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Original Article

Seasonal dynamics of heavy metal uptake in some aquatic plants of the Tigris River

Samar Jasim Mohammed, Ali Abdulrahman Fadhil*, Huda Hilo Ali

Department of Biology, College of Science, University of Misan, Maysan, Iraq.

Abstract: This work aimed to study the accumulation of heavy metals Cadmium, Lead, Chromium, and Nickel in different aquatic plants along the Tigris River. The research focused on the seasonal variations in heavy metal uptake by *Phragmites australis, Typha domingensis, Persicaria salicifolia, Azolla filiculoides,* and *Ceratophyllum demersum*. Samples were collected from three distinct locations along the river, each characterized by varied environmental conditions. Using Atomic Absorption Spectrophotometry, the quantified metal concentrations were measured, revealing significant differences across seasons and locations. The study provides crucial insights into the dynamics of heavy metal accumulation in riverine ecosystems, underscoring the role of environmental factors and plant species in metal uptake.

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Introduction

Aquatic plants play vital roles in river ecosystems, serving as bioindicators of environmental health and mediators in the bioaccumulation of pollutants. Among these pollutants, heavy metals, such as Cadmium (Cd), Lead (Pb), Chromium (Cr), and Nickel (Ni) pose significant ecological risks due to their toxicity and persistence (Tashla et al., 2018; Doğan et al., 2022; Hamidian et al., 2023; Rajak et al., 2024). These metals enter aquatic systems through various anthropogenic activities, including industrial discharges, agricultural runoffs, and urban wastewater (Alavian Petroody et al., 2017; Daripa et al., 2023). Industrial wastes are a significant global concern due to their extensive environmental pollution. These wastes originate from various industrial processes, each contributing differently in terms of toxicity (Khan et al., 2022). The pollutants include discarded materials, processed substances, or chemicals. When these pollutants exceed the environment's capacity to absorb, pollution occurs. Heavy metals in these wastes can have detrimental health effects, with tannery effluents being among the most polluting. They majorly contribute to chromium pollution and, to a lesser extent, cadmium and other heavy metals (Hölzle et al., 2022). The impact of these pollutants on humans, aquatic life, and plants highlights the critical need for effective treatment of heavy metals in wastewater. Various methods like electro-dialysis, reverse osmosis, and absorption are employed to remove these metals (Mojoudi et al., 2018). However, these methods are not always economically viable. On the other hand, phytoremediation, which involves using plants to remove metals, presents an eco-friendly and cost-effective alternative for treating heavy metals in wastewater (Arabi et al., 2022; Sarah et al., 2023).

The Tigris River, a crucial waterway with a rich biodiversity, faces environmental pressures from rapid urbanization and industrialization (Hamza, 2010; Al-Obaidy et al., 2013; Mensoor et al., 2018). This study focuses on the Tigris River, renowned for its ecological diversity and historical significance, yet increasingly burdened by pollution. Previous research highlights the increasing heavy metal concentrations in aquatic environments, but there remains a gap in understanding the seasonal dynamics of metal uptake by aquatic plants. The current study concentrates on five prevalent aquatic plant species in the Tigris River. *Phragmites australis, Typha domingensis, Persicaria*

*Correspondence: Ali Abdulrahman Fadhil
E-mail: alibiologist87@uomisan.edu.iq

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salicifolia, Azolla filiculoides, and *Ceratophyllum demersum* are known for their potential in bioaccumulating heavy metals, making them ideal subjects for studying environmental metal dynamics (Rai, 2008; Shaltout et al., 2014; Shaltout, 2018; Milke et al., 2020). The primary aim of this research is to assess the seasonal variations in heavy metal uptake by these plants. Understanding these dynamics is crucial for ecological monitoring and provides insights into the health of aquatic ecosystems. This study not only contributes to the field of environmental science but also aids in developing strategies for riverine ecosystem conservation and management. By examining the interactions between aquatic plants and heavy metals in a riverine context, our research seeks to fill the knowledge gap in seasonal bioaccumulation patterns, offering a critical perspective on ecological responses to heavy metal pollution in riverine ecosystems.

Materials and Methods

All reagents employed were of analytical grade, with acids and standards used for digestion and calibration sourced from certified suppliers to ensure the reliability of data. Leafs of *P. australis*, *T. domingensis*, *P. salicifolia*, *A. filiculoides*, and *C. demersum* were systematically harvested from three selected sites along the Tigris River during summer and winter, capturing the ecological diversity of the riverbank flora. Biotic and abiotic factors pertinent to each station, such as the presence of specific wildlife, the density of local flora, and the river's flow characteristics were taken into consideration along with the time of day and specific conditions under which the samples were collected. The stations are characterized by: Station (1): Al-Huda Village: Situated at the river's entrance near Al-Amarah City, surrounded by agricultural lands and orchards, with prevalent water traffic and diverse aquatic plants of *P. australis*, *T. domingensis*, *P. salicifolia*, *A. filiculoides*, and *C. demersum,* station (2): Residential Area subjected to domestic and agricultural effluent discharge, featuring similar flora to station 1, and station (3) Soudor Al-Majer, locating in a multifaceted environment with agricultural activity and wildlife at the river's south.

The collected leaves of the aquatic plants were prepared for analysis following standard protocols. However, post-collection, leaves were immediately rinsed with deionized water to remove surface contaminants, followed by drying at a consistent temperature in a laboratory-grade desiccator to maintain integrity. The concentrations of Ni, Cr, Pb, and Cd in the plant tissues were quantitatively measured. The detailed methodology focused on the calibration, operational settings of the spectrophotometer, and data analysis procedures to ensure accurate determination of heavy metal concentrations.

Preparation for heavy metal analysis: All the following step-by-step procedures for sample digestion filtration and neutralization processes before spectrophotometric analysis were conducted. Calibration curve preparation, including standards used, and the range of concentrations was done. The Shimadzu AA-7000 spectrophotometer was used to measure the concentrations of the heavy metal elements in the plant samples.

Statistical Analysis: The data were analysed using Analysis of Variance (ANOVA) to determine significant differences in heavy metal concentrations across different plant species and between seasons. A post-hoc Tukey's HSD test was employed for pairwise comparisons when significant differences were found. The level of significance was set at $P<0.05$. All statistical analyses were conducted using SPSS, 2022.

Results

The Cd concentration in various selected aquatic plants revealed distinct patterns of metal accumulation. The results showed that *C. demersum* accumulated the highest average concentration of Cd in both summer (0.0588 mg/L) and winter (0.0727 mg/L), suggesting a higher propensity for Cd uptake. Contrastingly, *P. salicifolia* exhibited the lowest concentration during summer (0.0010 mg/L) with a slight increase in winter (0.0069 mg/L) (Table 1). *Typha domingensis* showed significant seasonal variation, with winter concentrations (0.0450 mg/L)

Table 1. Seasonal variations of cadmium concentrations in the studied aquatic plants in Tigris River.

Cd concentrations (mg/L)		
Plant	Summer	Winter
Phragmites australis	0.0010	0.0012
Typha domingensis	0.0450*	0.0311*
Persicaria salicifolia	0.0069	0.0010
Azolla filiculoides	0.0692*	0.0021
Ceratophyllum demersum	0.0727*	0.0588*

*P<0.05

Table 2. Seasonal variations of lead concentrations in the studied aquatic plants in Tigris River.

Pb concentrations (mg/L)		
Plant	Summer	Winter
Phragmites australis	5.4354	0.9059
Typha domingensis	1.8113	22.6475*
Persicaria salicifolia	6.3413	9.9649
Azolla filiculoides	5.4354*	1.8118
Ceratophyllum demersum	3.6236	4.5295

*P<0.05

Table 3. Seasonal variations of chromium concentrations in the studied aquatic plants of Tigris River.

Cr concentrations (mg/L)		
Plant	Summer	Winter
Phragmites australis	2.5917	0.0097
Typha domingensis	6.8031*	5.8312*
Persicaria salicifolia	1.9437	0.0324
Azolla filiculoides	6.4792*	4.2115*
Ceratophyllum demersum	4.5354	2.9156

*P<0.05

surpassing summer values (0.0311 mg/L). *Phragmites australis* and *A. filiculoides* displayed moderate uptake, with *P. australis* having more consistency across seasons. The observed variations suggest that both plant species and seasonal factors significantly influence Cd bioaccumulation (Table 1).

The results indicated that *T. domingensis* had the highest accumulation of Pb during the summer (22.6475 mg/L), significantly higher compared to the winter (1.8113 mg/L). *Phragmites australis, P. salicifolia, A. filiculoides*, and *C. demersum* showed the ability to absorb Pb, with varying concentrations across seasons. Notably, *Azolla filiculoides* displayed a substantial increase in Pb concentration in the winter (5.4354 mg/L) compared to the summer (1.8118 mg/L) (Table 2). These results suggest seasonal influences on Pb uptake in these aquatic plants, with some species showing a marked increase in the colder months.

In the results for Cr, *T. domingensis* exhibited the highest uptake during summer (5.8312 mg/L) and winter (6.8031 mg/L). *Azolla filiculoides* showed substantial seasonal uptake, increasing from 4.2115 mg/L in summer to 6.4792 mg/L in winter. *Phragmites australis* and *P. salicifolia* presented lower concentrations, with *P. australis* showing a notable increase in winter (2.5917 mg/L) (Table 3). The data indicates a general trend of increased Cr accumulation during the winter across the species studied. For Ni, *C. demersum* displayed the highest levels with an increase from 110.453 mg/L in summer to 159.697 mg/L in winter, suggesting a significant seasonal influence. *Phragmites australis* and *A. filiculoides* showed elevated winter concentrations (Table 4). These results indicate a general trend of increased Ni accumulation in colder months across the

Table 4. Seasonal variations of nickel concentrations in the studied aquatic plants of Tigris River.

Ni concentrations (mg/L)		
Plant	Summer	Winter
Phragmites australis	57.3132	7.2337
Typha domingensis	152.186*	11.4070
Persicaria salicifolia	18.3625	24.7615
Azolla filiculoides	61.7647	35.3339
Ceratophyllum demersum	159.697*	110.453*

*P<0.05

examined species.

Discussions

The observed seasonal variation in heavy metal uptake among the examined aquatic plants suggests a complex interplay of physiological adaptations and environmental factors. Higher concentrations of Ni and Cr in winter could indicate reduced competition for uptake sites or changes in metal solubility due to temperature fluctuations (Gray et al., 2006). The considerable uptake of Pb in *T. domingensis* and the pronounced accumulation of all metals in *C. demersum* across both seasons might reflect inherent species-specific differences in metal handling or absorption efficiency (Xu et al., 2022).

The results revealed the seasonal variations of Cd concentrations within various aquatic plants between summer and winter. In the summer, the aquatic plants demonstrate varying levels of Cd uptake. *Azolla filiculoides* and *C. demersum* exhibit the highest concentrations and this could be indicative of higher metabolic activity during warmer months, leading to increased absorption of Cd (Jeong et al., 2023). Conversely, *P. australis* shows the lowest concentration, which may suggest a natural resistance to Cd accumulation or perhaps differences in the bioavailability of Cd in the habitat where it grows. Winter concentrations across all species were generally lower. The plant with the most significant seasonal fluctuation was *A. filiculoides*, which exhibits nearly a threefold decrease from summer to winter. This stark contrast might be due to its life cycle or specific physiological changes that occur in response to colder temperatures. Overall, the results imply that seasonal changes significantly impact Cd concentrations in aquatic plants. This could have implications for phytoremediation strategies, suggesting that the efficiency of Cd uptake by these plants may be optimized by harvesting them during specific times of the year.

A remarkable aspect of the results was the significant seasonal fluctuation in Pb levels across different species, which suggests that environmental factors and plant physiology both play a role in metal uptake (Ahmad et al., 2023). During the summer, the concentrations of Pb in all plants except *T. domingensis* were higher. However, in winter, the Pb concentration in *T. domingensis* experiences an unusual surge to 22.6475 mg/L. This increase could indicate a species-specific physiological adaptation that allows for a higher accumulation of Pb during colder months, or it might be a response to changes in the plant's environment, such as alterations in water chemistry or availability of Pb due to seasonal runoff patterns (Poff et al., 2002). For the other species, winter decreases Pb concentration, suggesting that its Pb uptake is heavily influenced by seasonal changes, possibly due to reduced metabolic activity or changes in the rhizosphere's chemistry (Luo et al., 2023). Conversely, Pb concentration in *C. demersum* slightly increased in the winter, suggesting a more consistent uptake mechanism that is less affected by temperature fluctuations. Our findings for *P. salicifolia* revealed a reduction in winter, yet its levels remain relatively high compared to other species, indicating that while it does absorb less Pb in the winter, it still maintains a considerable concentration showing that *P. salicifolia* has a strong ability to accumulate Pb (Jan and Abbas, 2018).

The results also showed a seasonal analysis of Cr concentrations in the aquatic plants. The high concentration in *T. domingensis* was significant, which could be due to its specific bioaccumulation capabilities or a greater exposure to Cr in its habitat (Outridge et al., 1993). In winter, all plants exhibit a decrease in Cr concentrations, suggesting the plant's Cr uptake is highly sensitive to seasonal changes, which could be related to reduced physiological activity during colder months (Ru et al., 2023). Interestingly, while *T. domingensis* also shows a decrease in Cr concentration during winter, its levels remain significantly high at 5.8312 mg/L, indicating a consistent ability to accumulate Cr across seasons indicating that this species has a robust mechanism for Cr uptake that operates across different temperatures, or they might be in environments with a steadier Cr supply.

The results illustrated the significant concentrations of Ni in some aquatic plants. Ni is a potentially toxic element, and its accumulation in plants can have both environmental and health implications. The high summer values are significant suggesting that the observed concentrations are not due to random variation but reflect an environmental or biological phenomenon in *C. demersum* and *T. domingensis*. In contrast, *P. australis* exhibits a substantial decrease in Ni concentration in winter (7.2337 mg/L) compared to summer (57.3132 mg/L). This stark contrast might be due to the plant's reduced metabolic activity in colder temperatures, which can lead to a lower uptake of metals (Pang et al., 2023; Vyas et al., 2024). *Persicaria salicifolia* presents a unique case where the Ni concentration increases in winter (24.7615 mg/L) compared to summer (18.3625 mg/L). This could suggest a species-specific adaptation that enables greater Ni uptake during colder months, possibly due to changes in the plant's physiology or alterations in the Ni bioavailability within its environment (Moy, 2023).

Conclusion

This research provides significant insights into the seasonal variations of heavy metal accumulation in aquatic plants along the Tigris River. The study highlights the differential uptake capacities of various plant species for metals like Cd, Pb, Cr, and Ni, underscoring the complex interactions between environmental factors and biological processes. These findings contribute to a deeper understanding of aquatic plant responses to pollution, offering valuable information for environmental monitoring and management strategies. The research emphasizes the need for ongoing monitoring and suggests potential applications in phytoremediation

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