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RESEARCH ARTICLE

Assessment of heavy metals contamination in fish cultured in selected private fishponds and associated public health risk concerns, Dar es Salaam, Tanzania

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ABSTRACT

Environmental pollution caused by the increase of heavy metals concentration in aquatic and terrestrial environments is a growing global concern due to their nature and toxicity. This paper aimed to undertake an assessment of the quality of fish cultured in individual-owned fishponds in Dar es Salaam city and their associated health risks. Data collection involved sampling and quantification of the quality of two species of fish, which were African catfish (*Clarias gariepinus)* and Nile tilapia (*Oreochromis niloticus*), from three selected fish ponds in Dar es Salaam and chemical analysis involved heavy metals analysis in gills, fins, guts, and muscles. The concentrations of heavy metals were analyzed using Atomic Absorption Spectrophotometer (AAS). Results of this study indicated that the concentrations of trace metals in fish tissues varied considerably. The fish gills had higher concentrations of Cr, Zn, Cu, and Pb than the fins and guts, while muscles had the lowest concentrations of heavy metals in all fish species. A highly significant difference in the heavy metal concentrations measured in both catfish and tilapia tissues was observed with a P value of less than 0.05. Individual risk assessment showed that there was a minimal risk caused by the concentrations of Cr, Zn, and Cu upon consumption of fish; however, the combined effect was higher caused by the high concentration of Pb in fish organs. Monitoring of fish quality in privately owned fish ponds is recommended to safeguard consumers.

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Introduction

Environmental pollution, population growth, and degradation of natural resources are among the top global concerns (Shaker et al., 2018). Directly or indirectly, pollution affects the aquatic ecosystem and, ultimately, human health (Kosygin et al., 2007; Shaker et al., 2018; Imlani et al., 2022). Among major pollutants, heavy metals pollution is a growing global concern due to their possible toxicity, long biological half-life, non-biodegradability, and bioaccumulation properties. They can also enter the human body through inhalation, ingestion, and dermal (Resma et al., 2020; Leonard & Mahengea, 2022). The presence of a low concentration of heavy metals such as Zn, Fe, Mn, Cu, Co, and Cr provides a key role in the biochemical process in many organisms (Darko et al., 2016) and is thus classified as essential (Resma et al., 2020). However, they can cause toxicity effects when they become available in high concentrations (Akoto et al., 2014). A low concentration of Fe is required for red blood cell production (Akoto et al., 2014); however, a high concentration of Fe and Mn could lead to pathological events, including iron oxides in Parkinson's diseases (Matusch et al., 2010). A high concentration of heavy metals like Cu can cause liver damage, and Zn reduces immune function.

Metals such as As, Hg, Pb, and Cd are toxic even at low concentrations and have no important functions in humans and thus are classified as non-essential or toxic metals (Resma et al., 2020). The concentration of Pb reduces cognitive development and intellectual performance in children (Darko et al., 2016), cause renal tumors and increases blood pressure in adults, and causes gastrointestinal disorders and liver impairments (Akoto et al., 2014); while Cd causes kidney dysfunctions, osteomalacia and reproductive deficiencies (Akoto et al., 2014). Elevated concentration of heavy metals in the aquatic environment may cause disorders in fish growth and reproduction (Darko et al., 2016) as well as histo-pathological alterations in the liver, skin, spleen gills, and kidney (Vitek et al., 2007), decreasing the plasticity of the cardiorespiratory responses, and hence reducing the survival chances of fish under hypoxic conditions in their wild environments (Leonard & Mahengea, 2022, Monteiro et al., 2013).

Fish farming plays a vital role in global food security, which is being practiced in most countries, including Tanzania, and provides millions of employments and billions of dollars to the country (URT, 2019). However, due to surface water pollution in urban areas, which used to provide natural habitats and food for fish, there is a gradual shift to the use of privately owned fish ponds which need a supply of food supplements, including factory-made feeds and farm-made feeds (Resma et al., 2020; Leonard & Mahengea, 2022). Such commercial fish feeds contain an elevated concentration of trace elements, including Pb, Cd, Cr, Cu, and Zn (Sarkar et al., 2022). Thus, there is a growing concern about the quality of fish and fish feeds used in aquaculture, which can affect consumers (Mohamad et al., 2017). Furthermore, environmental pollution in Tanzania, like other countries in the world, is reported to be polluted by heavy metals, especially in the aquatic environments located near and or within the urban areas (Mwegoha & Kihampa, 2010; Leonard et al., 2012; Leonard & Mahengea, 2022) that can also affect aquatic organisms including fish. A previous study in Dar es Salaam indicated that the quality of water from fish ponds had an elevated concentration of heavy metals (Leonard & Mahengea, 2022).

Freshwater fish demand in Tanzania, both rural and urban areas, is high that has attracted individuals to invest in aquaculture (Leonard & Mahengea, 2022), yet this demand has not been met by the current supplier because a part of the catch is exported that accounts to 10% value of the national exports contributing to 2.7% of the gross domestic product (URT, 2019). Freshwater fish farming in Dar es Salaam involves the Nile tilapia (*O. niloticus*) and the African catfish (*C. gariepinus*) (Deloitte, 2015), which have a high potential and are popular in local and international markets, hence the focus of this study.

Tilapia production in Tanzania ascended from 2856 metric tons worth TZS 12.8 billion in 2010 to 3118 metric tons worth TZS 18.7 billion in 2015 (URT, 2015) and according to the Ministry of Agriculture, Livestock, and Fisheries (MALF, 2015). The annual production of fish is 389,459.4 metric tons, and the per capita consumption is 8.2 kg. The annual export amounts to 38,114 metric tons, which yielded 15.6 billion TZS (URT, 2019). Fishponds scaled from 19,039 in 2010 to 21,300 in 2015 (Rukanda, 2016), while fish farmers increased from 16,284 in 2010 to 19,395 in 2015 (URT, 2015). Freshwater fish farming has recently become a popular source of income and business opportunity in Dar es Salaam (Leonard & Mahengea, 2022), attracting individuals to invest in fish farming. According to MALF (2015), there are more than 50 freshwater fish farms in Dar es Salaam City, with over 130 fishponds (Kyelu, 2016). However, low knowledge of water quality and fish quality was observed as a limiting factor in Tanzania (Rukanda, 2016; Leonard & Mahengea, 2022).

Monitoring fish tissue contamination provides information on any toxic pollutants in fish, which may be harmful to consumers, but also identify fish parts that can be consumed with minimal risk, hence protecting public health and the environment (Mohamad et al., 2017; Kumari & Maiti, 2019).

Fish consumption is the major route through which heavy metals accumulated in fish tissue get into the food chain and hence into the human body (Akoto et al., 2014). Various studies suggest that the rate at which heavy metals intake by fish in a contaminated environment depends on various factors, including exposure period and concentration of heavy metals. Thus, assessing heavy metals in fish parts helps to establish the direct transfer of such metals to humans through fish consumption (Akoto et al., 2014, Imlani et al., 2022). To our understanding, no study has been done to investigate heavy metals in fish grown in privately owned fish ponds in the study area. Thus, the main interest of this study was to establish the potential health risk concerns associated with heavy metals through ingesting fish grown in privately owned fish ponds by estimating daily intake (EDI) and health risk index (HRI) from a single and combined heavy metals including Cadmium (Cd), Lead (Pb), Copper (Cu), Zinc (Zn) and Chromium (Cr).

Material and Methods

Description of the Study Area

The study area is located within Dar es Salaam city, which is the largest city and economic capital in Tanzania, hosting over 10% of the country's population. Most industries, government offices, diplomatic missions, and non-governmental organizations are located in this city. It is the largest city in East Africa and the fifth city largest in Africa. The city is located at 6°48´S, 39°17´E, and covers a total area of 1493 km^2. The study location was chosen based on the availability of prospective fish farming systems, both extensive and intense, as well as respondents' willingness to participate. Thus, the study involved three fish farming ponds located in three municipalities, including Kinondoni, Ilala, and Kigamboni municipal councils, as shown in Figure 1.

Fish Sampling

Two types of fish were sampled using multi-mesh gill nets using stratified random sampling from three sampling points, which included African catfish and Nile tilapia. Three sampling campaign was conducted in the interval of two weeks. Fresh sampled fish were washed using fresh water to remove any mud or debris (Kumari & Maiti, 2019). Each sampled fish was weighed to obtain the total mass of each fish sampled, which ranged between 500 g to 1000 g, and then kept in plastic bags, transported to Ardhi University in the laboratory of School of Environmental Science and Technology, where they were frozen at -20°C until the instant of preparation and analysis.

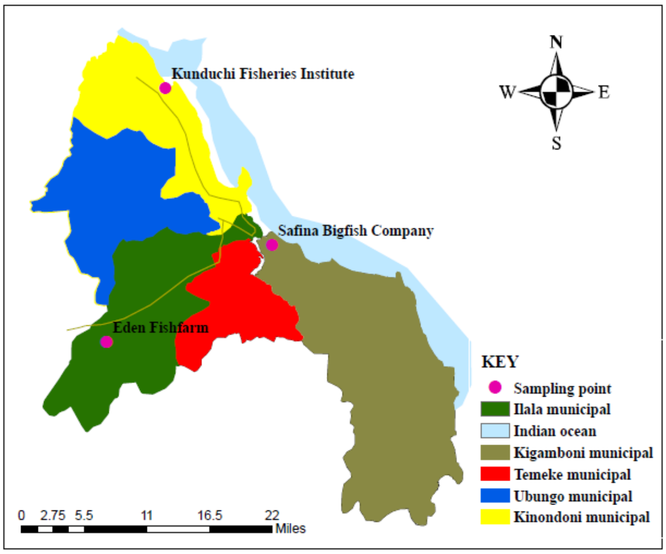

Figure 1. Location of sampled fishponds in Dar es Salaam city

Sample Preparation

Sampled fish were cleaned using distilled water, thawed, and carefully dissected using sterilized scissors, knives, and plastic forceps to elude metal pollution caused by the equipment in the laboratory. Fish organs were separated into four specimens, including muscles, gills, fins, and guts, and then each sample was taken into a microwave oven set at 103–105°C for 24 hours, where they reached a constant dry weight, followed by grinding into a fine powder using pestle and mortar.

All equipment used was rinsed and sterilized to avoid post-contamination. Before usage, the plastic and glasses were cleaned and steeped in 2% HNO_3 overnight, then rinsed three times with distilled water. Reagents used include: Hydrochloric acid (HCl), Nitric acid (HNO_3), Potassium iodide (KI), and Hydrogen Peroxide (H_2O_2) used as oxidants, as explained by Kumari & Maiti (2019). A sample for physical analysis was prepared by taking 2.0 g of each fish organ (gills, fins, guts, and muscles) and placed in a beaker, followed by the addition of 20 ml of distilled water. The mixture was well stirred with a glass rod for about 10 minutes before the analysis of physical parameters.

Samples for heavy metal analysis were prepared by taking 0.5 g of the prepared fine powder into a graduated test tube. For each test tube, 2 ml of the aqua regia (1:3 (Conc. HCl&HNO_3) was added, put in a hot air oven set at 103-105 °C for an hour, followed by the addition of 3 ml of H_2O_2 (35%), then digested at 90°C for 2 hours till the clear solution was attained. Then, all samples were left for cooling at room temperature. Next, 10 ml of distilled water was poured into each test tube to make a dilution and dissolve heavy metals in the water and left to settle overnight then, and the samples were filtered using Whatman filter paper (40) to make them clear and ready for analysis using Atomic Absorption Spectrophotometer. Samples were then allowed to cool at ambient temperature, followed by the addition of 10 ml of distilled water for dilution and dissolution of heavy metals in water, and left to settle overnight. Samples were then filtered using Whatman filter paper (40) for clarity clean ready for laboratory analysis using an Atomic Absorption Spectrophotometer as also described by previous studies (Kumari & Maiti, 2019).

Fish Feed Sampling

Fish feed samples were also collected from the same farmers who volunteered to provide fish samples, stored in polyethylene plastic bags, and transported to Ardhi University. The samples were then dried at 80°C for 24 hrs. in an oven and left to cool, followed by grinding using mortar and pestle available in the School of Environmental Science and Technology at Ardhi University. Two grams of samples were prepared in a graduated test tube (Mannzhi et al., 2021). For each test tube, 2 ml of the aqua regia (1:3) (Conc. HCl&HNO_3) was added, put in a hot air oven set at 103-105°C for an hour, followed by the addition of 3 ml of H_2O_2 (35%), then digested at 90°C for 2 hours till the clear solution was attained. Then, all samples were left for cooling at room temperature. 10 ml of distilled water was poured into each test tube to make a dilution and dissolve heavy metals in water and left to settle overnight; then, the samples were filtered using Whatman filter paper (40) to make them clear and ready for analysis using Atomic Absorption Spectrophotometer.

Laboratory Analysis

The concentrations of heavy metals were analyzed using Atomic Absorption Spectrophotometer with Parking Elmer AS 800 Auto-sampler to determine the concentrations of Pb, Cu Zn, and Cr. Heavy metal concentrations that were read in (mg/L) from AAS were converted into mg/kg through equation 1.

$$C\left(\frac{mg}{kg}\right) = \frac{C \times V}{M} \times 1000 \quad (1)$$

where: C is the metal concentration (mg/L) in the solution digested, V is the volume obtained after digestion, M is the mass of the sample (g) to be tested, and 1000 is the conversion factor from g to kg.

Health Risk Assessment

Health risk assessments resulting from consumption of the sampled fish types were established by applying a number of recommended parameters by the US EPA, such as estimated daily intake of metals (EDI) and target hazard quotient (THQ).

Calculating Estimated Daily Intake (EDI)

This was established by taking the mean concentration of heavy metals in mg/kg fresh and the average consumption of fish, which was established from the study done by Wenaty et al. (2018) and Maurya & Malik (2019) presented in equation 2.

$$EDI = \frac{C_{element} \times D_{food\ intake}}{B_{average\ weight}} \quad (2)$$

where: $C_{element}$: the average element concentration in fish, $D_{food\ intake}$: the daily fish consumption rate (0.0192 kg/person/day equivalent to 7 kg/person.year), $B_{average\ weight}$: the average body weight of the adult person.

Target hazard quotient (THQ)

In order to establish carcinogenic risk resulting from consuming fish was calculated using USEPA (2011) guidelines as provided in Maliki & Maurya (2015), equation 3.

$$THQ = \frac{Efr \times ED \times FIR \times C}{BW \times RfD \times ATn} \times 0^{-3} \quad (3)$$

where: *Efr*=Exposure frequency (365days/year), *ED*=Exposure duration (65.5 years), which is life expectancy in Tanzania, FIR=Fish ingestion rate (7 kg/person.year), C=Metal cocentration, BW=Average body weight of an adult (70 kg), *RfD*=Reference dose as established by US EPA (2011), *ATn*=The average exposure time for non-carcinogens (365 days x no of exposure 65.5 years).

Furthermore, since the exposure to two or more heavy metals concentration may cause additive and or interactive effects, the total HRI of heavy metals for specific fish organ was also treated as the arithmetic sum of the specific metal HRI (Zheng et al., 2007; Akoto et al., 2014).

$$Total\ HRI = HRI_{metal_1} + HRI_{metal_2} + HRI_{metal_3} + \cdots HRI_{metal_n} \quad (4)$$

Data analysis

The results obtained from laboratory analysis were subjected to statistical analysis using various tools; a descriptive tool was used to determine the mean, standard deviations, and coefficient of variation, while the Pearson correlation coefficient was done to establish the dependence of heavy metals in fish organs. The nearer the coefficient to one (1) indicated a stronger correlation between variables, and the nearer to -1 indicated a decrease in a linear relationship (Kumari & Maiti, 2019). Non-parametric test using One-Way ANOVA was used to establish if there was a significant difference between heavy metals among fish parts, and the $p<0.05$ was considered significant (Akoto et al., 2014; Imlani et al., 2022). Principal Component Analysis (PCA) with Varimax rotation was used to reduce the large multi-dimensional dataset to a small number of new variables that accounted for at least 75% of the total variance (Leonard & Mahengea, 2022). Also, Hierarchical Cluster Analysis (HCA), using average linkage between groups, was used to assess the similarities and differences between fish organs and identify possible patterns in distributions of measured data.

Results and Discussion

The Quality of Fish Feed Used in Individually Maintained Fishponds

The results of this study revealed that fish feeds employed in all sampled fish farms were obtained from one supplier in two forms, powdery and pellets forms; thus, only one sample of each type was analyzed. Results from laboratory analysis indicated that fish feed in the form of pellets contained a higher concentration of heavy metals compared to that of powdery form. All fish feeds contained, to some extent, the concentration of Pb, Cu, Cr, and Zn. The concentration of Cu ranged from 16.2 mg/kg in the powdery form to 31.62 mg/kg in pellets, which is above the 30 mg/kg recommended maximum limit by FAO, and Zn concentration ranged from 32 mg/kg in the powdery form to 46 mg/kg in pellets that is above 30 mg/kg recommended by FAO and WHO. In addition, the concentration of Pb ranged from 6.3 mg/kg in the powdery form to 6.44 mg/kg in pellets, which were both above 1.5-2 mg/kg as recommended by WHO food safety guidelines and Cr concentration ranged from 1.3 mg/kg in the powdery form to 1.5 mg/kg in pellets that were below 12-13 mg/kg as recommended by USFDA guideline. The presence of trace elements in fish feeds is likely to influence the level of heavy metals in fish parts, hence bioaccumulation (Cohen et al., 1993).

The Concentration of Heavy Metals in Fish Parts

The concentration of heavy metals (Cr, Zn, Cu, and Pb) analyzed in tilapia and catfish from different parts, including gills, fins, guts, and muscles, are presented in Table 1. Except for Zn and Pb, all concentrations of Cr and Cu were within food safety guidelines (FSG) as proposed by different agencies. The two fish species had the lowest concentrations in muscles, while the highest concentrations of metals were observed in gills, possibly because gills are in direct contact with water (Maurya & Malik, 2019; Kumari & Maiti, 2019). The average concentration of Cr ranged from 0.001 mg/kg in muscles obtained from tilapia to 0.022 mg/kg in gills of the same fish, which is below the recommended USFDA 12-13 mg/kg food safety guidelines.

The concentration of Zn ranged from 13.65 mg/kg in muscles of catfish to 40.5 mg/kg in gills of tilapia, which is above 30 mg/kg FAO recommended guidelines. 18 out of 24 samples, equivalent to 75% of all samples from different fish parts, had elevated concentrations of Zn above recommended FAO guidelines, coinciding with previous studies (Kumari & Maiti, 2019). The concentration of Cu ranged from 1.28 mg/kg in muscles of catfish to 4.12 mg/kg in gills of tilapia; however, all concentrations of Cu from all samples were within recommended WHO food safety guidelines, while the concentration of Pb ranged from 1.09 mg/kg in muscles of catfish to 2.95 mg/kg in gills of tilapia that is above 1.5-2 mg/kg WHO food safety guidelines. These findings showed that fish had some levels of Pb, which might pose health effects if consumed (Akoto et al., 2014; Kumari & Maiti, 2019). Generally, 7 out of 24 samples, equivalent to 29.2%, had elevated Pb concentrations above WHO recommended food safety guidelines.

The concentrations of trace elements like Cu and Zn in recommended levels are essential for body growth (Mapenzi et al., 2019). People consume fish as a source of food and protein (Mapenzi et al., 2019); however, if the concentration of trace elements exceeds the allowable limits can pose serious health effects (Akoto et al., 2014; Kumari & Maiti, 2019). The concentrations of trace elements vary in fish parts and from one type to another depending on the ability of fish to bio accumulate and consumption habits (Mapenzi et al., 2019). For example, the concentrations of trace elements were higher in catfish compared to that of tilapia that were obtained from lake Rukwa and attributed to the reasons that catfish consume other small fish of different species, including tilapia, which feeds on phytoplankton (Nzeve et al., 2014; Mapenzi et al., 2019). Carnivores have the ability to accumulate heavy metals in all organs, including gills, muscles, and livers, compared to herbivores (Maurya & Malik, 2019) which coincides with the findings of this study (Table 1).

Table 1. Average and Standard Deviations (Mean±SD) of heavy metal concentration analyzed in some fish organs sampled in individually owned ponds, Dar es Salaam

Location	Fish Species	Organs	Cr (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Pb (mg/kg)
L1	Tilapia	Gills	0.003±0.001	34.88±5.091	3.15±0.58	2.16±0.318
		Fins	0.0015±0.0005	33.07±1.51	2.06±0.33	2.07±0.08
		Guts	0.0014±0.0005	30.76±2.068	3.033±0.21	1.96±0.13
		Muscles	0.001±0.00008	16.75±1.41	3.29±0.25	1.67±0.12
	Catfish	Gills	0.006±0.0015	36.05±1.30	2.89±0.36	1.46±0.04
		Fins	0.002±0.0005	32.08±0.66	2.17±0.17	1.12±0.1
		Guts	0.002±0.0006	35.86±5.26	3.46±0.51	1.63±0.24
		Muscles	0.002±0.0005	13.65±1.22	1.28±0.23	1.09±0.08
L2	Tilapia	Gills	0.003±0.002	35.76±5.34	3.71±0.59	2.86±0.42
		Fins	0.003±0.0001	31.79±1.43	2.88±0.20	1.82±0.13
		Guts	0.002±0.0001	32.85±2.40	3.15±0.21	1.71±0.16
		Muscles	0.001±0.00007	21.86±1.64	3.41±0.25	2.09±0.46
	Catfish	Gills	0.004±0.0005	34.36±1.65	3.41±0.24	2.11±0.05
		Fins	0.002±0.001	34.14±1.34	1.55±0.11	1.09±0.065
		Guts	0.003±0.0006	38.51±5.71	2.29±0.34	1.35±0.23
		Muscles	0.002±0.0005	21.40±2.63	2.07±0.55	1.09±0.08
L3	Tilapia	Gills	0.022±0.016	40.50±5.90	4.12±0.60	2.95±0.45
		Fins	0.002±0.0004	33.69±1.34	3.07±0.16	1.64±0.06
		Guts	0.002±0.0002	30.78±2.12	2.88±0.19	1.63±0.13
		Muscles	0.003±0.0005	17.54±1.33	3.76±0.32	1.86±0.24
	Catfish	Gills	0.004±0.001	36.60±0.32	3.97±0.25	2.25±0.06
		Fins	0.003±0.0005	33.26±0.21	2.26±0.16	1.11±0.05
		Guts	0.002±0.0003	39.49±5.78	3.96±0.59	1.25±0.19
		Muscles	0.002±0.0005	20.87±2.23	1.33±0.12	1.21±0.13
FSG (Food Safety Guidelines, mg/kg)			**12.0-13.0 (USFDA, 1993)**	**30.0 (FAO, 1983)**	**3 (WHO, 1995)**	**1.5-2.0 (WHO, 1995)**

Table 2. Pearson correlation between heavy metals in fish organs

Heavy Metals	Cr	Zn	Cu	Pb
Cr	1			
Zn	0.366481	1		
Cu	0.356376	0.368952	1	
Pb	**0.5124**	0.308934	**0.693594**	1

Table 3. The results from ANOVA single factor indicated no significant difference between tilapia and catfish in accumulating heavy metals

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.030764	1	0.031	0.00004	**0.995**	5.987
Within Groups	4306.888	6	717.8147			
Total	4306.919	7				

Table 4. Results from Principal Component Analysis (PCA) of trace elements analyzed in fish organs from individually owned fishponds in Dar es Salaam, Tanzania

Location	Fish Type	Fish Organ	PCA 1	PCA 2	PCA 3	PCA 4
L1	Tilapia	Gills	**0.55054**	0.29437	0.77749	-0.71028
		Fins	0.30797	-0.78218	2.0355	-1.0901
		Guts	0.010971	0.2861	0.42235	-0.8095
		Muscles	-1.8192	**1.1471**	-0.67438	-0.04197
	Catfish	Gills	**0.70007**	-0.41978	-0.67235	0.8717
		Fins	0.1765	-1.1349	-0.56439	0.16016
		Guts	**0.67875**	0.27161	-1.0131	-0.41939
		Muscles	-2.2367	-1.0773	0.57774	0.80782
L2	Tilapia	Gills	**0.67049**	**1.2077**	1.817	-1.4644
		Fins	0.14436	-0.00381	0.2703	-0.24194
		Guts	0.284	0.15756	-0.38256	-0.4247
		Muscles	-1.1497	**1.2255**	0.24378	-0.69173
	Catfish	Gills	**0.48383**	0.56332	0.2933	-0.31642
		Fins	0.4423	-1.9021	0.2053	0.051454
		Guts	**1.018**	-1.2316	-0.13638	-0.03715
		Muscles	-1.2197	-0.67944	-0.5033	0.59187
L3	Tilapia	Gills	**1.2923**	**1.4248**	**1.4881**	3.8425
		Fins	0.39314	-0.00851	-0.45387	-0.38724
		Guts	0.011837	-0.05335	-0.21948	-0.28418
		Muscles	-1.713	**1.6935**	-0.82693	0.34852
	Catfish	Gills	**0.77992**	**1.0971**	-0.11146	-0.50052
		Fins	0.33114	-1.1111	-0.71338	0.42721
		Guts	**1.1547**	0.38426	-2.6769	-0.0852
		Muscles	-1.2926	-1.3489	0.81763	0.40341

Table 5. Eigenvalue and variance from principal component analysis

PCA	Eigenvalue	% Variance
1	58.4377	98.568
2	0.731589	1.234
3	0.117406	0.19803
4	1.17E-05	1.98E-05

Results of this study indicated that there were variations of heavy metals concentration in fish parts, with muscles accumulating the lowest concentration while the highest concentrations were observed in the gills of both fish species, which is also similar to what Kumari & Maiti (2019) reported. The sum of all analyzed metals i.e., Cr, Zn, Cu and Pb in the fish parts indicated that the concentration was in the order of gills > fins > guts > muscles for tilapia i.e., 130 > 112.1 > 108.8 > 72.2 mg/kg while for catfish were in the order of gills > guts > fins > muscles in mg/kg i.e., 123.1 > 127.8 > 108.8 > 64 mg/kg. Maurya & Malik (2019) and Kumari & Maiti (2019) obtained similar findings whereby gills accumulated more heavy metals compared to those muscles, which are in agreement with the findings of this study.

Statistical Results from Analyzed Heavy Metals in Fish Parts

Pearson correlation between heavy metal concentrations in fish parts indicated that most heavy metals were weak to moderate correlated. For example, Cu was moderately correlated with Pb by r=0.69, Cr was correlated with Pb by r=0.51, while Cr was weakly correlated with Zn and Cu. Also, there was a weak correlation between Zn and Pb, as summarized in Table 2, indicating variation in fish organs' ability to accumulate heavy metals (Mahjoub et al., 2020). In addition, there was a strong correlation between heavy metals in tilapia and catfish with r=0.9, indicating that both fish have the ability to accumulate heavy metals in their organs. The results from ANOVA-single factor analysis showed that there was no significant difference between the ability of tilapia and catfish to accumulate heavy metals as the p-value was greater than 0.05, p=0.99, as shown in Table 3; thus, all fish types have the ability to accumulate heavy metals in their organs.

Principal Component Analysis (PCA)

Results from Principal Component Analysis (PCA) which analyzed inter-element correlations (Kumari & Maiti, 2019), indicated that PC1 provided 98.6% variance (Table 4) and is explained by the higher concentration of trace elements in gills of both fish types and guts of catfish as shown in Table 5 caused by the concentration of Zn as presented in Table 6. This indicates that fish accumulates more heavy metals in gills and least in muscles regardless of their species which is similar as reported in previous studies (Akoto et al., 2014; Kumari & Maiti, 2019).

Hierarchical Clustering Paired Group (UPGMA)

Hierarchical clustering paired group (UPGMA) indicates that at 18 distances, 5 groups of fish organs were created (Figure 2). A group of muscles is clearly distinguished from the rest of the groups, while, at 4 distances, more clear groups are further formed, including that of gills, fins, and guts. This further confirms that the muscles of fish accumulated the lowest concentration of metals compared to that in gills, fins, and guts, as also presented in Figure 3, showing three clear clusters of fish organs.

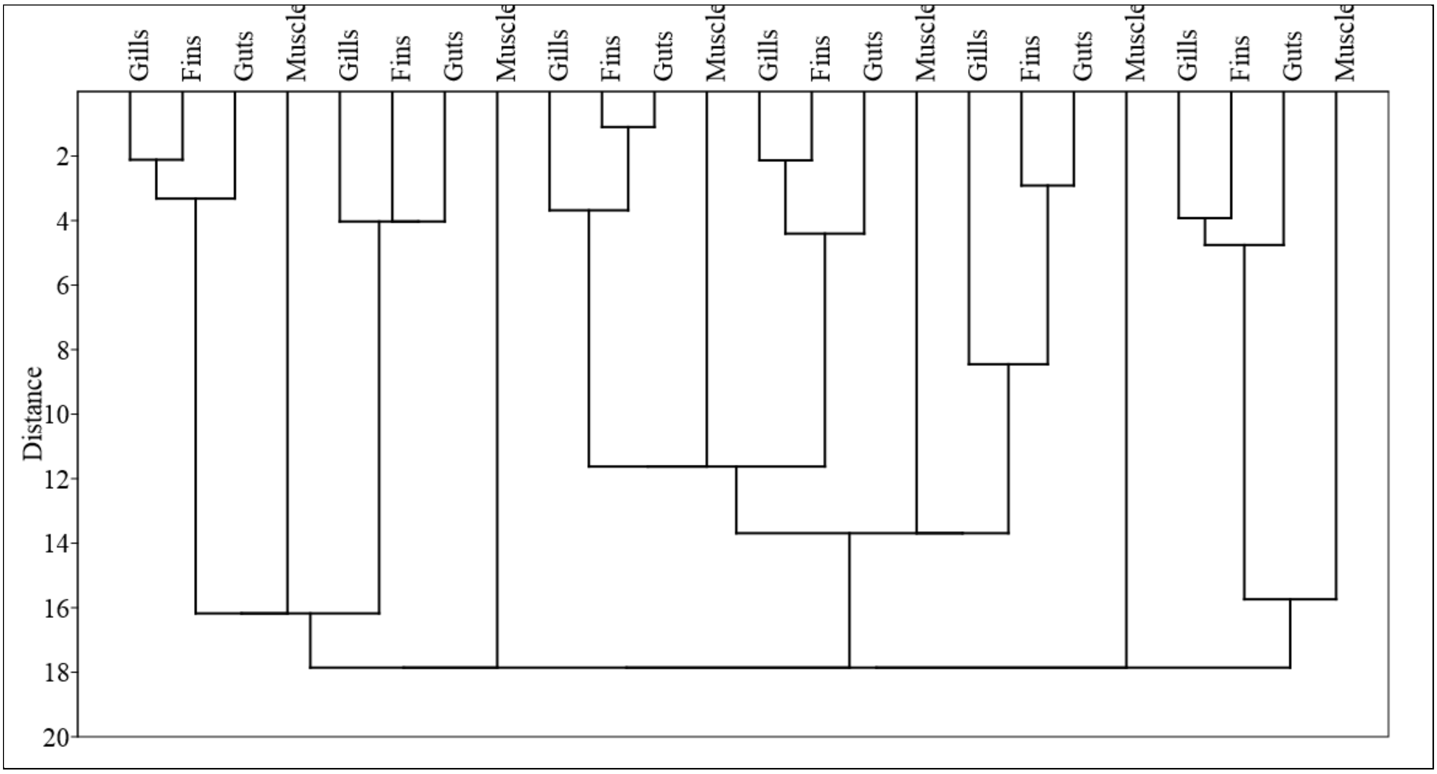

Figure 2. Hierarchical clustering paired group (UPGMA) using classical method among heavy metal concentrations in fish organs

Table 6. Loadings from principal component analysis

Heavy Metals	PCA 1	PCA 2	PCA 3	PCA 4
Cr	0.000199	0.001466	0.003526	0.99999
Zn	**0.99894**	-0.04606	-5.71E-05	-0.00013
Cu	0.040669	0.88262	-0.46832	0.000349
Pb	0.02162	0.46781	0.88355	-0.00381

Table 7. Results from estimated daily intake (EDI) and target hazard quotient (THQ) for different trace elements from consuming tilapia and catfish grown in privately-owned ponds

Fish type		Estimated Daily Intake (E_f x E_D x F_{IR} x C_f x C_m) /(W_{AB} xT_A)				Hazard Index (∑THQs)	Health Risk Index (HRI=EDI/RfD)			
		Cr	*Zn*	*Cu*	*Pb*		*Cr*	*Zn*	*Cu*	*Pb*
Tilapia	Gills	8.2x10^{-7}	0.0096	0.0009	0.0006	0.083	0.362	0.105	0.534	2.138
	Fins	4.1 x10^{-7}	0.0091	0.0006	0.0006	0.072	0.181	0.100	0.349	1.398
	Guts	3.8 x10^{-7}	0.0084	0.0008	0.0005	0.075	0.169	0.093	0.515	2.058
	Muscles	2.7 x10^{-7}	0.0046	0.0009	0.0005	0.061	0.121	0.051	0.558	2.233
Catfish	Gills	1.6 x10^{-6}	0.0099	0.0008	0.0004	0.073	0.724	0.109	0.490	1.961
	Fins	5.49 x10^{-7}	0.0088	0.0006	0.0003	0.059	0.241	0.097	0.368	1.473
	Guts	5.49 x10^{-7}	0.0098	0.0009	0.0004	0.079	0.241	0.108	0.587	2.348
	Muscles	5.49 x10^{-7}	0.0037	0.0004	0.0003	0.036	0.241	0.041	0.217	0.869
Tilapia	Gills	8.23 x10^{-7}	0.0098	0.0010	0.0008	0.097	0.362	0.108	0.629	2.518
	Fins	8.23 x10^{-7}	0.0087	0.0008	0.0005	0.074	0.362	0.096	0.489	1.954
	Guts	5.49 x10^{-7}	0.0090	0.0009	0.0005	0.075	0.241	0.099	0.534	2.138
	Muscles	2.7 x10^{-7}	0.0060	0.0009	0.0006	0.072	0.121	0.066	0.578	2.314
Catfish	Gills	1.1 x10^{-6}	0.0094	0.0009	0.0006	0.084	0.483	0.104	0.578	2.314
	Fins	5.49 x10^{-7}	0.0094	0.0004	0.0003	0.057	0.241	0.103	0.263	1.052
	Guts	8.23 x10^{-7}	0.0106	0.0006	0.0004	0.069	0.362	0.116	0.388	1.554
	Muscles	5.49 x10^{-7}	0.0059	0.0006	0.0003	0.049	0.241	0.065	0.351	1.405
Tilapia	Gills	6.03 x10^{-6}	0.0111	0.0011	0.0008	0.109	2.654	0.122	0.699	2.796
	Fins	5.49 x10^{-7}	0.0092	0.0008	0.0004	0.074	0.241	0.102	0.521	2.083
	Guts	5.49 x10^{-7}	0.0084	0.0008	0.0004	0.070	0.241	0.093	0.489	1.954
	Muscles	8.23 x10^{-7}	0.0048	0.0010	0.0005	0.067	0.362	0.053	0.638	2.551
Catfish	Gills	1.1 x10^{-6}	0.0100	0.0011	0.0006	0.092	0.483	0.110	0.673	2.694
	Fins	8.23 x10^{-7}	0.0091	0.0006	0.0003	0.061	0.362	0.100	0.383	1.534
	Guts	5.49 x10^{-7}	0.0108	0.0011	0.0003	0.080	0.241	0.119	0.672	2.687
	Muscles	5.49 x10^{-7}	0.0057	0.0004	0.0003	0.045	0.241	0.063	0.226	0.903

Health Risk Assessment

The results of human health risks from consuming fish grown in privately owned fishponds are summarized in Table 7. The estimated daily intake of all heavy metals in bodies was in the rank of Zn > Cu > Pb > Cr, which is in agreement with previous studies done by Maurya & Malik (2019). The EDI of Cr was the lowest in all four heavy metals ranging from 2.74 x 10^{-7} to 6.03 x 10^{-6} mg/kg, while the highest EDI was obtained in Zn, which ranged from 0.0037 to 0.011 mg/kg. The hazard index (HI) of all heavy metals ranged from 0.036 to 0.11, and the lowest was observed in muscles while the maximum was observed in gills, as shown in Table 7. However, the health risk index was in the order of Zn < Cr < Cu < Pb, as detailed in Table 7. The HRI for Cr, Zn, and Cu except for gills in tilapia were less

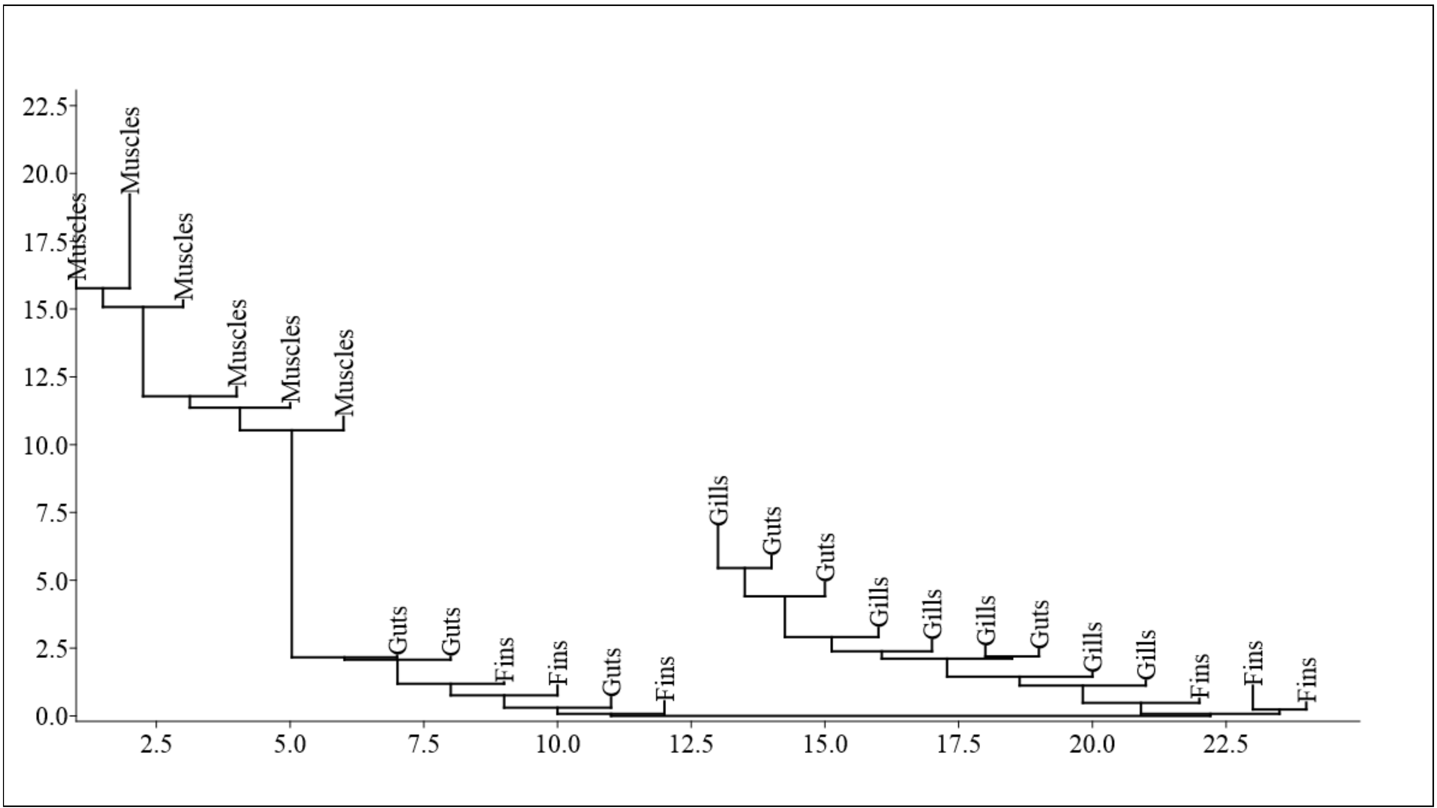

Figure 3. Hierarchical clustering paired group (UPGMA) using neighbor-joining clustering among heavy metal concentrations in fish organs

than one, indicating that humans would not experience any significant health risk caused by the Zn, Cr, and Cu concentrations in fish organs; however, they are likely to experience significant health effects caused by Pb as the HRI>1 across all fish organs. This indicates that humans consuming fish grown in privately owned fishponds are likely to experience effects of Pb concentration, including a reduction in cognitive development and intellectual performance in children (Darko et al., 2016), causing renal tumors and increased blood pressure in adults, cause gastrointestinal disorders and liver impairments (Akoto et al., 2014; Kumari & Maiti, 2019).

The findings of this study coincide with a study done by Kumari & Maiti (2019) in India and Mahjoub et al. (2020) in Morocco, who also established HR>1 for Pb in sampled fish and the concentration of Pb was significantly higher compared to other trace elements. Trace metals bioaccumulation is associated with fish type, type of heavy metals, age, and chemical characteristics of water (Mahjoub et al., 2020). Thus, consuming contaminated fish with non-essential elements especially trace elements, may pose a health risk to humans due to their resistance to degradation and their accumulation in the living organisms (Mahjoub et al., 2020).

Conclusion and Recommendation

This study concludes that there are considerable levels of heavy metals in fish grown in privately owned fish ponds, especially in tilapia and catfish; however, the concentrations vary from one fish organ to another in the order of muscles<fins<guts<gills. The levels of Cr, Cu, and Zn were within the permissible limit in almost all fish organs (gills, fins, guts, and muscles). However, the concentration of Pb was above the permissible limit across all fish organs, which portrays the possibility of carcinogens, especially when consuming fish gills and guts. The HRI indicated that there were no significant human health effects caused by the individual concentration of Cr, Zn, and Cu since HRI<1; however, the HRI>1 was caused by Pb concentrations across all fish organs, indicating that there would be some combined effects of all heavy metals to human health, and thus posing a possible health risk to consumers in the studied area. Since heavy metals have a tendency of bioaccumulation in body tissues due to the biodegradability of toxic metals, needed actions should be considered to minimize metal supplements in fish feeds, and frequent monitoring of fish feeds and fish quality grown in privately owned fish ponds is recommended so as to safeguard consumers. This study should be regarded as an open gate for the Tanzania National Bureau of Standard (TBS) to guide the fish farmers and consumers to accentuate public health by establishing relevant permissible limits and conducting spot checks to establish the quality of fish grown in privately owned fishponds.

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Compliance With Ethical Standards

Authors' Contributions

LSL: Study design, data evaluation, statistical analysis, article writing

AM: Article reviewing and editing

NCM: Sampling, handling, transportation of the samples, and laboratory analysis

All authors read and approved the final manuscript

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

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