

Bioaccumulation and Health Risk Assessment of Heavy Metals in *Clearias gariepinus* and *Tilapia zilli* in Barkin Ladi Abandoned Mining Ponds, Plateau State, Nigeria

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Fish Samples of average sizes were selectively collected from twelve (12) sampling sites in Barkin Ladi LGA. Samples were treated and analyzed using standard procedures as established in standard methods and the works of many other scholars and levels of heavy metals were determined using Atomic Absorption Spectrometry (AAS), Perkin Elmer, (Model 3100). The results confirmed the differences in the accumulation of elements in different catfish organs. The element concentrations in the catfish samples decreased in the sequence for the flesh as Ni > Cr > Pb > Hg > As > Cd, for the gills Ni > Hg > Cr > Pb > As > Cd, for kidney Ni > Pb > Hg > Cr > As > Cd, for liver Ni > Cr > Cd > Pb > Hg > As. Arsenic showed the least bioaccumulation in all the organs followed by Cd which is significantly higher in the liver. Important health risk parameters such as target hazard quotient (THQ) and estimated daily intake (EDI) were evaluated. THQ for adults in both species of fish in gave values > 1 thus indicating risk of consumption except for Cd, Hg, Ni, and Pb in catfish flesh with values 0.91, 0.83, and 0.46 respectively, gill Cd, Ni, Pb (0.40, 0.27, 0.46), kidney Cd (0.35) and liver Pb (0.70). For tilapia fish, the results revealed that flesh Cd, Ni, and Pb were 0.46, 0.29, and 0.84 respectively, gill Cd, Ni, and Pb Ni, and Pb (0.46, 0.58, 0.42), kidney Cd, Ni, and Pb (0.32, 0.78, 0.53) and liver Cd (0.38), Pb (0.36). On an average overall perspective, however, the two fish samples pose a great health hazard to consumers. Similarly, the EDI THQ values for both samples in adults and children for all the heavy metals examined gave values < 1, thus recommended for consumption at the rate of intake only. However, the need for heavy metal remediation of the ponds is highly recommended as they serve as good natural habitat for fish production and other economic activities such as irrigation and dry season farming so that the pond water can be a safe natural resource.

Keywords: Heavy Metal, Health Harzard, *Clearias gariepinus*, *Tilapia zilli*, Barkin Ladi

1.0 Introduction

Fish is an important staple diet, providing alternative nutrient dense food low in fat, but containing protein and vitamins and minerals. The main problem is that fish live in water. Heavy metals found in the water, sediment and food will be integrated into fish, and thus provide a main pathway for exposure in humans (Ugwu *et al.*, 2024; Singh and Sharma, 2024; Nangbes *et al.*, 2023). Heavy metals like mercury (Hg), lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr), nickel (Ni), and cobalt (Co) are elements that are found in the environment. They are introduced into water bodies through human activities like industrial operations, agriculture, via coal actions and waste management. Those that are persistent and stable, bio-accumulate and biomagnify in the environment. The process of bio-magnification also means that larger predatory fish will have more concentrated levels of toxic metals, tend to be larger as they have consumed smaller fish that have also absorbed the toxic metals. Fish also absorb metals via their gills, skin and intestines, and compartmentalize them to their gills, liver, kidney and muscles (Nangbes *et al.*, 2022; Nangbes *et al.*, 2023; Opoku *et al.*, 2024). Some metals like Cu, Fe, Mn, Ni, and Zn are essential in trace amounts and will also be toxic in excess, while Cd, Pb, Hg, and As also have no known beneficial roles and are also toxic to humans even in trace amounts. Health effects in humans. There are many acute and chronic dangers to health from eating fish that are from the food chain in their metals. Some of these threats are: Damage to the nervous system and development: Mercury and lead also have detrimental effects to others in development and in particular fetuses from their central nervous system and brain. Various system damage and circulatory stress: the metals As, Cd, Cr, Cu, Fe, Hg, Ni, and many others. Bioaccumulation of heavy metals in the human body systems can cause a lot biological disruptions, leading to numerous types of diseases such as cancer, kidney failure, DNA disruptions etc (Norvivor *et al.*, 2024; Almafrachi *et al.*, 2024; Nangbes *et al.*, 2023; Okonkwo *et al.*, 2023), thereby posing lots of public health complications. Residents of Barkin Ladi LGA rely mostly on the ponds for fishing and other agricultural practices such and dry season farming. These fishes are often eaten as important source of protein and often sold to the open markets and also supplied to other places, thus the need for this research so as to be sure the fishes are safe for human consumption.

2.0 Materials and Methods

2.1 Study Area

Barkin Ladi L.G.A is a local government are in Plateau state, Nigeria located on latitude located between latitude 9° 30'N and 9° 33'N. Barkin Ladi has over three hundred abandoned mining sites with large volumes of pond water that are usually used for fishing and fish production by the locals (Akintunde *et al.*, 2022).

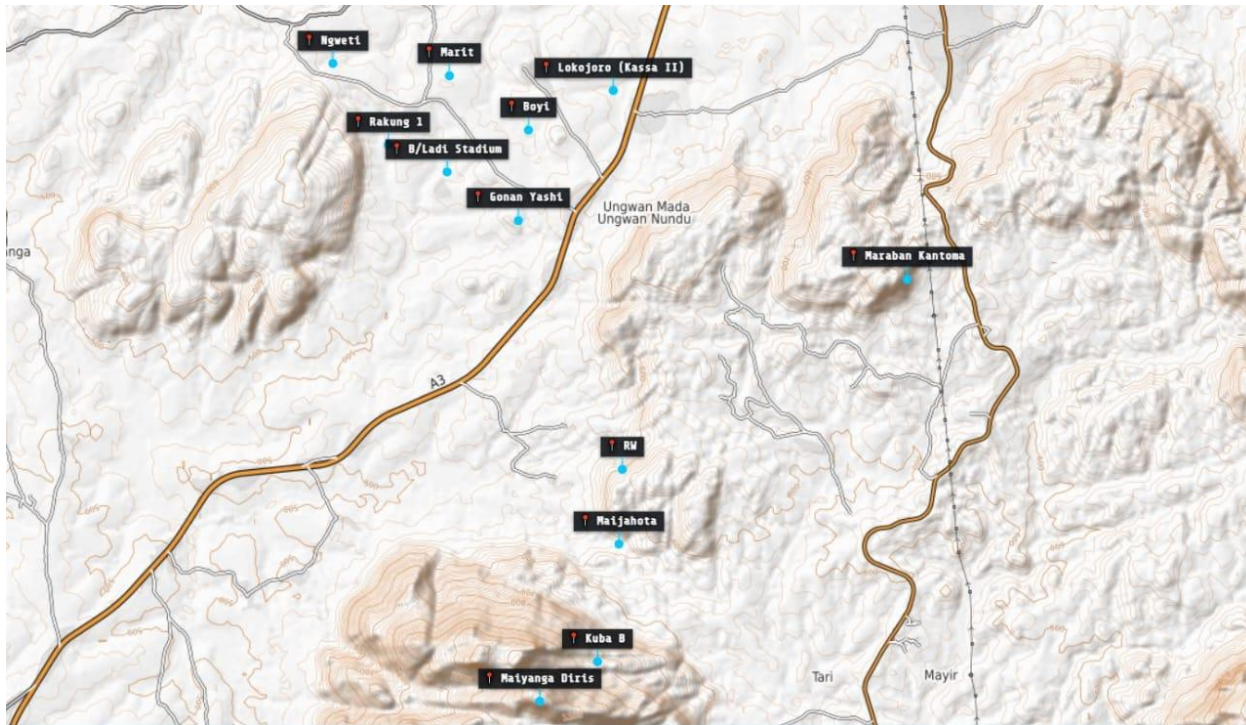


Figure 1: Sectional Map of Barik Ladi showing Sampling Sites

2.2 Sampling, Sample Preparation and Analysis

2.2.1 Fish Sampling

All glass wares used were washed with liquid detergent and rinsed thrice with distilled water followed by oven drying. Polyethylene sample bottles and Teflon beakers were washed with liquid detergent and rinsed with distilled water prior to sample collection (Ogunfowokan *et al.*, 1998, 2008).

Fish samples were obtained with the assistance of the local fishermen. Big nets were set overnight for a big catch of various fish species. *Clarias gariepinus* (Catfish) and *Tilapia zilli* (Tilapia fish) of approximately equal size and shape were collected using professional fishermen (Onyeka, *et al.*, 2024) and selected, bought, and taken to the laboratory for further preparation and storage.

After the fish were rinsed with distilled water, each fish was dissected using stainless-steel knife to extract the organs of interest (liver, gills, kidney and flesh). Polyethylene gloves were worn during dissection of fish tissues to reduce surface contamination of samples. After dissection, 20 g samples of each tissue were dried at 60 °C until they were reduced to constant weight. Dried tissues were ground, sieved and transferred to porcelain dishes. Preparation of Solution of Fish Samples and Analysis

Fish samples were collected and washed with distilled water to remove contaminated particles. Samples were dissected using a clean ceramic knife to remove the organs of interest (flesh, gills, kidney, liver and lungs) from each fish species. Respective sample organs were dried in an oven at 105° C until a constant weight was obtained to ensure complete dryness. The samples were separately ground into fine powder using a ceramic pestle and mortar, sieved using a 0.2-micron filter mesh, and stored in labeled polyethylene bags until ready for acid digestion.

A 2.00 g of ground tissue was separately weighed into a 500 cm³ beaker and 10.00 cm³ of concentrated HNO₃ and HClO₄ were added to the beaker in a volume ratio of 4:1. This was heated at 80 °C in a water bath until a transparent solution was obtained (Mohammed *et al.*, 2017). The digest was cooled, filtered using Whatman filter paper number 42 into a 50 cm³ volumetric flask, rinsed several times, and distilled was water added to the mark. The heavy metals of interest were determined at their respective wavelengths Atomic Absorption Spectrometry (AAS), Perkin Elmer, (Model 3100).

2.3 Health Risk Assessment

2.4

$$2.3.1 \text{ Bioaccumulation Factor (BAF)} = \frac{\text{Conc. of metal in edible portion } \left(\frac{\text{mg}}{\text{kg}}\right)}{\text{Conc. of metal in Water of Mining Pond } \left(\frac{\text{mg}}{\text{dm}^3}\right)} \quad (1)$$

The bioaccumulation factors (BAF and BSF) represent the ability of fish or vegetable tissues to accumulate a specific heavy metal from water and sediments. If the BAF value is significantly greater than 100, it indicates that the aquatic organism has a strong potential to accumulate metals or metalloids (Aydin *et al.*, 2023).

$$2.3.2 \text{ Biosedimentation Factor (BSF)} = \frac{\text{Conc.of metal in edible portion } (\frac{\text{mg}}{\text{kg}})}{\text{Conc.of metal in Sediment of Mining Pond } (\frac{\text{mg}}{\text{kg}})} \quad (2)$$

$$2.3.3 \text{ Hazard Quotient (HQ)} = \frac{\text{Exposure Dose } (\frac{\text{mg}}{\text{kg/day}})}{\text{Reference Dose } (\frac{\text{mg}}{\text{kg/day}})} \quad \dots\dots \quad (3)$$

$$2.3.4 \text{ Target Hazard Quotient (THQ)} = \sum \left(\frac{\text{Exposure Dose}}{\text{Reference Dose}} \right) \quad \dots\dots\dots (4)$$

The daily intake of metals (DIM) was calculated to estimate the daily loading of metals into the body system (via the consumption of fish meal) of a specified body weight of a consumer. This would entail the relative bioavailability of the studied metals in this study. The daily intake of metals (DIM) was determined by the following

2.4 Health Risk Index (HRI)

The health risk index (HRI) for the populations through the consumption of contaminated fish was assessed based on the daily intake of metals (DIM) relative to the reference oral dose (R_oD) for each metal. This is an index justifying an individual's risk of heavy metals. The HRI value of less than one implies safe tread and is considered acceptable; otherwise, the fish may pose heavy metals risk. The following formula was used for the calculation of HRI:

$$2.4.1 \text{ HRI} = \text{DIM/R}_o\text{D} \quad \dots\dots\dots (5)$$

(Kaba et al.,2023; Kumar et al.,2023; Muiyiwa et al.,2023; El-Zeiny and Abd El-Hami, 2022; Haseeb et al.,2022; Najy et al.,2022; Nangbes et al.,2022)

$$2.4.2 \text{ Estimated Daily Intake (EDI)} = \frac{E_F \times E_D \times F_{IR} \times C_F \times C_M}{W_{AB} \times T_A} \times 10^{-3} \quad \dots\dots\dots (6)$$

E_F = exposure frequency 365 days/year

E_D = Exposure Duration equivalent to verge lifetime (65 years for adults, and 12 years for children)

F_{IR} = Food ingestion rate (g/person/day)

C_F = Conversion Factor = 0.208

C_M = Metal concentration in food (mg/kg)

W_{AB} = Average body weight (taken as 65 kg for adults, and 15 kg for children)

T_A = Average Exposure over time for none carcinogens (E_F × E_D)

$$2.4.3 \text{ Target Hazard Quotient (THQ)} = \frac{EDI}{RFD_o} \quad \dots\dots\dots (7)$$

R_FD = reference dose (mg/kg/day)

R_FD; As = 0.0003, Cd = 0.001, Cr = 0.005, Hg = 0.001, Ni = 0.02, Pb = 0.00035 (mg/kg/day) (Kacholi et al., 2018; Kumar and Thakur, 2018); Liao et al., 2022)

3.0 Results and Discussion

3.1 Results

The result obtained are as given in tables 1 and 2 for *Clarias gariepinus* (Catfish) and *Tilapia zilli* (Tilapia fish) respectively.

Table 1:Concentration (mg/kg) of Heavy Metals in different Organs of *Clarias gariepinus* (Catfish) from Barkin Ladi ponds

Heavy Metals	Flesh	Gills	Kidney	Liver	FAO/WHO (2017)
As	2.50 ± 0.11	2.73 ± 0.04	2.23 ± 0.02	2.90 ± 0.66	0.005
Cd	2.65 ± 0.04	2.48 ± 0.17	2.18 ± 0.14	15.73 ± 1.98	0.01
Cr	38.80 ± 0.20	14.10 ± 0.13	16.15 ± 0.12	26.23 ± 2.97	0.10
Hg	5.70 ± 0.17	17.83 ± 0.12	16.20 ± 0.10	13.68 ± 0.69	0.005
Ni	103.23 ± 0.46	33.23 ± 0.20	151.83 ± 1.16	213.80 ± 1.63	0.10
Pb	10.03 ± 0.12	10.03 ± 0.12	35.70 ± 0.08	15.33 ± 0.19	0.01

Values are mean ± standard deviation (n = 20)

Table 2: Concentration (mg/kg) of Heavy Metals in different Organs of *Tilapia zilli* (Tilapia fish) samples from Barkin Ladi ponds

Heavy Metals	Flesh	Gills	Kidney	Liver	FAO/WHO 2017
As	2.50 ± 0.18	1.93 ± 0.44	2.23 ± 0.53	2.23 ± 0.70	0.005
Cd	2.85 ± 0.17	2.23 ± 0.44	2.03 ± 0.38	2.35 ± 0.40	0.01
Cr	13.98 ± 0.13	31.73 ± 1.05	32.65 ± 0.28	21.00 ± 0.11	0.10
Hg	14.18 ± 0.18	18.23 ± 1.06	14.08 ± 0.17	9.05 ± 0.60	0.005
Ni	36.25 ± 0.08	72.67 ± 1.19	97.28 ± 1.58	97.15 ± 1.69	0.10
Pb	1.83 ± 0.07	9.20 ± 1.01	1.15 ± 0.40	7.75 ± 0.22	0.01

Values are mean ± standard deviation (n = 20)

3.2 Discussion

4.2.1 Heavy Metal Concentration

The concentration of heavy metals determined in the *Clarias gariepinus* fish sample is shown in Table 1. The concentration of As in the flesh, gill, kidney, and liver organs was 2.50, 2.73, 2.23, and 2.90 mg/kg respectively. Reported works of Agwu *et al.* (2018); Bawuro *et al.* (2018) showed a nondetectable concentration as against the WHO (2017) maximum limit of 0.005 mg/kg. The high concentration recorded in this work indicates that the environment has been polluted, hence posing a health risk to consumers since the recorded values are much higher than that reported in other similar works and the WHO maximum limit.

Bawuro *et al.* (2018) and Agwu *et al.* (2018) reported a Cd concentration of 0.54 mg/kg in the flesh, 0.29 mg/kg in the liver, and 0.26 mg/kg in gill whereas Agwu *et al.* (2018) reported a Cd concentration of 0.07 mg/kg. However, in this study, Cd concentration was recorded as 2.65, 2.48, 2.18, and 15.73 mg/kg in the flesh, gill, kidney, and liver respectively. These values showed higher concentration than that reported in similar works and the WHO (2017) maximum limit of 0.01 mg/kg, thus posing a potential health risk to consumers.

Chromium concentration is observed to be 38.80, 14.10, 16.15, and 26.23 mg/kg in the flesh, gill, kidney, and liver respectively. These values are somehow comparable to 39.64 mg/kg reported by Agwu *et al.* (2018) but by far higher than the standard WHO (2017) value of 0.10 mg/kg. This indicates that the fish samples are polluted and hence consumers could be exposed to serious health risks.

Agwu *et al.* (2018) reported a mercury (Hg) concentration of 0.98 mg/kg, which is lower than that reported in this work with concentrations (mg/kg) of 5.70, 17.83, 16.20 and 13.68 in flesh, gill, kidney and liver respectively. These values indicate environmental pollution (Laoye *et al.*, 2025; Singh and Sharma. 2024) thus, fish samples are potential health risks to consumers since they are far higher than the WHO (2017) standard of 0.005 mg/kg.

The concentration of Nickel was found to be 103.23, 33.23, 151.83, and 213.80 in flesh, gill, kidney, and liver respectively. These values are much higher than that reported in the work of Agwu *et al.*, (2018), which is at not detectable limit and the WHO (2017) maximum limit of 0.10 mg/kg. This could be a result of the mining activities within the environment thus exposing the environment to heavy metal pollution, hence causing potential health risks to consumers.

Lead had a concentration of 10.03, 10.03, 35.70, and 15.33 mg/kg in the flesh, gill, kidney, and liver. These values are higher than the 0.23, 3.42, and 3.50 mg/kg in the flesh, gill, and liver respectively reported by Bawuro *et al.* (2018) and 0.22 mg/kg reported by Agwu *et al.* (2018), thus indicating environmental pollution and potential health risk to consumers since they are equally much higher than the WHO (2017) maximum limit of 0.01 mg/kg.

The results confirmed the differences in the accumulation of elements in different catfish organs. The element concentrations in the catfish samples decreased in the sequence for the flesh as Ni > Cr > Pb > Hg > As > Cd, for the gills Ni > Hg > Cr > Pb > As > Cd, for kidney Ni > Pb > Hg > Cr > As > Cd, for liver Ni > Cr > Cd > Pb > Hg > As. Arsenic showed the least bioaccumulation in all the organs followed by Cd which is significantly higher in the liver. Chromium showed the highest bioconcentration in the flesh of catfish followed by the liver and then kidney and gills which also showed similar bioaccumulation of the Cr element. Hg bioaccumulates most in the kidney and the gills followed by the liver with the flesh having the least bioconcentration of the element. For nickel, kidney and liver organs bioaccumulate more followed by flesh and gills having the least. Pb showed more bioconcentration in the kidney followed by flesh and then the liver, with gills having the least bioconcentration of the element (Omoregie, *et al.*, 2016; Shahsavani *et al.*, 2017; Yi *et al.*, 2017; Singh *et al.*, 2018; Ogundudu *et al.*, 2019; Adetutu, 2021).

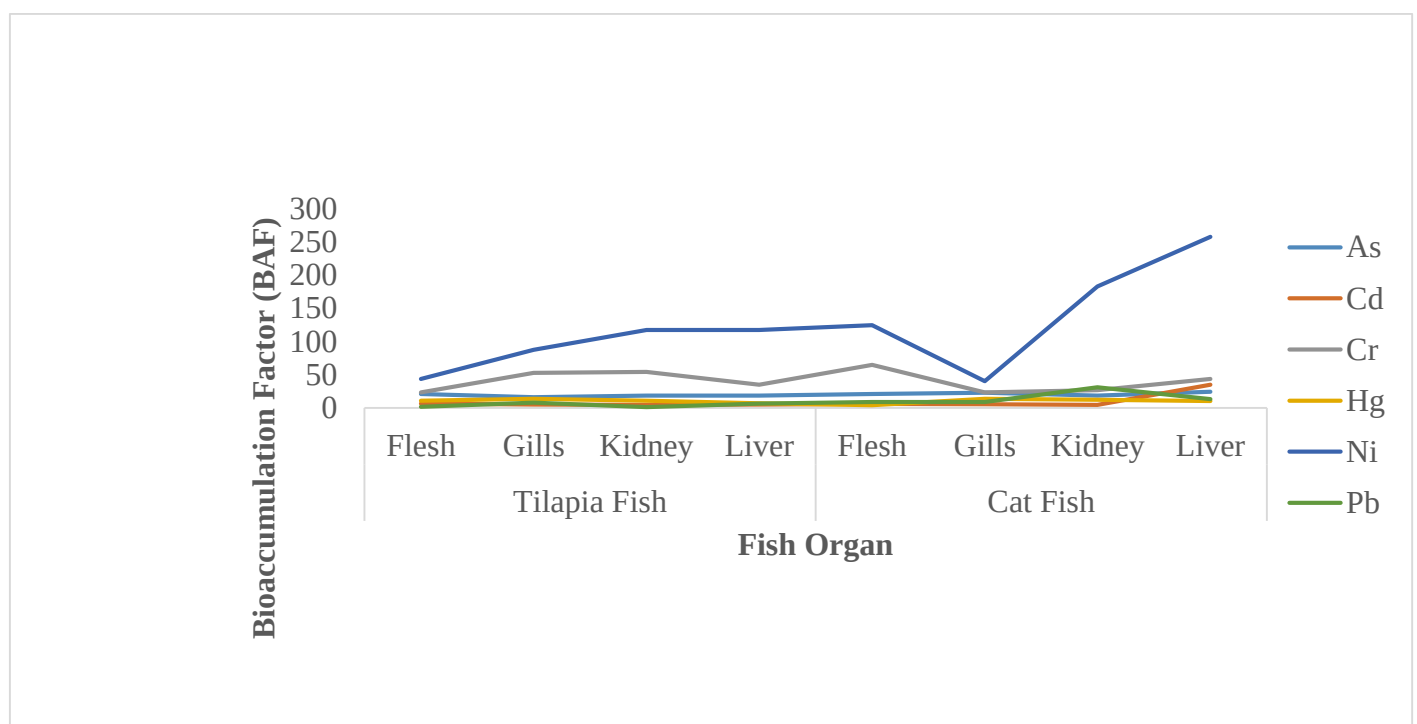


Figure 2: Bioaccumulation Factor (BAF) of Barkin Ladi Fish Samples

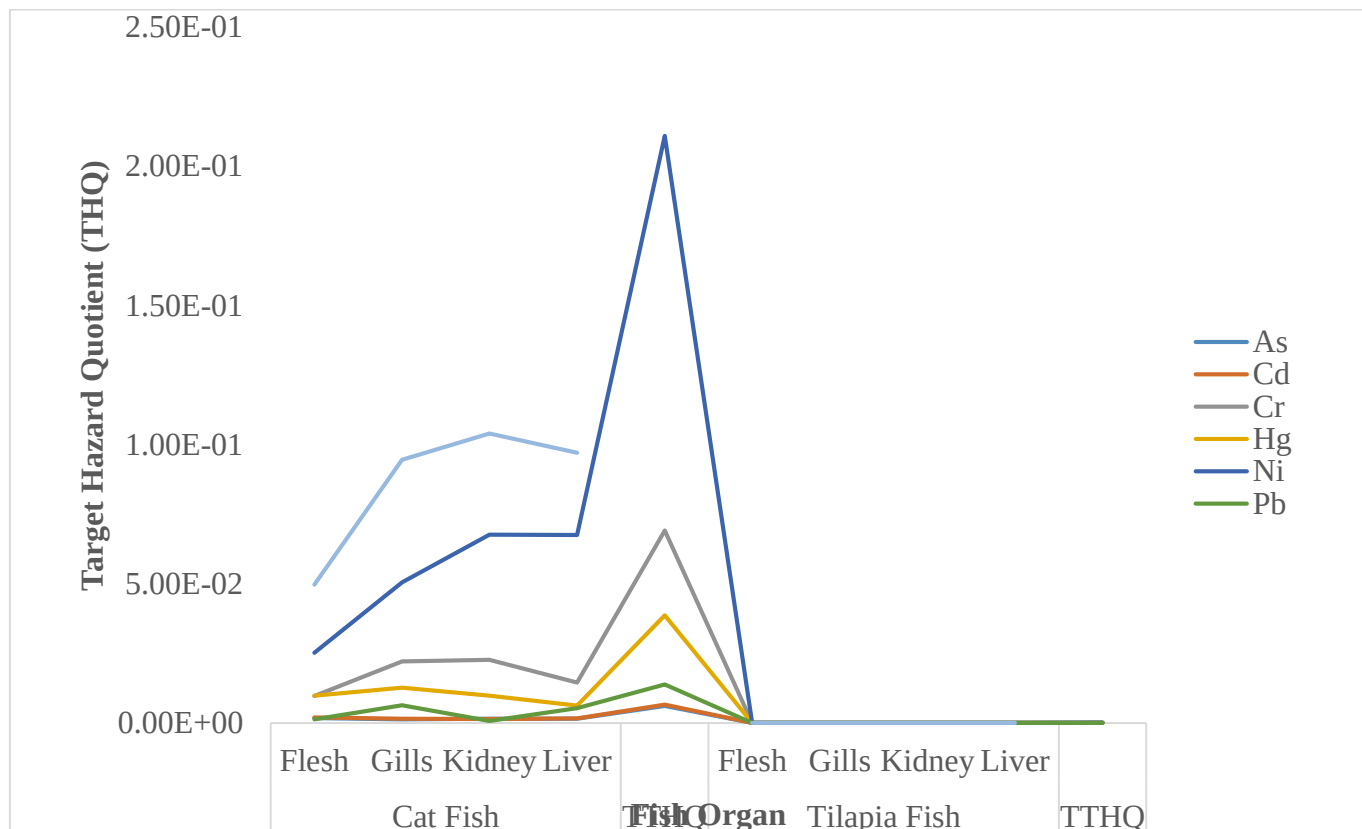


Figure 3: Target Hazard Quotient (THQ) of Barkin Ladi Fish Samples in Children

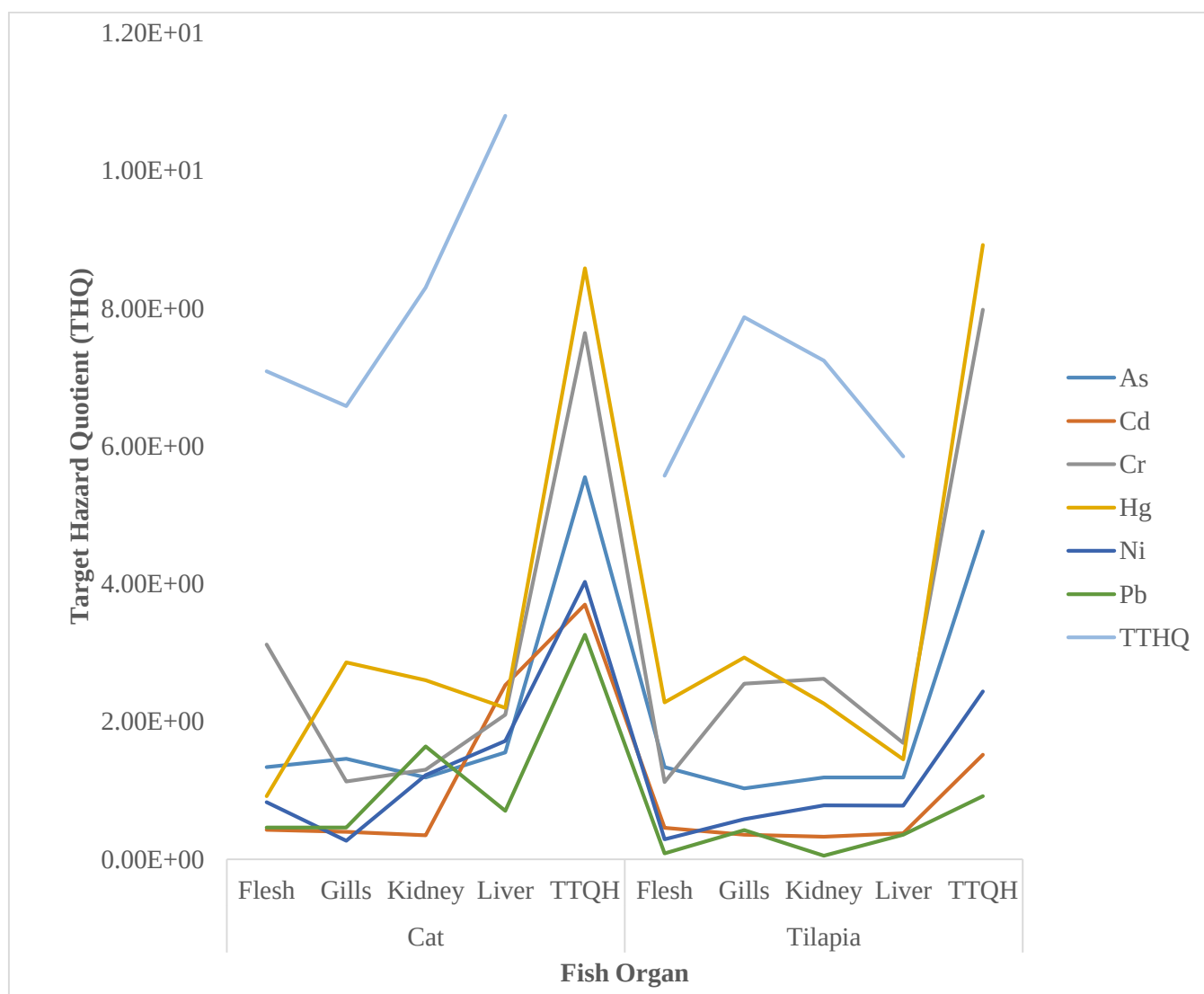


Figure 4: Target Hazard Quotient of Barkin Ladi Fish Samples in Human Adults

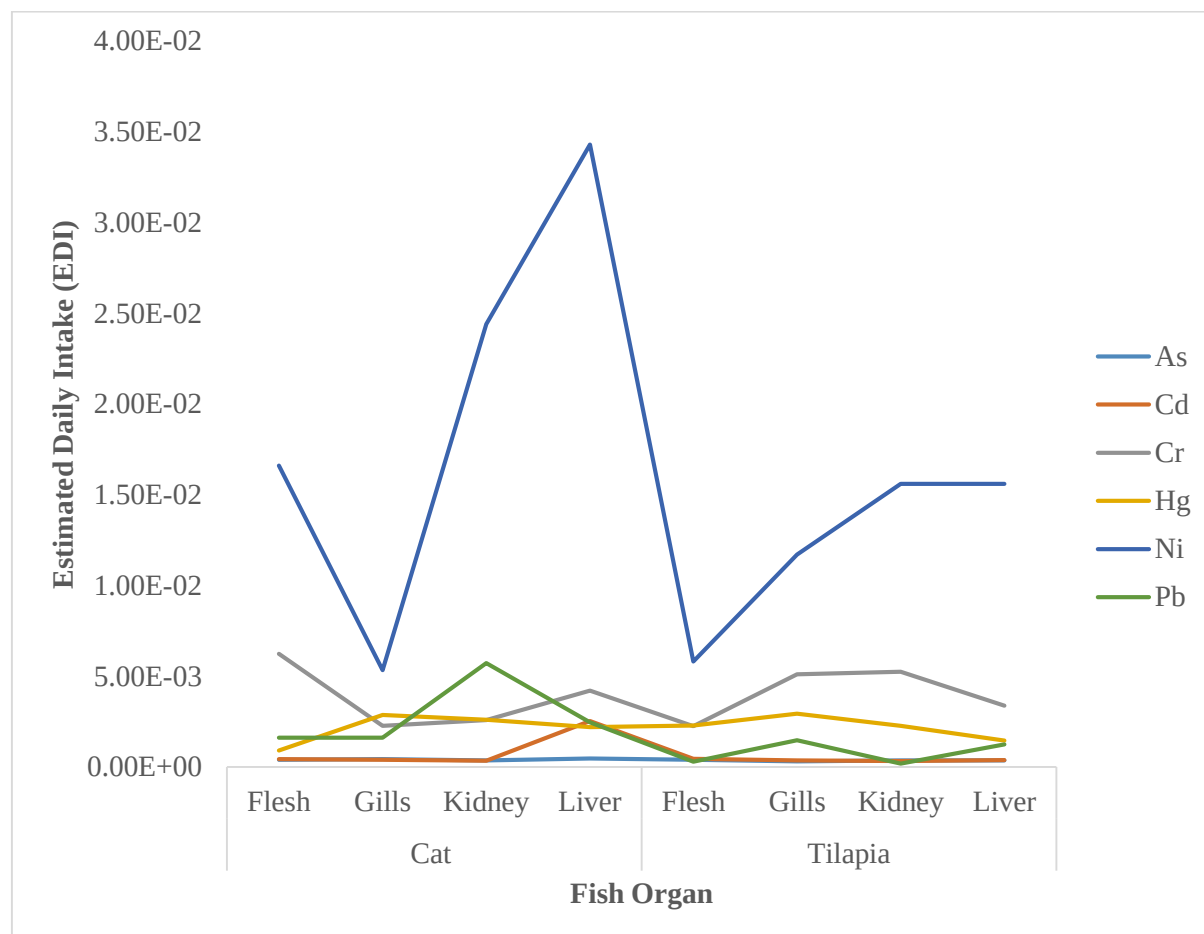


Figure 5: Estimated Daily Intake (EDI) of Metals from Barkin Ladi Fish Samples in Human Adults

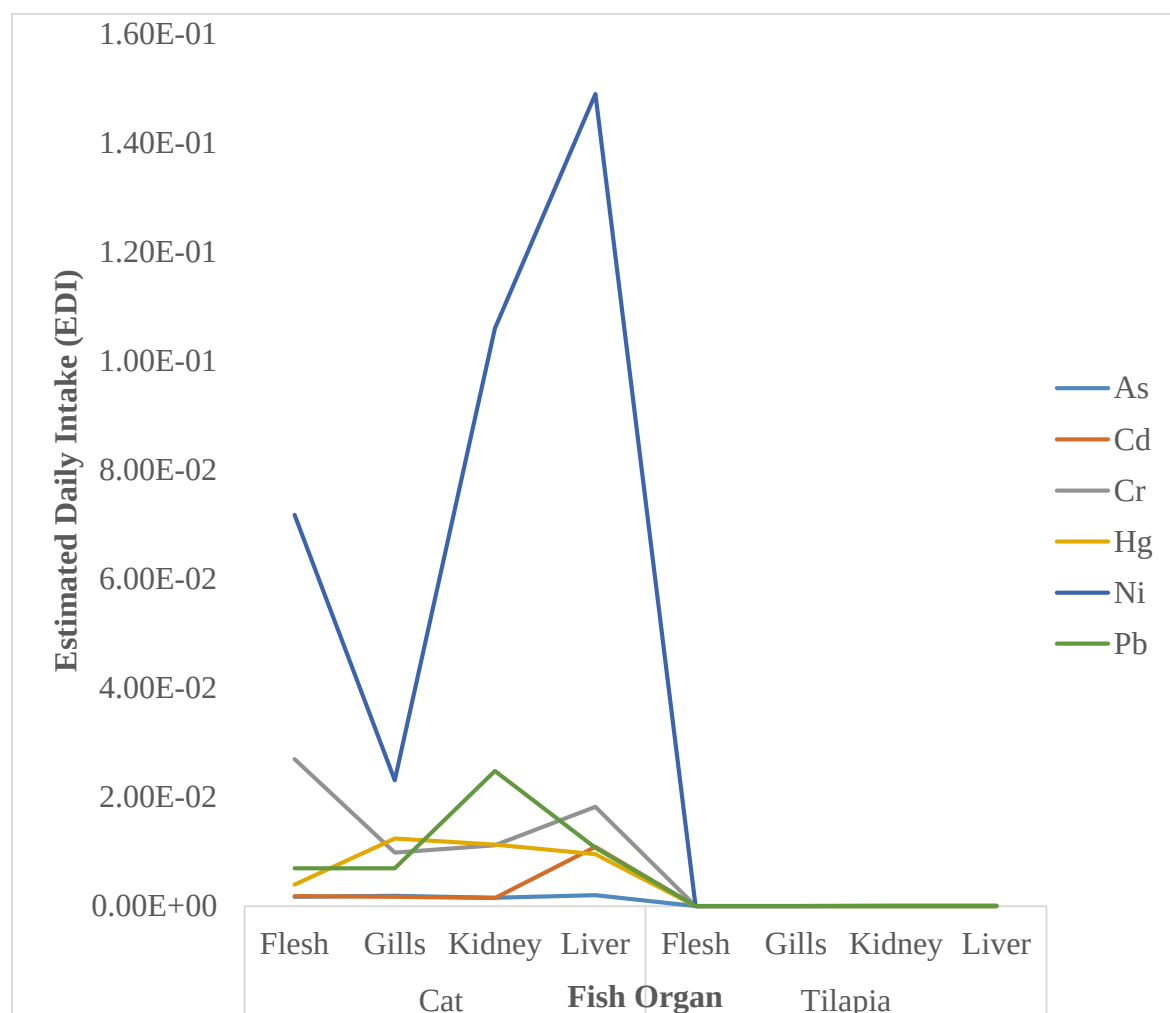


Figure 6: Estimated Daily Intake (EDI) of Barkin Ladi fish Samples in Children

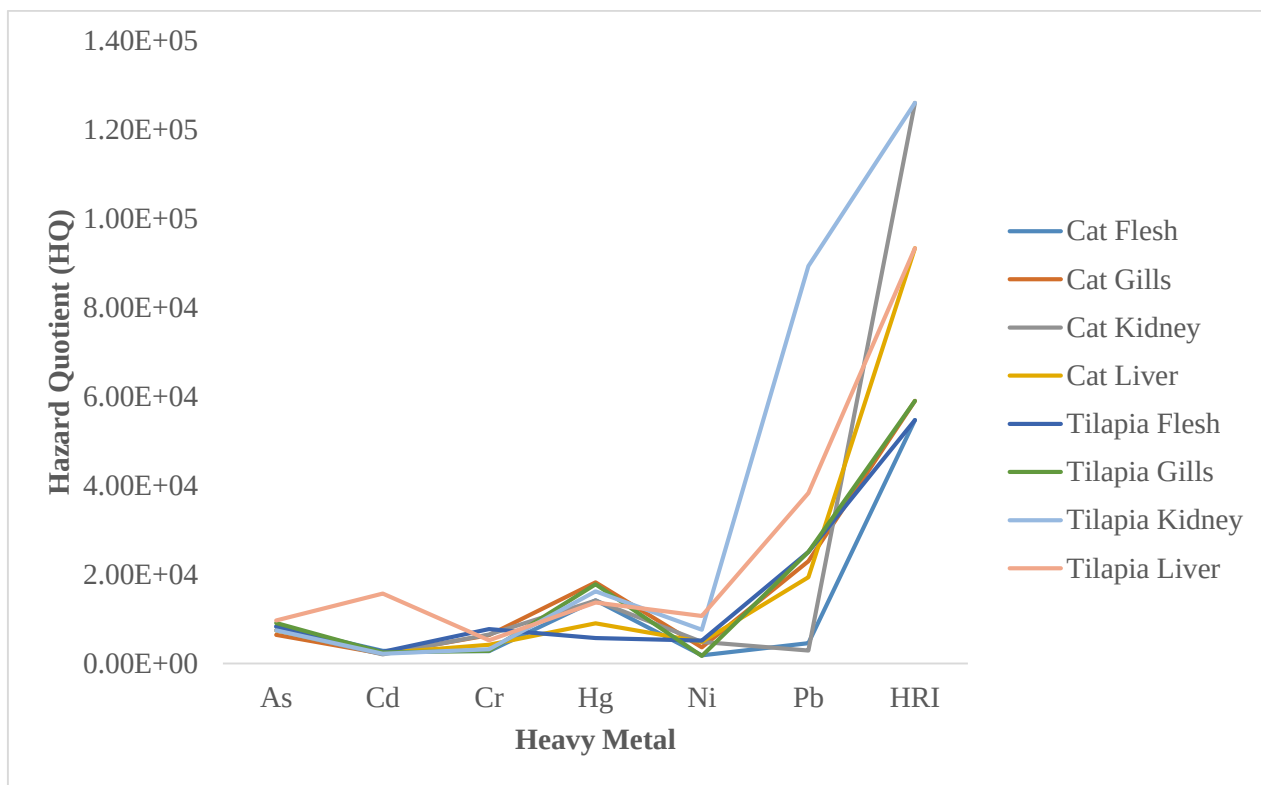


Figure 7: Hazard Quotient (HQ) of Barkin Ladi Fish Sample

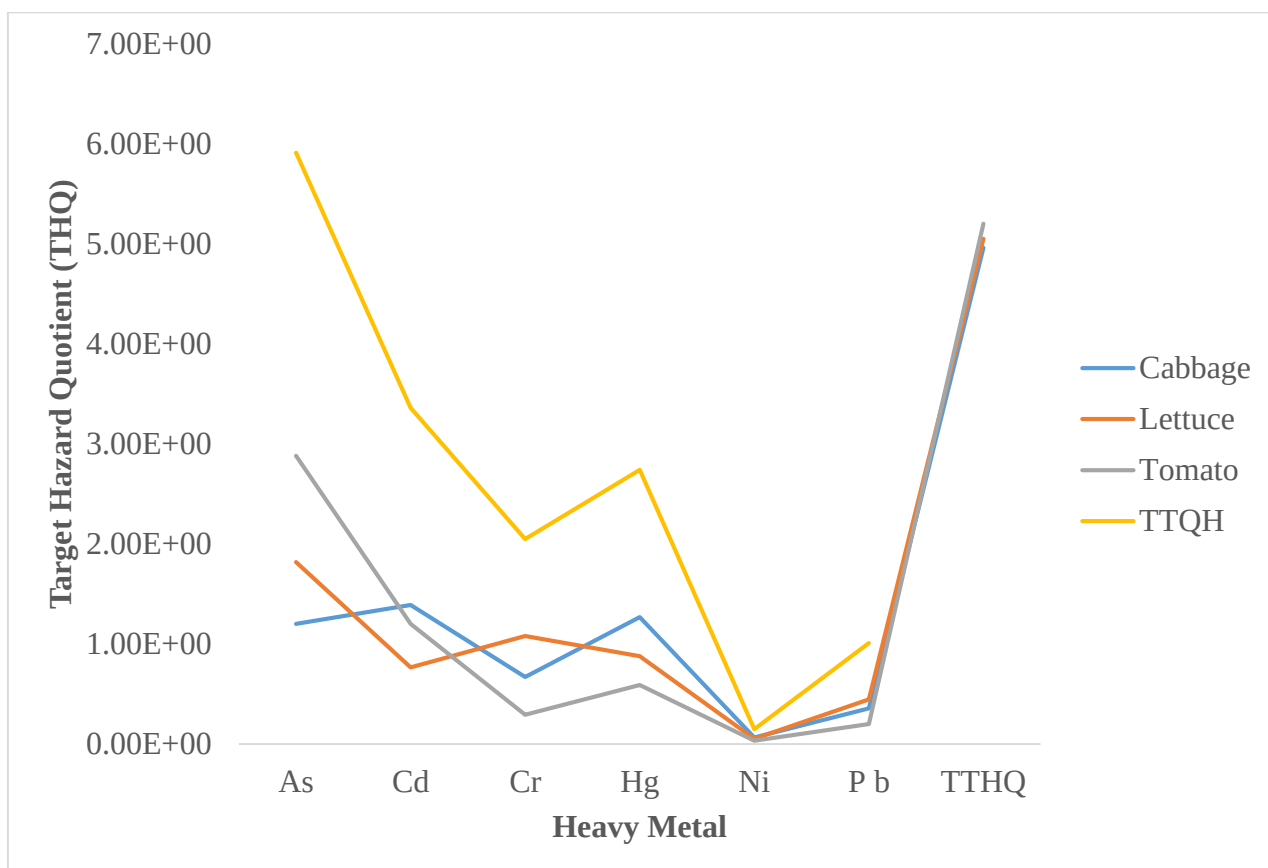


Figure 8: Target Hazard Quotient (THQ) of Barkin Ladi Vegetables in Human Adults

3.2.2 Health Risk Analysis

Metal absorption by biota from sediments occurs through a process known as bioaccumulation. The BAF value is used to determine metal bioaccumulation in the biota from sediments or soil (Roziwan *et al.*, 2024; Almahasheer, 2019). The value of BAF > 1 implies that the biota is an excluder; BAF = 1 implies that the biota is an indicator (Olawusi-Peters and Adejagbagbe, 2022).

The Hazard Quotient is the proportion between the exposure and the oral reference doses (R_{id}). The reference dose is the daily exposure of the estimated pollutant to which the people are continuously exposed throughout a life without any hazard (Yahaya, 2022; Adetutu *et al.*, 2021; Ogundudu *et al.* 2019) a THQ value greater than 1 signifies a potential health hazard upon consumption and bioaccumulation.

Target hazard quotient (THQ) for adults in both species of fish gave values > 1 thus indicating risk of consumption except for Cd, Hg, Ni, and Pb in catfish flesh with values 0.91, 0.83, and 0.46 respectively, gill Cd, Ni, Pb (0.40, 0.27, 0.46), kidney Cd (0.35) and liver Pb (0.70). for tilapia fish, the results revealed that flesh Cd, Ni, and Pb were 0.46, 0.29, and 0.84 respectively, and gill Cd, Ni, and Pb were 0.46, 0.58, and 0.42, respectively, kidney Cd, Ni, and Pb (0.32, 0.78, 0.53) and liver Cd (0.38), Pb (0.36). On an average overall perspective, however, the two fish samples pose a great health hazard to consumers. However, the THQ had values <1 in both fish species, depicting safety upon consumption.

The EDI values for all the sample matrices and each heavy metal investigated were found to be < 1 in both adults and children, suggesting the safety of consumption and the intake rate studied. In children, only catfish showed significant values that can be evaluated. The trends indicated that for flesh, Ni > Cr > Pb > Hg > As > Cd; gills Ni > Hg > Cr > Pb > As Cd and similar trend for kidney and liver.

The EDI trends for fish samples in human adults shows that for both fish samples, Ni had the highest value followed by Cr then mercury and Cd, although very small relative to their standard values. This shows that the fish samples do not pose and health threats when consumed. In children only catfish showed significant values that can be evaluated, the trends indicated that Ni > Cr > Pb > Hg > As > Cd (flesh), Ni > Hg > Cr > Pb > As > Cd > gills), Ni > Pb > Cr > Hg > As > Cd (kidney) and Ni > Cr > Cd > Pb > Hg > As (liver). It can be observed that in all the fish organs of both species, Ni had the highest EDI values while As is least except in flesh. However, the EDI values in both fish species indicated no health risk upon consumption since they much lower than the standard values for each heavy metal examined.

Table 3: ANOVA for *Clarias gariepinus*

ANOVA						
		Sum of Squares	Df	Mean Square	F	Sig.
As	Between Groups	0.001	3	0	2.049	0.115
	Within Groups	0.01	68	0		
	Total	0.011	71			
Cd	Between Groups	0.994	3	0.331	1949.6	0.000
	Within Groups	0.012	72	0		
	Total	1.006	75			
Cr	Between Groups	3.189	3	1.063	67.828	0.000
	Within Groups	1.191	76	0.016		
	Total	4.381	79			
Hg	Between Groups	0.523	3	0.174	64.445	0.000
	Within Groups	0.206	76	0.003		
	Total	0.729	79			
Ni	Between Groups	132.176	3	44.059	157.03	0.000
	Within Groups	21.324	76	0.281		
	Total	153.5	79			
Pb	Between Groups	3.022	3	1.007	65.49	0.000
	Within Groups	1.169	76	0.015		
	Total	4.191	79			

Table 3 shows the ANOVA of the catfish (*Clarias gariepinus*) sample. It can be seen that there is no significant difference in the mean of the results obtained within groups but there was a significant difference between groups. This can be attributed to the difference in the bioaccumulation capacity of the organs as well as their physiology and micro-environmental exposure rates to the heavy metals investigated.

Similarly, Table 4 shows the ANOVA for the tilapia fish (*Tilapia zili*). It can be seen in the table that there is no significant difference in the mean of the results obtained within groups but there is a significant difference between groups. This can be attributed to the difference in the bioaccumulation capacity of the organs as well as their physiology and microenvironmental exposure rates to the heavy metals investigated (Dahunsi *et al.*, 2012; Opasola *et al.*, 2019).

Table 4: ANOVA for *Tilapia zili*

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
As	Between Groups	0.002	3	0.001	3.944	0.012
	Within Groups	0.01	61	0		
	Total	0.012	64			
Cd	Between Groups	0	3	0	1.029	0.385
	Within Groups	0.004	74	0		
	Total	0.004	77			
Cr	Between Groups	1.298	3	0.433	85.29	0
	Within Groups	0.386	76	0.005		
	Total	1.684	79			
Hg	Between Groups	0.257	3	0.086	26.86	0
	Within Groups	0.243	76	0.003		
	Total	0.5	79			
Ni	Between Groups	20.325	3	6.775	63.12	0
	Within Groups	8.158	76	0.107		
	Total	28.483	79			
Pb	Between Groups	0.148	3	0.049	30.31	0
	Within Groups	0.08	49	0.002		
	Total	0.227	52			

Fish

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Similarly, Table 4 shows the ANOVA for the tilapia fish (*Tilapia zili*). It can be seen in the table that there is no significant difference in the mean of the results obtained within groups but there is a significant difference between groups. This can be attributed to the difference in the bioaccumulation capacity of the organs as well as their physiology and microenvironmental exposure rates to the heavy metals investigated (Dahunsi *et al.*, 2012; Opasola *et al.*, 2019).

Fish Organs

Heavy metals of interest in these sample matrices were determined in the flesh, gills, kidney and liver because several researchers have indicated that heavy metals can bioaccumulate heavy metals in their flesh and organs (Radwan *et al.*, 2006; Agah *et al.*, 2009; Ashraf *et al* 2012; Rahman *et al.*, 2012; Ofosu *et al.*, 2018; Opesola *et al.*, 2019).

Catfish organs

Flesh

Flesh As in this sample matrix had a weak and strong positive correlation with Hg in gills and Cr in liver respectively, which suggested the availability of the soluble species of both metals in the water in which the Cr species must have passed through the metabolic system of the fish thereby reaching the liver, which is the final organ of biochemical metabolism.

Cd in the flesh showed a weak positive correlation with Cd in the kidney and Pb in the liver, showing that Cd passes through the excretory system whereas Pb is stored in the liver for further biochemical metabolism.

Hg in the flesh showed a weak positive correlation with Cd in the gills and Cd in the kidney. This indicates that the metals could have similar sources, species, or metabolic pathways.

Ni in flesh had a weak positive correlation with Cr in gills and Pb in both kidney and liver, indicative of similar sources, species, or metabolic pathways.

Pb in the flesh showed a weak positive correlation with Ni in the kidney. This suggests the similarity of heavy metal sources and metabolic pathways.

Gills

Cd in catfish gills had a moderate correlation with Hg in flesh at 95.95% significant level, while Cr in the same sample matrix had a strong positive correlation of 0.727 at 99.99% significant level with Hg in gills, whereas it had a weak and strong positive correlation with Ni in flesh and Pb in kidney respectively, indicating a strong affinity to bioaccumulate such metals (Beltrame *et al.*, 2009; Dahunsi *et al.*, 2012; Singh *et al.*, 2018; Łuczyńska *et al.*, 2019). Hg in the same sample matrix showed a strong positive correlation with Cr and Pb in gills and kidneys respectively, while it showed a weak correlation with As and Ni in flesh and kidney respectively.

Kidney

Cd in the kidney showed a weak positive correlation with both Cd and Hg in the flesh as well as Ni in the liver, indicative of similarity in source, species, and metabolic pathways of these metals. Cr in the kidney showed a weak positive correlation with Cd in the liver, this suggests similarity in bioaccumulation rate, similarity in metabolic pathways, and chemical species or source. Ni in the kidney had a strong positive correlation with Pb in the kidney, while it had a weak positive correlation with Pb in the flesh and Ni in the liver. This shows that the absorptive and bioaccumulation rates of the heavy metals could be similar as well as their metabolic pathways.

Pb in the kidney showed a strong positive correlation with Cr and Hg in the gills and Ni in the kidney, while it showed a weak positive correlation with Ni in the flesh and kidney.

Liver

Cd in the liver of catfish showed a weak positive correlation with Cr in the kidney of the same sample matrix. Cr in the liver had a strong positive correlation with As in flesh, while it showed a weak correlation with Cr in flesh, signifying discrete bioaccumulation rate and chemical species and sources (Beltrame *et al.*, 2009; Omeregie *et al.*, 2016; Reda and Ayu, 2016; Singh *et al.*, 2018; Łuczyńska *et al.*, 2019). Ni in the liver had a weak correlation with the Cd, Ni, and Pb in the kidney, indicating, indicative of similar bioaccumulation rate and biochemical pathways. Pb in the liver had a weak negative correlation with Cd in the flesh, suggesting discrete biochemical interaction within the microenvironment of the chemical species.

Tilapia fish organs

Flesh

In the flesh of tilapia fish, As had a weak correlation with Hg in the liver, and similarly Cd showed a weak correlation with Cr in the liver of the same sample.

Hg in the flesh of tilapia showed a weak positive correlation with Cd in gills, Cr in gills, and As in the kidney, while the correlation is strong between Cr in the liver.

Gills

Cr in gills showed a strong negative correlation with Cd in gills while it had a weak correlation with Pb in the kidney. Gills Hg showed a weak negative correlation with Pb in the kidney. However, Ni in gills showed a weak correlation with Cr in the kidney and Hg in the liver, while the correlation was negatively weak with Hg in the kidney. Similarly, Pb in the gills of tilapia fish showed a weak correlation As in gills and Cd in the liver, which indicated the discrete chemical interaction within these organs and their bioaccumulation rates and sources.

Kidney

In this sample matrix, As showed a weak correlation with Hg in flesh and a strong correlation with Cr in the liver. However, Cd showed a strong positive correlation with Cd in the liver, which indicates that these metals have similar heavy metal species, sources, and biochemical pathways. Also, Hg in the kidney showed a weak positive correlation with Ni in gills, indicative of micro-environmental and biochemical interactions. Ni in the kidney had a weak negative correlation with Pb

in the gills, which indicates differential biochemical and microenvironmental interactions within the sample matrices and similarly Pb in the kidney showed a weak negative correlation with Cr and Hg in gills.

Liver

In the liver sample matrix of tilapia fish, As showed a weak positive correlation with Hg and Cr in flesh and liver respectively. Similarly, Cd in the liver showed a weak positive correlation with As and Pb in the gills, while the correlation is positively strong with Cd in the kidney.

Cr in the liver showed a weak correlation with Cd and As in the flesh and liver respectively, while it showed a strong correlation with Hg and As in the flesh and kidney respectively.

Hg in liver of tilapia fish showed a weak correlation with Hg and Ni in flesh and gills respectively.

Heavy metals correlated showed either similarity in metal species or sources, which can further be substantiated by other statistical tools such as Cluster Analysis (CA) and Principal Component analysis (PCA). Although significant positive relationships were also observed between organ As, Cr, and Cd, these three organ metals were not significantly correlated with the other metals in other organ sample matrices, which indicated that the behaviors or the sources of organ As, Cr, and Cd were different from the other particulate metals. The complexation of particulate As, Cr and Cd with a particular sample matrix, as discussed above, may be the main reason that led to their different behaviors from other particulate metals (Beltrame *et al.*, 2009; Łuczyńska *et al.*, 2019).

5.0 Conclusion

The heavy metal concentration in some of the sample matrices is above the WHO/FAO maximum tolerable limits. These when bioaccumulated over time in the tissues and organs of humans based on the food chain can pose several public health challenges, leading to toxicities such as cytotoxicity, oxidative stress, immunotoxicity, hepatotoxicity, nephrotoxicity, neurotoxicity, and the eventual development of cancer (Anyanwu *et al.*, 2018).

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From this research, it can be deduced that the consumption of fishes harvested from Barkin Ladi abandoned mining ponds may not cause any significant public health threats. However, the need for heavy metal remediation strategy is critical. This is due to the fact that the ponds serve as important water reservoir for economic purposes such as fishing and dry season farming.

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