IJRAR.ORG E-ISSN: 2348-1269, P-ISSN: 2349-5138

INTERNATIONAL JOURNAL OF RESEARCH AND ANALYTICAL REVIEWS (IJRAR) | IJRAR.ORG

An International Open Access, Peer-reviewed, Refereed Journal

Heavy Metal Concentration Levels in Some Selected Fish from Lake Turkana, Kenya

Vincent Otwori Atambo*, Sylvia Opiyo, Sharon Kiprotich

Department of Physical and Biological Sciences, Murang'a University of Technology, P.O.BOX 75-10200, Murang'a, Kenya.

ABSTRACT: Heavy metal pollution in water poses a risk to both drinking water and fish consumed by people. This study aimed to assess how various heavy metals are distributed among different fish species. The study measured the levels of copper, zinc, lead, nickel, chromium, barium, arsenic, and cadmium in the tissues of three different fish species from Lake Turkana. These species – Synodonis catfish (*Synodontis schall*), Nile tilapia (*Oreochromis niloticus*) and Nile perch (*Lates niloticus*) were collected from the Kalokol and Longech fish markets in June 2022. Heavy metal concentrations in the fish muscles were determined using an Agilent 4210 Microwave Plasma Atomic Emission Spectrometer (MP-AES). The concentrations of most metals were consistently highest in Nile Perch followed by Catfish, and then Nile tilapia. For instance, the average concentration of zinc for the two markets was: Nile perch (0.769 ± 0.057 mg/kg), catfish (0.559 ± 0.084 mg/kg) and Nile tilapia (0.327 ± 0.041 mg/kg). Overall, the heavy metal concentrations in all the sampled fish were low and well within the World Health Organization's established minimum permissible levels. Non-carcinogenic health risks were evaluated by calculating the Estimated Daily Intake, Target Hazard Quotient, and Hazard Index. Nile perch had the highest hazard index (0.4099500) followed by catfish (0.3690927), and Nile tilapia (0.3448890). The fish from Lake Turkana are safe for consumption. Continued monitoring is recommended to ensure heavy metals remain within safe limits.

Key words: Heavy metals, concentration, fish samples, health risk.

1.0 INTRODUCTION

Heavy metal contamination in aquatic environments has emerged as a significant global concern due to its detrimental effects on aquatic organisms, particularly fish. While these metals naturally exist in the environment, anthropogenic activities such as industrial discharges, agricultural runoff, and urban waste have substantially increased their concentrations in water bodies[1]. Fish are particularly vulnerable to heavy metal exposure as they absorb these pollutants through their gills, skin, and digestive systems. Once inside, metals like mercury, lead, cadmium, and arsenic accumulate in vital organs such as the liver, kidneys, gills, and muscles. This bioaccumulation can lead to oxidative stress, where the production of reactive oxygen species (ROS) overwhelms the fish's antioxidant defenses, causing cellular damage to DNA, proteins, and lipids[2]. The physiological impacts on fish are profound. Exposure to heavy metals can impair growth, disrupt reproductive processes, and alter behavior. For instance, reduced gonadosomatic index (GSI), decreased fecundity, and abnormal development of embryos and larvae have been observed[3]. Additionally, behavioral changes such as altered feeding patterns and impaired predator avoidance can reduce survival rates[4]. Beyond individual health, these contaminants pose risks to entire aquatic ecosystems. The bioaccumulation of heavy metals in fish can lead to biomagnification, where higher concentrations of toxins are found in predators at the top of the food chain, including humans who consume contaminated seafood[5].

Many studies[6–10] have demonstrated anthropogenic pollution of water by heavy metals. In a study that determined heavy metal concentrations in fish tissues from Gilgel Gibe (I) Hydroelectric Dam Reservoir, the order of concentrations of the metals muscle of *Labeoberbus infermedius* and *Orochromis niloticus* was Cr > Pb > Cu > Co and Cr > Pb > Cu > Co, respectively[11]. Heavy metal levels in fish tissues from Epe lagoon, Lagos, Nigeria ranged from: Zn: 1.128 to 4.875 mg/kg; Cu: ND to 0.488 mg/kg; Mn: 0.5 to 7.480 mg/kg; Fe: 0.125 to 9.125 mg/kg; Pb: ND to 0.875 mg/kg; and Cd: 1.750 to 2.750 mg/kg[12]. In a study, that determined concentrations of some heavy metals concentration in the tissues of Tilapia and Catfish, cat-fish showed concentration levels of Pb (7.60 ± 2.33 mg/kg) and Cu (0.506 ± 0.4 mg/kg) in muscle tissues[13].

While fishing in Lake Turkana, Kenya, is crucial there's limited data on concentrations of heavy metals and the associated health indices in the muscle tissues of fish from the lake. This study aimed to quantify the concentrations of selected heavy metals copper (Cu), zinc (Zn), lead (Pb), nickel (Ni), chromium (Cr), barium (Ba), arsenic (As), and cadmium (Cd) in the muscle tissues of *Synodontis schall* (Synodontis catfish), *Oreochromis niloticus* (Nile tilapia), and *Lates niloticus* (Nile perch) fish species collected from Lake Turkana. Furthermore, the study assessed human health risk indices, such as the Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI), to evaluate the potential non-carcinogenic health risks associated with the consumption of these fish species from Lake Turkana.

2.0 MATERIALS AND METHODS

2.1 Study area

Kalokol and Longech are notable fish markets in Kenya, each serving as vital hubs for the local fishing communities along Lake Turkana. Kalokol is situated on the western shore of Lake Turkana in Turkana County, Kenya, Latitude: 3.521130° N, Longitude: 35.832940° E. Fish processing activities, such as sun-drying and smoking, are prevalent in Kalokol. These methods help preserve the fish, making it suitable for both local consumption and export. Kalokol is considered the main fish market in Turkana County, facilitating a substantial portion of the estimated 15,000 tonnes of fish pulled from Lake Turkana annually[14]. The fish from Kalokol reach various markets, including regional and international destinations [15].

Longech is an island located about 5 km from Kalokol. Like Kalokol, Longech serves as a significant fish market for the local communities, supporting the livelihoods of fishermen and traders. Similar to Kalokol, fish processing methods like sun-drying and smoking are common in Longech. The fish products from Longech are distributed to various markets within Kenya and potentially for export [14]. Figure 1 presents a google map showing Kalokol and Longech fish markets where sampling was done.

Figure 1: Google map showing fish sampling locations.

2.2 Sample Collection and Preparation

Eighteen (18) sun-dried fish samples were collected from the Kalokol and Longech markets in August 2022. These two markets served as representative sampling locations for the entire lake due to their active fishing boat docks. From each market, three specimens of Synodontis catfish (*Synodontis schall*), Nile tilapia (*Oreochromis niloticus*), and Nile perch (*Lates niloticus*) were purchased, totaling nine samples per market. Upon collection, the three individual samples of each fish species from each market were cut into smaller pieces and then thoroughly mixed together to create a single, composite sample for that species and market. Each composite sample was then placed in a clean, non-polythene paper bag, and appropriately labeled for identification. The samples were further dried in an oven, maintained at a temperature of 105°C for a continuous period of 24 hours. Once adequately dried, the samples were allowed to cool, then ground into a fine powder using a mortar and pestle. To ensure uniform particle size and eliminate any larger fragments, the resulting powder was sieved using a 150-mesh sieve in preparation for digestion [16].

The dry ashing method was used to digest the samples. First 2.0 g of each powdered sample was placed in a crucible then 6.0 mL of deionized water and 4.0 mL of 35% nitric acid were added. The crucibles were then placed on a hotplate and heated at 120℃ to dryness. The resultant samples were then transferred to a muffle furnace where they were further heated for 1 hour at 510℃. This ensured all organic matter were eliminated. The samples were cooled down, some deionized water added and then filtered through Whatman filter papers No. 42 into to 100 mL volumetric flasks. The volumetric flasks were topped with a solution of 2% of HNO_3 and the mixture shaken thoroughly to homogenize then filtered through 0.22 μm filters into the Microwave Plasma Atomic Emission Spectrometer (MP-AES) plastic reagent bottles and subsequently used for atomic absorption spectrometry.

2.3 Elemental analysis

The concentrations of zinc, barium, cadmium, lead, copper, arsenic, nickel and chromium in the samples were determined using an Agilent 4210 MP-AES. To evaluate the effectiveness of the MP-AES techniques and the experimental procedures, quality control tests were conducted. A pre-digested sample was spiked with 5 mg/l, prepared by serial dilution of a 1000 mg/l stock standard solution, ensuring quality assurance [16]. Thereafter, the concentrations of the eight elements were determined using an eight-point calibration curve of a multi-element standard in emission mode.

2.4 Health risk assessment

Non-carcinogenic health risks were evaluated by calculating the Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI).

The EDI quantifies the average daily exposure of an individual to a specific substance, such as a metal, based on dietary intake. The EDI is commonly expressed in units of milligrams per kilogram of body weight per day (mg/kg bw/day). It was calculated using Equation 2.1.

$$EDI = \frac{CF \times IR \times MC}{BW} \qquad (2.1)$$

Where MC is the metal concentration in the fish muscle (mg/kg dry weight), IR is the ingestion rate assumed to be 0.0123 kg/person/day, CF is the conversion factor, taken as 0.21, considering 79% moisture content in fish, used to convert the results of the metal from dry weight (dw) to wet weight (ww) [17] and BW is the average body weight of an African adult, taken as 60.7 kg [18]

The THQ was calculated to assess the non-carcinogenic risk to humans from consuming fish contaminated with heavy metals. The THQ was calculated as using Equation 2-2.

$$THQ = \frac{EDI}{RfD} \qquad (2.2)$$

Where each metal has an oral reference dose (RfD**)**, expressed in milligrams per kilogram per day (mg/kg/day). These values represent the estimated daily exposure to a substance that is unlikely to cause adverse health effects over a lifetime. The specific

RfD values mentioned are; As: 0.00006 mg/kg/day, Cd: 0.001 mg/kg/day, Ba: 0.2 mg/kg/day, Cr: 0.003 mg/kg/day, Cu: 0.04 mg/kg/day, Ni: 0.02 mg/kg/day, Pb: 0.0035 mg/kg/day and Zn: 0.3 mg/kg/day [17].

If the THQ value is less than 1, it suggests that the daily exposure level is below the reference dose (RfD)[18]. This indicates that adverse health effects are unlikely to occur over an individual's lifetime. Conversely, if the THQ value is greater than 1, it implies that the exposed population consuming contaminated foods is likely to experience noticeable harmful effects. A higher THQ value signifies an increased probability of health hazards for the human body [18].

The total health risk attributed to the presence of multiple metals in fish was determined by calculating a Hazard Index (HI). Consequently, the HI provides a comprehensive representation of the combined risk posed by all the metals identified. This index is derived by summing the individual Target Hazard Quotient (THQ) values for each metal as indicated in Equation 2.3 [18].

$$HI = \sum_{i=1}^{n} THQ_i \qquad (2.3)$$

where THQ_i is the target hazard quotient of an individual element of heavy metals, *HI* is the total hazard index for all the eight metals studied in the present study (n = 8). When the HI is less than one, there's no significant risk of non-carcinogenic effects and when the HI is greater than one, there is a probability of non-carcinogenic risk effects occurring[19].

3.0 RESULTS AND DISCUSSIONS

3.1 Heavy metal concentrations in fish samples

The table 1 summarizes the average concentrations of various heavy metals in muscle tissue in fish specimens from Kalokol and Longech markets. The samples were categorized into three groups: Catfish, Nile Perch, and Nile Tilapia. The metals analyzed were: Cu, Zn, Pb, Ni, Cr, Ba, As and Cd. The concentrations are reported in milligrams per kilogram (mg/kg) on a dry weight basis.

Table 1: Concentration of Heavy Metals (mg/kg) in Fish Muscle Tissue Samples from Kalokol and Longech markets

	Kalokol market			Longech market		
Metal	Catfish	Nile Perch	Nile Tilapia	Catfish	Nile Perch	Nile Tilapia
As	0.510 ± 0.015	0.723 ± 0.082	0.363 ± 0.027	0.480 ± 0.010	0.740 ± 0.070	0.357 ± 0.028
Ba	0.060 ± 0.012	0.053 ± 0.006	0.027 ± 0.006	0.063 ± 0.006	0.047 ± 0.011	0.020 ± 0.006
Cd	ND	ND	ND	ND	ND	ND
Cr	0.013 ± 0.003	0.027 ± 0.015	0.017 ± 0.006	0.017 ± 0.006	0.028 ± 0.011	0.016 ± 0.006
Cu	0.373 ± 0.027	0.400 ± 0.015	0.213 ± 0.006	0.357 ± 0.037	0.400 ± 0.015	0.193 ± 0.048
Ni	0.026 ± 0.003	0.047 ± 0.006	0.010 ± 0.001	0.023 ± 0.006	0.043 ± 0.006	0.017 ± 0.006
Pb	0.020 ± 0.006	0.023 ± 0.006	0.013 ± 0.006	0.020 ± 0.006	0.023 ± 0.006	0.010 ± 0.006
Zn	0.560 ± 0.081	0.767 ± 0.042	0.323 ± 0.048	0.557 ± 0.086	0.770 ± 0.072	0.330 ± 0.033

The heavy metal concentrations in fish samples, exhibit spatial variability among different sampling sites. These variations are attributed to the environmental and anthropogenic factors influencing the lake's ecosystem. The average arsenic concentration in samples from Kalokol market were Catfish – 0.510 ± 0.015 mg/kg, Nile Perch – 0.723 ± 0.082 mg/kg and Nile Tilapia – 0.363 ± 0.027 mg/kg. For Longech market, the average concentration of arsenic in the fish samples were Catfish – 0.480 ± 0.010 mg/kg, Nile Perch – 0.740 ± 0.070 mg/kg, Nile Tilapia – 0.357 ± 0.028 mg/kg. Nile Perch had the highest concentration of arsenic in both markets (~0.73 mg/kg), reflecting potential species-specific uptake. Levels are slightly higher in Longech Nile Perch but overlapping within error. Barium concentrations in fish samples from Kalokol market were: 0.060 ± 0.012 mg/kg (Catfish), 0.053 ± 0.006 mg/kg (Nile Perch), 0.027 ± 0.006 mg/kg (Tilapia). The corresponding concentrations for samples from Longech market were: 0.063 ± 0.006, 0.047 ± 0.011, and 0.020 ± 0.006 mg/kg respectively. Ba was lowest in Tilapia for both markets. Catfish consistently had the highest Ba, attributed to feeding or environmental factors specific to that species. Cadmium was not detected (ND) in all samples from both markets. Nile Perch showed slightly higher Cr concentrations (0.027–0.028 mg/kg). The other species had lower and fairly consistent Cr concentration in samples from both markets. Nile Perch remained the highest in concentration of

Cu across the species Cu (~0.40 mg/kg) while Nile Tilapia had the lowest Cu concentration. The two markets had similar Cu concentration levels in all fish species, a trend that was replicated for Ni, Pb, and Zn concentrations.

Generally, across both markets, Nile Perch consistently had the highest concentrations for several metals (As, Cr, Cu, Ni, Zn), suggesting higher bioaccumulation while Nile Tilapia often had the lowest values, particularly for Ba, Ni, Cu, Zn. Metal concentration levels in same species were approximately identical in samples from Kalokol and Longech markets, with slight variance. Therefore, no strong evidence indicating that one market consistently yielded higher metal contamination was established.

The table 2 presents average concentrations of various metals in Catfish, Nile Perch, and Nile Tilapia from the two markets.

Table 2: Average heavy metal concentrations (mg/kg) in fish samples from the two markets.

	Average heavy metal concentration ± SE (mg/kg) for the two markets		
Metal	Catfish	Nile Perch	Nile Tilapia
As	0.495 ± 0.013	0.732 ± 0.045	0.360 ± 0.055
Ba	0.062 ± 0.009	0.050 ± 0.009	0.024 ± 0.006
Cd	ND	ND	ND
Cr	0.015 ± 0.005	0.028 ± 0.013	0.017 ± 0.006
Cu	0.365 ± 0.032	0.400 ± 0.021	0.203 ± 0.027
Ni	0.025 ± 0.005	0.045 ± 0.006	0.014 ± 0.004
Pb	0.020 ± 0.006	0.023 ± 0.006	0.012 ± 0.006
Zn	0.559 ± 0.084	0.769 ± 0.057	0.327 ± 0.041

Cadmium (Cd) was not detected in any of the fish species. However, all other listed metals, including Arsenic were found in varying concentrations across the fish species. Nile Perch consistently exhibited the highest average concentrations for several metals. For instance, it showed the highest Arsenic concentration at 0.732 ± 0.045 mg/kg, which was notably higher than the levels in Catfish (0.495 ± 0.013 mg/kg) and Nile Tilapia (0.360 ± 0.055 mg/kg). The higher concentrations of metals in Nile Perch can be attributed to its predatory nature. In contrast, Nile Tilapia generally showed the lowest concentrations for most of the detected metals. Its Arsenic concentration, at 0.360 ± 0.055 mg/kg, was the lowest among the three species, as were its Barium (0.024 ± 0.006 mg/kg) and Nickel (0.014 ± 0.004 mg/kg) levels. This could have been due to its feeding habits, as it is often herbivorous which might expose it to lower levels of contaminants compared to predatory species. Catfish typically presented intermediate levels of metal concentrations. For example, it had the highest Barium concentration at 0.062 ± 0.009 mg/kg, surpassing both Nile Perch and Nile Tilapia. However, its Copper concentration (0.365 ± 0.032 mg/kg) was comparable to that of Nile Perch (0.400 ± 0.021 mg/kg), while still being higher than Nile Tilapia.

The table 3 presents a comparative analysis of heavy metal concentrations in fish muscle tissues from Kalokol and Longech markets located along shores of Lake Turkana, Kenya (referred to as "This Work"), the Omo Delta in Ethiopia as reported by Andemo et al., 2024, and the Maximum Permissible Limits (MPLs) established by the Food and Agriculture Organization (FAO) and World Health Organization (WHO). The concentrations are reported in milligrams per kilogram (mg/kg) on a wet weight basis.

Table 3: Comparative Analysis of Heavy Metal Concentrations in Fish Muscle Tissue from Lake Turkana, Kenya to studied done at Omo Delta, Ethiopia Gilgel Gibe (I), and WHO Guidelines

Trace element concentration levels in muscle tissue of fish (mg/kg)								
	This work			Lake.Turkana[20]	Omo delta[21]		Gilgel Gibe (I)[11]	MPL[22]
Metal	Catfish	Nile Perch	Nile Tilapia	Red belly Tilapia	Catfish	Nile Perch	Nile Tilapia	
As	0.495 ± 0.013	0.732 ± 0.045	0.360 ± 0.055					
Ba	0.062 ± 0.009	0.050 ± 0.009	0.024 ± 0.006					
Cd	ND	ND	ND	<0.005	ND	ND	ND	0.200
Cr	0.015 ± 0.005	0.028 ± 0.013	0.017 ± 0.006	0.232	ND	0.039 ± 0.085	10.31	0.150
Cu	0.365 ± 0.032	0.400 ± 0.021	0.203 ± 0.027	0.808	0.071 ± 0.198	0.129 ± 0.283	4.64	3.000
Ni	0.025 ± 0.005	0.045 ± 0.006	0.014 ± 0.004		0.013 ± 0.006	0.019 ± 0.003		0.500
Pb	0.020 ± 0.006	0.023 ± 0.006	0.012 ± 0.006	<0.007	0.597 ± 0.153	0.89 ± 0.099	8.39	0.500
Zn	0.559 ± 0.084	0.769 ± 0.057	0.327 ± 0.041	26.900	0.394 ± 0.26	0.428 ± 0.393		40

Cadmium was not detected in any of the samples of this study, aligning with findings from both the Omo Delta[21] and Gilgel Gibe I Reservoir[11]. Chromium concentrations in this study ranged from 0.015 ± 0.005 in catfish to 0.028 ± 0.013 mg/kg in Nile Perch, which was significantly lower than the maximum permissible limit (MPL) of 0.150 mg/kg set by the FAO and WHO[22] . Cu levels ranged from 0.203 ± 0.027 Nile Tilapia to 0.365 ± 0.032 mg/kg Catfish, Ni: 0.014 ± 0.004 to 0.043 ± 0.006 mg/kg, Pb: 0.012 ± 0.006 to 0.023 ± 0.006 mg/kg and Zn: 0.327 ± 0.041 to 0.769 ± 0.057 mg/kg. Concentrations of Cr and Pb in Nile Perch was higher in this study compared to Nile perch from Omo delta. Cr was not detected in catfish of Omo delta while in this study catfish had average Cr concentration of 0.015 ± 0.005 mg/kg. Overall, the trace metal concentrations in this study were below MPLs of heavy metals, indicating that the fish from Kalokol and Longech markets do not pose significant health risks to fish consumers related to heavy metal contamination.

3.2 Health risk assessment

Table 4 presents the average EDI, THQ and HI due to heavy metals resulting from the commonly consumed fish species in Kalokol and Longech markets.

Table 4: Non-carcinogenic health risk assessment for metals in fish samples.

	Health Risk Parameters					
	EDI (mg/kg)			THQ		
Metal	Catfish	Nile Perch	Nile Tilapia	Catfish	Nile Perch	Nile Tilapia
As	0.0000221	0.0000245	0.0000206	0.3680881	0.4088686	0.3439745
Ba	0.0000022	0.0000020	0.0000017	0.0000109	0.0000101	0.0000084
Cd	ND	ND	ND	ND	ND	ND
Cr	0.0000008	0.0000009	0.0000008	0.0002695	0.0003156	0.0002766
Cu	0.0000143	0.0000146	0.0000124	0.0003574	0.0003644	0.0003093
Ni	0.0000011	0.0000013	0.0000010	0.0000574	0.0000654	0.0000495
Pb	0.0000008	0.0000008	0.0000007	0.0002310	0.0002401	0.0002006
Zn	0.0000235	0.0000257	0.0000211	0.0000783	0.0000857	0.0000702
HI	------	------	------	0.3690927	0.4099500	0.3448890

3.2.1 Estimated Daily Intake (EDI) of Metals from Fish Consumption

The data presented table 4 provided insights into the potential health risks associated with the consumption of Catfish, Nile Perch, and Nile Tilapia, based on the estimated daily intake (EDI) and target hazard quotient (THQ) for various metals. The EDI values for all analyzed metals across the three fish species were exceedingly low, ranging from 0.0000008 mg/kg for Chromium and Lead in Nile Tilapia to 0.0000257 mg/kg for Zinc in Nile Perch. Arsenic generally showed the highest EDI among the metals, with Nile

Perch having the highest EDI for Arsenic (0.0000245 mg/kg) compared to Catfish (0.0000221 mg/kg) and Nile Tilapia (0.0000206 mg/kg). Cadmium (Cd) was consistently "ND" (Not Detected) in all fish samples, indicating its absence or presence below the detection limits, which was a positive finding from a health risk perspective. The other metals, Barium, Chromium, Copper, Nickel, Lead, and Zinc, all exhibited very low EDIs across all fish types, suggesting minimal daily exposure through consumption.

3.2.2 Target hazard quotient (THQ) and total hazard index (HI)

The Target Hazard Quotient (THQ) was used to assess the non-carcinogenic health risk from individual metals. Arsenic presented the highest THQ values across all fish species. Nile Perch again showed the highest THQ for Arsenic (0.4088686), followed closely by Catfish (0.3680881) and Nile Tilapia (0.3439745). While these values were notably higher than those for other metals, all individual THQ values remained significantly below 1. A THQ value less than 1 generally indicated that the exposure level was unlikely to cause adverse non-carcinogenic health effects over a lifetime. For other metals like Barium, Chromium, Copper, Nickel, Lead, and Zinc, their respective THQ values were considerably lower, well within the safe limits, further reinforcing the minimal individual risk. Similar to EDI, Cadmium's THQ was also "ND" due to its non-detection.

Finally, the Hazard Index (HI), which represented the cumulative non-carcinogenic risk from multiple metals, aggregated the individual THQ values. The calculated HI values for Catfish (0.3690927), Nile Perch (0.4099500), and Nile Tilapia (0.3448890) were all less than 1. This was a critical finding, as an HI value below 1 suggested that there was no significant cumulative non-carcinogenic health risk associated with the combined consumption of these metals from the respective fish species. While Nile Perch exhibited a slightly higher overall HI compared to Catfish and Nile Tilapia, all three species fell within the acceptable risk range. Therefore, based on the provided data for these specific metals, the consumption of Catfish, Nile Perch, and Nile Tilapia pose negligible non-carcinogenic health risk to consumers.

Conclusion

The heavy metal concentrations in all the sampled fish were low and well within the WHO's established minimum permissible levels. For instance, the MPL of Zn is 40 mg/kg which quite high when compared to this study's average concentration of zinc in Nile perch (0.769 ± 0.057 mg/kg), catfish (0.559 ± 0.084 mg/kg) and Nile tilapia (0.327 ± 0.041 mg/kg). Nile perch had the highest hazard index (0.4099500) followed by catfish (0.3690927), and Nile tilapia (0.3448890). The low concentrations of heavy metals in fish samples from Kalokol and Longech fish markets show that the lake's ecosystem is relatively unpolluted. However, the presence of these metals, even at low levels, indicates the need for continuous monitoring to assess potential sources and trends over time. Future studies should focus on identifying specific sources of contamination and evaluating the bioaccumulation of these metals in different fish species to better understand the ecological and health implications.

CONFLICT OF INTEREST

We affirm that there are no conflicts of interest related to the research conducted and presented in this study.

REFERENCES

(1) Zahran, E.; Mamdouh, A.-Z.; Elbahnaswy, S.; El-Son, M. M. A.; Risha, E.; ElSayed, A.; Barbary, M. I. E.; Sebaei, M. G. E. The Impact of Heavy Metal Pollution: Bioaccumulation, Oxidative Stress, and Histopathological Alterations in Fish across Diverse Habitats. *Aquac. Int.* **2025**, *33* (5), 371. https://doi.org/10.1007/s10499-025-02045-1.

(2) Paschoalini, A. L.; Bazzoli, N. Heavy Metals Affecting Neotropical Freshwater Fish: A Review of the Last 10 Years of Research. *Aquat. Toxicol.* **2021**, *237*, 105906. https://doi.org/10.1016/j.aquatox.2021.105906.

(3) Ogindo, B. A. Heavy Metal Pollutants and Their Concentrations in Fish (Barbus Species) in Sosiani River, Kenya. *Discov. Innov.* **2001**, *13* (3), 178–183. https://doi.org/10.4314/dai.v13i3.15611.

(4) Taslima, K.; Al-Emran, M.; Rahman, M. S.; Hasan, J.; Ferdous, Z.; Rohani, M. F.; Shahjahan, M. Impacts of Heavy Metals on Early Development, Growth and Reproduction of Fish - A Review. *Toxicol. Rep.* **2022**, *9*, 858–868. https://doi.org/10.1016/j.toxrep.2022.04.013.

(5) Simionov, I.-A.; Cristea, V.; Petrea, S.-M.; Sirbu, E. B. Evaluation of heavy metals concentration dynamics in fish from the Black sea coastal area: an overview. *Environ. Eng. Manag. J.* **2019**, *18* (5), 1097–1110. https://doi.org/10.30638/eemj.2019.106.

(6) Sawe, S.; Amasi, A.; Wynants, M. Assessment of Potentially Toxic Metals in Fish from Lake Manyara, Northern Tanzania. *Bull. Environ. Contam. Toxicol.* **2023**, *111* (3), 39. https://doi.org/10.1007/s00128-023-03794-6.

(7) Njogu, P. M.; Keriko, J. M.; Wanjau, R. N.; Kitetu, J. J. Distribution of heavy metals in various lake matrices; water, soil, fish and sediments: a case study of the Lake Naivasha basin, Kenya. *J. Agric. Sci. Technol.* **2011**, *13* (1), 91–106.

(8) Asnake, W. Nile Perch (Lates Niloticus): The Promising White Meat of the World. *J. Nutr. Food Sci.* **2018**, *08* (02), 680.

(9) Irunkwor, T. C.; Abanjo N; Ogboi, K. C. Assessment of Natural Radioactivity and Radiological Hazard Indices in Cassava Cultivated in Oil Producing Area, Rivers State, Nigeria. *Int. J. Appl. Sci. Res.* **2023**, *05* (05), 174–188. https://doi.org/10.56293/IJASR.2022.5444.

(10) El-Batrawy, O. A.; El-Gammal, M. I.; Mohamadein, L. I.; Darwish, D. H.; El-Moselhy, K. M. Impact Assessment of Some Heavy Metals on Tilapia Fish, Oreochromis Niloticus, in Burullus Lake, Egypt. *J. Basic Appl. Zool.* **2018**, *79* (1), 13. https://doi.org/10.1186/s41936-018-0028-4.

(11) Gure, A.; Kedir, K.; Abduro, F. Heavy Metal Concentrations in Fish Tissues from Gilgel Gibe (I) Hydroelectric Dam Reservoir, Ethiopia. *J. Appl. Sci. Environ. Manag.* **2019**, *23* (8), 1411. https://doi.org/10.4314/jasem.v23i8.1.

(12) Mustapha, A. M.; Ugya, A. Y.; Mustapha, Z. Assessment of heavy metal levels in fish tissues, water and sediment from epe lagoon, lagos, nigeria. **2021**, *16* (4).

(13) Sani, U. Determination of Some Heavy Metals Concentration in the Tissues of Tilapia and Catfishes. **2011**, *23* (2).

(14) Lati, A. *County To Establish A Fish Processing Plant In Kalokol - Turkana County Government*. https://turkana.go.ke/2023/02/17/county-to-establish-a-fish-processing-plant-in-kalokol/ (accessed 2025-06-18).

(15) Ratemo, C. M.; Ogendi, G. M.; Huang, G.; Ondieki, R. N. Application of Traditional Ecological Knowledge in Food and Water Security in the Semi-Arid Turkana County, Kenya. *Open J. Ecol.* **2020**, *10* (06), 321–340. https://doi.org/10.4236/oje.2020.106020.

(16) Bilalo, S. Q.; Andayi, A. A.; Njagi, E. C.; Ptoton, B. M. Concentrations of Selected Heavy Metals in Soil and Tomatoes (Lycopersicon Esculenta Mill.) Grown in Kirinyaga County, Kenya. **2024**, *11* (2), 932–942.

(17) Samantara, M. K.; Panigrahi, S.; Mohanty, A. K.; Sahu, G.; Mishra, S. S.; Palaniswami, K.; Subramanian, V.; Venkatraman, B. Heavy Metal Concentration in Marine Edible Fishes and Associated Health Risks: An Assessment from Tamil Nadu Coast, Bay of Bengal. *Environ. Chem. Ecotoxicol.* **2023**, *5*, 193–204. https://doi.org/10.1016/j.enceco.2023.09.002.

(18) Esilaba, F.; Moturi, W. N.; Mokua, M.; Mwanyika, T. Human Health Risk Assessment of Trace Metals in the Commonly Consumed Fish Species in Nakuru Town, Kenya. *Environ. Health Insights* **2020**, *14*, 1178630220917128. https://doi.org/10.1177/1178630220917128.

(19) Alabi, O. D.; Gounden, A.; Naidoo, K. K.; Mellem, J. J.; Paul, V. The Detrimental Influence of Heavy Metals and Contaminants on Food Production and Consumption. *J. Environ. Prot.* **2024**, *15* (12), 1035–1055. https://doi.org/10.4236/jep.2024.1512062.

(20) Plessl, C.; Otachi, E. O.; Körner, W.; Avenant-Oldewage, A.; Jirsa, F. Fish as Bioindicators for Trace Element Pollution from Two Contrasting Lakes in the Eastern Rift Valley, Kenya: Spatial and Temporal Aspects. *Environ. Sci. Pollut. Res.* **2017**, *24* (24), 19767–19776. https://doi.org/10.1007/s11356-017-9518-z.

(21) Andemo, A.; Yimer, G. T.; Sota, S. S.; Berego, Y. S. Level of Heavy Metals in Fish and Associated Human Health Risk From the Omo Delta in Southern Ethiopia: A First-Hand Report. *Environ. Health Insights* **2024**, *18*, 11786302241238180. https://doi.org/10.1177/11786302241238180.

(22) World Health Organization; Food and Agriculture Organization of the United Nations; Joint FAO/WHO Expert Committee on Food Additives. Meeting (80th: 2015, R., Italy). *Evaluation of Certain Food Additives and Contaminants: Eightieth Report of the Joint FAO/WHO Expert Committee on Food Additives*; WHO technical report series;995; World Health Organization: Geneva, 2016.