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Research Article

Removal of Heavy Metals through Environmental Purification Methods

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Abstract

The current study involved treating two types of aquatic plants, Phragmites (common reed) and Lemna minor (duckweed), with heavy metal elements—lead and cadmium—at concentrations of 0.10, 0.25, 0.50, 1.0, and 2.0 mg/L for two weeks to evaluate their bioaccumulation potential. The results showed that Lemna minor accumulated lead more efficiently, with a concentration of 1.724 µg/g of its dry weight, whereas, at a 2 mg/L treatment, Phragmites accumulated lead at 1.579 µg/g of its dry weight. In contrast, cadmium accumulation was higher in Phragmites, recording 1.08 µg/g of its dry weight, compared to Lemna minor, which accumulated 0.63 µg/g of its dry weight under the same treatment conditions. A significant variation in metal concentrations was observed across different treatments. As the treatment concentrations increased, the accumulation of both metals in the two plant species showed a gradual increase.

1. Introduction

Water is one of the most vital natural resources from the environment, serving as a fundamental element for human life and various socio-economic activities. Unlike other natural resources, water maintains a constant quantity on Earth and is renewed within specific timeframes through the hydrological cycle. Consequently, all terrestrial life forms depend on water for survival. The reproduction of organisms in oceans, land, and humid areas is inherently linked to water availability.

However, water is among the most consumed and most polluted resources, with pollution stemming primarily from human activities, including industrial discharges, agricultural fertilizers, and urban wastewater that is directly released into water bodies [1]. Water pollution is considered one of the most serious types of environmental pollution, occurring due to the excessive use of clean water in various industrial processes, after which it is discharged contaminated with solid, liquid, and gaseous chemical substances, leading to alterations in its physical and chemical properties that are harmful to ecosystems and human health [2].

The industrial sector is a major contributor to aquatic pollution, as untreated or partially treated industrial wastewater is frequently discharged into nearby water bodies, streams, canals, and lakes.

Zaghloul [3] identified heavy metal pollutants, such as lead and cadmium, as primary contaminants of aquatic environments due to their toxic chemical composition, which includes nitrates, phenols, and their derivatives. These pollutants reach humans through direct water consumption or the consumption of contaminated aquatic organisms. Heavy metals enter ecosystems through physical processes or industrial waste, originating from power plants, petroleum industries, chemical and textile industries, mining operations, paper manufacturing, electronics, fiber production, and the food industry. Heavy metal elements play a crucial role in biological processes at low concentrations, but at higher levels, they can cause physiological damage or even mortality. These metals tend to accumulate in organisms and transfer through the food chain. Some heavy metals, however, are essential for enzymatic systems, such as copper, which is required in minimal amounts as part of the cellular biochemical composition. However, an excess of these metals in aquatic plants can inhibit growth, reduce photosynthesis, prolong dormancy, and increase cell size beyond normal limits [4].

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Certain plants have the ability to remove or reduce pollution levels through metabolic processes, which enable them to absorb, sequester, or degrade pollutants—a process known as phytoremediation, which is a branch of bioremediation [5]. The aquatic plants Phragmites (common reed) and Lemna minor (duckweed) are among the most widely used species in bioremediation due to their high capacity for nutrient absorption from both sediments and water columns. These plants possess rhizomes that provide a large surface area, allowing bacteria to break down pollutants. Additionally, Phragmites secretes enzymes capable of tolerating organic contaminants and produces antibiotic compounds that help degrade pollutants [6].

Al-Shafei [7] highlighted the role of aquatic plants in improving water quality and assessed their efficiency in pollutant removal in constructed wetland systems (FWS – Free Water Surface flow). These methods are essential for addressing challenges in wastewater treatment and enhancing conventional treatment systems. The current study aims to utilize an eco-friendly and cost-effective modern technology that has no side effects to evaluate the efficiency of Phragmites (common reed) and Lemna minor (duckweed) in purifying wastewater to a level that makes it safe for discharge into water bodies or for reuse. The study also compares the results of this method with traditional wastewater treatment techniques currently applied in treatment units and assesses the efficiency of a wastewater treatment plant.

2. Materials and Methods

Sample Collection

Samples were collected from three sites along the Shatt al-Kufa River. Young, newly grown Lemna minor and Phragmites plants were selected. These plants were thoroughly washed with drainage water to remove algae while preserving the root hairs. The samples were then stored in polyethylene bags until they reached the laboratory.

A 50 g fresh weight sample of each plant was used. The plants were cultivated separately in ten (10) plastic containers, each with a 15-liter capacity, filled with 10 liters of dechlorinated distilled water, which was left to stand for 24 hours. The containers were exposed to sunlight in outdoor tanks, and plant growth was monitored for two weeks. The heavy metal elements lead (Pb) and cadmium (Cd) were introduced at five different concentrations, following the methodology outlined by [8, 9].

Preparation of Heavy Metal Solutions

Standard solutions of 1,000 mg/L for cadmium and lead ions were prepared by dissolving cadmium acetate [$Cd(CH_3COO)_2$] and lead acetate [$Pb(CH_3COO)_2$] in deionized distilled water. The solutions were prepared at concentrations of 2.0, 1.0, 0.50, 0.25, and 0.10 mg/L for each element and added to the respective treatment containers.

Plant Sample Digestion

Plant samples were processed by separating leaves from stems in Phragmites and Lemna minor. The samples were then oven-dried at 70°C for 72 hours, finely ground, and weighed (3 g per sample). The samples were placed in ceramic crucibles and incinerated in a muffle furnace at 550 ± 50°C for 4–5 hours. After combustion, 10 mL of 20% hydrochloric acid (HCl) was added, and the samples were heated on a hot plate until boiling to ensure complete dissolution of metal elements. The crucibles were then washed, the final volume was adjusted to 50 mL, and the solutions were filtered and stored in plastic containers until analysis [8, 10].

Statistical Analysis

The results were statistically analyzed using a factorial experimental design with two factors and three replicates: Factor 1: Two aquatic plant species (Phragmites and Lemna minor).

Factor 2: Five heavy metal concentrations (2.0, 1.0, 0.50, 0.25, and 0.10 mg/L).A Completely randomized design (CRD) was applied for the treatments. The SPSS- 2003 statistical program was used for data analysis, and the least significant difference (L.S.D.) test was conducted to analyze variance at a significance level of $P < 0.05$ [11].

3. Results and Discussion

The use of bioremediation technology through certain aquatic plants aims to create a healthy environment using cost-effective methods. This technology leverages the ability of aquatic plants to either remove toxins or restrict the mobility of heavy metals. The primary goal of this study was to compare Phragmites (common reed) and Lemna minor (duckweed) —two of the most widely distributed and native aquatic plants in Iraq's aquatic ecosystems—to determine which plant is more efficient for phytoremediation and environmental treatments.

One of the major challenges facing ecosystems today is the accumulation of heavy metals in the food chain, due to their widespread industrial use. Heavy metals are now considered significant environmental stress factors [12, 13].

Heavy metal adsorption and absorption mechanisms make plants ideal bioindicators of pollution, as contamination is often more pronounced in plants than in water. Bioaccumulation of heavy metals in plant tissues varies depending on:

- The plant species
- The physicochemical properties of water and soil.

The specific uptake and translocation mechanisms of each element The physiological, chemical, and molecular responses of plant tissues.

Heavy metal detoxification in plants occurs through binding the metals to cellular components at targeted sites. Plants can prevent metal accumulation by converting them into inert crystalline salts, storing them in non-sensitive compartments such as vacuoles, or transforming them into non-toxic forms that can be redistributed and reused in metabolic processes [14].

The continued growth and survival of aquatic plants in contaminated environments is largely due to their ability to maintain a balance of enzymatic and molecular antioxidants, such as peroxides, proline, and total phenols. Additionally, plants may increase the secretion of metabolic byproducts, including cysteine and glutamine, which help mitigate heavy metal toxicity.

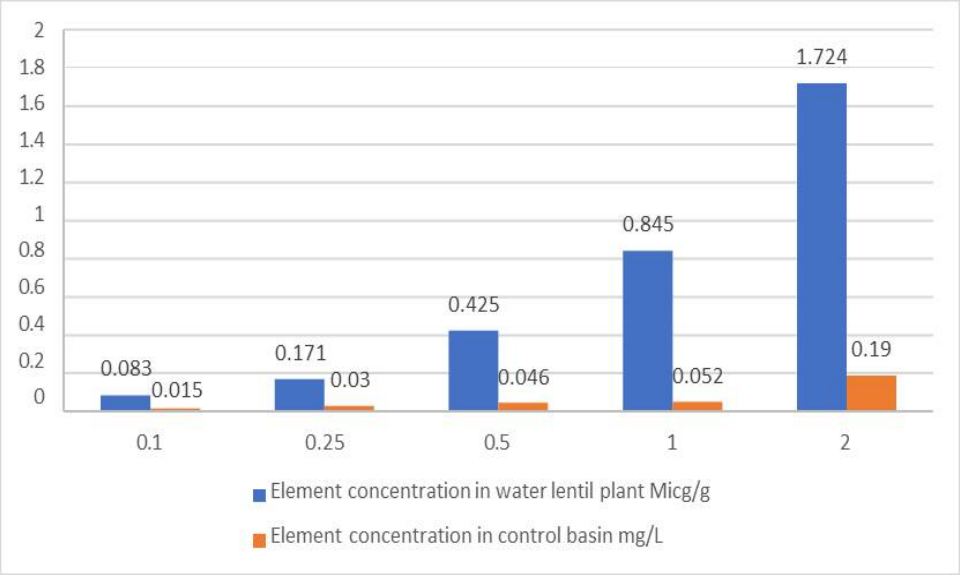

Figure 1: Lead (Pb) Concentration (µg/g) in Lemna minor and Control Ponds (mg/L) Based on Experimental Treatments (mg/L)

Similarly, the study by Abdul-Kareem et al. [15] confirmed that aquatic plants are reliable bioindicators of water pollution, as they accumulate heavy metals in their tissues in higher concentrations than in their surrounding water. This accumulation is facilitated by their rapid growth, adapt to various environments, and minimal environmental requirements.

The concentration of heavy metals in plant tissues may differ based on the plant species and the specific plant organ studied. In natural ecosystems, heavy metals are not freely available for plant uptake; instead, they exist as soluble complexes, and their availability depends on the chemical and physical conditions of the environment. These factors strongly influence ion absorption processes.

Some plants, known as hyperaccumulators, have the ability to absorb heavy metals at significantly higher levels than other plant species. These plants take up both essential and non-essential metals due to similarities in their chemical properties, leading to the unselective transport of metal ions [16].

Lead (Pb) Accumulation in Duckweed (Lemna minor)

As shown in Figure 1, the highest lead (Pb) accumulation in Lemna minor was 1.724 µg/g at the highest treatment concentration of 2.0 mg/L. In contrast, the lead concentration in the control ponds was only 0.190 mg/L at the same concentration.

A gradual increase in lead accumulation was observed in Lemna minor, depending on the experimental conditions. Statistical analysis confirmed a significant difference in lead accumulation at 2.0 mg/L compared to the lower treatment concentrations (0.50, 0.25, and 0.10 mg/L). However, no significant difference was observed between 2.0 mg/L and 1.0 mg/L treatments. No significant differences were recorded in the control group [5, 9, 17].

Lead (Pb) Accumulation in Phragmites (Common Reed)

As shown in Figure 2, Phragmites exhibited a maximum lead accumulation of 1.579 µg/g at a treatment concentration of 2.0 mg/L. In contrast, the lead concentration in the control ponds was 0.130 mg/L, and the lowest concentration was 0.08 mg/L at the 0.10 mg/L treatment. A statistically significant difference was observed between the 2.0 mg/L and 1.0 mg/L treatments, indicating the ability of Phragmites to accumulate lead effectively under increasing contamination levels.

• Numbers that share the same alphabetical letters do not show significant differences at a probability level of $P<0.05$.

The results presented in Figure 3 illustrate the accumulation of cadmium in duckweed plants. At a concentration of 2.0 mg/L, cadmium accumulation in the plant reached 0.63 µg/L, whereas in the control basins for the same plant, the cadmium concentration was 0.73 mg/L. A gradual increase in cadmium concentration in duckweed was observed.

Statistical analysis results demonstrated no significant differences among the concentrations across all applied treatments. However, significant differences were recorded in the control containers between the concentrations of 2.0 mg/L and 0.10 mg/L, while no significant differences were observed among the treatments at 1.0, 0.50, 0.25, and 0.10 mg/L. Gradual increase with rising treatment concentrations. The highest bioaccumulation value was recorded at 2.0 mg/L, reaching 1.08 µg/g, compared to the control basins, where the highest value recorded was 0.91 mg/L. These findings are consistent with those of [18]. Statistical analysis confirmed significant differences between the cadmium concentrations at the 2.0 mg/L treatment compared to the 0.50, 0.25, and 0.10 mg/L treatments. However, no significant differences were observed between the 2.0 mg/L and 1.0 mg/L treatments. In comparison to the control basins, a significant difference was recorded between the concentrations at 2.0, 0.25, and 0.10 mg/L, whereas no significant differences were found among the 1.0, 0.50, 0.25, and 0.10 mg/L treatments, nor among the 2.0, 1.0, and 0.50 mg/L treatments.

The results of the current study revealed a variation between the two plant species in their ability to accumulate lead and cadmium over the experimental period. This difference is attributed to the type and concentration of the element and the plant species used [19]. The experiment demonstrated the high bioaccumulation efficiency of duckweed for lead and cadmium, which can be explained by its large surface area, the formation of aerial roots that enhance metal absorption, and differences in cell membrane composition compared to sugarcane [20].

The mechanisms of heavy metal tolerance in these plants involve binding to thiol (- SH) containing peptides, known as phytochelatins, as

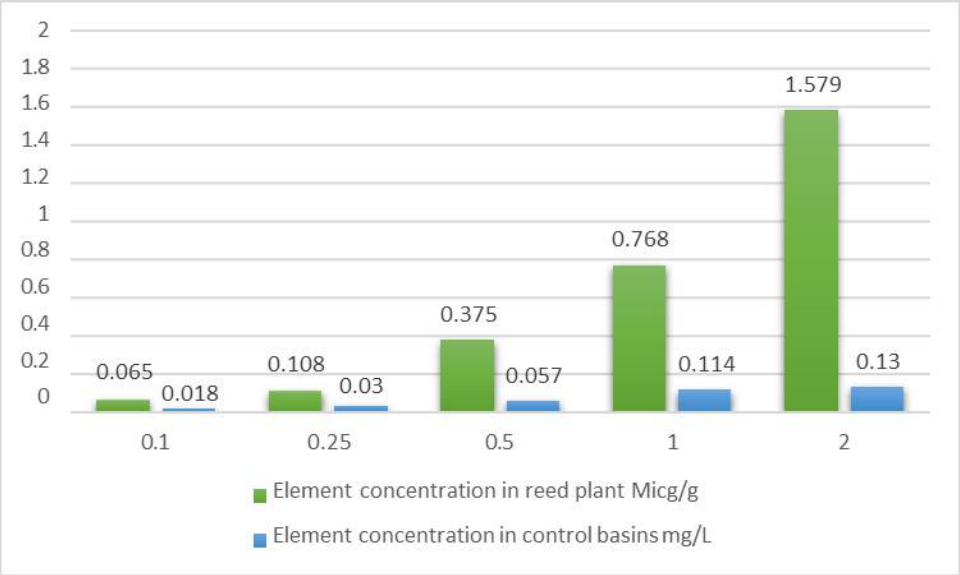

Figure 2: Lead concentration (µg/g) in sugarcane plants and control basins (mg/L)

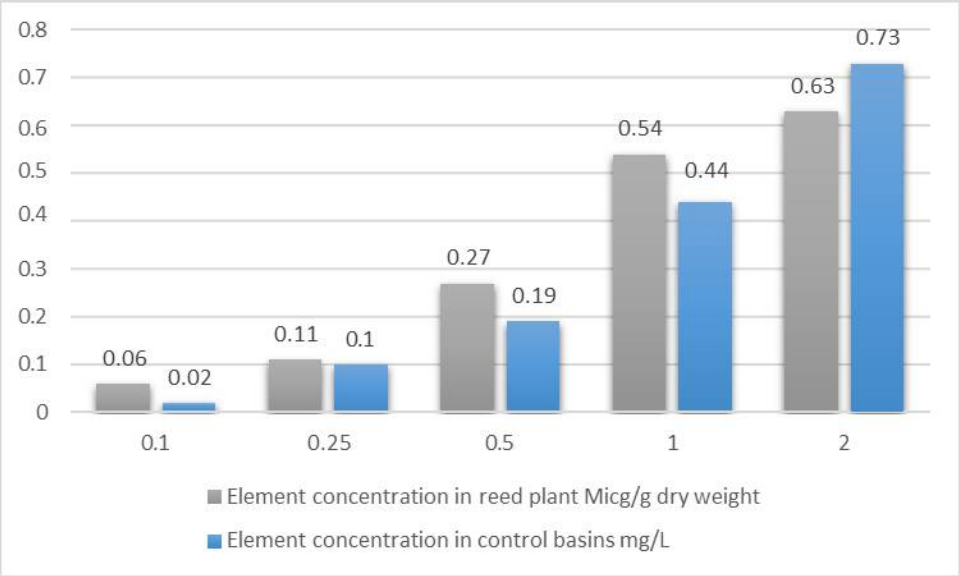

Figure 3: Cadmium concentration (µg/g dry weight) in sugarcane plants and control basins

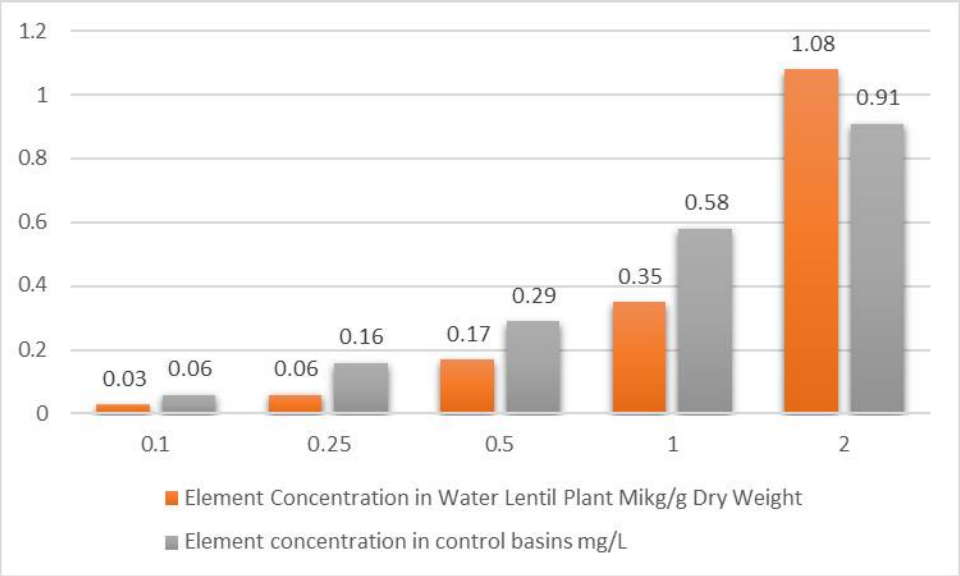

Figure 4: Concentration of cadmium element (mykg/g dry weight) in water lentil plant and control basins

well as the presence of metallothioneins, which help transform heavy metals into their inactive forms. Additionally, these plants exhibit resistance mechanisms against metal toxicity [9, 21]. These findings align with [22], who studied lead accumulation in the vegetative parts of maize (Zea mays), sunflower (Helianthus annuus), and radish (Raphanus sativus). They also support the results of [18], who measured lead accumulation in sugarcane leaves. The study by [23] highlighted the resistance mechanisms of sugarcane to heavy metals, showing that these plants detoxify metals by secreting organic acids, phenols, and superoxide (O_2) from their aquatic roots, which influences the bioavailability of heavy metals in their environment, thereby facilitating their absorption. These plants develop complex defense mechanisms, including sequestering metals in vacuoles, reducing their transport across membranes, or binding them to cell walls [24].

Furthermore, these plants contain antioxidant enzymes, which help neutralize and eliminate reactive oxygen species (ROS) produced due to increased oxidative enzyme activity in plant tissues exposed to contaminated environments [8].

The use of plants for bioremediation is an emerging technology for removing pollutants, leveraging the genetic, chemical, and physiological properties of certain plant species. Unlike chemical treatments, which can be harmful to the environment, phytoremediation offers an eco-friendly alternative for treating contaminated water. The World Health Organization (WHO) has classified cadmium, lead, mercury, and arsenic, as among the top ten most hazardous substances to human health for the year 2018 [1].

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