Seasonal Variations in Heavy Metal Accumulation in Common Carp (*Cyprinus carpio*) and Tigris River Water – Khalis District, Diyala Governorate, Iraq

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Abstract

An environmental study was conducted to evaluate the effects of seasonal variation and geographical location on the accumulation of selected heavy metals in the water of the Tigris River and in the tissues of common carp (*Cyprinus carpio*) within the Al-Khalis region. The study included two sampling sites, namely Al-Sindiyah and Jadidat Al-Shatt. Concentrations of four heavy metals—cadmium (Cd), copper (Cu), zinc (Zn), and lead (Pb)—were determined in river water and fish tissues (gills, liver, and muscles) following extraction using standard procedures and analysis by Atomic Absorption Spectrophotometry (AAS). Analysis of variance (ANOVA) revealed no statistically significant differences in cadmium (Cd) concentrations in river water , either among the different seasons or between the two study sites. Conversely, copper (Cu) concentrations exhibited statistically significant differences, with the highest concentration recorded at Al-Sindiyah site (0.831 mg/L), compared to the lowest concentration recorded at Jadidat Al-Shatt site (0.471 mg/L). Zinc (Zn) concentrations also showedna significant increase during winter and spring compared to autumn, with the highest concentration recorded at Al-Sindiyah site during spring (0.766 mg/L), whereas Jadidat Al-Shatt site recorded the lowest concentration (0.487 mg/L). Spring recorded the highest concentration, with a mean of 0.805 mg/L, compared with the autumn and winter seasons. No significant effect of area or season was observed on lead concentration. With regard to bioaccumulation in the tissues examined (gills, liver, and muscle), zinc exhibited the highest significant accumulation in the liven during spring (144.737 µg/g dry weight) relative to autumn and winter. This element also displayed the highest significant accumulation in muscle tissue during autumn (82.82 µg/g dry weight) relative to winter and spring. In contrast, cadmium, copper, and lead (Cd, Cu, Pb) showed no statistically significant differences ($p > 0.05$) in tissue concentrations across the seasons.

Keywords:. Common Carp; Heavy metals; Water Pollution

Introduction

Environmental pollution stands at the forefront of expansive global concerns in modern times, largely due to the impacts of rapid industrialization, unchecked urbanization, and the intensification of agri-business. One of the most pressing examples of pollution is aquatic contamination. Water is integral to not only the health of ecosystems, but the health of people. Water bodies, ecosystems themselves, sustain the waste of human civilization and, for many, the primary source of their food and water [23]. Of the many forms of pollution, heavy metals make one of the most dangerous forms of aquatic contamination. Heavy metals resist biological degradation and the only other option, degradation through the

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environment, simply does not occur. They threaten aquatic life for an indefinite period of time [11].

Heavy metals are generally defined as metals with an elevated density, and are divided into organic pollutants and metals needed in trace amounts to facilitate the functioning of many life processes. The former resist degradation, while the latter are only toxic when present in excess.Cadmium (Cd), mercury (Hg), lead (Pb), and arsenic (As) are metals with no known benefits to biology and are toxic even in trace amounts [16]. The risks of both categories of metals are magnified by biomagnification, which is the increasing toxic metal concentration at each level of a food chain. Metals absorbed by primary producers and aquatic invertebrates are transferred and increasingly concentrated at each consecutive level of the food chain. This ultimately affects apex predators, including humans Pb and Cd biomagnification has been extensively studied in freshwater ecosystems, with Cyprinus carpio being one of the fish with the highest trophic magnification factors of all fish studied [19]. This makes even slightly polluted environments turn into major threats to public health, especially to the population who consume these fish [1]. The Tigris is one of Iraq's most important rivers, being 1,718 km long, and flowing through multiple governorates, eventually merging with the Euphrates in the south to form the Shatt Al-Arab. For the past decades, many human activities have lead to the river becoming even more polluted. Untreated wastewater, both domestic and industrial, is routinely dumped directly into the river, and agricultural runoff containing pesticides and chemical fertilizers is drained into the river from large scale farming along the river banks [20]. An Al-Karkh University of Science study from 2021 found that sections of the Tigris River near Baghdad contained elevated levels of heavy metals, including cadmium, copper, and chromium, and that lead levels reached 13 times the safe level in some samples [12]. The Diyala River, a main tributary of the Tigris River, is also known to be a severely polluted river, adding more loads of pollution to the main river [2]. The region is marked by intensive agriculture and the presence of vehicle repair workshops and light industry. All are considerable local sources of lead, copper and zinc contamination of the surrounding waterways [5].

The Common Carp is a prevalent and commercially significant species in Iraq's freshwater systems. Its dietary habits, social structure, and physiology make Common Carp an effective bioindicator for aquatic system pollutants [10]. Experimental studies have shown that Common Carp responds to the changes in water metal concentrations in a predictable and proportional way [24]. Given this knowledge, there is an urgent need to monitor the water quality in which Common Carp resides. Also making Common Carp significant is that it serves as an important source of protein for public health systems in the Khalis Region. Heavy metal concentration in the tissues of Common Carp, as a bioindicator for aquatic pollutants, presents an imminent public health concern. It is unjustifiable to allow the presence of pollutants to put the health of the local population at risk, especially when the World Health Organization is continually refining the acceptable levels of exposure for consumers [14].

Material and Methods

Study Area and Sampling

Samples were taken from two sites on the Tigris River in the Khalis District. Al-Sindiya Site: Northern (upstream) site, coordinates 33°54'N / 44°35'E, next to cultivated fields and light

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industries. Jadida Al-Shatt Site: Southern (downstream) site, coordinates 33°47'N / 44°33'E, receives more drainage and has a higher population. The approximate distance between the two sites is 12 km. Sampling occurred in three seasons: Autumn (October–November), Winter (January–February), and Spring (April–May)

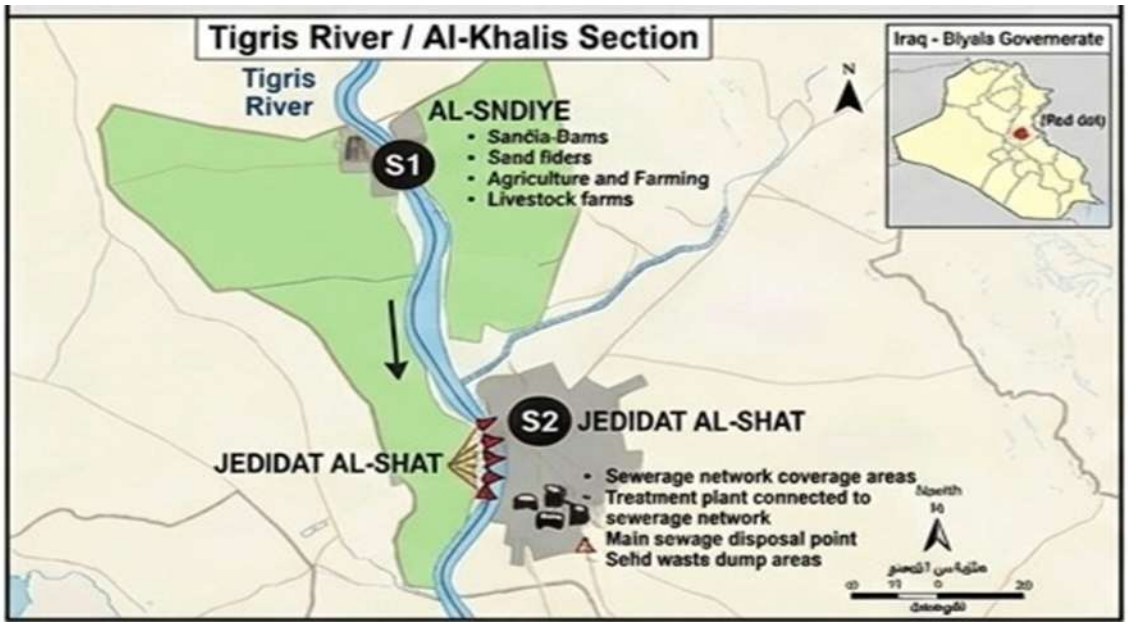


Figure (1): Map of the study area showing the two sampling sites (S1: Al-Sindiya and S2: Jadida Al-Shatt) on the Tigris River, Khalis District, Diyala Governorate, Iraq, along with major pollution sources.

Water Analysis

Heavy metal concentrations in the river water were determined using the following method:Water samples were collected using pre-acidified polyethylene bottles (1 L capacity, 10% HNO_3), taken from mid-stream at depths ranging between 30–50 cm. Following collection, the samples were placed in a cooler at 4°C and analyzed within one day of collection to ensure the accuracy of the results. The samples were subjected to acid digestion, whereby 5 mL of concentrated nitric acid (HNO_3) was added, followed by heating to complete dryness. The acid addition process was repeated several times to ensure complete digestion, after which the sample volume was made up to 25 mL with deionized water, then filtered using a 0.20 µm pore-size membrane filter. Finally, metal concentrations were determined using Atomic Absorption Spectrophotometry (AAS, PYE Unicam model British in origin.), at the characteristic wavelengths for each element as follows:

Cadmium (Cd): 228.8 nm

Copper (Cu): 324.7 nm

Zinc (Zn): 213.9 nm

Lead (Pb): 283.3 nm

The measurement results were reported in mg/L. [6].

Fish Tissue Analysis

Thirty specimens of Common Carp per season (15–20 cm; 80–150 g) were collected. Gills, liver, and dorsal muscle were excised from three individuals per tissue. Tissues were dried (105°C), ground, and sieved (0.5 mm). Digestion occurred per [21] Briefly, 1 g tissue, HNO3, H2SO4, and 70% HClO4 were mixed and heated (80–120°C) until clear, then centrifuged (3500 rpm, 30 mins). Supernatant was diluted to 50 mL with deionized water, and results expressed as µg/g d.w. of tissue.

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Bioconcentration Factor (BCF)

BCF was calculated as follows (USEPA, 2019)

BCF = C (tissue, µg/g d.w.) ÷ C (water, µg/mL)

In the USEPA assessment, BCF > 1000 categorizes the organism as a high bioaccumulator.

Statistical Analysis

Data were analyzed using a Completely Randomized Design (CRD); means were compared by Duncan's Multiple Range Test [9] at $P \leq 0.05$. For water, Season × Site interactions were analyzed using a 3×2 factorial CRD. All analyses were carried out using [21] software. N.S. = non-significant.

Results and Discussion

Heavy Metal Concentrations in River Water

Cadmium (Cd)

The results presented in Table (1) indicate that cadmium (Cd) concentrations in the study area's water ranged between 0.005 and 0.012 mg/L, exhibiting relative stability across the four seasons and the two geographical sites studied, with no clear significant variation observed. These findings are consistent with those reported by [3] and [4] in similar aquatic environments.When comparing these values with the adopted standard limits, it was found that all recorded concentrations remained within the maximum permissible limit set by the Iraqi Drinking Water Standard (IQS 417). However, they exceeded the international guideline value issued by the World Health Organization (WHO), which is 0.003 mg/L. This discrepancy reflects the difference in stringency between national and international standards, as the World Health Organization adopts a more conservative threshold given cadmium's known bioaccumulative capacity and its long-term toxic effects, even at relatively low exposure concentrations.This exceedance underscores the necessity for continuous environmental and health monitoring of cadmium levels in the river water, particularly since [3] demonstrated that chronic exposure to this element is associated with skeletal and renal disorders in exposed organisms. This suggests the importance of adopting the more conservative guideline value (WHO) as a primary reference when assessing the environmental quality of river water, rather than relying solely on compliance with the local standard.

Some studies conducted at other sites along the Tigris River reported higher cadmium levels exceeding the internationally permissible limits; cadmium concentration ranged between 0.012 and 0.018 mg/L [18] exceeding the World Health Organization's guideline value of 0.003 mg/L, which reflects the variation in pollution levels according to geographic location and local sources of contamination (such as industrial and agricultural activities and sewage discharge). Based on this, it can be concluded that the cadmium concentrations recorded at the two current study sites (Al-Sindiyah and Jadidat Al-Shatt) fell within the natural and permissible limits, in comparison with other sites along the river that exhibit higher levels of pollution.

Table (1): Cadmium (Cd) concentrations (mg/L) in Tigris River water at both study sites across the three seasons

Season	Al-Sindiya	Jadida Al-Shatt	Season Effect	WHO (mg/L)
Autumn	0.006±0.000	0.012±0.004	0.009±0.002	—
Winter	0.007±0.000	0.005±0.000	0.006±0.000	—
Spring	0.007±0.000	0.007±0.000	0.007±0.000	—
Site Effect	0.007±0.000	0.008±0.001	N.S.	0.003

N.S. = Non-Significant; Values represent Mean ± Standard Error

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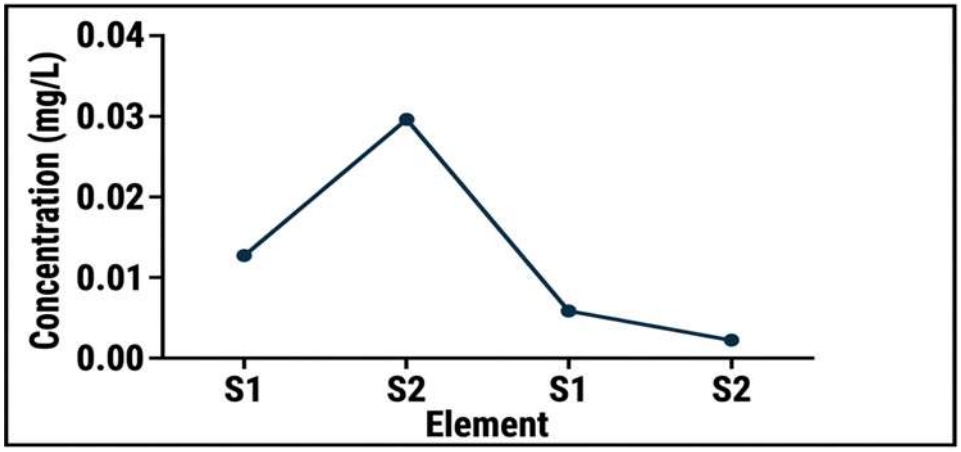


Figure (2): Cadmium (Cd) concentrations (mg/L) in Tigris River water at both study sites compared with the WHO maximum permissible limit (0.01 mg/L).

Copper (Cu)

The results of the analysis of variance presented in Table (2) revealed statistically significant differences in copper (Cu) concentrations with respect to site, season, and their interaction. The highest mean copper concentration was recorded in the Al-Sindiyah area, reaching 0.831 mg/L, whereas the Jadidat Al-Shatt area recorded the lowest mean concentration, at 0.471 mg/L. This reflects a clear spatial variation that can most likely be attributed to differences in pollution sources and human and industrial activities between the two sites. On the seasonal level, the highest mean concentration was recorded during spring (0.812 mg/L), while values declined to their lowest during autumn (0.427 mg/L). This seasonal pattern is consistent with the findings of recent studies addressing the seasonal fluctuation of heavy metals in Iraqi rivers, which attributed the spring rise to increased surface runoff resulting from rainfall, along with the associated soil leaching and transport of metal-laden sediments toward the water, as seasonal fluctuation is considered a key factor in evaluating element concentrations in river sediments and surface waters and is strongly correlated with rainfall intensity [19]. Regarding the interaction between the site and season factors, the results showed that the Al-Sindiyah area, during the winter and spring seasons, recorded the highest interaction value at 0.951 mg/L, while the value declined to its lowest level (0.264 mg/L) in the Jadidat Al-Shatt area during autumn. This dual variation indicates that the combined effect of site and season is more decisive in explaining copper dynamics than the effect of either factor alone, a finding corroborated by recent studies addressing the spatiotemporal heterogeneity of water quality in Iraqi rivers, which demonstrated significant spatial and temporal differences in most water quality parameters As for the season–site interaction, the Al-Sindiyah area recorded the highest copper concentration during the winter and spring seasons, at 0.951 mg/L, while the lowest concentration was recorded in the Jadidat Al-Shatt area during autumn, at 0.264 mg/L. Despite the relatively elevated copper concentrations, all values remained within the limits permitted by World Health Organization standards, which set the upper limit for copper at 12 mg/L in freshwater and 3 mg/L in drinking water, noting that copper toxicity increases in hard water with low alkalinity [17]. Despite the spatial and seasonal variation in copper concentrations, all recorded values remained within the internationally permitted limits [13]. .

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Copper toxicity and bioavailability are influenced by the physicochemical properties of water, as Health Canada indicated that sites with low alkalinity (less than 25 mg $CaCO_3$ /L) at a pH below 7 are the most prone to elevated copper concentrations (12). Furthermore, human activity, alongside climatic factors such as temperature, actual evapotranspiration, precipitation, and surface runoff, is considered among the most prominent determinants of copper, zinc, cadmium, and chromium concentrations in inland waters [13], which supports the interpretation of the seasonal and spatial variation recorded in the present study.

Table (2): Copper (Cu) concentrations (mg/L) in Tigris River water at both study sites across the three seasons

Season	Al-Sindiya	Jadida Al-Shatt	Season Effect	WHO (mg/L)
Autumn	0.591±0.024 c	0.264±0.028 e	0.427±0.075 B	—
Winter	0.951±0.017 a	0.475±0.033 d	0.713±0.107 A	—
Spring	0.951±0.017 a	0.673±0.029 b	0.812±0.063 A	—
Site Effect	0.831±0.060 A	0.471±0.061 B	—	≤ 2.0

Lowercase letters = interaction comparison; Uppercase letters = main effect comparison (P ≤ 0.05)

Zinc (Zn)

The results presented in Table (3) revealed highly significant differences ($p < 0.01$) in zinc (Zn) concentrations between the study areas and seasons. The Al-Sindiyah area recorded the highest mean zinc concentration, at 0.766 ± 0.056 mg/L, compared with the Jadidat Al-Shatt area, where it reached 0.487 ± 0.058 mg/L. At the seasonal level, spring recorded the highest concentration, with a mean of 0.805 ± 0.072 mg/L, whereas autumn recorded the lowest value, at 0.515 ± 0.031 mg/L, with no significant difference between the autumn and winter seasons. The elevated zinc concentrations recorded during certain seasons are attributed to the increased load of pollutants carried by rainfall and runoff into the river water, in addition to the discharge of untreated wastewater from outfalls and the leaching of agricultural land, as well as the effect of low water levels and elevated The observed increase in zinc concentrations during certain seasons is attributed to the convergence of several environmental and anthropogenic factors, most notably the increased pollutant load carried by rainfall and surface runoff into the river's course, in addition to the discharge of untreated wastewater from surrounding outfalls, and the leaching of agricultural residues from adjacent lands. Compounding this is the dual effect of reduced water levels and elevated temperatures, both of which jointly contribute to the overall rise in heavy metal concentrations.This effect can be scientifically explained by the fact that reduced water levels, particularly during hot seasons, diminish the effectiveness of the natural dilution process, while rising temperatures increase the ionic activity of heavy metal elements, thereby enhancing their solubility and mobility within the water column. This mechanism is consistent with findings from a study conducted on the Indus River at the Chashma Barrage in Pakistan, which reported that summer was characterized by the highest water temperature and the lowest dissolved oxygen level, conditions that enhance the dissolution of metallic elements and increase their bioavailability [15]. These findings align with the relative increase in zinc concentrations observed in the present study area, coinciding with reduced water levels.Nevertheless, despite this seasonal variation, the overall mean zinc concentration throughout the study period remained within the natural and permissible limits set by both the Iraqi water quality standard and World Health Organization (WHO) guidelines [13], indicating that zinc contamination in the study area remains, as of the time of this research, within a relatively safe range despite the presence of influential local pollution sources.

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Table (3): Zinc (Zn) concentrations (mg/L) in Tigris River water at both study sites across the three seasons

Season	Al-Sindiya	Jadida Al-Shatt	Season Effect	WHO (mg/L)
Autumn	0.569±0.028 d	0.461±0.035 e	0.515±0.031 B	—
Winter	0.787±0.051 b	0.331±0.049 f	0.559±0.107 B	—
Spring	0.941±0.005 a	0.670±0.087 c	0.805±0.072 A	—
Site Effect	0.766±0.056 A	0.487±0.058 B	—	≤ 3.0

Lowercase letters = interaction comparison; Uppercase letters = main effect comparison (P ≤ 0.05)

Lead (Pb)

The results shown in Table (4) revealed a significant interaction effect between season and site on lead (Pb) concentrations, with the highest value recorded during spring in the Jadidat Al-Shatt area, at 0.403 mg/L, while the lowest values were recorded during autumn in both the Jadidat Al-Shatt area (0.291 mg/L) and the Al-Sindiyah area (0.292 mg/L). No significant independent effect was observed for either season or site alone, indicating that the response of lead concentration to seasonal change was not uniform across sites, but rather varied according to the nature of each site and the potential pollution sources surrounding it. The elevated lead concentrations recorded during certain seasons are attributed to increased evaporation and low water levels, which reduce the river's capacity to dilute the pollutants reaching it and consequently raise their relative concentration—a mechanism documented in a number of river-based studies. A study conducted on the Narmada River in India indicated that the pre-monsoon period witnessed an increase in manganese and lead concentrations resulting from elevated evaporation rates during the summer season [8]. which is consistent with the mechanism explaining lead behavior in the present study area under conditions of low water levels. This is in addition to the discharge of industrial waste and residues from automobile repair workshops into the river, which is consistent with what was reported by [4 and 5].

Table (4): Lead (Pb) concentrations (mg/L) in Tigris River water at both study sites across the three seasons

Season	Al-Sindiya	Jadida Al-Shatt	Season Effect	WHO (mg/L)
Autumn	0.292±0.029 b	0.291±0.040 b	0.291±0.022	—
Winter	0.395±0.009 a	0.324±0.010 b	0.360±0.017	—
Spring	0.297±0.003 b	0.403±0.012 a	0.350±0.024	—
Site Effect	0.328±0.019	0.339±0.020	N.S.	≤ 0.01 *Exceeded

All recorded values exceeded the WHO maximum permissible limit for freshwater (0.01 mg/L). Different letters within the same column indicate significant differences at P≤0.05P \le 0.05P≤0.05. N.S.: Non-significant.

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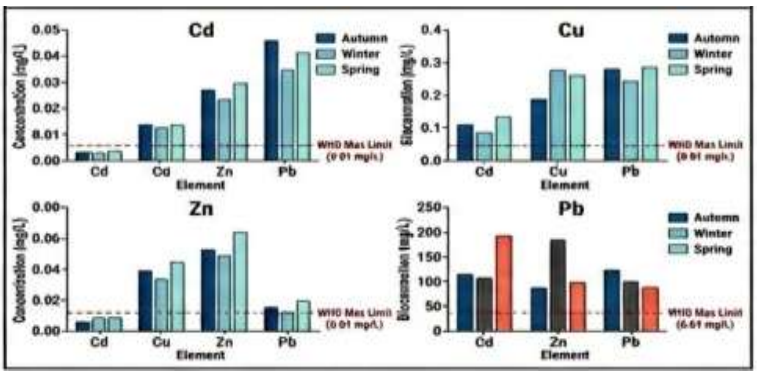


Figure (3): Seasonal concentrations of heavy metals (Cd, Cu, Zn, Pb) in Tigris River water during the three study seasons (Autumn, Winter, Spring).

Bioaccumulation in Common Carp Tissues

Statistical analysis revealed significant differences in the concentrations of the heavy metals Cd, Cu, Zn, and Pb among the different fish tissues across the studied seasons (autumn, winter, and spring). In autumn, cadmium (Cd) recorded its highest concentration in the liver (15.360±0.580 µg/g) compared to the gills (12.646±0.186 µg/g) and muscles (7.126±0.705 µg/g), with clear significant differences among all tissues (P<0.01). Similarly, zinc (Zn) showed the highest accumulation in the liver (133.850±0.620 µg/g), followed by the gills (101.193±2.525 µg/g) and then the muscles (82.823±0.618 µg/g), with highly significant differences among tissues (P<0.01). Copper (Cu), on the other hand, recorded its highest values in the gills (12.253±0.711 µg/g) and liver (12.133±0.737 µg/g) with no significant difference between them, whereas its concentration decreased significantly in the muscles (7.687±0.234 µg/g) (P<0.01). As for lead (Pb), the gills recorded the highest value (15.837±1.000 µg/g) followed by the liver (14.127±0.602 µg/g) with no significant difference between them, while its concentration in the muscles (8.327±0.110 µg/g) was significantly lower (P<0.05). During winter, the general accumulation pattern of cadmium and zinc persisted, as the liver recorded the highest concentrations of cadmium (16.430±0.504 µg/g) and zinc (137.873±0.241 µg/g), while the muscles recorded the lowest values (3.916±0.551 and 73.303±0.691 µg/g, respectively), with highly significant differences among tissues for both elements (P<0.01). Copper also showed higher concentrations in the liver (12.627±0.248 µg/g) and gills (10.610±0.252 µg/g) compared to the muscles (7.203±0.595 µg/g), with no significant difference between the liver and gills, while the difference between them and the muscles was significant (P<0.05). Lead reached its highest concentration in the liver (14.480±0.355 µg/g) and gills (13.133±0.375 µg/g) with no significant difference between them, while the muscles recorded the lowest concentration (4.763±0.692 µg/g), with highly significant differences among tissues (P<0.01(. In spring, the liver recorded the highest concentrations of cadmium (15.776±0.626 µg/g) and zinc (144.737±1.536 µg/g), followed by the gills (12.773±0.185 and 123.047±0.547 µg/g, respectively), while the muscles recorded the lowest concentrations (5.716±0.460 and 76.770±0.507 µg/g, respectively); the differences among tissues were significant for cadmium (P<0.05) and highly significant for zinc (P<0.01). Regarding copper, its concentration did not differ significantly between the liver (14.257±0.626 µg/g) and gills (13.397±0.757 µg/g), while its concentration in the muscles (6.810±0.390 µg/g) was significantly lower (P<0.05). Lead exhibited a pattern similar to that observed in autumn and

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winter, showing no significant difference between the gills (16.153±0.568 µg/g) and liver (14.690±0.417 µg/g), while its concentration in the muscles (6.347±0.172 µg/g) was significantly lower (P<0.05).The results of the present study are consistent with numerous previous studies indicating that heavy metal accumulation varies according to tissue type, with the liver and gills being the tissues most prone to accumulation, whereas muscles tend to accumulate lower proportions of heavy metals, owing to the presence of a mucous layer that acts as a protective barrier reducing the transfer of heavy metals to muscle tissue [19]. The changes occurring in heavy metal levels among body organs are attributed to agricultural waste, which leads to contamination [17]. The results further indicate that fish acquire heavy metals not only from the aquatic environment but also from their diet, particularly from benthic organic matter to which these elements are bound [25].

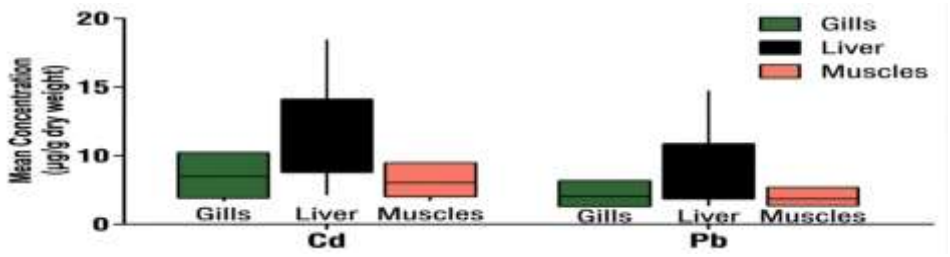


Figure (4): Box plot of Cd and Pb mean concentrations (µg/g dry weight) in gills, liver, and muscles of Common Carp compared with FAO/WHO and European Commission (EC) maximum permissible limits

Table (5): Heavy metal concentrations (µg/g dry weight) in Common Carp tissues across the three study seasons

Season	Tissue	Cd (µg/g)	Cu (µg/g)	Zn (µg/g)	Pb (µg/g)
Autumn	Gills	12.646±0.186 b	12.253±0.711 a	101.193±2.525 b	15.837±1.000 b
Autumn	Liver	15.360±0.580 a	12.133±0.737 a	133.850±0.620 a	14.127±0.602 b
Autumn	Muscles	7.126±0.705 c	7.687±0.234 b	82.823±0.618 c	8.327±0.110 a
Significance (Autumn)	—	**	**	**	*
Winter	Gills	11.330±0.684 b	10.610±0.252 a	114.493±0.603 b	13.133±0.375 b
Winter	Liver	16.430±0.504 a	12.627±0.248 a	137.873±0.241 a	14.480±0.355 b
Winter	Muscles	3.916±0.551 c	7.203±0.595 b	73.303±0.691 c	4.763±0.692 a
Significance (Winter)	—	**	*	**	**

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Spring	Gills	12.773±0.185 b	13.397±0.757 a	123.047±0.547 b	16.153±0.568 b
Spring	Liver	15.776±0.626 a	14.257±0.626 a	144.737±1.536 a	14.690±0.417 b
Spring	Muscles	5.716±0.460 c	6.810±0.390 b	76.770±0.507 c	6.347±0.172 a
Significance (Spring)	—	*	*	**	*
Season	Tissue	Cd (µg/g)	Cu (µg/g)	Zn (µg/g)	Pb (µg/g)
Autumn	Gills	12.646±0.186 b	12.253±0.711 a	101.193±2.525 b	15.837±1.000 b
Autumn	Liver	15.360±0.580 a	12.133±0.737 a	133.850±0.620 a	14.127±0.602 b

**** Highly significant (P ≤ 0.01); * Significant (P ≤ 0.05); Different letters denote significant differences among tissues within the same season**

Bioconcentration Factor (BCF)

Table (6) reveals that Cd had the highest bioaccumulation potential (BCF > 1000 in liver and gills), placing Common Carp at this site as a highly efficient cadmium bioaccumulator according to the [12]. Zinc had the next highest levels of BCF (152–258) and accumulation of Pb and Cu was even lower. The high BCF for Cd indicates that Common Carp is a sensitive and a good bioindicator for cadmium in the Tigris River system.

Table (6): Bioconcentration Factor (BCF) values of heavy metals in Common Carp tissues (seasonal average)

Element Tissue	Gills	Liver	Muscles	BCF Interpretation
Cd	1587	1970	898	Very High Accumulation (BCF > 1000)
Cu	19	22	12	Low Accumulation
Zn	191	258	152	Moderate Accumulation
Pb	45	43	22	Limited Accumulation

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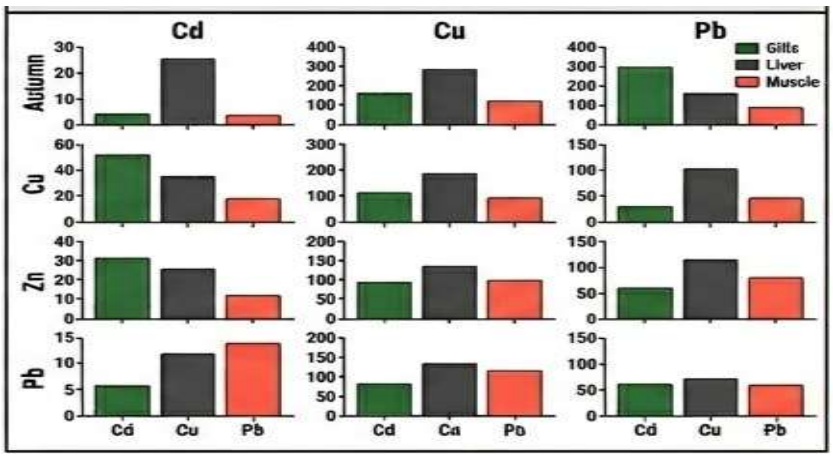


Figure (5): Bioconcentration Factor (BCF) of heavy metals (Cd, Cu, Zn, Pb) in gills, liver, and muscles of Cyprinus carpio across study seasons.

Comparison with International Standards

Table (7): Comparison of heavy metal concentrations in Common Carp muscles with international maximum permissible limits

Element (Muscles)	This Study (µg/g d.w.)	EC (µg/g)	FAO/WHO (µg/g)	Status
Cd	3.9 – 7.1	0.05	0.10	EXCEEDED
Cu	6.8 – 7.7	—	30.0	Within Limit
Zn	73.3 – 82.8	—	100.0	Within Limit
Pb	4.8 – 8.3	0.30	0.50	EXCEEDED

EC = European Commission food safety standards; FAO/WHO = Food and Agriculture Organization / World Health Organization

Conclusions

The study conducted on the water of the Tigris River and common carp (*Cyprinus carpio* L.) in Al-Khalis District, Diyala Governorate, demonstrated that cadmium concentrations in the river water remained within the nationally permissible limits, with no significant seasonal or spatial differences observed. In contrast, lead concentrations in the water (0.29–0.40 mg/L) exceeded the World Health Organization's maximum permissible limit at both sites across all three seasons, indicating persistent contamination that warrants immediate remedial action. Copper and zinc concentrations exhibited pronounced spatial and seasonal variation, with the highest values recorded at the Al-Sindiyah site, most likely attributable to the intensive agricultural activity surrounding the area. With regard to fish tissues, the liver was identified as the organ exhibiting the highest accumulation of heavy metals in most seasons, owing to its physiological role as the principal storage site for accumulated metals. Furthermore, cadmium and lead concentrations in the muscle tissue of common carp exceeded the maximum permissible limits established by the FAO/WHO and the European Commission (EC), indicating a potential risk to the public health of local consumers. Bioconcentration factor (BCF) values further revealed that cadmium exhibited the highest bioaccumulation potential (BCF > 1000 in the liver and gills), confirming common carp as a sensitive and reliable bioindicator of cadmium contamination within the Tigris River system. The study concluded with several practical recommendations, including the intensification of routine environmental monitoring programs, the enactment of regulations prohibiting the discharge of industrial and agricultural effluents into the river, and the

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implementation of formal health risk assessment studies for local fish consumers.

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