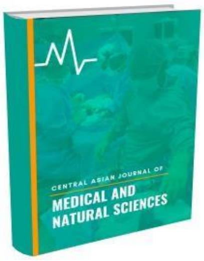

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Article

Detection of Some Heavy Metals in Tigris River Fish, South of Baghdad, Iraq

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Abstract: The presence and concentrations of several heavy metals in fish species discovered in the Tigris River, especially in southern Baghdad, Iraq, are investigated in this work. Essential for the neighbouring inhabitants, the Tigris River is becoming more polluted by urban, agricultural, and industrial activities. The research aimed to identify and analyze the concentrations of heavy metals (Cadmium, Copper, Nickel, Lead, and Zinc), evaluating the probable health dangers connected to fish consumption from this location. Different fish samples were collected from many points along the river, and advanced analytical techniques were used to ascertain the metal concentrations. The results showed varying degrees of contamination among the investigated species; several species exceeded accepted worldwide safety criteria. The findings of this research cause concerns about the possible long-term consequences of heavy metal pollution in the Tigris River on human health and ecology. This underlines the necessity of regular monitoring and more stringent environmental restrictions.

Keywords: heavy metals, fish, Tigris River, pollution

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1. Introduction

Historically, the Tigris River—which flows through Baghdad, Iraq, has been a major source of water for fishing, drinking, and agricultural usage. Still, the river has significant environmental problems, mostly related to heavy metals (Cadmium, Copper, Nickel, Lead, and Zinc) from rapid industry, urbanization, and farming activities. Particularly in fish, heavy metals are well-known for their longevity in the environment and their accumulation in aquatic life. For adjacent populations depending mostly on fish as their source of nutritional protein, the process of bioaccumulation poses major health risks (Mensoor and Said, 2023).

The probable negative effects heavy metal pollution of aquatic ecosystems has on human health and the environment lead to a general concern about it. The Tigris River, namely in Baghdad's southern area, Iraq, has shown elevated levels of heavy metals. Many other routes contaminate the river, including industrial effluents, agricultural drainage, and treated urban sewage. Aquatic life like fish may absorb heavy metals, which are vital elements of the local diet (Abed et al., 2023).

Fish may act as bioindicators of pollution and are sensitive to environmental changes. In addition to affecting the fish themselves, the bioaccumulation of heavy metals in fish tissues seriously affects human health. Studies on heavy metals, including cadmium and mercury, have shown that their presence may have major toxicological effects, including renal damage, neurological abnormalities, and cancer risk increases (Aljanabi et al., 2023). Guidelines for the highest allowable concentrations of certain metals in food have been developed by the World Health Organization (WHO) and other international health organizations. Recent studies, however, show that fish from the Tigris River often have above-recommended amounts of these metals. The Tigris River is important to the local population. Hence, regular monitoring and evaluation of heavy metal pollution levels is essential (Mansoor and Said, 2023; Abed et al., 2023). Possible health hazards implicated call for this as well. This study intends to find and quantify certain heavy metal (Cadmium, Copper, Nickel, Lead, and Zinc) concentrations in fish species present in southern Baghdad.

2. Materials and Methods

2.1. Research Location and Specimen Collection

The study was conducted on a section of the Tigris River south of Baghdad-Iraq. This location was selected based on its significance as a water supply and its close proximity to urban, agricultural, and industrial activity, which have the potential to result in heavy metal pollution. Fish specimens were obtained from three separate sites along the river to enable a thorough evaluation of the region.

A total of fish samples, which include species often eaten by the local populace, were gathered in autumn and winter from the three designated sampling stations: Al-Buitha (S1), Arab Jabour (S2), and Beige (S3) as Figure 1. Every station was chosen based on its distinct environmental attributes, such as its closeness to agricultural runoff, urban wastewater outflow, and industrial effluents. The fish were captured using conventional fishing techniques and promptly stored on ice for transportation to the laboratory (Sfakianakis, 2015).

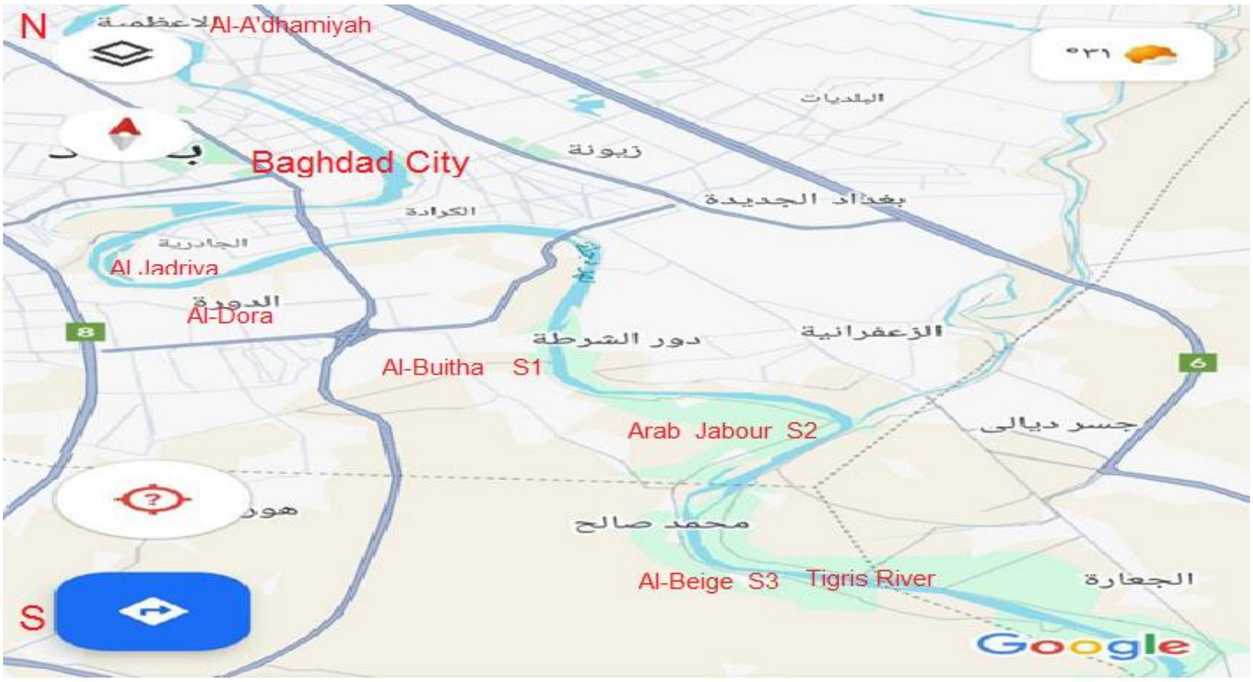

Figure 1. A map of Baghdad city-Iraq showing the course of the Tigris River

2.2. Preparation and Digestion of Tissue

Upon reaching the laboratory, the fish samples were meticulously dissected to obtain certain parts for investigation, such as the gills, liver, and muscle. These tissues were selected based on their significance in the accumulation of heavy metals and their critical role in human intake. The weight of each tissue sample was precisely measured using an analytical balance, and roughly 1 gram was transferred into a clean conical flask. To break down the organic materials and release the heavy metals into a liquid solution, 5 ml of concentrated nitric acid (HNO_3) and 1 ml of perchloric acid ($HClO_4$) were introduced into the flask. The samples were left at room temperature for one hour to undergo pre-digestion before being cooked on a hot plate at 100°C until violet fumes were seen. The temperature was further raised to 150-200°C until the appearance of thick white vapors, signifying the conclusion of the digesting process. The filtered solution was further adjusted to a volume of 25 ml using distilled water that had been acidified with 1% HNO_3 (Authman et al., 2015)

2.3. Analysis of Heavy Metal

The levels of toxic metals (Cadmium, Copper, Nickel, Lead, and Zinc) in the processed fish tissues were measured using Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS). This approach is very responsive and appropriate for identifying minute quantities of metals. Calibration curves were generated by measuring each element at its particular wavelength using meticulously prepared reference solutions. As an example, the measurement of cadmium was conducted at a specific wavelength of 228.8 nm using a lamp current of 8 mA and a slit width of 0.5 nm. Furthermore, the measurement of copper was conducted at a wavelength of 324.8 nm, using a lamp current of 6 mA. Three absorbance values were recorded to assure precision, and the average amounts were determined (Authman et al., 2015).

2.4. Quantitative Data Analysis

The results acquired from the GFAAS were subjected to statistical analysis to ascertain the average concentrations of each heavy metal in the various tissues. Statistical approaches ANOVA were used to evaluate differences across sample sites and fish species. A significance criterion of $p < 0.05$ was established for all tests to ascertain the statistical significance of the data.

3. Results

3.1. Heavy Metal Concentrations in Fish Tissues

The findings of the study revealed the concentrations of cadmium (Cd), copper (Cu), lead (Pb), nickel (Ni), and zinc (Zn) within the gills, liver, and muscle tissues of fish collected from the Tigris River, examining the variations in concentrations across sampling sites and seasons.

3.1.1 Cadmium (Cd)

Cadmium (Cd) is a hazardous heavy metal that can accumulate in fish tissues, potentially impacting aquatic ecosystems and human health. Gill tissues are the first point of contact between fish and their aquatic environment, acting as a primary filtration system for elements, including heavy metals (Surya & Malsoor, 2023: Phil, 2010), from the water. In the Tigris River, Cd concentrations in fish gills exhibited notable seasonal variation. In autumn, ST1 had no detectable levels of Cd, while ST2 and ST3 had concentrations of 63 ppb and 7 ppb, respectively. However, in winter, ST1 showed 66 ppb, ST2 had 55 ppb, and ST3 increased to 64 ppb. The increase in Cd concentrations during winter at these sites correlates with higher Cd levels in the water during this season, where concentrations at ST1 were recorded at 0.8 mg/L and ST3 at 0.25 mg/L. This suggests that the elevated water Cd levels directly influence the accumulation of Cd in the gills. High levels of Cd in gills can impair respiratory functions and lead to various fish diseases or even mortality.

Table 1. Effect of Location and Season on Cadmium (Cd) Concentration (ppb) in Fish Gills of the Tigris River

Location	Autumn	Winter	LSD
ST1	B.D.L.	66	14.93*
ST2	63	55	8.77 NS
ST3	7	64	13.98*
LSD	17.02*	10.76*	---

The liver plays a crucial role in detoxifying harmful substances, including heavy metals (Alijani et al., 2017), from a fish's body. However, when the liver becomes overwhelmed by high levels of toxins, such as Cd, it may redirect these toxins to other tissues, including muscles. In the Tigris River, Cd concentrations in liver tissues were significantly higher in autumn compared to winter. For instance, ST1 had 137 ppb in autumn and 60 ppb in winter, ST2 recorded 69 ppb in autumn and only 2 ppb in winter, and ST3 had 92 ppb in autumn and a marked increase to 450 ppb in winter. This increase in winter at ST3 could be attributed to the higher Cd concentration in water, recorded at 0.25 mg/L during winter. The liver's ability to process and store these toxins can lead to hepatotoxic effects, including liver dysfunction, which could eventually result in the liver sending excess Cd to other parts of the body.

Table 2. Effect of Location and Season on Cadmium (Cd) Concentration (ppb) in Fish Liver of the Tigris River

Location	Autumn	Winter	LSD
ST1	137	60	16.75*
ST2	69	2	12.55*
ST3	92	450	28.48*
LSD	15.86*	34.62*	---

The muscle tissue is particularly concerning due to its role as the primary portion of fish consumed by humans (Gao et al., 2023). High levels of Cd in muscle tissue can pose significant health risks to consumers. In the Tigris River, Cd concentrations in fish muscles were significantly higher in autumn than in winter. ST1 had 813 ppb in autumn and 76 ppb in winter, ST2 had 36 ppb in autumn and 94 ppb in winter, and ST3 showed 21 ppb in autumn and 99 ppb in winter. The higher autumn concentrations can be linked to the increased Cd levels in water at ST1, recorded at 0.8 mg/L during autumn. The ingestion of Cd-contaminated fish poses serious health risks to humans, including kidney damage, skeletal damage, and increased cancer risk. Consuming such contaminated fish regularly could result in chronic Cd exposure, leading to adverse health effects.

Table 3. Effect of Location and Season on Cadmium (Cd) Concentration (ppb) in Fish Muscles of the Tigris River

Location	Autumn	Winter	LSD
ST1	813	76	43.07*
ST2	36	94	18.37*
ST3	21	99	17.51*
LSD	32.63*	15.24*	---

Overall, Cd concentrations in fish tissues from the Tigris River are consistently higher across all types of tissues, indicating more significant pollution sources in the Tigris River. The seasonal variations observed in both rivers suggest that environmental factors and pollution inputs fluctuate with the seasons, affecting Cd accumulation in fish.

The elevated levels of Cd in fish, especially in the Tigris River, have serious implications for both aquatic health and human consumption. Cadmium exposure can lead to a range of health issues, including renal dysfunction, bone damage, and increased cancer risk. Consuming fish from contaminated waters poses a significant health risk, particularly for populations relying heavily on fish as a dietary staple. Thus, effective pollution control measures and regular monitoring of Cd levels are crucial to safeguarding both aquatic ecosystems and public health.

3.1.2 Copper (Cu)

Copper (Cu) is an essential trace element for aquatic organisms, but at elevated concentrations, it can become toxic, causing adverse effects on fish health and potentially impacting ecosystems. Gill tissues serve as the first point of contact between fish and their environment, functioning as a filtration system that allows elements, including heavy metals like copper, to enter the fish's body (Choudhary et al., 2023). In the Tigris River, the Cu concentration in gill tissues displayed significant seasonal variation. During autumn, ST1 showed 83 ppb, while both ST2 and ST3 had 23 ppb. In winter, the concentration at ST1 dropped sharply to 10 ppb, ST2 showed no detectable levels, and ST3 increased to 164 ppb. This seasonal fluctuation in Cu concentration can be directly linked to the Cu levels in the water. For example, the Cu concentration in the water at ST3 increased significantly in winter (with recorded levels of 0.20 mg/L), correlating with the elevated Cu levels in the gills at this site. High concentrations of Cu in gills can disrupt respiratory processes and lead to tissue damage, potentially causing respiratory distress or even mortality in fish.

Table 4. Effect of Location and Season on Copper (Cu) Concentration (ppb) in Fish Gills of the Tigris River

Location	Autumn	Winter	LSD
ST1	83	10	7.93*
ST2	23	B.D.L.	6.20*
ST3	23	164	17.55*
LSD	9.72*	15.94*	---

The liver is a critical organ for detoxification in fish, responsible for processing and eliminating toxins, including heavy metals like copper (Alvariño et al., 2024). However, when the liver is overwhelmed by high levels of Cu, it may start redistributing these toxins to other tissues, including muscles. In the Tigris River, Cu concentrations in liver tissues were considerably higher in autumn compared to winter. ST1 had 137 ppb in autumn, dropping to 60 ppb in winter, ST2 recorded 69 ppb in autumn and just 2 ppb in winter, while ST3 had 92 ppb in autumn, with a dramatic increase to 450 ppb in winter. The significant increase in Cu levels at ST3 during winter coincides with the elevated water Cu levels observed during the same season. Prolonged exposure to high Cu concentrations can overwhelm the liver's detoxification capabilities, leading to liver dysfunction and the subsequent redistribution of excess copper to other tissues, which can result in systemic toxicity and contribute to the deterioration of fish health.

Table 5. Effect of Location and Season on Copper (Cu) Concentration (ppb) in Fish Liver of the Tigris River

Location	Autumn	Winter	LSD
ST1	137	60	16.56*
ST2	69	2	14.91*
ST3	92	450	32.59*
LSD	13.95*	35.86*	---

Muscle tissues are particularly concerning from a public health perspective, as they are the primary portion of fish consumed by humans (Huang et al., 2022). Elevated levels of Cu in muscle tissues can pose significant health risks to consumers. In the Tigris River, Cu concentrations in muscle tissues were generally low. ST1 had 17 ppb in autumn, with no detectable levels in winter, ST2 showed 48 ppb in autumn and 49 ppb in winter, and ST3 had 4 ppb in autumn with no detectable levels in winter. The relatively low concentrations of Cu in muscle tissues compared to gills and liver suggest that copper is less likely to accumulate in muscle tissues, though chronic exposure to copper-contaminated fish can still pose health risks to humans. High Cu levels in consumed fish could lead to gastrointestinal distress, liver damage, and kidney dysfunction in humans.

Table 6. Effect of Location and Season on Copper (Cu) Concentration (ppb) in Fish Muscles of the Tigris River

Location	Autumn	Winter	LSD
ST1	17	B.D.L.	5.78*
ST2	48	49	3.41 NS
ST3	4	B.D.L.	4.01 NS
LSD	9.67*	8.25*	---

The seasonal variations observed suggest that environmental factors, such as industrial discharges and agricultural runoff, significantly influence copper accumulation in fish. The elevated levels of Cu in fish in the Tigris River have serious implications for both aquatic health and human consumption. Chronic copper exposure can lead to various health issues, including gastrointestinal distress, liver and kidney damage, and even neurological effects in severe cases. Consuming fish from contaminated waters poses a significant health risk, particularly for populations that rely heavily on fish as a dietary staple. Therefore, regular monitoring of Cu levels in fish tissues, along with measures to reduce industrial discharges and agricultural runoff, is crucial for safeguarding both aquatic ecosystems and public health.

3.1.3 Lead (Pb)

Lead (Pb) is a highly toxic heavy metal that poses significant health risks to both aquatic life and humans. Its presence in fish tissues, particularly in ecosystems like the Tigris River, indicates environmental contamination that can have severe biological and ecological consequences. Gill tissues in fish are the primary interface with the aquatic environment, serving as the first line of defense and the main site for the absorption of waterborne pollutants, including heavy metals like lead. The concentration of Pb in gill tissues of fish from the Tigris River showed significant seasonal and locational variation. During autumn, ST1 recorded a Pb concentration of 73 ppb, which dramatically increased to 1105 ppb in winter. ST2 and ST3 also showed high levels of Pb, with ST2 increasing from 737 ppb in autumn to 1039 ppb in winter, and ST3 from 1012 ppb to 1163 ppb during the same period. The increase in Pb concentration in gills during winter can be correlated with elevated Pb levels in the water, likely due to industrial runoff and increased pollution during this season. High Pb concentrations in gills can impair respiratory functions, leading to hypoxia, and can also cause damage to the gill tissues, which are crucial for the fish's survival.

Table 7. Effect of Location and Season on Lead (Pb) Concentration (ppb) in Fish Gills of the Tigris River

Location	**Autumn**	**Winter**	**LSD**
ST1	73	1105	67.43*
ST2	737	1039	89.67*
ST3	1012	1163	62.77*
LSD	82.95*	54.19*	---

The liver plays a crucial role in detoxifying harmful substances, including heavy metals like Pb. However, when the liver is overwhelmed by excessive Pb, it can no longer effectively detoxify the body, leading to systemic toxicity. In the Tigris River, Pb concentrations in liver tissues varied significantly between seasons. ST1 recorded 36 ppb in autumn, with no detectable levels in winter. ST2 showed a high Pb concentration of 430 ppb in autumn, but like ST1, had no detectable levels in winter. Interestingly, ST3 had no detectable Pb in autumn but showed 80 ppb in winter. The fluctuation in Pb levels could be linked to varying levels of Pb in the water, where autumn saw higher contamination, leading to higher Pb uptake by the liver. High Pb concentrations in the liver can impair its function, leading to liver damage, reduced ability to detoxify other harmful substances, and increased risk of disease and mortality in fish.

Table 8. Effect of Location and Season on Lead (Pb) Concentration (ppb) in Fish Liver of the Tigris River

Location	**Autumn**	**Winter**	**LSD**
ST1	36	B.D.L.	11.76*

ST2	430	B.D.L.	47.93*
ST3	B.D.L.	80	14.37*
LSD	52.35*	16.08*	---

Muscle tissues are of particular concern when assessing the risk to human health, as they are the primary part of the fish consumed by humans. The presence of Pb in muscle tissues indicates the potential risk of lead poisoning for consumers. In the Tigris River, Pb concentrations in muscle tissues were variable across seasons. During autumn, ST1 recorded 218 ppb, which increased to 618 ppb in winter. ST2 showed a decrease from 377 ppb in autumn to 504 ppb in winter, while ST3 had 174 ppb in autumn, increasing significantly to 736 ppb in winter. The increase in Pb levels during winter correlates with higher Pb concentrations in the water, leading to increased accumulation in muscle tissues. Consumption of fish with high Pb levels poses significant health risks, including lead poisoning, which can cause neurological damage, especially in children, as well as kidney damage and cardiovascular issues in adults.

Table 9. Effect of Location and Season on Lead (Pb) Concentration (ppb) in Fish Muscles of the Tigris River

Location	Autumn	Winter	LSD
ST1	218	618	52.79*
ST2	377	504	77.04*
ST3	174	736	72.25*
LSD	48.07*	37.44*	---

Overall, Pb concentrations in fish tissues from the Tigris River show significant seasonal and locational variation, with generally higher levels observed during winter. The elevated Pb levels in gills and liver tissues suggest that these organs are more prone to lead accumulation, which can severely impair their function and lead to increased mortality rates among fish. The presence of Pb in muscle tissues, although variable, poses a direct risk to human health, particularly for populations that consume fish from these waters. Chronic exposure to lead through fish consumption can lead to serious health problems, including neurological disorders, kidney damage, and cardiovascular diseases (Dippong et al., 2024).

The observed Pb concentrations indicate the need for strict regulation and monitoring of industrial discharges and agricultural runoff to prevent further contamination of aquatic ecosystems. Reducing lead levels in water and, consequently, in fish tissues is essential for protecting both aquatic life and human health. Continued research and implementation of pollution control measures are crucial for mitigating the impact of lead contamination on the environment and public health.

3.1.4 Nickel (Ni)

Nickel (Ni) is a transition metal that, while essential in trace amounts for some biological processes, can become toxic at higher concentrations. Its presence in fish tissues, particularly in areas such as the gills, liver, and muscles, can indicate significant environmental contamination.

The gills are the primary organs for the exchange of gases and also serve as the first line of defence against contaminants. Elevated levels of Ni in gill tissues can indicate significant pollution in the surrounding water. In the Tigris River, Ni concentrations in gill tissues showed notable seasonal and locational variations. During autumn, ST1 had a Ni concentration of 307 ppb, which increased to 336 ppb in winter. ST2 recorded 78 ppb in autumn, rising to 111 ppb in winter, while ST3 had 248 ppb in autumn and decreased to 106 ppb in winter. The higher concentrations in winter could be attributed to increased industrial and domestic discharges, which may contribute to higher Ni levels in the water, leading to greater accumulation in the gills. Elevated Ni levels in gills can impair respiratory functions and overall health of fish.

Table 10. Effect of Location and Season on Nickel (Ni) Concentration (ppb) in Fish Gills of the Tigris River

Location	**Autumn**	**Winter**	**LSD**
ST1	307	336	22.84*
ST2	78	111	13.68*
ST3	248	106	24.71*
LSD	34.09*	38.26*	---

The liver plays a critical role in detoxifying and processing heavy metals such as Ni. However, excessive Ni levels can overwhelm the liver's detoxification capacity, leading to potential health issues in fish. In the Tigris River, Ni concentrations in liver tissues varied significantly. ST1 had 186 ppb in autumn, which surged to 2718 ppb in winter. ST2 recorded 2265 ppb in autumn, decreasing to 473 ppb in winter, while ST3 showed 2536 ppb in autumn, dropping to 1100 ppb in winter. The dramatic increase in Ni concentrations during winter suggests a significant rise in water pollution levels, possibly due to industrial activities or runoff. High Ni levels in the liver can lead to liver damage, impaired detoxification, and overall poor health in fish.

Table 11. Effect of Location and Season on Nickel (Ni) Concentration (ppb) in Fish Liver of the Tigris River

Location	**Autumn**	**Winter**	**LSD**
ST1	186	2718	68.52*
ST2	2265	473	81.04*
ST3	2536	1100	61.75*
LSD	75.37*	91.87*	---

Nickel concentrations in muscle tissues are of particular concern due to their direct impact on human health. High Ni levels in fish muscles can be a direct source of contamination for humans, potentially leading to various health issues. In the Tigris River, Ni levels in muscle tissues varied greatly. ST1 had 4.7 ppb in autumn, which increased significantly to 78 ppb in winter. ST2 recorded 15 ppb in autumn, rising drastically to 2718 ppb in winter, while ST3 showed 115 ppb in autumn, decreasing to 56 ppb in winter. The substantial increase in winter could be attributed to elevated Ni levels in the water, which are then transferred to muscle tissues. Consuming fish with high Ni levels can lead to adverse health effects, including gastrointestinal and renal problems.

Table 12. Effect of Location and Season on Nickel (Ni) Concentration (ppb) in Fish Muscles of the Tigris River

Location	**Autumn**	**Winter**	**LSD**
ST1	4.7	78	8.05*
ST2	15	2718	41.78*
ST3	115	56	13.65*
LSD	17.02*	56.84*	---

Nickel concentrations in fish tissues from both the Tigris River exhibit significant seasonal and locational variations. In the Tigris River, higher Ni concentrations in winter across all tissues suggest increased environmental contamination during this period, likely due to enhanced industrial or domestic discharges. The elevated levels in gills and liver tissues indicate that these organs are heavily impacted by Ni pollution, which can impair fish health and reduce their survival rates. The high Ni levels in muscle tissues raise concerns about human health risks, as consuming fish with elevated Ni concentrations can lead to various health issues, including gastrointestinal disorders and renal damage (Kousar et al., 2020).

3.1.5 Zinc (Zn)

Zinc (Zn) is an essential trace element necessary for various biological functions in aquatic organisms, including enzyme activity and immune system support. However, excessive levels can disrupt these functions and indicate environmental contamination.

The gills, being the primary site for the exchange of gases and filtering of contaminants, are the first organs affected by changes in water quality. In the Tigris River, Zn concentrations in gill tissues showed minimal variation between autumn and winter. ST1 had 11.5 ppb in autumn and 8.9 ppb in winter. ST2 showed a slight increase from 17.8 ppb in autumn to 12.1 ppb in winter, while ST3 had 10.5 ppb in autumn and 12.4 ppb in winter. The low and stable levels of Zn suggest that the Tigris River's Zn pollution levels might not be significantly impacting the gills in either season.

Table 13. Effect of Location and Season on Zinc (Zn) Concentration (ppb) in Fish Gills of the Tigris River

Location	**Autumn**	**Winter**	**LSD**
ST1	11.5	8.9	2.25 NS
ST2	17.8	12.1	4.37*
ST3	10.5	12.4	2.87 NS
LSD	4.83*	3.39*	---

The liver is crucial for detoxifying metals like Zn. Elevated Zn levels in the liver can stress the detoxification processes and lead to potential health issues. In the Tigris River, Zn levels in liver tissues varied significantly. ST1 had 10.7 ppb in autumn and 13 ppb in winter. ST2 saw a decrease from 9.6 ppb in autumn to 1.5 ppb in winter, and ST3 exhibited an increase from 11.7 ppb in autumn to 63.5 ppb in winter. The increase in ST3 could be linked to higher Zn pollution in winter, possibly from increased industrial or agricultural runoff.

Table 14. Effect of Location and Season on Zinc (Zn) Concentration (ppb) in Fish Liver of the Tigris River

Location	Autumn	Winter	LSD
ST1	10.7	13	2.97 NS
ST2	9.6	1.5	4.06*
ST3	11.7	63.5	7.17*
LSD	0.87*	6.38*	---

High Zn levels in muscle tissues are critical as they directly affect human health upon consumption. In the Tigris River, Zn concentrations in muscle tissues showed a decrease in winter. ST1 had 7.4 ppb in autumn, dropping to 3.4 ppb in winter. ST2 recorded 2.3 ppb in autumn and increased to 4.1 ppb in winter. ST3 had 3.1 ppb in autumn and 3.5 ppb in winter. The variations in muscle Zn levels suggest seasonal fluctuations in water pollution or changes in fish exposure to contaminants.

Table 15. Effect of Location and Season on Zinc (Zn) Concentration (ppb) in Fish Muscles of the Tigris River

Location	Autumn	Winter	LSD
ST1	7.4	3.4	2.95*
ST2	2.3	4.1	2.06 NS
ST3	3.1	3.5	1.88 NS
LSD	3.07*	2.27 NS	---

Zinc concentrations in fish tissues from the Tigris River exhibit variability based on location and season. In the Tigris River, Zn levels in gills, liver, and muscles suggest a stable yet slightly elevated presence of Zn, particularly in winter, which could be indicative of increased environmental contamination.

The observed Zn levels in muscle tissues from both water bodies are critical for human health, as high Zn concentrations can cause health issues such as gastrointestinal disturbances and, in extreme cases, neurological problems if consumed over long periods (Elliott et al., 2023). Monitoring and managing Zn pollution is essential to safeguard both aquatic ecosystems and human health (Duan et al., 2010).

4. Discussion

4.1. Accumulation of Cadmium (Cd)

The study's results indicated that the levels of cadmium (Cd) in fish tissues from the Tigris River differed greatly depending on the season and location of sample. Elevated concentrations of Cd were specifically seen in the gills during the winter season, indicating a clear association with heightened Cd levels in the water at that time. Due to their direct exposure to the aquatic environment, the gills have a tendency to absorb heavy metals from the water. The buildup of Cd in fish may result in respiratory dysfunction, since Cd has been shown to harm the gill tissues, thus impacting the general well-being and survival of fish populations. The results of this study are consistent with prior research that has shown that gill tissues are prone to accumulating Cd owing to their direct contact with waterborne contaminants (Kalay et al., 1999; Tüzen, 2003).

The research revealed that Cd concentrations in the liver were notably elevated at station ST3 during the winter season, indicating the liver's crucial function as a key organ for detoxification in fish. The liver's capacity to accumulate heavy metals is well established, but, excessive accumulation may result in liver injury and other physiological abnormalities. Yilmaz et al. (2007) made similar findings, noting that fish exposed to polluted settings had elevated levels of Cd in their livers compared to other organs. The hepatotoxic effects of Cd pose a significant issue due to their potential to impair liver function and overall fish health.

The occurrence of Cadmium (Cd) in the muscle tissue, which is the main portion of the fish that is ingested by people, is especially concerning. The investigation revealed that the levels of Cd in fish muscles above the prescribed safety thresholds in many instances, hence presenting a substantial health hazard to consumers. Long-term exposure to Cadmium (Cd) from eating fish that is polluted may result in serious health issues, such as kidney dysfunction and loss of minerals from the bones, as emphasized by Jarup (2003). The World Health Organization (WHO) and Food and Agriculture Organization of the United Nations (FAO) maximum permissible levels of Cd in freshwater fishes is 0.05 mg/kg (World Health Organization, 1995). These results emphasize the need of closely monitoring the levels of Cd in fish and implementing efficient pollution control strategies to safeguard both aquatic organisms and human well-being.

4.2. Accumulation of Copper (Cu)

Copper (Cu) is a vital micronutrient for several biological processes in aquatic creatures, but it becomes harmful when present in high levels. The research found that the levels of Cu (copper) in the gills of fish changed greatly depending on the season. Higher concentrations were seen during the fall at ST1 and ST3. This pattern indicates a potential connection between Cu pollution and seasonal causes, such as increased agricultural runoff or industrial effluents, which occur throughout certain periods of the year. Increased copper (Cu) levels in the gills may cause physical harm and hinder the ability to breathe properly, aligning with the observations made by Al-Yousuf et al. (2000) who documented comparable impacts of copper on fish gills in polluted environments.

Higher quantities of Cu were identified in the liver throughout fall, especially at station ST3, suggesting that the liver plays a role in detoxifying Cu and storing excessive amounts. Kamunde et al. (2001) extensively studied the liver's reaction to Cu exposure, which involves an augmentation in the creation of metal-binding proteins (William,1993). Nevertheless, an excessive amount of copper might surpass the liver's ability to handle it, resulting in oxidative stress and the possibility of liver damage, as shown by Vinodhini and Narayanan (2008).

The levels of Cu in muscle tissues were significantly lower in comparison to the gills and liver, but remained significant. The presence of high levels of copper (Cu) in muscle tissue may be detrimental to human health, particularly when routinely consuming fish from polluted environments. The study of Malik et al. (2010) provides support for the idea that consuming fish contaminated with Cu might pose significant health hazards. The World Health Organization (WHO) and Food and Agriculture Organization of the United Nations (FAO) maximum permissible levels of Cu in freshwater fishes is 10 mg/kg (World Health Organization, 1995). Prolonged exposure to copper via dietary intake may result in gastrointestinal discomfort, as well as harm to the liver, kidneys, and other aspects of health.

4.3. Accumulation of Lead (Pb)

Lead (Pb) was detected in different amounts in all fish tissues examined, showing notable variations depending on the season and location. The gills had the greatest levels of Pb during the winter months, namely at station ST3. Exposure to Pb is recognized to result in significant harm to the gill tissues, impacting the breathing efficiency of fish and resulting in hypoxia. These results align with the research conducted by Burger et al. (2002), which indicated that Pb tends to accumulate significantly in gill tissues as a result of their direct contact with the polluted water.

Significant lead (Pb) buildup was seen in the liver, particularly in fall at station ST2. This statement highlights the liver's function in metabolizing and eliminating harmful heavy metals, while simultaneously emphasizing its susceptibility to lead intoxication. Various investigations, such as those conducted by Patra et al. (2011), have established the harmful impact of Pb on liver function. This includes disturbances in enzyme activity and heightened oxidative stress.

The presence of high levels of Pb in muscle tissues is a major public health hazard, since these tissues are ingested by people (Geneva et al., 2004). The research discovered that the levels of Pb in fish muscles beyond the established safety thresholds, especially in the winter season. This is concerning due to the neurotoxic properties of Pb, particularly in children, since prolonged exposure may result in cognitive deficits, developmental delays, and other significant health problems. Jarup (2003) stressed the need of regularly monitoring The World Health Organization (WHO) and Food and Agriculture Organization of the United Nations (FAO) maximum permissible levels of Pb in freshwater fishes is 0.3 mg/kg (World Health Organization,1995). lead (Pb) levels in food sources to safeguard public health, particularly in relation to fish intake (Dvorak, 2004).

4.4. Accumulation of Nickel (Ni)

Significant variations in Nickel (Ni) concentrations were seen across different organs and seasons, with the liver exhibiting the greatest levels during the winter. The liver plays a crucial role in metabolizing nickel, but an excessive buildup may result in toxic consequences, such as liver dysfunction and altered metabolic activities (Velez, 1998). These results align with the research conducted by Heath (1995), which observed that the liver is often the main location for the buildup and harmful effects of heavy metals in fish.

The research also observed substantial Ni buildup in the gills, which is worrisome considering the gills' function in gas exchange and their direct contact with waterborne pollutants. Vinodhini and Narayanan (2008) revealed that elevated levels of nickel in the gills may cause structural harm and impair breathing efficiency. These factors may have a cascade impact on the health of fish, resulting in decreased rates of growth, heightened vulnerability to illnesses, and elevated death rates (Hassan et al., 2016).

The presence of Ni in muscle tissues, although typically lesser compared to the gills and liver, nonetheless presents a potential danger to those who ingest them. The European Food Safety Authority (EFSA, 2015) has proven the capacity of Ni to induce allergic responses, skin irritations, and other health problems when consumed via contaminated seafood. The World Health Organization (WHO) and Food and Agriculture Organization of the United Nations (FAO) maximum permissible levels of Ni in freshwater fishes 0.5–1.0 mg/kg (World Health Organization, 1995). This emphasizes the need of monitoring nickel levels in fish to guarantee food safety and safeguard public health (Andrew et al., 2013).

4.5. Accumulation of Zinc (Zn)

Zinc (Zn) is a necessary micronutrient, although it may be toxic at high levels. The research observed that the levels of Zn in fish organs were largely consistent across different seasons, however there were minor variations seen in the liver and gills. The liver has a well-established function in the metabolism of Zn, and its capacity to control Zn levels is essential for maintaining homeostasis. Nevertheless, if the levels of Zn surpass the liver's ability to detoxify, it might result in hepatic stress and harm, as seen by Canli and Atli (2003).

The presence of Zn buildup in the gills suggests a potential rise in water pollution caused by higher levels of zinc. Although Zn is essential for several physiological functions, an excessive amount of Zn may interfere with gill function, resulting in breathing problems and general physiological strain (Lall, 1979). These results align with the research conducted by Heath (1995), which indicated that elevated amounts of zinc may disrupt the functioning of fish gills and decrease their ability to transport oxygen.

The amounts of zinc in muscle tissues, albeit comparatively lower than in other tissues, are nonetheless a cause for worry since people directly consume them (Phyllis et al. 2007). Prolonged exposure to elevated quantities of zinc via dietary intake might result in gastrointestinal discomfort and several other health complications. Studies conducted by Allen-Gil and Martynov (1995) have emphasized the health hazards linked to excessive consumption of Zn from polluted fish, thereby emphasizing the need of consistent monitoring and control of Zn levels in aquatic ecosystems. The World Health Organization (WHO) and Food and Agriculture Organization of the United Nations (FAO) maximum permissible levels Zn in freshwater fishes is 30 mg/kg (World Health Organization, 1995).

5. Conclusion

This research measured heavy metals in Tigris River fish species south of Baghdad, Iraq, including Cadmium (Cd), Copper (Cu), Nickel (Ni), Lead (Pb), and Zinc (Zn). Variations in metal concentrations across tissues (gills, liver, and muscle) and sample sites suggest that urban runoff, industrial discharge, and agricultural activities affect these metals. Some heavy metal concentrations surpass the prescribed safety limits for human eating, causing health dangers to the local community that depends on these fish as a mainstay. These metals bioaccumulating in fish tissues harm human health and disturb the aquatic ecology, which may have long-term ecological effects. This research emphasizes the necessity of continual monitoring and strict management of Tigris River pollution sources to prevent additional contamination. Public awareness and policy initiatives are needed to protect environmental and public health in the area. In conclusion, heavy metals in Tigris River fish indicate environmental contamination, requiring quick action from appropriate authorities to protect this crucial water resource.

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