2.E-06	1.E-07	1.E-07	2.E-06
***Oreochromis niloticus* Mean**	**0.139**	**0.001**	**0.000**	**0.000**	**0.003**	**0.144**	**2.E-06**	**1.E-07**	**5.E-06**	**7.E-06**
Lutjanus agennes Flesh	0.081	0.000	0.000	0.000	0.000	**0.082**	1.E-06	1.E-07	1.E-07	1.E-06
Lutjanus agennes Head	**0.124**	0.000	0.000	0.000	0.000	**0.125**	7.E-07	1.E-07	1.E-07	1.E-06
Lutjanus agennes Bone	0.156	0.000	0.000	0.000	0.000	**0.157**	9.E-07	1.E-07	1.E-07	1.E-06
***Lutjanus agennes* Mean**	**0.120**	**0.000**	**0.000**	**0.000**	**0.000**	**0.121**	**9.E-07**	**1.E-07**	**1.E-07**	**1.E-06**
Mugil cephalus Flesh	0.074	0.000	0.000	0.000	0.000	**0.075**	1.E-06	1.E-07	1.E-07	1.E-06
Mugil cephalus Head	0.042	0.001	0.000	0.020	0.000	**0.063**	3.E-06	8.E-06	1.E-07	1.E-05
Mugil cephalus Bone	0.060	0.001	0.000	0.000	0.000	**0.061**	2.E-06	1.E-07	1.E-07	2.E-06
***Mugil cephalus* Mean**	**0.058**	**0.001**	**0.000**	**0.007**	**0.000**	**0.066**	**2.E-06**	**3.E-06**	**1.E-07**	**5.E-06**
Chryzichthys nigrodigitatus Flesh	0.048	0.000	0.000	0.020	0.000	**0.068**	7.E-07	8.E-06	1.E-07	9.E-06
Chryzichthys nigrodigitatus Head	0.019	0.000	0.000	0.000	0.014	**0.034**	6.E-07	1.E-07	2.E-05	2.E-05
Chryzichthys nigrodigitatus Bone	0.093	0.001	0.000	0.000	0.000	**0.095**	3.E-06	1.E-07	1.E-07	3.E-06
***Chrysichthys nigrodigitatus* Mean**	**0.053**	**0.001**	**0.000**	**0.007**	**0.005**	**0.066**	**1.E-06**	**3.E-06**	**7.E-06**	**1.E-05**

Discussion

PTMs Distribution in the Parts of Fishes species from the Makoko Fish Market in Lagos

Kortei *et al.,* (2020) in their study of Mud fish (*Clarias anguillaris)* found that the concentration of Cd and Pb had a range of 0-0.08 mg/Kg and 0.04-0.42 mg/Kg respectively. Concentrations of 0.002–0.004 mg/Kg and 0.021–0.047 mg/Kg were found for Cd, while 0.001-0.002 mg/Kg and Not detected (ND)-0.001 mg/Kg were the concentration of Pb in European hake and Atlantic mackerel respectively by Djedjibegovic *et al.,* (2020). Bolawa *et al.,* (2012) reported values between 0.08±0.04 and 2.82±0.03 mg/Kg for Pd in Croaker fish (*Pseudolithus senegalensis*) from Makoko river while Adetutu *et al.,* (2023) who studied two fish species from the Makoko fish landing site in Lagos from where fishes are taken to the Makoko market reported Cd, Cr, and Pd concentrations of 0.004, 0.008, 0.003 mg/Kg respectively in *Chrysichthys nigrodigitatus* muscle and 1.39, 0.16, 2.06 mg/Kg respectively in *Ethmalosa fimbriata* (Bonga) Muscle. In this study *Chrysichthys nigrodigitatus* flesh (also called muscle) had concentrations of 0.665± 0.191, <0.001 and <0.001 mg/kg for Pb, Cd and Cr. Lower values of Cd and Cr were reported in this study for *Chrysichthys nigrodigitatus* compared with other studies for fishes from similar sampling area. However, the concentrations of Pd in this study for *Chrysichthys nigrodigitatus* was (0.665± 0.191 mg/Kg dry weight concentration in flesh) lower than in Bolawa *et al.,* (2012)) (1.57 ± 0.16 mg/Kg dry weight concentration) but higher than in than in Adetutu *et al.,* (2023) (0.098 ±0.004 mg/Kg dry weight concentration for fish flesh). The concentration appears to be reducing with time. This samples were sampled and analysed in 2019. The 2012 samples had higher concentration than the 2019 samples and 2019 sample had higher concentration than the 2023 samples. Dry weight concentration of Pd in this study varied between 0.525± 0.134and 2.32± 0.226 mg/Kg for fish flesh in all the fishes (Table 2).

The Distribution of PTM concentrations in relation to the Tropic level found in this study

Sphyraena barracuda is a predatory carnivore that feed on other aquatic animals (Florida Museum, 2024), *Oreochromis niloticus* is omnivorous. It feeds on phytoplankton,

periphyton, aquatic plants, small invertebrates and benthic fauna, detritus, bacterial films and even other fishes and fish eggs (El-Sayed, 2020, Tesfahun and Temesgen 2018). *Galeoides decadactylus* is a carnivorous and vulturelike species (Ezekiel *et al.,* 2013, Sossoukpe *et al.,* 2016). *Pomadasys jubelini* is a non-piscivorous predatory fish which feeds mainly on other macroscopic animals other than fish (Agbugui, *et al*., 2014, Adebiyi., 2011). *Lutjanus agennes* are carnivorous opportunistic predators (Chukwu and Oyana, 2022). *Pseudotolithus typus* feeds on shrimps and juvenile fishes (carnivores) (Nunoo *et al.,* 2013). For *Mugil cephalus,* plant materials were found to be the preferred food where it occurred in 67.0% of the examined fishes in the study by Jamabo and Maduako, (2015) and it was determined to be omnivorous but primarily plant eaters and are benthic in nature. *Chrysichthys nigrodigitatus* are omnivorous. Their food consisted of phytoplankton, crustaceans, molluscs, plant materials and fish parts (Babalola *et al.,* 2018).

Generally, the carnivorous fishes (*Sphyraena barracuda, Lutjanus agennes, Pseudotolithus typus*) had higher concentration of PTMs compared with the omnivores. However, *Oreochromis niloticus* fishes though omnivores in nature had mean concentration of PTMs higher than all other fishes in this study except the *Sphyraena barracuda* fishes. This may be because *Oreochromis niloticus* can survive in poor environmental conditions (which are usually associated with high PTMs and other pollutants) because of its powerful disease resistance, slight respiratory demands, low oxygen tolerance and high ammonia levels (Ibrahim, 2020). The *Oreochromis niloticus* fishes in this study may have been from more polluted waters than other fishes sampled. Wu *et al.,* (2023) and Liu *et al*., (2020) who also studied PTMs in various fish species from other part of the world also observed that metals accumulated more in carnivores than in omnivores but Hassim *et al.,* (2014) observed that omnivorous fishes had with elevated concentrations of Cd and Ni, while carnivorous fishes had the highest concentration of Pb

The Distribution of PTM concentrations in the parts of the fishes

Comparing the concentration of PTMs in the flesh, head and bone for the various fishes no clear trend was seen (Table 2). The sum of Pd, Zn, Cu, Cr, and Cd ($PTMs_{total}$) flesh, head and bones varied from fish species to fish species. In *Pseudotolithus typus,* the bone (2.601±0.518 mg/Kg) had higher concentration of $PTMs_{total}$, followed by the head (2.521±0.352 mg/Kg) and flesh (1.077±0.227 mg/Kg) but in *Sphyraena barracuda* the concentration was high in the bone (3.786±0.821 mg/Kg), and followed by the flesh (3.771±0.988 mg/Kg), while the head (3.38±0.711 mg/Kg) accumulated the highestAsgedom *et al*., (2006) and Staniskiene *et al*., (2006) found the PTMs concentrations in fish bone were higher than in fish flesh. In this study,the highest concentration of Pd and Zn in fish flesh was found in the flesh of *Sphyraena barracuda* **(**Pd DW and Zn DW 2.32 mg/kg and 1.150 mg/Kg respectively**)**, which is above the recommended FAO limit for Pb (0.3 mg/kg for wet weight) and Croaker flesh had lowest lead level in its flesh (0.525 mg/kg). Generally, Cu levels were low across all the species and parts.

Comparison of PTMs concentration with Set Limits

The only FAO regulations/limit for PTMs of fish in this study were for Cd and Pb. FAO limits for PTMs are based on wet weight concentration after the intestines were removed as stipulated in the FAO (2023). The cadmium wet weight concentration (CdWW) for this study were below the FAO limit (0.05 mg/Kg) but the lead wet weight concentrations (PbWW) were above the FAO limit for Pb concentrations (0.3 mg/Kg) (FAO, 2023).

Potential Health Risk Assessment of Fishes in this study

MPi value is a measure of toxicity. MPi simultaneously measures the potential harm from multiple metals by combining the accessed PTMs. A high MPi value indicates a tendency to accumulate high amount of diverse metals. The higher the MPi value the greater tendency to accumulate metals and the greater the toxicity from trace metals associated with the part of the

fish. MPI values of 10 to 20, 5 to 10, 2 to 5, and less than 2 indicate medium, low, very low, and no toxicity, respectively (Pinkey *et al.,* 2024). . In this study all the MPi values were less than 2 implying that no toxicity is associated with these fishes from a combined metal perspective. The MPi values of species in this study decreased in the following order; *Sphyraena barracuda* (Carnivore; 0.762±0.157), *Pseudotolithus typus* (Carnivoure;0.340 ±0.071), *Pomadasys jubelini* (Carnivoure; 0.261±0.039), *Galeoides decadactylus* (Carnivoure;0.252±0.055), *Chrysichthys nigrodigitatus* (Ominivore; 0.204±0.013), *Mugil cephalus* (Ominivore;0.118±0.004), *Oreochromis niloticus* (0.077±0.014) and *Lutjanus agennes* (carnivorous; 0.038±0.022). The order again shows that the carnivorous fishes were associated with higher MPi. *Lutjanus agennes* had the lowest MPi value. Though *Lutjanus agennes* fishes are carnivores they are not true carnivore. They are carnivorous opportunistic predators. They alter their foraging behaviour when food resources change, by hunting less and scavenging more (Chukwu and Oyana, 2022). MPi values in the studies by in Lia *et al.,* (2019), Miao *et al.,* (2020) Kwaansa-Ansah *et al.,* (2019) were 0.034 - 0.164, 0.02 - 0.12 and 0.021 and 0.036 respectively for the various species of fishes from rivers in China and Ghana. These values are lower than the values obtained in this study but the mean MPi value in Hao *et al.,* (2013) was 0.91 which was higher than in this study (0.762±0.157-0.038±0.022).

In this study, metals concentration in the flesh, head, bones were used to estimate the health risk of fishes to adult but since children do not eat fish bones, only fish flesh concentrations of metals were used to estimate the risk to children. Iyorah and Uzoamaka, (2023), recorded values of 0.00 - 0.76 µg/ day/Kg and 0.02 - 1.42 µg/ day/Kg for adults and children respectively in their assessment of PTMs from fishes while Sani *et al*., (2022) recorded 0.03 - 11.26 µg/ day/Kg as EDI for adults as being associated with fishes from Northern Nigerian River.

The hazard quotient (HQ) indicates non cancer risk health risk when its value is more than 1. When the value is greater than 0.6 it calls for caution (Adegbola *et al.,* 2021). Since the individual HQsfor the various PTMs in the fishes with respect to childremand adults were all below 1, there is no significant health risk associated with ingesting a single metal type. However, higher values were associated with children than with adults. Indicating that more risks are associated with the children eating PTM contaminated fishes. The HI which is a sum of all HQs were all below 1 for both adults and children (Table 4 and 5) indicating that no intervention is required. When HI equal to or higher than 1.0, interventions and protective measures are required (Tamang e*t al.,* 2023). Naseri *et al.,* (2021), Okogwu *et al.*, (2019), Hassan *et al.,* (*2023*) all had HI values of less than 1.

CR was also used to predict the probability of cancer in the population as a result of eating the fishes in this study and the results are as shown in Table 4 and 5 for adults and children respectively. CR value for children was calculated only for fish flesh because children do not eat bony parts of fish nor head while for adults all the parts of the fishes were used. The acceptable limit for CR to humans is 1×10^{-4} (Egun *et al.,* 2023, Hao *et al.,* 2022) and a Delphi method grading ICR has been established (Egun *et al.,* 2023). The Delphi method grades the ICR from grade 1 to 7. Where grade 1 means the risk is extremely low- for values $<10^{-6}$ and can be accepted, grade 2 means low risk for values from 10^{-6} to 10^{-5} and at this level there is no will to care about the risk, Grade 3 means Low-medium risk for values from 10^{-5} to 5×10^{-5} and no care may be given to the risk, grade 4 means medium risk and care must be given for values from 5×10^{-5} to 10^{-4}, grade 5 means medium high risk and care must be given about the risk / to investment must also be done for values from 10^{-4} to 5×10^{-4}, grade 6 means high risk 5×10^{-4} to 10^{-3} – at this point attention must be paid and taken to sought it out, grade 7 means extremely high risk $>10^{-3}$- at this point the risk must be rejected and the problem must to solved (Egun *et al.,* 2023). The ICR which tell the total cancer risk varied from grades 1 to grades 4 for adults and from grades 2 to 4 for children. All the $CR_{Pb,}$ CR_{Cd} , CR_{Cr} and ICR values were less than the 1×10^{-4} thus were in the acceptable range for both adults and children. However, higher CR values for the children compared with adults were recorded for the same part of fish eaten indicating that higher risks are associated

with the children who eat them than with adults. CR values in Egun *et al,* (2023) were also within the 1 x10^{-4} similar to this study and ICR values for fishes in was grade 3 while in this study it varied from 1 to 4. ICR values of 3 were reported *C. gariepinus* and *P. obscura* from the Owan River in Hossain *et al*., (2022) and in *C. zillii* and *P. obscura* from Osu Reservoir (Obayemi, *et al.,* 2023). With the risks associated with this study and other studies, there are concerns on the safety of aquatic food, the need to educate the fisher men on where to fish and the need to safeguard the water bodies for the good of public health. The Limitations of this study is age of samples (2019).

Conclusion

This study determined the concentration of PTMs in eight fish species purchased from the Makoko Fish Market in Lagos, Nigeria with Pb levels exceeding FAO limits though others were all within their limits. The study showed that the Pb, Cd, Zn, Cu and Cr varied in the various fish species and parts (flesh, head, and bones). Carnivorous predatory species such as *Sphyraena barracuda and Oreochromis niloticus* exhibited higher PTMs concentrations compared to omnivorous species, suggesting biomagnification across the food chain . No immediate systemic health risk (HI<1) was observed with the fishes. However, low but non-negligible lifetime cancer risk, particularly for children was observed.

In conclusion, this study shows thatpollution control at the source (Lagoon) is the most critical need, followed by monitoring and community education. Ongoing surveillance and education efforts will be critical to ensuring food safety and public health protection.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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