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Environmental chemistry and ecotoxicology of heavy metals in water, sediment, and aquatic plants in lotic ecosystem

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Abstract

Background: This study examined the effects of the Al-Rustumiya sewage treatment station on the heavy metals (Fe, Zn, and Mn) that pollute the Diyala River.

Methods: Samples of water, sediment, and aquatic vegetation were collected monthly from Diyala River at four locations between March 2022 and February 2023. The samples were collected using standard sampling methods and analyzed with an atomic absorption spectrophotometer.

Results: The order of heavy metals in water was: Fe > Mn > Zn, both in the dissolved and particulate phases. The sediment was ordered in the exchangeable and residual phases: Fe > Mn > Zn, while in aquatic plants, the order in leaves was: Fe > Zn > Mn, and in roots: Zn > Fe > Mn. According to the findings, the particulate phase of water contained greater quantities of heavy metals than the dissolved phase. The sediment concentrations in the residual phase exceeded those in the exchangeable phase, while the roots of aquatic plants had higher concentrations than their leaves.

Conclusion: As Al-Rustumiya station's streams flow into the river, the concentrations of heavy metals in the water increase. This has a deleterious effect on aquatic life and the agricultural area on both sides that rely on the river's water for irrigation. This research concentrates on the destiny and processes of transmission in the lotic aquatic system for heavy metals (Fe, Zn, and Mn). As there is a cumulative effect from these metals, appropriate measures are necessary by the relevant agencies to address this problem.

Keywords: Heavy metals, Water, Sediments, Plants, Environmental pollutants

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Introduction

Heavy metals exist naturally in a variety of environmental media, but their extensive dispersion has generated questions about their potential effects (1). This is because of its many industrial, residential, agricultural, medicinal, and technical uses (2). Due to their persistence in sediments and biota, heavy metals pose a threat even at trace levels (3). Trace metal levels can rise because of things like volcanic events, the weathering of rocks, and the movement of water into rivers, lakes, and seas.

The major issues associated with heavy metal persistence are toxicity, bioaccumulation, and biomagnifications, which have long-term consequences for the ecosystem, human health, and other living organisms (4,5). Otherwise, human actions include dumping sewage waste, mining, farming, and dumping industrial waste into the water environment. Many studies have examined the role of heavy metals on human health in various aquatic environments (6-10).

Heavy metals may have a wide variety of harmful consequences, from mild discomfort to terminal organ failure. Although some heavy metals (Cu, Fe, Mn, and Zn) are necessary for survival only at significant trace levels, others (Pb, Cd, As, and Hg) are poisonous and damaging regardless of quantity (11). The latter may do irreversible harm, and this should be borne in mind as their contamination has an adverse impact on water quality and may be harmful to human health.

In this regard, mine runoff, fossil fuel combustion, alloy manufacturing, and soil erosion are all potential sources of zinc pollution (12). Deficiencies in zinc have been linked to impaired immunological and nervous system function, as well as slowed development (13). Moreover, an iron shortage may lead to anemia, and iron is essential for the production of hemoglobin in the blood; on the other hand, having too much iron in the blood can be harmful (14).

Salman et al (15) investigated Cd, Cu, Pb, Fe, and Zn in the water and sediment of lotic ecosystems, and they concluded that the concentrations of heavy metals in water for the particulate phase were higher than in the dissolved phase. Their attention in the residual phase was higher than in the exchangeable phase, except for Cu, which had higher concentrations in the switchable phase than in the residual phase in sediment. Habeeb et al (16) conducted a study on the water quality, heavy metal levels, silt, and marine macrophytes in the lotic ecosystem of Babylon province. The aim was to investigate any potential environmental impacts on the eastern Euphrates flow.

Al-Zughaiby et al (17) found that some levels of trace elements in the Euphrates River in Iraq were correlated. This study measured the concentrations of trace elements in both aqueous and soluble forms at different research sites. Heavy concentrations of cadmium, chromium, iron, manganese, nickel, and zinc were discovered in the Warri River in Nigeria (18). There has been extensive research on the presence of heavy metals in waterways, sediments, and aquatic species, as demonstrated by multiple studies (19-21).

As such, this research aimed to determine the transmission and fate of heavy metals in water, sediment, and aquatic plants by analyzing water quality and quantifying various heavy metal concentrations in the lotic aquatic system.

Materials and Methods

Study area

The Diyala River is an essential branch of the Tigris and one of the Iraq's primary water sources. Figure 1 shows the course of the river as it flows through Diyala province, north of Baghdad. The entire distance of the route is 445 kilometers, approximately equivalent to 275 miles. The Diyala River flows through an area between 33° 13 00" N and 35° 50 00" N and 44° 30 00" E and 44° 50 00" E, with numerous cities settled along its banks. It receives runoff from farms and factories and drains a total of 32,600 square kilometers between the borders of Iraq and Iran (22).

The southern Al-Rustumiya WWTP (old project F0, the first extension F1, and the second extension F2) and the northern Al-Rustumiya WWTP (third extension F3) are the primary wastewater treatment facilities constructed to serve the east side of Baghdad city (Rusafa). They are considered one of the most significant projects (23). The plant uses an activated sludge system, which biologically processes carbon compounds in raw wastewater (24). Al-Rustumiya Wastewater Treatment Plant treats sewage, and the effluent is released into the Diyala River, and thus, into Tigris River (25).

Sample collection

Diyala River was surveyed at four different locations. The first location was 800 m north of the Al-Rustamiya wastewater treatment plant. The second location was near the new Diyala bridge, about 1.8 kilometers from the first station. The third location was at the army channel, which was approximately 3 kilometers from the second location. Finally, the fourth location was near the ALRasool bridge, which was around 3 kilometers from the third location (Figure 1).

Samples of monthly water, sediment, and aquatic plants were taken from Diyala River at four different locations

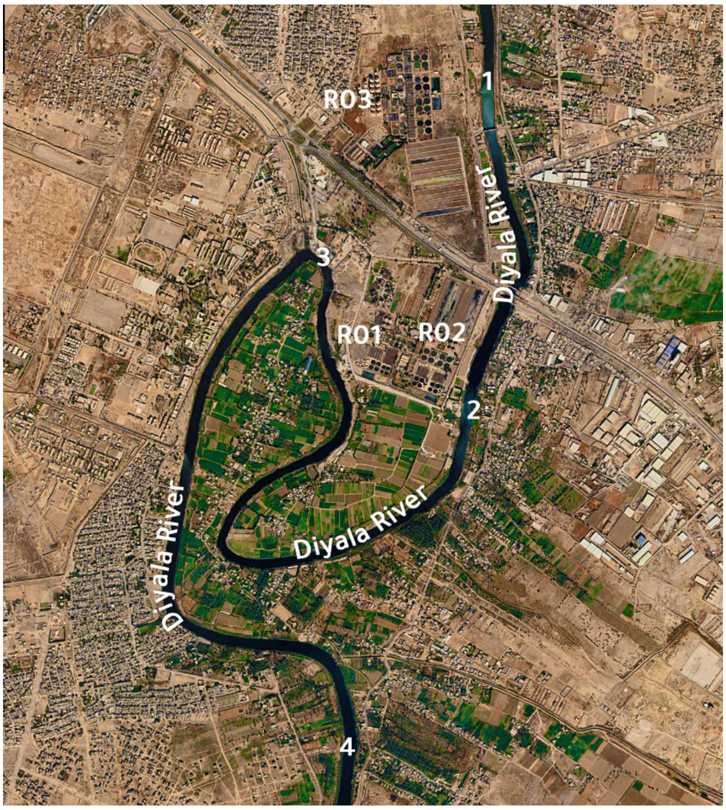

Figure 1. Map of the study area with sample locations

from March 2022 to February 2023. The results were carried out in four seasons: Spring, summer, autumn, and winter. Polyethylene bottles containing three copies of each sample were used to collect water from the center of the river and banks to analyze heavy metals (26). After being rinsed in river water to get rid of any particles in suspension, samples of aquatic plants were taken, put in plastic bags, and taken to the laboratory (27). Benthic sediment samples were collected using a grab sampler from the same location as the plant samples and stored in labeled plastic bags until analysis.

Heavy metal detection methods

Heavy metals in water

Heavy metal concentrations in water were determined using an ion exchange technique described in the study of American Public Health Association (27) to measure dissolved heavy metals. The particulate heavy metal was measured by digesting particulates collected on Millipore filter membranes of 0.45 µm with HCL: HNO_3: $HClO_3$: HF. Eventually, the heavy metal concentrations in the samples (in mg/L) were measured using a flash atomic absorption spectrophotometer (FAAS).

Heavy metals in sediment

According to the study of Turek et al (28), estimates were made for heavy metals in sediment samples. Heavy metals in exchangeable and residual phases were extracted. We weighed 2 g of air-dried sediment, transferred it into a clean glass flask, and added 10 mL of a mixture containing 1 mL each of H_2SO_4, HNO_3, and 3 mL of $HClO_4$. These heavy metals are determined by flame atomic absorption spectrophotometer (Model Pyeunicam SP9). This absorption was then converted into concentration units, and the numbers were given as (mg/g) dry weight.

Heavy metals in aquatic plant

Samples (collected, dried, and milled) were used to estimate heavy metal concentrations, with the powdered samples being digested using an acid method (28). When the combination reached the dehydration stage, 3 ml each of nitric acid and perchloric acid ($HClO_4$) was added to the solution. After the sample was filtered to remove any undissolved particles, the volume of the solution was adjusted to be either 100 mL, 50 mL, or less so that it would be suitable for analysis with a flame atomic absorption spectrophotometer (Model Pyeunicam SP9).

Statistical analysis

The data collected were analyzed using SPSS version 26, and a statistical significance level of $P < 0.05$ was applied. The statistical analysis program was used to evaluate the impact of various factors, such as seasons and stations, on the study parameters. The least significant difference (LSD) test was used to determine significant differences between means in this study (29,30).

Results

Energy dispersive spectroscopy (EDS)

The acidity levels of both sediment and plant samples were measured, and the results ranged from 7.42 to 7.09. These results indicate that both sediment and plants have exceptional buffering abilities. Figure 2 (a and b) displays the EDS curves, which reveal that the sediment contains Se, Si, Ca, Al, C, Mg, O, Fe, and K in relatively high amounts. In comparison, the plant contains SE, C, Cl, In, Ca, O, Si, Al, Na, Mg, and Fe in relatively high amounts.

Scanning electron microscopy (SEM)

The sediment and plants found in the Diyala River were analyzed through SEM, which involved the examination of SEM images of both sediment and plant particles and the pore architecture. The sediment and plants were magnified to a 20 µm scale through SEM near the Al-Rustumiya wastewater treatment plant. In Figure 3, the physical characteristics of the sediment and plant samples are presented. The sediment and plant surfaces in Figure 3a and 3b have a white coating, which is caused by pollution residues that have seeped into the sediment and plant particles. This has led to a reduction in sorption, meaning that the sediment and plant can no longer absorb any more contaminants (31,32).

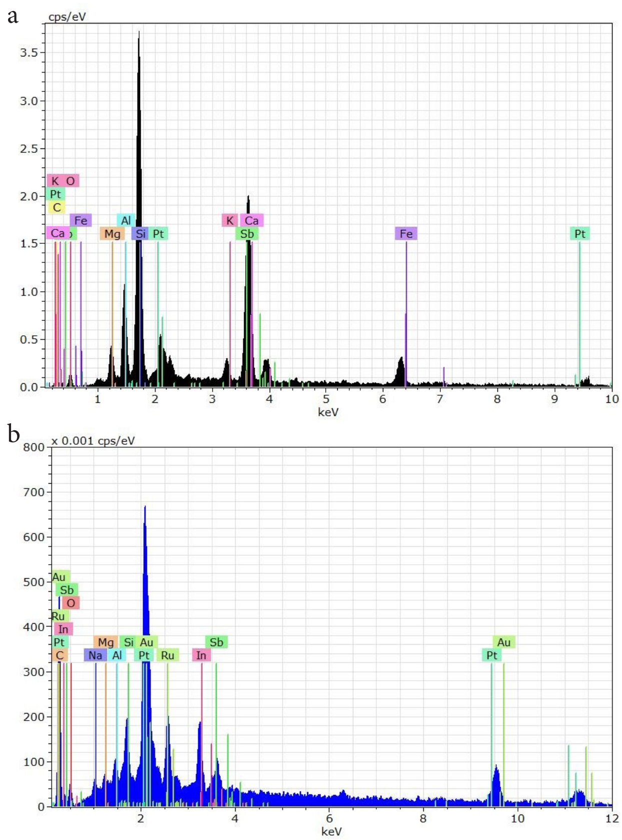

Figure 2. EDS for the composition: (a) sediment sample, (b) plant sample

a

b

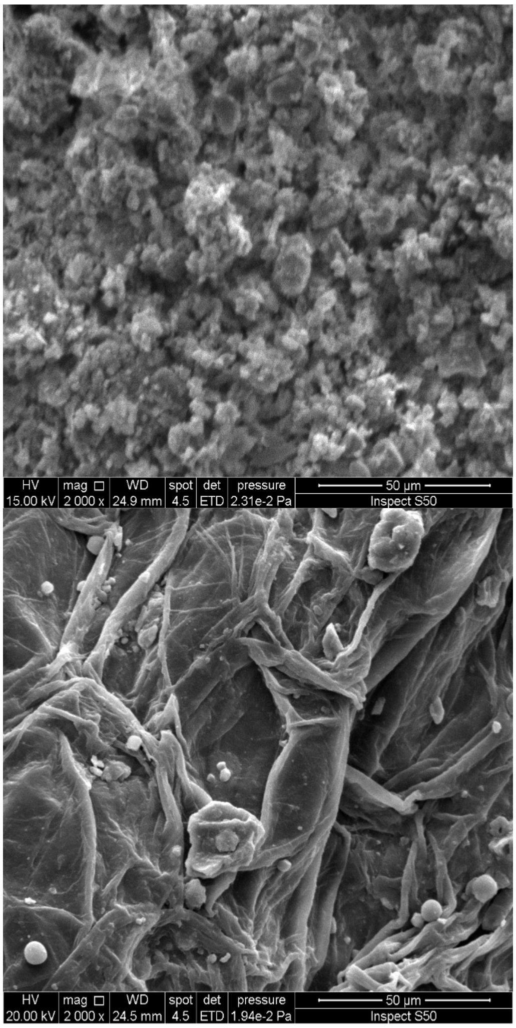

Figure 3. SEM images for the samples: (a) sediment sample, (b) plant sample

Heavy metals in water

The heavy element concentrations in the water from the four research locations are detailed in Tables 1 and 2. During autumn, site 3 had the highest iron content (0.32 mg/L), while site 2 had the lowest manganese concentration (0.03 mg/L). The order of the dissolved phase is Fe > Mn > Zn. Site 4 in the autumn had the greatest iron content (1057.8 mg/L), while site 3 in the spring had the lowest manganese concentration (1.21 mg/L) in the particulate phase (Fe > Mn > Zn).

The statistical analysis of water samples showed

Table 1. The seasonal variation of heavy metals in the dissolved phase

Dissolved	Site	Season				LSD
		Spring	Summer	Autumn	Winter	
(a) Fe (mg/L)	St1	0.22	0.24	0.26	0.17	0.06 S
	St2	0.21	0.24	0.26	0.11	0.11 S
	St3	0.24	0.23	**0.32**	0.28	0.07 S
	St4	0.24	0.23	0.21	0.11	0.10 S
	LSD	0.02 NS	0.01 NS	0.07 S	0.13 S	-
(b) Zn (mg/L)	St1	0.07	0.08	0.09	0.05	0.03 S
	St2	0.06	0.08	0.08	0.04	0.03 S
	St3	0.08	0.07	0.09	0.05	0.03 S
	St4	0.05	0.08	0.08	0.04	0.03 S
	LSD	0.02 S	0.01 S	0.01 S	0.01 S	-
(c) Mn (mg/L)	St1	0.13	0.15	0.21	0.24	0.08 S
	St2	0.17	0.15	**0.03**	0.13	0.10 NS
	St3	0.05	0.06	0.09	0.17	0.09 NS
	St4	0.04	0.09	0.13	0.18	0.10 S
	LSD	0.10 S	0.07 NS	0.12 NS	0.08 NS	-

P < 0.05, S: Significant, NS: Non-significant.

Table 2. The seasonal variation of heavy metals in the particulate phase

Particulate	Site	Season				LSD
		Spring	Summer	Autumn	Winter	
(a) Fe (mg/L)	St1	11.69	527.59	211.82	228.71	338.37 NS
	St2	41.58	71.47	309.28	38.99	207.08 NS
	St3	6.24	23.39	592.57	819.99	652.29 S
	St4	46.02	805.69	**1057.8**	483.42	695.03 NS
	LSD	32.33 NS	597.68NS	603.67NS	537.89 S	-
(b) Zn (mg/L)	St1	3.44	3.11	19.68	2.33	13.32 NS
	St2	5.15	2.79	5.65	9.47	4.40 S
	St3	3.75	3.34	2.21	6.06	2.57 S
	St4	1.86	2.08	16.74	4.41	11.25 NS
	LSD	2.15 NS	0.87 NS	13.44 NS	4.80 NS	-
(c) Mn (mg/L)	St1	33.76	19.29	25.92	6.63	18.28 NS
	St2	6.03	36.77	42.80	10.85	29.23 NS
	St3	**1.21**	24.11	25.92	19.29	17.98 S
	St4	16.28	18.08	28.33	18.08	8.74 S
	LSD	22.92 NS	13.60 NS	12.92 NS	9.57 NS	-

P < 0.05, S: Significant, NS: Non-significant.

variations in dissolved Fe levels in Table 1 (a) across different seasons (except spring and summer) and stations. Meanwhile, Table 2 (a) indicated that the levels of particulate Fe did not significantly differ across stations (except site 3) or seasons (except winter).

According to Table 1 (b), the amount of dissolved Zn showed significant variation across monitoring sites and seasons. On the other hand, Table 2 (b) indicates that the levels of particulate Zn did not vary significantly from station to station or season to season, except for sites 2 and 3. Table 1 (c) displays the statistical analysis showing that there is no statistically significant difference in Mn (dissolved) between seasons except in spring, and that there are no statistically significant differences among stations except in sites 1 and 4. According to the statistical analysis in Table 2 (c), there is no significant difference in Mn (particulate) between seasons. Additionally, there are no significant differences among most stations, except for sites 3 and 4. The consistency of these findings may be due to variations in heavy metal concentrations in the water supply, such as station activity and volume of station deposits.

Heavy metals in sediment

Tables 3 and 4 display the study's measurements of heavy metal concentrations in the exchangeable and residual phases of the sediments, respectively. During autumn, site 2 had a concentration of 22.75 mg/g for the exchangeable phase of Zn, while site 4 had a concentration of 1012.13 mg/g for Fe. Residual phase measurements for Zn during autumn were approximately 35.70 mg/g, and Fe concentrations peaked at about 1937.04 mg/g at site 1.

The analysis of sediment heavy metals in Table 3 (a) indicates that there is no significant difference in Fe (exchangeable) between seasons or stations. Table 4 (a) also shows that there is no significant variation in Fe (residual) between seasons or stations, except for in the summer.

According to Table 3 (b), there was no significant difference in Zn (exchangeable) levels between seasons or stations, except for summer and autumn. Similarly, Table 4 (b) shows that there was no significant variation in Zn (residual) levels between stations, except for summer and winter.

Table 3 (c) shows no significant seasonal or inter-station differences in Mn (exchangeable), and Table 4 (c) shows no significant seasonal or inter-station differences in Mn (residual), except for autumn and winter.

Heavy metals in aquatic plant

At each of the four research locations, Tables 5 and 6 display the heavy metals concentrations found in the aquatic plant. During the winter season, site 3 had the highest concentration of iron (7.89 mg/g), while the lowest concentration of manganese (0.01 mg/g) was found during the autumn season (leaves: Fe > Zn > Mn). Zinc was found in the roots at site 1 at a concentration of 6.28 mg/g during the spring season, while manganese was found in the roots at site 3 at a quantity of 0.32 mg/g during the winter season.

Table 5 (a) shows that Fe (in leaves) did not vary significantly between seasons, but there were substantial changes across stations in heavy metals found in aquatic plants. Table 6 (a) shows that Fe (in roots) had slight variation among seasons, except at site 4, but varied greatly among stations.

Table 3. The seasonal variation of heavy metals in the exchangeable phase

Exchangeable	Site	Season				LSD
		Spring	Summer	Autumn	Winter	
(a) Fe (mg/g)	St1	989.44	932.45	970.26	979.07	39.53 NS
	St2	928.78	954.67	928.71	949.21	21.60 NS
	St3	953.03	967.14	996.46	969.79	28.85 NS
	St4	1000.6	974.32	**1012.13**	920.67	64.78 NS
	LSD	52.65 NS	29.21 NS	58.03 NS	41.19 NS	----
(b) Zn (mg/g)	St1	38.62	26.24	32.68	31.55	8.08 NS
	St2	23.31	31.65	**22.75**	30.19	7.32 NS
	St3	32.91	39.29	36.88	34.04	4.57 NS
	St4	35.72	34.95	43.56	36	6.40 NS
	LSD	10.57 NS	8.76 S	13.87 S	4.12 NS	----
(c) Mn (mg/g)	St1	186.84	139.91	157.28	167.76	31.25 NS
	St2	155.73	154.71	149.89	153.84	4.07 NS
	St3	178.59	180.31	195.61	183.06	12.25 NS
	St4	219.15	197.50	206.78	113.1	76.66 NS
	LSD	41.77 NS	40.96 NS	44.59 NS	47.79 NS	----

P < 0.05, S: Significant, NS: Non-significant.

Table 4. The seasonal variation of heavy metals in the residual phase

Residual	Site	Season				LSD
		Spring	Summer	Autumn	Winter	
(a) Fe (mg/g)	St1	1331.1	1166.31	**1937.04**	1389.43	532.01 NS
	St2	1045.6	1425.68	1306	1387.61	272.40 NS
	St3	1147.7	1372.14	1311.46	1382.54	172.59 NS
	St4	1619.1	1583.83	1671.29	1596.96	61.29 NS
	LSD	400.35 NS	274.32 S	486.81 NS	167.49 NS	----
(b) Zn (mg/g)	St1	92.16	83.36	**35.70**	86.35	41.45 NS
	St2	52.90	114.08	55.33	52.89	48.07 NS
	St3	101.16	90.68	80.28	81.69	15.34 NS
	St4	153.61	90.62	74.09	123.34	56.22 NS
	LSD	65.96 NS	21.29 S	32.02 NS	46.02 S	----
(c) Mn (mg/g)	St1	371.27	533.70	480.59	247.52	201.64 NS
	St2	391.90	489.70	384.34	520.64	109.51 NS
	St3	463.92	569.11	647.32	583.89	121.06 NS
	St4	346.01	375.05	266.42	287.56	80.22 NS
	LSD	80.67 NS	134.29 NS	256.19 S	266.06 S	----

P<0.05, S: Significant, NS: Non-significant.

Table 5. The seasonal variation of heavy metals in the leaves phase

Roots	Site	Season				LSD
		Spring	Summer	Autumn	Winter	
(a) Fe (mg/g)	St1	0.22	3.17	1.05	3.30	2.45 S
	St2	0.27	1.05	3.06	5.23	3.54 S
	St3	0.25	2.04	2.08	**7.89**	5.29 S
	St4	0.29	1.07	3.03	4.87	3.27 S
	LSD	0.05 NS	1.60 NS	1.51 NS	3.03 NS	-
(b) Zn (mg/g)	St1	0.15	1.72	0.75	0.19	1.16 S
	St2	0.15	0.75	0.85	0.32	0.53 S
	St3	0.15	2.25	0.26	0.70	1.54 S
	St4	0.15	1.11	0.76	0.27	0.71 S
	LSD	0.004 NS	1.05 NS	0.42 NS	0.36 NS	-
(c) Mn (mg/g)	St1	0.06	0.08	0.05	0.03	0.04 NS
	St2	0.05	0.03	0.03	0.04	0.02 S
	St3	0.05	0.09	**0.01**	0.04	0.05 S
	St4	0.05	0.06	0.04	0.03	0.02 NS
	LSD	0.002 NS	0.05 NS	0.03 NS	0.01 NS	-

P<0.05, S: Significant, NS: Non-significant.

Table 6. The seasonal variation of heavy metals in the root phase

Leaves	Site	Season				LSD
		Spring	Summer	Autumn	Winter	
(a) Fe (mg/g)	St1	4.21	2.13	5.12	1.52	2.70 NS
	St2	2.07	3.16	2.13	2.35	0.80 NS
	St3	3.93	3.01	3.17	1.80	1.40 NS
	St4	1.36	1.02	3.04	1.33	1.46 S
	LSD	2.22 S	1.57 NS	1.99 NS	0.70 NS	-
(b) Zn (mg/g)	St1	**6.28**	4.79	2.91	1.89	3.11 S
	St2	4.35	3.22	4.72	3.78	1.05 NS
	St3	5.88	3.86	4.11	2.49	2.22 S
	St4	4.28	4.37	1.90	3.03	1.86 NS
	LSD	1.65 NS	1.08 NS	1.99 NS	1.28 NS	-
(c) Mn (mg/g)	St1	3.64	2.39	0.89	0.36	2.36 S
	St2	1.39	1.20	3.82	0.92	2.13 NS
	St3	0.56	1.06	0.54	**0.32**	0.49 NS
	St4	5.20	2.64	2.12	0.31	3.21 S
	LSD	3.37 NS	1.28 NS	2.36 NS	0.47 NS	-

P<0.05, S: Significant, NS: Non-significant.

Table 5 (b) showed that the Zn levels in leaves did not change significantly across seasons, but there were noticeable differences between stations. On the other hand, Table 6 (b) revealed that there were no significant differences in Zn levels in roots between seasons or stations, except for sites 2 and 4.

The statistical results in Table 5 (c) indicate that there was no significant difference in Mn (in leaves) between seasons. However, there were significant differences among stations, except for site and site. Similarly, Table 6 (c) shows that there was no significant difference in Mn (in roots) between seasons, but there were significant differences among stations, except for site 2 and site 3.

Discussion

This study focused on monitoring the levels of water, sediments, and aquatic vegetation in Diyala River. The results were compared to both Iraqi quality standards for river water (33) and international standards set by the WHO (34). The study found that the concentrations of heavy metals, specifically Fe and Zn, in the dissolved phase were within the permissible limits of 0.3 mg/L for

Fe and 0.5-3 mg/L for Zn, respectively. The decrease in their concentration is due to many factors, such as water levels and alkalinity, formation complexes with organic matter, the amount of particulates, and the density of phytoplankton. Anthropogenic activities and the throwing of wastes directly into the river may also affect their concentrations (35,36).

Various studies indicate that heavy metals found in water due to human waste, mining activities, and agricultural practices such as fertilizer and pesticide use have negative impacts on river ecosystems (37). There are several reasons why iron levels may increase, such as pollution from different sources, varying amounts of pollutants entering the river, changes in water levels, and the behavior of specific organisms. These organisms are affected by factors like food availability, opportunities for reproduction, and exposure to light (38).

The idea that low levels of manganese are due to its accumulation in plankton and aquatic plants through filter feeding and sediment uptake is supported by the study of Almamoori and Salman (39). The number of iron atoms in the particles is greater than in the solution. Floating particulate matter in the water column contains clay and biological matter on its surface. This is because most elements tend to attract and adhere to other substances. Clay dissolves in water to create suspended colloids that are then fixed by organ plankton or cations.

After examining the accumulation of heavy metals in sediment and plants, it was determined that sediments tend to have higher levels of heavy metal accumulation than plants. This is because sediments serve as a storage area for all the contaminants and decomposing organic matter that descend from the ecosystem above, according to the results of some studies (40,41). Many bodies of water contain sediments at the bottom, which act as a natural filter for various water toxins that may settle and adhere to the top of these particles. Numerous studies have identified heavy metals as a prevalent form of pollution in waterways and oceans worldwide (42,43). Research conducted by Peng et al (44) has revealed that erosion frequently reintroduces these harmful chemicals into water sources. The quality and composition of sediment can serve as indicators of the extent of this pollution, with continued contamination from the source contributing to an increase in pollutants within sediment over time (45). Suppose these components become mixed or are transferred through the food chain and return to the water. In that case, the quality of the sediment and its constituents will indicate the extent and severity of pollution present.

The sediment's residual phase had larger quantities of iron, manganese, and zinc compared to the exchangeable phase, arranged from the highest to the lowest concentration, Fe > Mn > Zn. Decomposition and plant wastes, as well as outflow from drinking water treatment facilities, are other contributing factors (46).

Aquatic plants have the impressive ability to absorb harmful substances like biogenic components, poisonous compounds, and heavy metals. Heavy metal contamination of water sources is a global issue that poses significant health and ecological risks. Heavy metals are particularly dangerous because they can dissolve and move easily, leading to their accumulation throughout the food chain and causing harmful effects even at low concentrations (47,48). It was observed that plant roots had higher concentrations of heavy metals compared to leaf systems. The accumulation of higher metal concentrations in the roots is believed to reduce the negative impact of metals. The reason for this is the perennial nature of the aquatic plant, causing an increase in accumulation over time. The research confirms that these metals serve as suitable markers, as significant amounts of them were found in plant tissues.

Conclusion

Heavy metals in Diyala River showed seasonal and site-specific oscillations, as well as temporal and geographical variability, throughout the research period. Their concentrations were found to be higher in the roots of aquatic plants than in their leaves, in the residual phase of sediment than in its exchangeable phase, and the particulate phase of water. This research demonstrated the transit of heavy metals via food chains in rivers and their bioaccumulation in aquatic biota as a possible source of pollution by heavy metals since iron concentrations are greater in water, sediments, and aquatic plants. The high concentrations of the investigated heavy metals were alarming due to potential human exposure. Dumping sewage and excreta into the river affects environmental factors and raises trace element concentrations in water, sediment, and aquatic plants. The high levels of heavy metals studied are concerning for potential human exposure through various means. Aside from assessing the current state of the Diyala River's quality in Baghdad, it's crucial to consider the potential harm to humans and the environment due to water pollution. This pollution can also affect the surrounding land, as a significant portion of it can accumulate there. It is suggested that all manufacturing units and contaminated resources be examined in the catchment area to determine the leading causes of water contamination. Failure to monitor and control these resources will exacerbate the influence of heavy metals, threatening the welfare of people in Iraq.

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Competing interests

The author declares that there is no conflict of interests.

Ethical issues

The author hereby certifies that all data in the field of study described in the manuscript and data from the study have been or will not be published separately elsewhere.

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