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Analysis of heavy metal levels in fish of the Diwaniyah River: Environmental impacts and health risks to humans

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ABSTRACT
This study examines the presence of heavy metal pollution in three prevalent species of river fish, namely Cyprinus carpio, Spondyliosoma cantharus, and Liza bandialensis Diouf, from the Al-Diwaniyah River. The concentrations of lead (Pb), cadmium (Cd), zinc (Zn), iron (Fe), and copper (Cu) in the muscle tissue, gills, and liver of these fish were analyzed during both summer and winter seasons. The Ecological Risk Index (ERI), Geo-accumulation Index (Igeo), Pollution Load Index (PLI), Estimated Daily Intake (EDI), Carcinogenic Risk (CR), and Target Hazard Quotient (THQ) were computedto evaluate the dangers to both the environment and human health. The results indicate that contamination levels differ across seasons and places, with S4 demonstrating the highest. The Igeo data reveal most sites are classified as heavily to extremely contaminated, especially for Cd and Fe. The PLI values indicate the level of pollution in some locations, particularly in winter. The Ecological danger Index (ERI) indicates a moderate to significant ecological danger for the majority of metals, with Cd presenting the greatest risk. The EDI (Estimated Daily Intake) values of heavy metals indicate potential dangers of dietary exposure, with the levels of Pb (lead) and Cd (cadmium) beyond the recommended limits. The THQ values for the majority of metals are less than 1, which suggests a low risk of non-carcinogenic health effects. Nevertheless, the CR values for Pb and Cd indicate possible carcinogenic hazards, especially at sites S3 and S4. The investigation reveals substantial heavy metal pollution in the Al-Diwaniyah River, which has important consequences for ecosystem well-being and the safety of humans. The study's limitations are due to its narrow focus on time and space, which necessitates additional research to cover wider periods and more thorough risk evaluations. Future research should additionally investigate the process of bioaccumulation and devise methods to minimize the contamination of heavy metals to protect both the environment and public health.

Keywords: Heavy Metal, Pollution, Al-Diwaniyah River, River Fishes, Health Risk.

1 INTRODUCTION

The escalation of geological and anthropogenic activity in Iraq has led to a significant rise in the severity of environmental problems associated with the poisoning of rivers by heavy metals(Budi et al., 2024). These activities have elevated the concentration of these components to levels that pose a threat to the ecosystem as well as human health risk(Hou et al., 2019). The fast industrialization and urbanization have led to an increase in traffic activity, which in turn has significantly contributed to the accumulation of heavy metals released by automobiles in the environment. The presence of heavy metals in agricultural areas due to traffic emissions has the potential to poison the aquatic species growing in that environment(Raj & Maiti, 2020). The fish inhabiting these polluted rivers exhibit diminished growth, performance, and yield. Recorded growth reductions have been observed in fish inhabiting rivers contaminated with heavy metals, due to alterations in their physiological and metabolic processes(Al-Asadi & Al-Kafari, 2022). Heavy metals can be absorbed by humans through consuming contaminated fish, and this can be particularly significant in agricultural regions where heavy metal uptake is common. People living near the source might be readily affected by heavy metal pollutants through suspended dust or direct contact. If these toxins surpass the threshold limit, they have the potential to enter the food chain by being absorbed by edible river organisms. This can lead to significant health hazards. Monitoring the quantities of heavy metals in the riverenvironment is crucial due to their toxicity, particularly for Cd and Pb, as well as their persistence and non-degradability(Hasham & Ramal, 2022).
Heavy metals pose a significant risk due to their propensity for accumulation(Shuhaimi-othman et al., 2013). Compounds in living organisms accumulate when they are absorbed and stored at a higher rate and they are

broken down or degraded(Adegbola et al., 2021a).Heavy metals can infiltrate the water system through industrial or consumer waste, as well as through the breakdown of soils by acidic rain, which releases heavy metals into streams, lakes, rivers, and groundwater. Heavy metals poisons are responsible for causing a range of negative health impacts. More than 20 distinct heavy metal toxins are released, which have adverse effects on human health(Jaishankar et al., 2014). Each toxin induces unique behavioral, physiological, and cognitive alterations in persons who are exposed to them. The extent to which a system, organ, tissue, or cell is impacted by a heavy metal toxin is contingent upon both the specific toxin and the level of exposure experienced by the individual. The relative toxicity of heavy metals can be ranked in descending order as follows: Hg>Cd>Cu>Zn>Ni>Pb>Cr>Al>Co(Rajeshkumar & Li, 2018). However, it is important to note that the susceptibility of different species to specific metals may vary, making this ranking simply an approximation. The toxicity of metals is influenced by the environmental circumstances that regulate their chemical speciation.

Heavy metals in the environment harm aquatic species. The toxicity mostly depends on the chemical properties of the water and the makeup of the sediment in the surface water system(Gerenfes et al., 2019). Moreover, the capacity of aquatic species to absorb metal is mostly influenced by the physical and chemical properties of the metal(Rajeshkumar & Li, 2018). Aquatic organisms generally do not accumulate significant amounts of metals, save for mercury. Metals can infiltrate the systems of aquatic species through three primary pathways. Metal ions that are absorbed through the respiratory surface, such as gills, can easily permeate into the bloodstream(Zheng et al., 2019). Free metal ions that have been adsorbed onto the surface of the body can passively permeate into the bloodstream(Sonone et al., 2021). Metals that adhere to food and particles can potentially be consumed, together with free ions that are consumed by water intake(Afzaal et al., 2022). Fish, for instance, are able for extracting excessive amounts of critical metals like copper, zinc, and iron(Shah, 2017). Additionally, certain methods can recover non-essential metals like mercury and cadmium, although these efforts often provide less favorable results.

Environmental pollution by these metals has become a growing ecological and worldwide public health concern in recent years(Vanisree et al., 2022; Fatima et al., 2020; Pandey & Sharma, 2014; Parvez et al., 2023). Heavy metals are significant environmental contaminants, as their concentrations in air, soil, and water are consistently rising due to human activity. The issue of environmental contamination caused by toxic metals is a significant concern in the majority of large urban areas. The introduction of hazardous metals into the ecosystem can result in the accumulation of these metals in the environment, as well as their buildup in organisms through the food chain, leading to an increase in concentration at each trophic level. The global issue of heavy metal pollution in the natural environment arises from the fact that these metals are non-biodegradable and possess harmful properties that can adversely affect living creatures when their concentration is above a specific threshold(Akcali & Kucuksezgin, 2011; Fatima et al., 2020; Leite et al., 2022). Environmental pollution is caused by heavy metals including copper, lead, and zinc. These metals come from sources such as leaded petrol, industrial effluents, and the leaching of metal ions from the soil into lakes and rivers due to acid rain. Environmental contamination is particularly prevalent in point source areas, such as mining sites, foundries, smelters, and other metal-based industrial processes(Man et al., 2020). The ecosystem has been altered due to the rapid industrialization and introduction of harmful compounds into the environment(Danladi & Akoto, 2021).

There has been very little study in recent times in assessing the status of heavy metal concentration the Al-Diwaniyah River in Iraq. In our previous studyHameed & Al-Taie (2024), we reported a complete assessment of heavy metal concentration in both water and sediment of the Al-Diwaniyah River as well as evaluated the Water Quality Index (WQI) of the Al-Diwaniyah River. However, in this study, we expanded the scope of the study and investigated the heavy metal pollution in common river fishes that the majority of people consume as a part of their daily protein intake. Therefore, it became necessary to assess the environmental and human health risk factors that are associated with the contamination of heavy metals. This study can be considered the first attempt to evaluate the heavy metals pollution in sediments and three common species of river fishes, Cyprinus carpio, Spondyliosoma cantharus, and Liza bandialensis Diouf, of the Al-Diwaniyah River sediment by using various environmental and health risk indices.

2 MATERIALS AND METHODS

2.1 Study Area and Sampling Stations

Four sites in the city of Diwaniyah were selected for the research sample collection and analysis. The initial location (Station 1) was located inside the Diwaniyah water purification facility (coordinates: N = 31°96'27.5": E = 44°94'81.6"), which supplies drinking water, to the north of the city. The second station, Station 2, was situated at Abd Al Rasool (coordinates: N = 32°00'42"; E = 44°53'54"), in the residential zones authorized for drinking water delivery. Now, for the third station (Station 3), its coordinates were N = 31°59'21" and E = 44°54'45"; it was located south of the city, near Rivers Elementary School, on Al Naher Street. Last but not least, the Diwaniyah Rubber Factories was home to Station 4 (coordinates: N = 31°37'35"; E = 44°56'41"). These four sampling locations were used to distinguish between the levels of heavy metal pollution in various regions. While station 1 is mostly an agricultural area and is less populated, station 4 is an industrial area. Additionally, residents use Station 2 for residential purposes, and Station 3 is used for educational purposes. As a result, it is anticipated that these four locations will highlight the variations in heavy metal contamination and the health risks associated with eating contaminated fish.

2.2 Sample Collection

From the Al-Diwaniyah River, three of the most popular fish species—Cyprinus carpio, Spondyliosoma cantharus, and Liza bandialensis Diouf—were chosen. From each station, three duplicates of every species were gathered from the research area. Following collection, the fish samples were transported to the lab after being kept refrigerated in an icebox to minimize environmental exposure. Before the fish were dissected, the samples were defrosted for anthropometric measurements. Since the fish samples' livers, gills, and muscle tissues are the main organs where heavy metal accumulation occurs, these organs were removed for the heavy metal examination. Every tissue sample was subjected to oven drying at 80°C and monitored until a consistent weight was achieved.

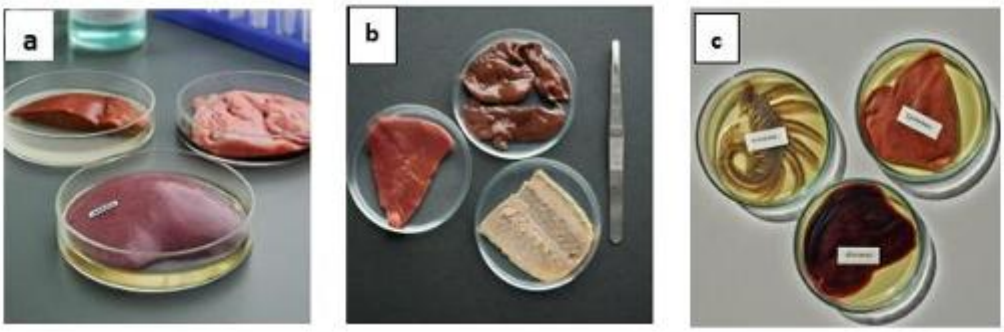

Figure 1: Liver, Gills and Muscle Tissue of (a)Cyprinus carpio, (a) Spondyliosoma cantharus and (c) Liza bandialensis Diouf.

2.3 Digestion of Fish Tissues

Fish liver, gills, and muscle were sliced and dehydrated in an oven at 110°C until a consistent weight was achieved. A 5 g dry weight sample was placed in a 50 ml beaker together with 5 ml of HNO_3 and 5 ml of H_2SO_4. The fish tissue was heated at 60°C for 30 minutes when it no longer reacted with HNO_3 and H_2SO_4 in the beaker. After cooling the beaker, 10 ml of HNO_3 was added and then slowly heated to 120°C on the hot plate. The temperature was raised to 150°C, and the beaker was taken off the hot plate after the samples darkened. The sample was cooled before adding H_2O_2 till it became transparent. The beaker's contents were poured into a volumetric flask and then diluted. Prior to use, all glassware must be immersed in diluted nitric acid for 24 hours and rinsed with distilled deionized water. The process of fish digestion was also discussed in other works by Gebremedhin (2015) and Greenfish et al. (2019). The fish tissues were prepared for atomic absorption spectroscopy (AAS) analysis to determine the concentration of heavy metals in specific tissues of the selected fish species. Refer to Appendix A for a detailed description of instrument calibration and the various reagents used for the analysis.

2.4 Environmental Indices

When heavy metals are present in the soil, they pass via the plants as well as aquatic species and eventually reach the human body. Plant and animal metabolisms are eventually affected. Base-line data is important for figuring out how much of each element is present in soil samples in terms of environmental indices like the geo-accumulation index (I_{geo}), Pollution Load Index (PLI) and Potential Ecological Risk Index (ERI). In the following, each of the indices is presented in brief along with their respective equation.

A. Geo-accumulation Index (I_{geo})

I_{geo} was used to measure the amount of heavy metal pollution in both land and water environments (Abrahim & Parker, 2008). The following equation was used to describe the geo-accumulation index (I_{geo}):

$$\mathbf{Igeo} = \mathbf{Log_2}\left(\frac{\mathbf{C_n}}{\mathbf{1.5 \times B_n}}\right) \qquad \mathbf{1}$$

Where Cn represents the measured concentration of metal n and Bn represents the geochemical background concentration of metal n. As a result of the influence of the lithosphere, a background matrix correction factor of 1.5 will be applied. The geo-accumulation index categorizes into the following classes or grades, which are defined as follows (Ma et al., 2016):

Table 1: Various Classes of Geo-accumulation Index (Igeo)

Class	Igeo Value	Status
0	Igeo = 0	Represents a practically uncontaminated state
1	Igeo ≤ 0	Indicates an uncontaminated to moderately contaminated condition
2	0 < Igeo < 1	Denotes a moderately contaminated status
3	1 < Igeo < 2	Represents a moderately to heavily contaminated situation
4	2 < Igeo < 3	Indicates a heavily contaminated state
5	3 < Igeo < 4	Represents a heavily to extremely contaminated condition
6	4 < Igeo < 5	Denotes an extremely contaminated level
7	Igeo > 5	An open class that encompasses all values of the index higher than that of class 6. In class 7, elemental concentrations may be 100 times greater than the geochemical background value.

B. Pollution Load Index (PLI)

This practical index provides a convenient and direct approach assessing the extent of heavy metal contamination. The Contamination Factors (CFs) of specific heavy metals at a given sampling location are utilized to establish the Pollution Load Index (PLI) (Mohiuddin et al., 2011), which is defined as follows:

$$\mathbf{CF} = \frac{(\mathbf{C_n})_{\mathbf{sample}}}{(\mathbf{C_n})_{\mathbf{background}}} \qquad \mathbf{2}$$

Where C_n is the concentration of any element or metal. Moreover, based on CF values, environmental pollution may be classified as low (CF < 1), moderate (CF: 1–3), considerable (CF: 3–6), or high (CF > 6) (Mohiuddin et al., 2011). From the CF values, PLI can be written as follows:

$$\mathbf{PLI} = \mathbf{CF_1} \times \mathbf{CF_2} \times \mathbf{CF_3} \ldots\ldots\ldots \times \mathbf{CF_n} \qquad \mathbf{3}$$

Where CF = contamination factors, n = total number of CFs. For geological samples, a PLI value over 1 implies ongoing degradation, whereas a PLI value below 1 suggests just baseline levels of pollutants (Zhao et al., 2012).

C. Potential Ecological Risk Index (ERI)

Potential ecological risk index (ERI) was used to figure out how much the sediment sample is polluted (Fu et al., 2014). ERI was evaluated by the following equation:

$$\mathbf{ERI} = \sum_{\mathbf{i=1}}^{\mathbf{n}} \mathbf{Er^i} = \sum_{\mathbf{i=1}}^{\mathbf{n}} \mathbf{Tr^i} \times \mathbf{CF^i} \qquad \mathbf{4}$$

Where, Er^i is the potential ecological risk factor of an individual element, Tr^i is the biological toxic factor of an individual element and CF^i is the single element contamination factor. RI is the comprehensive potential ecological risk index. The sensitivity of the biological community to the toxic substance, as well as the potential ecological risk caused by the overall contamination, is illustrated by the RI. However, the potential ecological risk index (ERI) can be categorized as ERI < 40 (low potential ecological risk), 40 ≤ ERI < 80 (moderate potential ecological risk), 80 ≤ ERI < 160 (considerable potential ecological risk), 160 ≤ ERI < 320 (high potential ecological risk), and 320 ≤ ERI (very high potential ecological risk)(Zhou et al., 2016).

2.5 Health Risk Assessment

Human health risk assessment associated with five heavy metals is classified into three separate classes: Estimated daily intake (EDI), Carcinogenic risk (CR) and Targeted Hazard Quotient (THQ).

A. Estimated daily intake (EDI)

The daily intake of heavy metals will be estimated based on the concentration in the muscle samples of the fish species. The daily intake by consuming the fish sample was estimated using the equation:

$$\mathbf{EDI} = \frac{\mathbf{C} \times \mathbf{IR}}{\mathbf{BW_a}} \qquad \mathbf{5}$$

C is the average concentration of heavy metals in fish (mg/kg of the dry weight); IR (Fish consumption ratio: 24.7 g/person/day (Adegbola et al., 2021b; Taiwo et al., 2018). BWa is the average adult body weight.

B. Carcinogenic risk (CR)

Since, heavy metals are extremely carcinogenic; therefore, assessing the carcinogenic risk is an important indicator of health hazards. Thecarcinogenic risk could be referred as the incremental probability of developing cancer over ahuman lifetime when exposed to the carcinogens. The suggested limit of lifetime exposure to carcinogens is between 10^{-4} (risk of developing cancer over a lifetime is 1 in 10, 000) to 10^{-6} (risk of developing cancer over a lifetime is 1 in 1,000,000) (Traina et al., 2019; Vieira et al., 2011). The Carcinogenic risk by consuming the fish sample can be estimated using equation:

$$\mathbf{CR} = \frac{\mathbf{C} \times \mathbf{IR} \times \mathbf{ED} \times \mathbf{EFR} \times \mathbf{CSF}}{\mathbf{BW_a} \times \mathbf{ATn} \times \mathbf{1000}} \qquad \mathbf{6}$$

Where C, IR and BWa are similar to Equation 3.12. ED is the exposure duration (average lifetime of Iraqi people); EFR is the exposure frequency (365 days/year); CSF is the oral carcinogenic slope factor (mg/kg/day) derived from the Integrated Risk Information System (National Research Council of the National Academies, 2014); and ATn is the average exposure time for non-carcinogens.

C. Targeted Hazard Quotient (THQ)

The targeted hazard quotient indicates the level of human health risk due to exposure to the heavy metals of such pollutants. The higher value of THQ implies that there is a higher probability of experiencing long- term non-carcinogenic effects during the lifetime when exposed toheavy metals or such pollutants (Chien et al., 2002; Wang et al., 2005). The THQ value is estimated by the following equation:

$$\mathbf{THQ} = \frac{\mathbf{C} \times \mathbf{IR} \times \mathbf{ED} \times \mathbf{EFR}}{\mathbf{BW_a} \times \mathbf{ATn} \times \mathbf{RFD} \times \mathbf{1000}} \qquad \mathbf{7}$$

Where; RFD is the oral reference dose. The RFD for metals obtained from Integrated Risk. The combined THQ effects of all heavy metals indicate Hazard Index (HI) for a specific sample.

3 RESULTS AND DISCUSSION

3.1 Heavy Metal Concentration in Cyprinus Carpio

Figure 3 displays the levels of heavy metals (Pb, Cd, Zn, Fe, Cu) in the muscle tissue, gills, and liver of Cyprinus carpio (common carp) from the Al-Diwaniyah River during both summer and winter. The measurements were taken at four different locations (S1-S4). Typically, the levels of heavy metals are greater during the summer season compared to winter for all fish organs. The concentration of Pb in muscle tissue at location S3 is 1.9899 ppm during the summer, but it is 0.8912 ppm during the winter. Comparatively, the concentration of Fe in the muscle of Cyprinus carpio is 19.654 ppm during summer, while it is 15.161 ppm during winter. However, at site S4, the concentration of Pb in gills is 2.4407 ppm in summer and 1.1577 ppm in winter. Similarly, the concentration of Fe is 21.477 ppm in summer and 15.893 ppm in winter. The concentration of Pb in the liver of Cyprinus carpio at site S4 is 0.5051 ppm during the summer and 0.3857 ppm during the winter. Similarly, the concentration of Cd is 0.0324 parts per million (ppm) during summer, compared to 0.0166 ppm during winter. The observed trend of elevated summer levels is consistent for the majority of locations and metals, suggesting seasonal fluctuations in the metal accumulation. Based on the data, it can be concluded that Site S4 consistently shows the greatest concentrations of most metals during both seasons, indicating the most polluted site. The general pattern indicates that environmental conditions and sources of pollution play a role in the seasonal buildup of heavy metals in fish's liver.

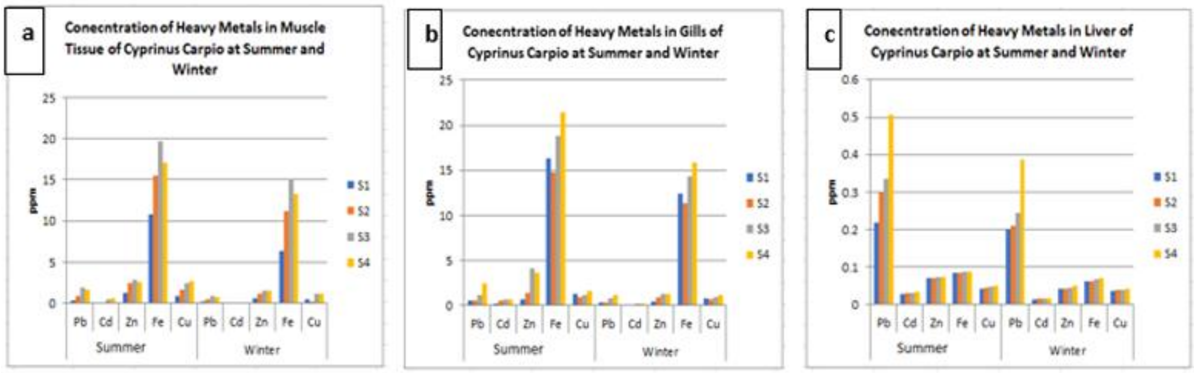

Figure 2: Heavy Metal Concentration in the (a) muscle tissue, (b) gills and (c) liver of Cyprinus carpio

3.2 Heavy Metal Concentration in Liza bandialensis Diouf

Figure 4 displays the levels of heavy metals (Pb, Cd, Zn, Fe, Cu) found in the muscle tissue of Liza bandialensis Diouf from the Al-Diwaniyah River. The measurements were taken throughout both summer and winter at four different locations (S1-S4). In general, the concentrations are elevated during the summer months in comparison to the winter months. In summer, the concentration of Pb in muscle tissue at site S4 is 1.5251 ppm, whereas in winter it is 0.7902 ppm. Similarly, the concentration of Fe in muscle tissue is 9.6781 ppm in summer and 5.3803 ppm in winter. However, at site S4, the concentration of Pb in the gills of Liza bandialensis Diouf is 1.442 ppm during the summer and 0.6642 ppm during the winter. Similarly, the concentration of Fe is 14.316 ppm during the summer and 7.6352 ppm during the winter. The liver of Liza bandialensis Diouf from the Al-Diwaniyah

River was analyzed for Pb and Fe concentrations during summer and winter at site S4. The Pb content was found to be 1.0721 ppm in summer and 0.7483 ppm in winter, while the Fe concentration was 11.389 ppm in summer and 6.4177 ppm in winter. The observed trend of increased summer concentrations is uniform across the majority of locations and metals, suggesting that there are seasonal fluctuations in the buildup of heavy metals in the liver. Site S4 consistently displays the greatest concentrations of most metals over both seasons, indicating that it is the most polluted site. The results suggests that environmental variables and sources of pollution are probable contributors to the seasonal buildup of heavy metals in the liver of Liza bandialensis Diouf.

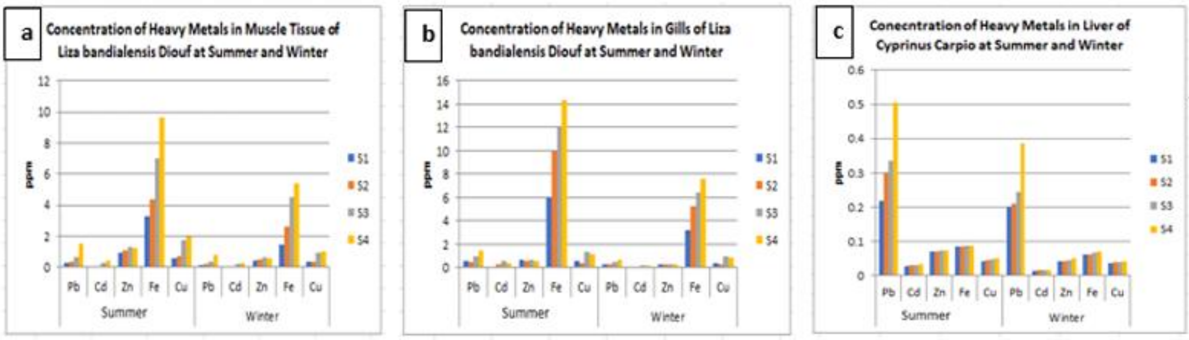

Figure 3: Heavy Metal Concentration in the (a) muscle tissue, (b) gills and (c) liver of Liza bandialensis Diouf.

3.3 Heavy Metal Concentration in Spondyliosoma cantharus

Figure 5 illustrates the levels of heavy metals (Pb, Cd, Zn, Fe, Cu) in the muscle tissue of Spondyliosoma cantharus from the Al-Diwaniyah River. The measurements were taken throughout both summer and winter at four different locations (S1-S4). In general, the levels of these metals are elevated during the summer months in comparison to the winter season. In summer, the concentration of Pb in muscle tissue at site S4 is 0.473567 ppm, while in winter it is 0.258633 ppm. Similarly, the concentration of Fe in summer is 15.7619 ppm, whereas in winter it is 11.25287 ppm. However, at site S4, the concentration of Pb in the gills of Spondyliosoma cantharus is 1.5693 ppm during the summer and 1.098167 ppm during the winter. Additionally, the concentration of Zn is 3.1352 ppm during the summer and 1.3101 ppm during the winter. At site S4, the concentration of Pb in the liver is 0.160467 ppm in summer and 0.072933 ppm in winter. The concentration of Fe is 6.2083 ppm in summer and 3.531433 ppm in winter. This tendency of greater summer concentrations is evident across most sites and metals, showing seasonal differences in heavy metal accumulation. Site S4 regularly exhibits the greatest concentrations of most metals during both seasons, indicating that it is the most polluted area. The findings suggests that environmental conditions and sources of pollution play a role in the seasonal buildup of heavy metals in the liver of Spondyliosoma cantharus.

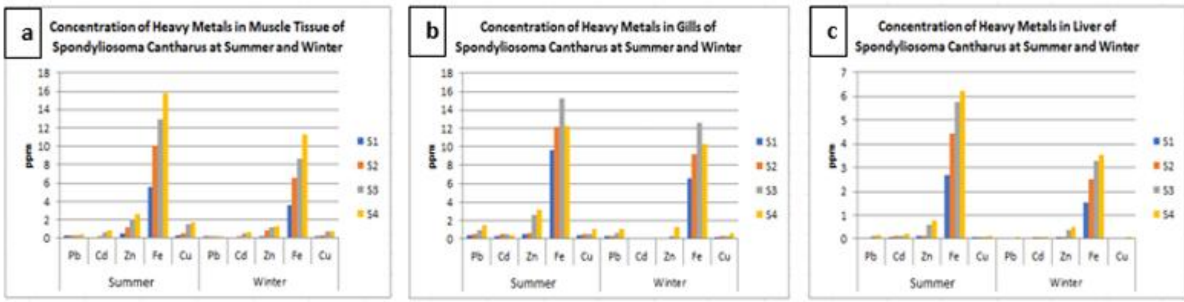

Figure 4: Heavy Metal Concentration in the (a) muscle tissue, (b) gills and (c) liver of Spondyliosoma cantharus.

3.4 Geo-accumulation Index (Igeo)

Figure 6 depicts the Geo-accumulation Index (Igeo) for the aquatic environment of the Al-Diwaniyah River. The index indicates notable pollution levels observed in different places and seasons. During the summer, Site S1 experiences significant pollution, as indicated by the Igeo values for Pb (3.2841), Cd (4.1478), Zn (4.742), Fe (7.135), and Cu (7.263). Based on the Igeo classification, Pb is categorized as Class 5, indicating a high to very high level of contamination. Cd is classified as Class 6, indicating an extremely high level of contamination. Zn is also classified as Class 6. Both Fe and Cu are classified as Class 7, which is an open class indicating an extremely high level of contamination. This suggests a significant amount of pollution in the water environment throughout the summer, with high concentrations of heavy metals that are greatly beyond the normal levels found in nature. When comparing, Site S2 has somewhat reduced levels of contamination throughout the summer with Pb (2.556), Cd (3.226), Zn (3.804), Fe (6.019), and Cu (6.121). Pb is classified as Class 4, indicating heavy contamination. Cd, Zn, Fe, and Cu are classified as Class 5 and Class 6, respectively. This indicates that although Site S2 is similarly significantly polluted, the level of contamination is relatively less severe when compared to Site S1. Significantly, the elevated levels of copper (Cu) and iron (Fe) suggest that there are substantial sources of pollution that are contributing to the presence of these metals. In winter, the pollution levels remain elevated but exhibit some seasonal fluctuations. Site S3 in winter exhibits concentrations of Pb (4.463), Cd (5.42), Zn (6.18), Fe (15.64), and Cu (16.05), which classify Pb as Class 5, Cd as Class 6, Zn as Class 6, and both Fe and Cu as Class 7. During the winter, Site S4 exhibits the following concentrations of heavy metals: Pb (3.813), Cd (5.147), Zn (5.438), Fe (10.537), and Cu (10.871). These values categorize Pb as Class 5, Cd as Class 6, Zn as Class 6, and both Fe and Cu as Class 7. The elevated readings indicate that the river is still experiencing significant pollution, with winter levels that are similar to or higher than those in summer, especially for Cu and Fe, suggesting ongoing and potentially worsening contamination throughout the year(Kamel et al., 2023; Al-Atbee & Al-Saad, 2019).

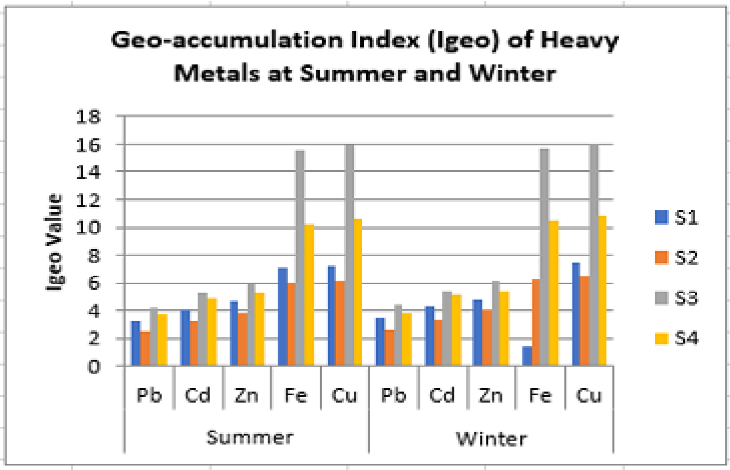

Figure 5: Geo-accumulation Index (Igeo) for the Al-Diwaniyah River.

Table 2: Sites with Igeo values equal to or above Class 4 (heavily contaminated to extremely contaminated)

Site	Pb	Cd	Zn	Fe	Cu
S1 Summer	3.2841	4.1478	4.742	7.135	7.263
S1 Winter	3.453	4.368	4.857	1.478	7.426
S3 Summer	4.2193	5.3328	5.9109	15.5925	15.8805
S3 Winter	4.463	5.42	6.18	15.64	16.05
S4 Summer	3.6971	4.918	5.2904	10.3126	10.5594
S4 Winter	3.813	5.147	5.438	10.537	10.871

3.5 Pollution Load Index (PLI)

Figure 7 displays the Pollution Load Index (PLI) data for the Al-Diwaniyah River, illustrating differing levels of pollution at different locations and during different seasons. At Site S1, the PLI values during summer and winter are 1.35 and 1.48, respectively, both beyond the threshold of 1. These findings suggest that Site S1 experiences persistent pollution throughout the year, with slightly elevated pollution levels during the winter season. The enduring pollution indicates a substantial and continuous origin of contamination that detrimentally affects this location throughout the year. In contrast, Site S2 has PLI values of 0.62 during summer and 0.7 during winter, both falling below the threshold of 1. These findings indicate that Site S2 is not polluted. However, the data shows that pollution levels are somewhat higher during the winter season, suggesting a minor rise in contamination during this time. During the summer, Site S3 has a Pollution Load Index (PLI) of 0.95, which suggests that there is no pollution. However, in the winter, the PLI increases to 1.02, surpassing the threshold and indicating the presence of pollution during the colder season. These findings indicate that Site S3 undergoes seasonal contamination, likely caused by heightened industrial or agricultural runoff during the winter months. Site S4 exhibits PLI values of 1.65 during summer and 1.71 during winter, surpassing the threshold and indicating elevated pollution levels in both seasons. Winter exhibits somewhat greater contamination compared to summer. The persistent and elevated pollution level indicates ongoing and potentially severe sources of pollutants impacting this location. In general, the PLI data indicates that Site S4 is the most contaminated, with Site S1 being the second most polluted throughout the winter season. Nevertheless, S2 is the only area that remains unpolluted.

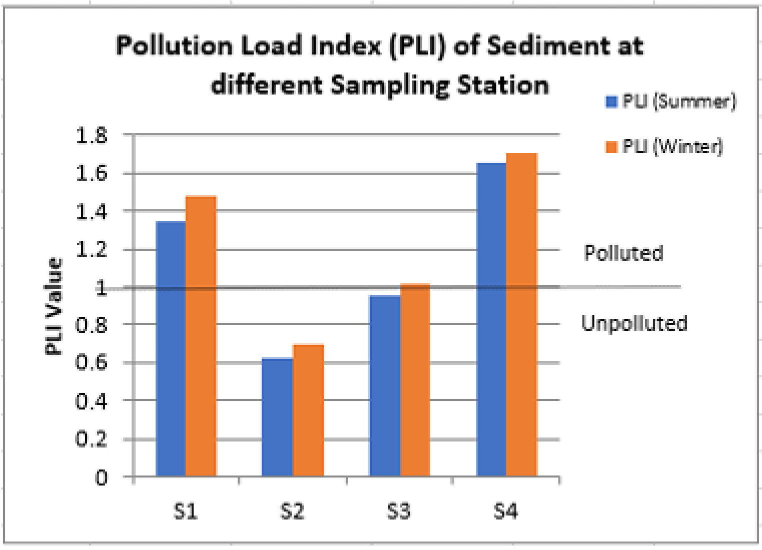

Figure 6: The Pollution Load Index (PLI) data for the Al-Diwaniyah River.

3.6 Potential Ecological Risk Index (ERI)

The Ecological Risk Index (ERI) for heavy metals in the sediments of the Al-Diwaniyah River assesses the ecological risks associated with heavy metals during both summer and winter at four specific locations (S1 to S4). The figure below illustrates the Ecological Risk Index (ERI) for heavy metals in the sediments of the Al-Diwaniyah River. The quantities of Pb in summer vary from 9.42 at S1 to 13.16 at S4, Cd from 6.37 at S1 to 15.92 at S3, Zn from 0.64 at S1 to 0.77 at S4, Fe from 0.64 at S1 to 0.83 at S4, and Cu from 12.83 at S1 to 22.12 at S4. These data indicate that Pb and Cu pose a greater potential ecological harm, especially at S3 and S4, where Cd also exhibits a notable rise. During the winter season, the concentration of Pb ranges from 10.86 at S1 to 15.07 at S4. Cd concentrations vary from 6.66 at S1 to 16.79 at S3. Zn concentrations range from 0.70 at S1 to 0.84 at S4. Fe concentrations vary from 0.71 at S1 to 0.93 at S4. Lastly, Cu concentrations range from 14.61 at S1 to 25.18 at S4. Once again, the greatest concentrations of Pb, Cd, and Cu are found at sampling points S3 and S4. Throughout both seasons, the levels of Pb, Zn, and Fe consistently fall between the low to moderate danger ranges. Nevertheless, the concentrations of Cd, specifically in S3 during the summer (15.92) and winter (16.79), as well as the levels of Cu across all locations and seasons, are classified as having a significant to high potential for ecological harm. More precisely, the presence of Cu at S4 during both summer (22.12) and winter (25.18) represents a significant ecological danger, highlighting the necessity for immediate remediation actions. The high ERI values for Cd and Cu observed at these locations indicate substantial human activities that are causing heavy metal pollution in the Al-Diwaniyah River. These sources encompass industrial discharges, agricultural runoff, and urban wastewater, all of which must be regulated to alleviate ecological hazards(El-amier et al., 2018; Issa & Qanbar, 2016; Salah et al., 2012). Consistent surveillance and enforcement of more stringent laws for the release of wastewater into the river are crucial in safeguarding the aquatic ecology and mitigating the accumulation of these hazardous metals in the food chain.

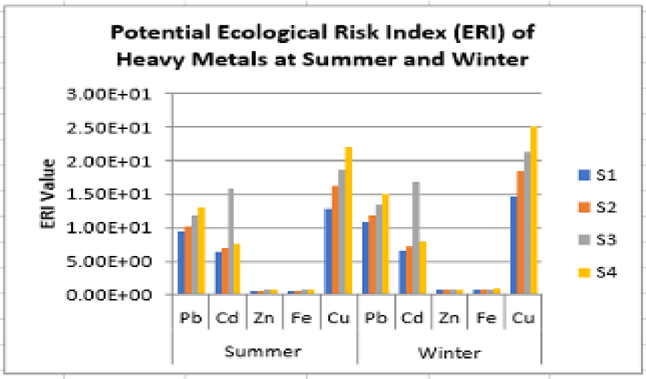

Figure 7: Potential Ecological Risk Index (ERI) of heavy metals in the sediments of the Al-Diwaniyah River.

3.7 Estimated Daily Intake (EDI)

Significant seasonal fluctuations in the Estimated Daily Intake (EDI) of heavy metals from consuming three kinds of fish from the Al-Diwaniyah River have been observed. During the summer, the EDI values for Pb vary from 0.47094 at S1 to 1.85588 at S4. For Cd, the values range from 0.068889 at S1 to 1.017094 at S4. Zn values range from 1.435709 at S1 to 3.319026 at S4. The values for Fe range from 10.14969 at S1 to 21.8159 at S4, and for Cu, they range from 0.884256 at S1 to 3.311077 at S4. The data suggests that there is a greater consumption of heavy metals at S4, specifically with regard to Pb, Cd, and Cu, which exhibit higher levels of concern. The high Environmental Deprivation Indices (EDIs) observed at S4 indicate a potential health hazard for individuals who regularly consume fish from this location throughout the summer season. The levels of Pb (lead) and Cd (cadmium) are substantially beyond the acceptable thresholds for chronic exposure, further increasing the health risks. During the winter season, the EDI values tend to be lower but, they nevertheless remain a cause for concern. The concentration of Pb ranges from 0.29894 at S1 to 0.961402 at S4, Cd ranges from 0.037983 at S1 to 0.547026 at S4, Zn ranges from 0.699333 at S1 to 1.772479 at S4, Fe ranges from 5.87988 at S1 to 15.3647 at S4, and Cu ranges from 0.540171 at S1 to 1.495282 at S4. The decrease in EDI (Exposure-Dose Index) values for the majority of metals indicates reduced bioavailability throughout the winter season. However, the levels of Pb (lead), Cd (cadmium), and Cu (copper) at S4 still present a significant health hazard. Significantly, the levels of Pb (lead) continue to exceed the thresholds considered acceptable for ingestion, which highlights the ongoing problem of contamination that requires attention. The presence of these health hazards emphasizes the importance of consistently monitoring and implementing actions to reduce the risks, to guarantee the safety of individuals who consume fish from the Al-Diwaniyah River region.

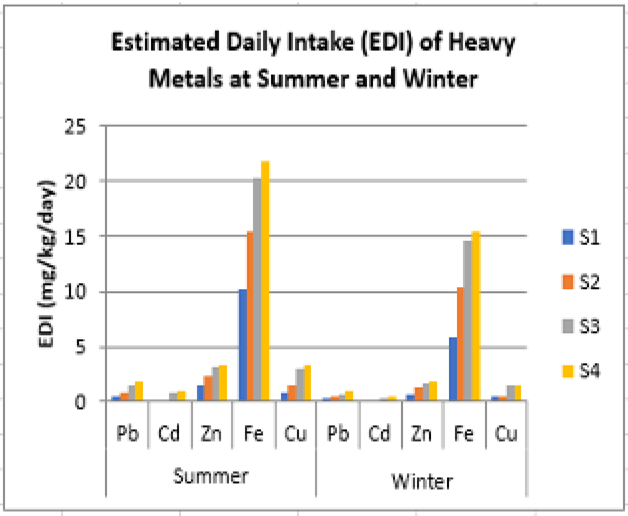

Figure 8: Estimated Daily Intake (EDI) of heavy metals from consuming fishes from the Al-Diwaniyah River.

3.8 Carcinogenic Risk (CR) of Pb and Cd Intake

The Carcinogenic Risk (CR) values for lead (Pb) and cadmium (Cd) resulting from the consumption of fish from the Al-Diwaniyah River throughout both summer and winter seasons are a significant measure of the potential health risks involved. Cancer risk (CR) values are computed to approximate the likelihood of developing cancer across a person's entire lifetime of being exposed to certain factors. The critical level for significant public health concern is 10^-4 (equivalent to 1 in 10,000), but some of 10^-6 (equivalent to 1 in 1,000,000) is deemed acceptable or insignificant. Within this particular framework, Site 1 exhibits CR values of 2.60E-05 during the summer season and 1.80E-05 during the winter season. These numbers suggest a comparatively low likelihood of developing cancer due to exposure to lead, which is much below the threshold for a severe risk but greater than the threshold for a tolerable risk. It implies that although there is a risk, it is not substantial enough to constitute a significant worry for public health. The concentration-response (CR) values for cadmium (Cd) during the summer season vary from 2.20E-06 at site S1 to 4.20E-06 at site S4. During the winter season, the values vary between 1.60E-06 at site S1 and 3.40E-06 at site S4. Like lead (Pb), cadmium (Cd) also shows the highest values of CR at site S4 during both seasons, while the lowest values are seen at site S1. The coefficient of correlation (CR) values for Cadmium (Cd) exhibits a consistent decrease throughout winter in comparison to summer at all locations. While the CR values generally fall within tolerable limits, continuous exposure to these heavy metals could potentially result in long-term health hazards, especially at sites S3 and S4, where the CR values are elevated. It is necessary to employ regular monitoring and management measures mitigate these risks.

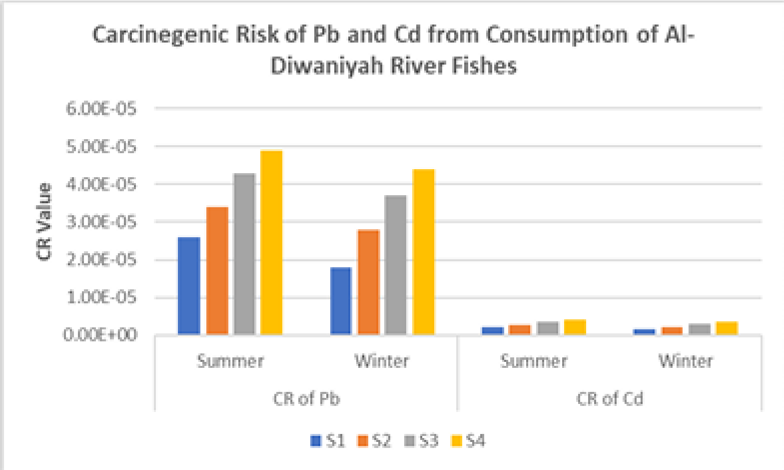

Figure 9: Carcinogenic Risk (CR) for Pb and Cd due to consuming fish from the Al-Diwaniyah River.

3.9 Target Hazard Quotient (THQ)

The Target Hazard Quotient (THQ) values for heavy metals in fish from the Al-Diwaniyah River, measured for both summer and winter, offer valuable information regarding the potential health risks to humans who consume these species. During the summer, the THQ values for Pb range from 4.30E-05 at S1 to 4.85E-05 at S4. For Cd, the values range from 9.60E-06 at S1 to 1.50E-05 at S4. The values for Zn range from 1.42E-04 at S1 to 4.30E-04 at S4. For Fe, the values range from 5.00E-05 at S1 to 3.90E-04 at S4. Lastly, the values for Cu range from 9.00E-06 at S1 to 4.10E-05 at S4. At S4, the levels of Zn and Fe in the THQ values are significantly elevated, suggesting an increased likelihood of health hazards associated with these metals. While the THQ values for all heavy metals are below 1, suggesting no immediate danger of non-carcinogenic consequences, the combined impact of numerous heavy metals may present health risks. During the winter season, the THQ values exhibit a little decrease while still adhering to a comparable pattern. The Pb THQ values vary from 3.79E-05 at S1 to 4.27E-05 at S4. The Cd values range from 8.72E-06 at S1 to 1.36E-05 at S4. The Zn values range from 1.18E-04 at S1 to 3.58E-04 at S4. The Fe values range from 4.29E-05 at S1 to 3.35E-04 at S4. Lastly, the Cu values range from 7.46E-06 at S1 to 3.40E-05 at S4. The concentrations of Zn and Fe at S4 exhibit elevated levels once more, indicating the presence of ongoing pollution. The modest decrease in readings during winter may be ascribed to seasonal fluctuations in metal bioavailability or fish metabolism. Nevertheless, even these reduced levels still emphasize the necessity for prudence, since the combined exposure to many metals continues to be a cause for concern. The main health concerns for humans from eating these fish are mostly caused by long-term exposure to heavy metals. While the individual values of THQ (Toxic Hazard Quotient) are less than 1, indicating a lack of major health risks from any single metal, the cumulative impact of numerous metals can amplify the total danger. Extended exposure to Pb can result in cognitive deficits and developmental delays, particularly in children. Exposure to Cd is associated with renal impairment and musculoskeletal disorders. Elevated concentrations of Zn can disturb the equilibrium of other vital minerals and induce gastrointestinal discomfort.Consumption of iron can lead to liver damage, whereas elevated amounts of copper can cause harm to both the liver and kidneys. Consistent monitoring and attempts to reduce harm are crucial to safeguard the well-being of populations that depend on these fish as a source of nourishment.

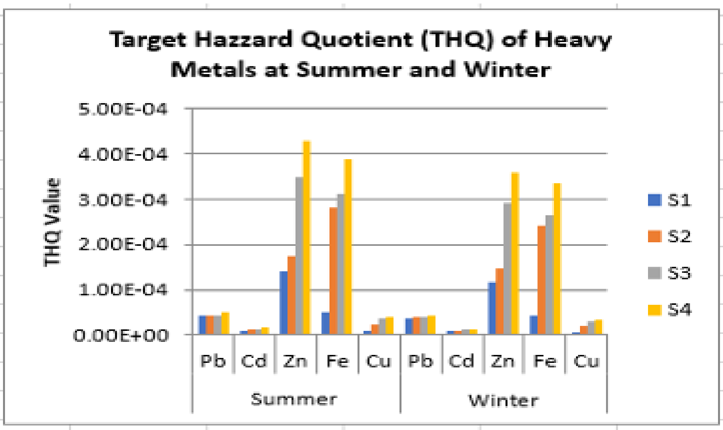

Figure 10: Target Hazard Quotient (THQ) values for heavy metals in fish from the Al-Diwaniyah River.

CONCLUSION

This study conducted an extensive investigation of the presence of heavy metals in the fish species Liza bandialensis, Spondyliosoma cantharus, and Cyprinus carpio from the Al-Diwaniyah River. The findingsdemonstrate notable differences in metal levels among various tissues (muscle, gills, and liver) and seasons (summer and winter). The data from the Geo-accumulation Index (Igeo) shows that the river is contaminated to different extents. Many locations in the river are classified as heavily to extremely contaminated for metals like Cd, Zn, Fe, and Cu. The Pollution Load Index (PLI) provides additional evidence, indicating that many sites (S3 and S4) exhibit pollution in both seasons. The Ecological Risk Index (ERI) indicates significant to extremely high ecological dangers at some locations, emphasizing the necessity for immediate remedial measures. The Estimated Daily Intake (EDI) values indicate that there may be health concerns associated with consuming fish from the river, particularly due to high levels of Zn, Fe, and Cu. The Target Hazard Quotient (THQ) readings, while generally below the level of concern, suggest an accumulated risk for heavy metals, namely in sites S3 and S4. The Carcinogenic Risk (CR) values for Pb and Cd, although within permissible limits, indicate potential long-term health hazards, particularly at higher concentrations found at sites S3 and S4.

The study is constrained by its narrow focus on only two seasons (summer and winter), which may not fully capture the temporal fluctuations in heavy metal concentrations. Additionally, the study's limited spatial coverage hinders the comprehension of contamination levels along the entire river. In addition, the study does not examine the potential for heavy metals to accumulate in organisms over time, nor does it offer a thorough assessment of the health risks to humans, taking into account the combined exposure from all sources of contamination. Subsequent research should incorporate more comprehensive evaluations of time and space, explore the accumulation of substances in living organisms over extended durations, and ascertain the origins of contamination. Furthermore, it will be essential to create and execute plans to reduce risks and evaluate potential dangers by taking into account eating habits and various ways of being exposed to harmful substances. This is necessary to safeguard both the environment and human well-being.

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