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Research Article

Comparative Pot Experimental Studies for Phyto-Remediation of Heavy Metals in Contaminated Water Using Ludwigia Decurrens

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ABSTRACT

Heavy metal pollution in surface and groundwater bodies has become a major environmental concern, largely driven by the rapid expansion of industries. However, an effective and sustainable solution lies in the use of hydrophytes for phytoremediation. This approach offers an environmentally friendly and cost-effective way to remove heavy metals from contaminated water bodies. This study assessed the efficiency of hydrophytes (*Ludwigia decurrens)* for the removal of some selected heavy metals (HMs) in a combined state under a controlled pot experiment, using four different heavy metal concentrations. *L. decurrens* plant was obtained at a swampy area of university of Ilorin farm. The metals were combined in a pot at four different concentrations (10, 20, 30 & 40) ppm using 5 mL of each metal concentration. Samples of water and plants parts were taken at 7 days interval, digested using wet acid digestion and the digestates were analyzed for Cd, Cr, Pb and Zn using atomic absorption spectrophotometer (AAS). The plants were separated into different parts, root, stem and leaf. The average HMs percentage removal at different concentrations of (10, 20, 30 & 40) ppm for four weeks was Cd - 94.09%, 97.69%, 99.01% and 99.17%, Cr - was 91.46%, 91.37%, 82.20% and 84.25%, Pb - 90.69%, 85.56%, 97.71`% and 94.53%, while Zn - 50.31%, 51.34%, 77.79% and 83.24% respectively. The heavy metals were removed in order of Cd >Pb> Cr>Zn. The results show that the hydrophyte, *L. decurrens* can efficiently remove HMs at varied concentrations with maximum affinity for Cd among the four heavy metals studied.

Keywords: Pollution, heavy metals, *L. decurrens,* effluent, bio-concentration factor, translocation factor.

1. INTRODUCTION

Agricultural sustainability and industrialization including mankind civilization relied on water. The Earth's surface is comprised of approximately 70% water, yet the majority of these resources have been severely degraded or polluted due to intense anthropogenic activities.[1]

This exploitation has significant environmental and ecological consequences, highlighting the urgent need for sustainable management and conservation of global water resources. Heavy metal pollution in surface and groundwater has become a significant concern for several developing nations. The lack of effective mitigation measures and the high cost of remediation have exacerbated this issue, posing serious environmental and health risks. Heavy-metal are known to be non-biodegradable and tend to accumulate in natural water bodies.,[2] and linger in soil and water for extended periods.[3] Once discharged into the environment, heavy metals can enter surface and groundwater streams through various pathways. They eventually settle in aquatic bodies, causing severe health issues and even death among aquatic animals.[4] Polluted soil and water reduces food quality, land usability for agricultural practice and may lead to food insecurity and land tenure problems.[5]

Several control and conventional techniques have been used to remediate heavy metals from water include ion exchange, membrane filtration, reverse osmosis, electrolysis, chemical precipitation and adsorption.[6] However, these techniques have the drawbacks including maintenance costs, expensive operation, and secondary contamination due to the formation of toxic sludge.[7]

Based on the above context, there is a need for simple, cheap, ecological and profitable alternatives for the removal of these metals. In this direction, plants induce physiological and biochemical mechanism to eliminate metals from effluents.[8] Aquatic plants' exceptional accumulation capacity makes them ideal for phytoremediation, effectively absorbing and removing pollutants from contaminated water.

Plant-centered (Phytoremediation) is a technique that uses plants to restore polluted water and soil sources.[9] Hydrophytes such as *Ludwigia* species are free-floating and known for pollution absorption particularly for HMs in polluted water. *Ludwigia* belonging to *Onagraceae*. family is commonly called wing leaf Primrose-willow. It is a native species that stands upright with a height of 3-6 feet, making it the tallest water primrose and typically trail along water or ground.[10] Their rapid growth, high bioconcentration factor (BCF), and translocation factor (TF) values make them ideal candidates for phytoremediation. Notably, their BCF and TF values often exceed 1, characteristic of an ideal hyperaccumulator plant.[11] Although hydrophyte-based phytoremediation has been explored in previous studies, further research is necessary to fully confirm its effectiveness and potential applications in removing heavy metals from contaminated aquatic environments.[9,10]

Research has shown that certain aquatic plants, such as water hyacinth and water willow, can effectively remove heavy metals from wastewater. However, *L. decurrens*, a plant commonly found in South West, Nigeria, has received little attention for its potential in phytoremediation, despite being abundant and not typically used as a food source by locals.[10] This study aimed to explore the effectiveness of *L. decurrens* in removing heavy metals from contaminated water through a controlled experiment, where the plant was exposed to varying levels of lead, cadmium, chromium, and zinc. The selection of *L. decurrens* for this study was driven by its ability to thrive in diverse water conditions and its widespread presence in the region. As a result, the research aimed to assess the plant's effectiveness in removing specific heavy metals, namely Cd, Cr, Pb & Zn, from polluted water, with a focus on determining its efficiency as a phytoremediation agent.

The research study had several key objectives, including, a). Assessing the capacity of *L. decurrens* to absorb heavy metals in a controlled environment, b). Investigating how the plant concentrates and transports the metals within its tissues, c). Identifying which part of the plant retains the highest amount of heavy metals, and d). Evaluating the overall effectiveness of the plant in removing heavy metals from contaminated water, expressed as a percentage of the initial metal concentration. The significance of this research is to explore the potential of *L. decurrens* in phytoremediation, providing a green solution to combat heavy metal contamination in water. The findings could have broad applications, from local community water treatment to industrial wastewater management, offering a cost-effective and eco-friendly solution.

2. MATERIALS and METHOD

2.1 Experimental Plants Description

L. decurrens were collected from a swampy farm area located within the University of Ilorin, Kwara State, Nigeria. The species was taxonomically identified by Mr. Bolu Ajayi, department of plant biology (University of Ilorin, Nigeria). Latitude 8.4788779 and longitude 4.64553941, DMS: $8^0$28’43.96”N/ $4^0$38’43.94”E. UTM: 681143.188E, 937622.784N 31P.

2.2 Plant Samples Preparation and Analysis

Fresh plants were collected from the site in order to determine the residual Lead, Chromium, Zinc and Cadmium contents. The plants were washed to remove attached sediments; air-dried for about 2 days; separated into roots, stem and leaves and further oven-dried at 70^{o}C for 24 hours.

The plant parts were homogenized using a mortar and pestle, followed by further pulverization with an electric blender to achieve a uniform powder. 0.2g each of the plant parts were taken and 10 mL of aqua regia reagent was added for wet acid digestion.[12]
The samples were digested through thermal decomposition on a hot plate, conducted under a fume

hood to ensure safe handling of potentially hazardous fumes. The digestates were allowed to cool and filtered. The filtrates were made up to 100 mL with distilled water using a 100 mL standard flask. The prepared samples were subsequently analyzed for elemental composition using a Buck Scientific Atomic Absorption Spectrophotometer (AAS), Model 210VGP, under optimized instrumental conditions.

2.3 General Specifications and Calibration values for AAS

Electrical: 110V AC nominal (+10%), 50/60 Hz 220, 240V AC, 50/60 Hz Power Consumption: 50W

Optics: Detector: model 928; wide range general purpose, 190-930nm Optional.

Detectors: model 955; UV enhanced, wide-range, 190-930nm model EMI9783B; narrow range furnace/hydride application, 165-600nm

Lenses: Supracil – amorphous silica

Monochromator: 0.25m Ebert mount Grating: 32nm x 27nm; 600 grooves/mm Wavelength adjustment: 3-digit mechanical, 0 to 1000nm +1 nm Reproducibility: +0.2 nm Resolution: variable slit - 2Å, 7Å, and 20Å

Operating Modes: Absorbance/Emission: -0.0820 to 3.2000 Concentration: to 5 significant digits Integration Period: 0.5 to 10 seconds

Screen Refresh: 0.5 to 1.5 seconds Recorder

Output: 1V/ABS (-0.08 to 3.2V) Background

Correction: In-line Deuterium Arc Giant Pulse (Self-reversal)

Hollow Cathode Lamps: Dimension: 1.5” OD

Striking Voltage: 500V Lamp Current: 0 to 18 mA average current Duty Cycle: 25%.

Modulation Frequency: variable; 33 to 200 Hz (142 Hz Norm.)

Burner Assembly: Design: Polyethylene Pre-mix chamber, glass impact bead dispersion

Burner Head: Titanium; air-acetylene head – 4” x 0.026” single slot (nitrous oxide head – 2” x 0.019” single slot) Adjustments: Horizontal g

Performance: Average Noise (at 3s): 0.0018 ABS (Cu at 324.7nm, 7Å slit, 5 sec. int.)

Reproducibility: <+5%

2.4 Pot Experiment

The hydrophytes were transplanted into sixteen (16) plastic containers each accommodating 3 liters of water, in a green-house illuminated with natural light. The hydrophytes were allowed to acclimatize into the new environment for one week. Nitrate of Pb, Cr, Cd, and Zn with varied concentration of (10, 20, 30 and 40) ppm were introduced into plastic containers containing the hydrophyte. The soil used in the containers is hydric soil, which is constantly saturated with water, resulting in the formation of anaerobic conditions that mimic those found in natural wetland environments.

The plastic containers were divided into four (4), four (4) containers each. In each set, 5 mLs of the prepared solution (Pb, Cr, Cd, and Zn nitrate) with the same concentrations were added in a container and labelled. This indicates four containers with 10 ppm, four with 20 ppm, four with 30 ppm and the last four with 40 ppm.

2.5 Weekly Plants and Water Samples Collection

The *L. decurrens* and water were collected at 7 days intervals for 28 days in different concentrations (10, 20, 30 & 40) ppm (Figure 1).

The hydrophytes were separated into roots, stem and leaves and were air dried for about 2 days, and then oven dried at 70^{o}C for 24 hours before being ground with mortar and pestle and further milling with an electric powered blender. The water samples were acidified immediately with 2-3 drops of concentrated HNO_3 to preserve the sample before digestion.

Figure 1. *L. decurrens* experimental set-up.

2.6. Reagent Preparation

2.6.1. Preparation of Aqua Regia

The Aqua regia reagent used was prepared using concentrated Nitric acid, concentrated hydrochloric acid and perchloric acid in the ratio 1:2:1. The digestion method was adapted from Anton Pear's multiwave 3000 micro wave digestion system.

2.6.2. Preparation of Solutions

For this purpose, 0.77 g of chromium nitrate nonahydrate ($Cr(NO_3)_3.9H_2O$) was weighed to make a 100 ppm Stock solution of Chromium, from which varied concentration (10, 20, 30 and 40) ppm were prepared by serial dilution.

The same method was used to prepare the solutions of Lead from $Pb(NO_3)_2.6H_2O$, Cadmium from $Cd(NO_3)_2.6H_2O$ and Zinc from $Zn(NO_3)_2.6H_2O$

2.7. Metal Analysis

The experimental analytes were Pb, Cr, Cd, and Zn concentrations inside the medium (water) and in the plant tissues (root, stem and leaf). Pb, Cd, Cr and Zn concentration were analyzed separately for their lower (root) and upper (stem and leaf) parts of plant.

2.7.1 Digestion of Water Samples and Analysis

The dissolution of the samples was done by weighing accurately 10 mL of the water sample into the digestion flasks and 10 mL of concentrated nitric acid, conc. HNO_3, was added. The same was heated to almost dryness. 10 mL of concentrated hydrochloric acid (HCl) was added to the sample flask and heated until nearly dry.[13]

Subsequently, 10 mL of perchloric acid ($HCLO_4$) was added, and the mixture was heated again until almost dry, ensuring complete digestion of the sample.[13] 10 mL of concentrated HCl was finally added and heated. After the dissolution, the filtrate was then transferred into a clean 100 mL volumetric flask and diluted to the mark with distilled water for AAS analysis. The digestate was analyzed for Cd, Cr, Pb & Zn.

2.7.2. Digestion of Plants and Analysis

A wet digestion method was employed to digest the ground plant parts and samples. The procedure involved accurately weighing 0.2 g of each sample into digestion flasks, followed by the addition of 10 mL of concentrated nitric acid (HNO_3). The mixture was heated to near dryness. Subsequently, 10 mL of concentrated hydrochloric acid (HCl) was added, and the mixture was again heated to near dryness.[12, 13]

This step was repeated with the addition of 10 mL of perchloric acid ($HClO_4$), followed by a final addition of 10 mL of concentrated HCl. After complete dissolution, the resulting filtrate was transferred to a 100 mL volumetric flask and diluted to the mark with distilled water.[13]

The prepared digestate was then analyzed for the presence of Pb, Cr, Cd, and Zn using Atomic Absorption Spectroscopy (AAS).

2.8. Formula

2.8.1. Percentage Removal (%)

The percentage removal (%) was measured,[14] using Equation (1):

$$\% \, Removal = \frac{C_i - C_f}{C_i} \times 100 \qquad 1$$

C_I = Initial concentration
C_f = Final concentration

2.8.2. Bio-concentration Factor (BCF)

The bio-concentration factor (BCF) of *L. decurrens* efficiency for heavy metal accumulation from the water samples was determined[14], using Equation (2)

$$BCF = \frac{C_{plant\ tissues}}{C_{growth\ media}} \qquad 2$$

Where $C_{Plant\ tissues}$ refers to the metal concentration in the (root, stem & leaf) and $C_{Growth\ media}$ is the metal concentration in the water. BCF= Bio-Concentration Factor, BCF <1: plant does not accumulate contaminant, BCF $=1^{-1}$ 0: Plant moderately accumulates contaminants and BCF> 10: plant highly accumulates contaminant

2.8.3 Translocation factor (TF)

The translocation factor (TF) was employed to quantify the translocation of metals from the water to the hydrophyte's tissues[15], using Equation (3):

$$TF = \frac{\mathrm{Caerial}}{\mathrm{C_{root}}} \qquad 3$$

Where, C_{aerial} refers to the metals accumulated in the aerial parts such as root, stem & leaf, and C_{root} refers to the metal concentrations in the root part.
TF =Translocation Factor, TF< 1: contaminant mostly retained in the roots, TF = 1: contaminants evenly distributed between roots and shoots and TF > 1: contaminants primarily trans-located to the shoots.[15]

2.9. Statistical Analysis

The data were statistically analyzed using one-way analysis of variance (ANOVA) with Microsoft Excel and SPSS software, with a significance level of $P < 0.05$. Post-hoc tests were applied to determine significant differences in mean values between variables for each parameter.

3. RESULTS and DISCUSSION

3.1 Cadmium (Cd)

Table 1 shows the mean concentration of cadmium in water samples at initial and final stages of pot experiment at different concentrations (10, 20, 30 & 40) ppm were observed in the range of 7.44–0.44 mgL^{-1}, 14.74- 0.34 mgL^{-1}, 24.29- 0.24 mgL^{-1} and 34.97- 0.29 mgL^{-1} respectively.

The highest concentration of heavy metals was observed in the initial water samples, whereas the lowest concentrations were recorded at the end of the 4-week experimental period, indicating a significant reduction in metal concentrations over time.

The decrease in concentrations of Cd at the 4th week shows that the metal has been uptake by the hydrophytes. At the first week, Cd-30 has the highest percentage removal (94.67%) followed by Cd-20 (79.04%).

A high and rapid percentage removal was observed at all the different concentrations (Table 1). The average percentage removal of cd from the contaminated water was (94.09 - 99.01%) for all the concentrations.

These findings were similar to the results of,[16] (78.7–95.3% removal efficiency) observed for *E. crassipes*,[17] (97.8%),[18] (91.9%) but higher than,[19] (44.9%) for *Limna minor*,[20] (90%) for *Duck weed* and (60%)[21] for *P. australis and T. latofolia.*

Table 1. Cadmium initial and final concentrations and removal efficiency (%).

		Final concentration and percentage removal efficiency (%)							
		Wk1		**Wk2**		**Wk3**		**Wk4**	
Ppm	**Initial**	**mgL^{-1} ± S. D**	**%**	**mgL^{-1} ± S. D**	**%**	**mgL^{-1} ± S. D**	**%**	**mgL^{-1} ± S. D**	**%**
10	7.44±0.500	1.64±0.003	77.96	1.02±0.002	86.29	0.77±0.002	86.65	0.44±0.001	94.09
20	14.74±0.004	3.09±0.003	79.04	1.87±0.003	87.31	0.67±0.002	95.45	0.34±0.002	97.69
30	24.29±0.004	0.82±0.004	96.67	0.72±0.001	97.36	0.57±0.002	96.65	0.24±0.002	99.01
40	34.97±0.003	8.25±0.000	76.41	0.69±0.006	98.03	0.37±0.001	98.94	0.29±0.006	99.17

Wk1 = week 1, Wk1 = week 2, Wk3 = week 3 and Wk4 = week 4

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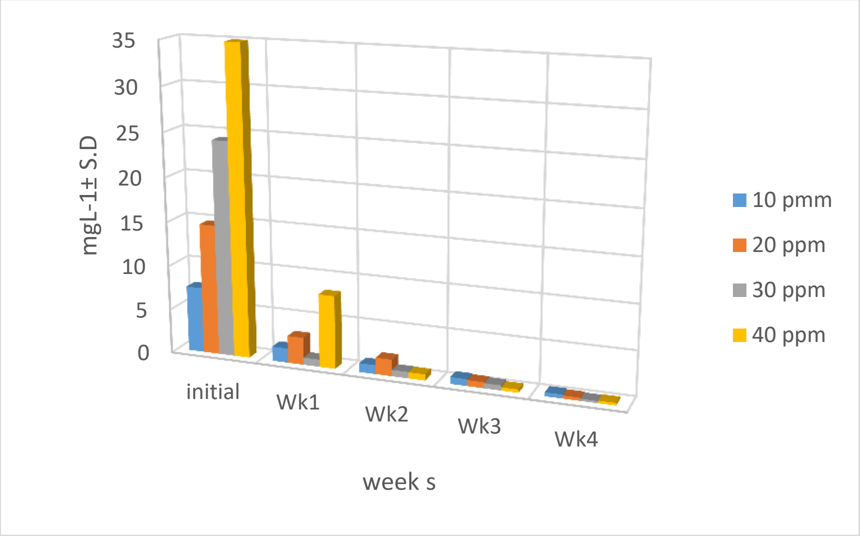
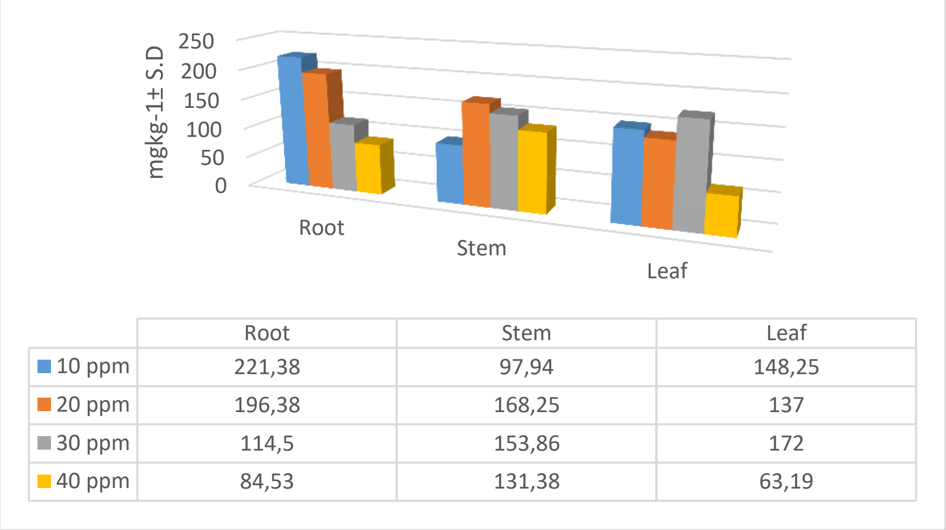


Figure 2. Cd concentrations in water (mgL^{-1}).

The results of cadmium ion uptake by the plant tissues are presented in (Figure 3), which reveal that Cd is mostly stored in the root part of the plant as compared to the other parts (stem & leaf). At 10 ppm, 221.38 mgkg^{-1} was accumulated at the root, 97.94 mgkg^{-1} at the stem and 148.25 mgkg^{-1} at the leaf.

The highest concentration of cadmium (221.38 mgkg^{-1}) was found in the root at 10 ppm concentration. This results also shows that cadmium ion is readily absorbed by the plant root. A study by Yang and co-worker,[22] also reported a similar pattern. Akhter co-worker[23] reported that a greater amount of Cd is translocate into leaves of lettuce (*Lactuca sativa*) compared to barley (*Hordeum vulgare*), where most of the Cd was retained in the roots. According to Nocito and co-worker,[24] exposing rice plants to environmentally relevant, low concentrations of cadmium (Cd) significantly enhanced root retention capacity.

The study found that Cd ion retention increased from 49% to 79% as external Cd^{2+} concentrations rose from 0.01 to 1 µM. Further analysis revealed that Cd immobilization in roots occurred through a multi-step process, involving various mechanisms such as chelation by thiols, vacuolar sequestration, and adsorption, ultimately contributing to the plant's ability to sequester and tolerate Cd.



	Root	Stem	Leaf
🟦 10 ppm	221,38	97,94	148,25
🟧 20 ppm	196,38	168,25	137
◼ 30 ppm	114,5	153,86	172
🟨 40 ppm	84,53	131,38	63,19

Figure 3. The mean accumulations of Cd ion in the plant parts at the different concentrations.

3.2 Chromium (Cr)

The mean concentration of chromium in water samples at initial and final stages of pot experiment for different concentrations (10, 20, 30 & 40) ppm were observed in the range of 8.45–0.72 mgL^{-1}, 15.29-1.2 mgL^{-1}, 23.99- 4.27 mgL^{-1} and 35.49- 5.59 mgL^{-1} respectively as presented in (Table 2 and Figure 4). The highest concentration was recorded in initial samples of water and the least concentrations at the end of the 4th week of the work. The decrease in concentrations of Cr at the 4th week shows that the metal has been taken up by the hydrophytes. At the first week, Cr-40 has the highest percentage removal (70%) followed by Cr-30 (46.96%). Cr^{-1} 0 had the slowest and steady removal but had the highest percentage removal (91.48%) at the 4th week.

The average percentage removal of Cr from the contaminated water was (91.48, 91.34, 82.20 & 84.25%) respectively. This is similar to the findings of[25] (85.29% & 87.5%) using water hyacinth but higher than the result of,[21] (68.1%) using P.*australis and T. latofolia* and[23] (67%) using CuI–polyvinyl alcohol nano-composite containing bacterial co-cultures.

Table 2. Chromium initial and final concentrations and removal efficiency (%)

		Final concentration and percentage removal							
	Initial	**Wk1**		**Wk2**		**Wk3**		**Wk4**	
ppm	**mgL^{-1} ± S. D**	**mgL^{-1} ± S. D**	**%**	**mgL^{-1} ± S. D**	**%**	**mgL^{-1} ± S. D**	**%**	**mgL^{-1} ± S. D**	**%**
10	8.45±0.007	7.09±0.003	16.09	6.59±0.002	22.01	4.67±0.003	44.73	0.72±0.002	91.48
20	15.29±0.004	8.11±0.005	46.96	6.82±0.003	55.40	6.49±0.004	57.55	1.32±0.005	91.37
30	23.99±0.003	20.52±0.002	14.46	7.59±0.011	66.70	6.51±0.006	72.86	4.27±0.001	82.20
40	35.49±0.007	10.52±0.003	70.36	9.77±0.003	72.47	8.84±0.002	75.09	5.59±0.003	84.25

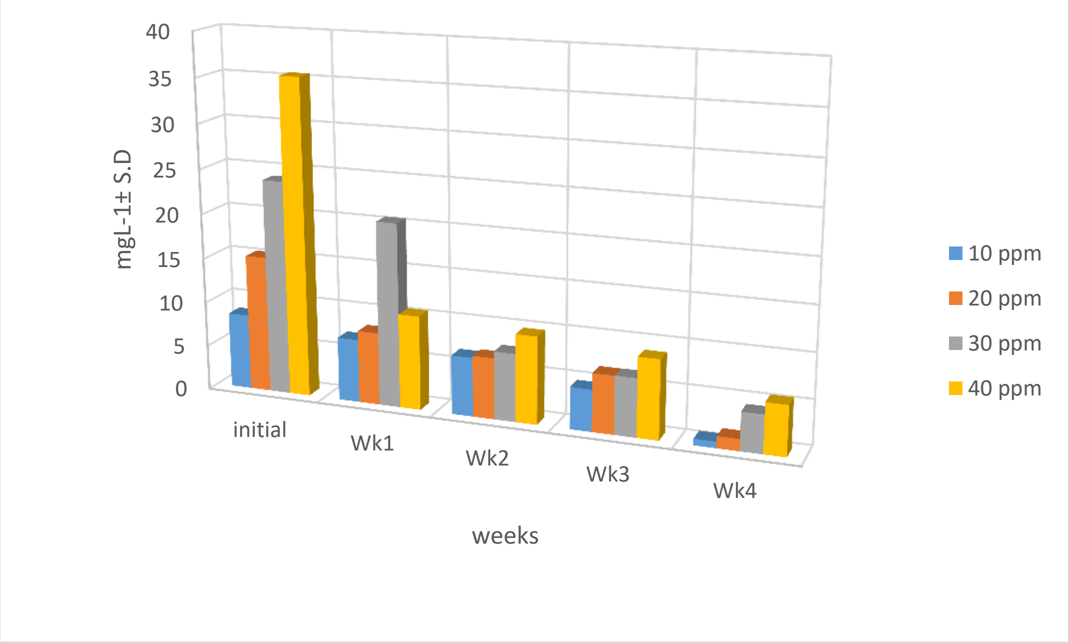


Figure 4. Cr concentrations in water (mgL^{-1}).

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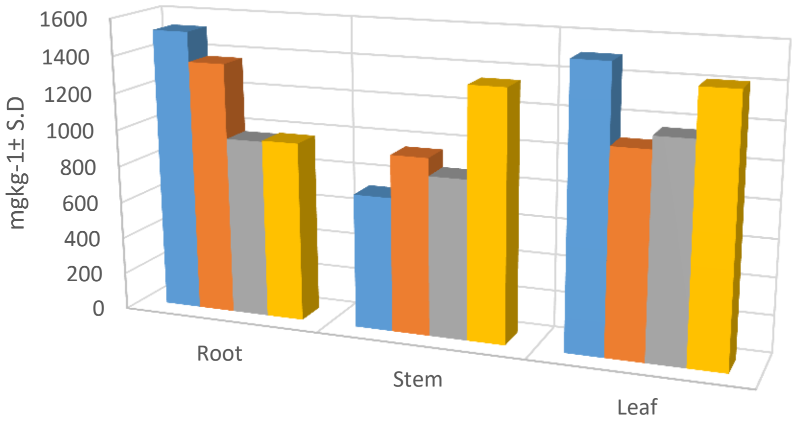
Figure 5, presents the result of Cr uptake by the plant. It can be deduced from the result that at 10 & 20 ppm concentrations, the plant significantly took up Cr ions and stored them in its roots and stem compared with the 30 & 40 ppm concentrations where it was mostly stored at the leaf. It was observed that most of the Cr ion were stored more in the root, followed by the leaf, then stem. 10 ppm concentration seemed to be the most favourable for phytoremediation of Cr by the plant.

The roots of *L. decurren* were found to absorb the most chromium, a pattern consistent with,[25] which concluded that regardless of the form of chromium absorbed, a majority of it remains in the roots. A study by Bingol and co-worker,[26] A similar trend was observed in *Lythrum salicaria L.*, where chromium (Cr) accumulation was significantly higher in the roots compared to the leaves and stem, indicating preferential retention of Cr in the root tissue.

These findings suggest that while some plants may be effective in accumulating heavy metals like chromium and zinc, their translocation to the above-ground parts is often limited, potentially hindering their use in phytoremediation



	Root	Stem	Leaf
🟦 10 ppm	1526,38	725,79	1506,69
🟧 20 ppm	1367	954,43	1091,25
⬛ 30 ppm	965,75	860,23	1159,19
🟨 40 ppm	972	1345,75	1412,31

Figure 5. The mean accumulations of Cr ion in the Plant Parts at the different concentrations.

3.3. Lead (Pb)

Lead (Pb) concentration in the initial and final stages water samples of pot experiment for different concentrations (10, 20, 30 & 40) ppm were observed in the range of in the range of 9.34-0.87 mgL^{-1} , 18.49-2.67 mgL^{-1} , 23.59-0.54 mgL^{-1} & 37.84 mgL^{-1} .07 mgL^{-1} respectively (Table 2 and Figure 6).

The highest concentration was found in the initial water samples and a decrease in the final water sample. The decrease in concentrations of Pb at the 4th week shows that the metal has been taken up by the hydrophytes. The percentage removal of Pb was recorded and shown in Table 3.

The average percentage removal of Lead from the contaminated water at different concentrations were (90.69, 85.56, 97.71 & 94.53 %) respectively. Ayaz and co-worker,[27] reported 95.9%, 78.0%, 91.3% and 97.1% for Cattail, water hyacinth, duck weed and water cabbage respectively and (94%), 20 for duck weed. These results did not show a similar trend with the results of [23] (79.1%) for *L. minor*.

Table 3. Lead initial and final concentrations and removal efficiency (%).

		Final concentration and percentage removal							
		Wk1		**Wk2**		**Wk3**		**Wk4**	
ppm	**Initial**	**mgL^{-1} ± S. D**	**%**	**mgL^{-1} ± S. D**	**%**	**mgL^{-1} ± S. D**	**%**	**mgL^{-1} ± S. D**	**%**
10	9.34±0.002	8.47±0.000	9.31	4.22±0.004	54.82	2.49±0.004	73.34	0.87±0.002	90.69
20	18.49±0.004	5.67±0.004	69.33	4.79±0.004	74.09	3.19±0.001	82.75	2.67±0.006	85.56
30	23.59±0.003	4.61±0.001	80.46	3.04±0.002	87.11	2.37±0.001	89.95	0.54±0.004	97.71
40	37.84±0.002	10.52±0.002	72.20	5.52±0.002	85.41	2.07±0.008	94.52	1.07±0.004	94.53

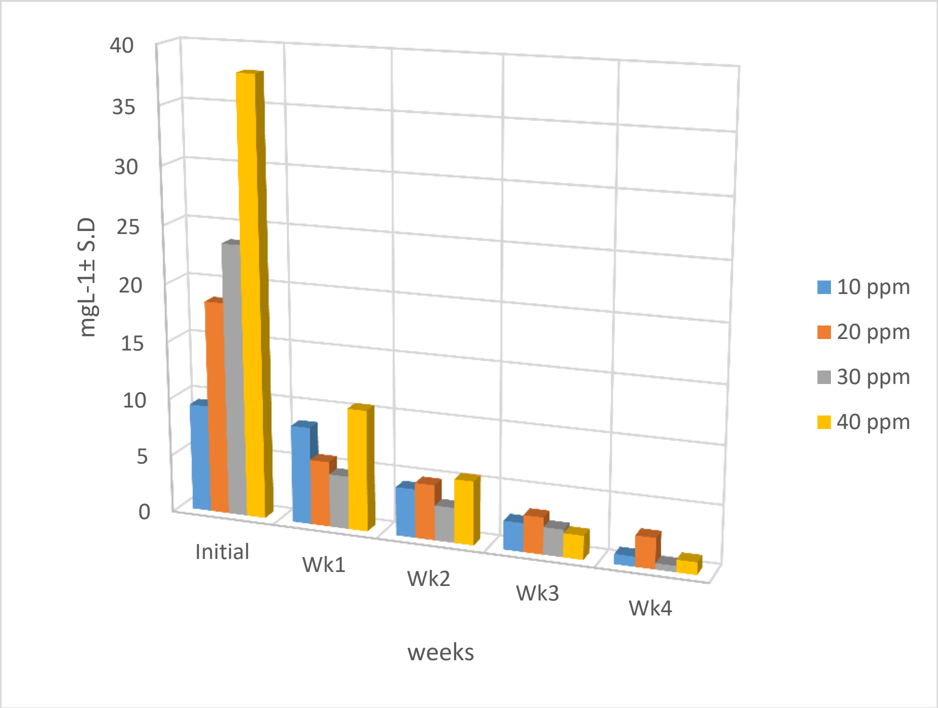


Figure 6. Pb concentrations in water (mgL^{-1}).

The concentrations of Pb uptake by the plant tissues are represented in Figure 7. At 10 ppm, the concentrations of the lead ion at the root, stem and leaves are, 567.31, 529.19, 486.69 $mgkg^{-1}$ respectively. It was observed that the concentration is higher at the root, followed by the stem, then the leaf with the root having the highest concentration. For 20, 30 & 40 ppm, the concentrations are more at the stem than at the root and leaf. Chanu and co-worker[28] found that lead (Pb) accumulation in plants followed a descending order: root > stem > leaf. Notably, translocation factor (TF) values were consistently below unity, indicating limited Pb translocation from root to shoot. Conversely, bioconcentration factor (BCF) values exceeded unity for all plant parts (root, stem, and leaf), suggesting efficient Pb uptake and accumulation from the surrounding environment. Ashraf and co-worker[29] reported that rice cultivars readily take up Pb ions from soil to roots and migrate it to other parts of the plant with root having the highest concentration followed by stems, leaves, ears and grains. The highest accumulation of lead (577.63 $mgkg^{-1}$) was recorded at 20 ppm concentration in the stem. Leaves had the lowest lead accumulations. From the results, it was observed that the 4 different concentrations (10, 20, 30 & 40) ppm did not affect rate lead uptake, this implies that *L. decurrens* can readily absorb lead at these different concentrations.

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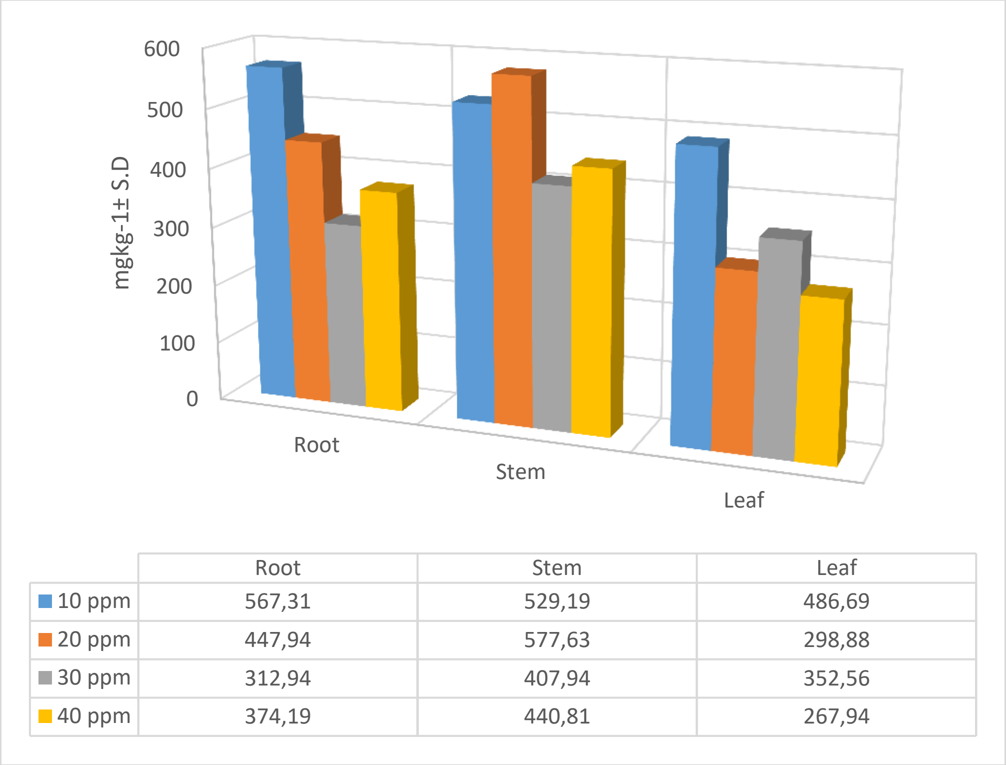

	Root	Stem	Leaf
🟦 10 ppm	567,31	529,19	486,69
🟧 20 ppm	447,94	577,63	298,88
⬜ 30 ppm	312,94	407,94	352,56
🟨 40 ppm	374,19	440,81	267,94

Figure 7. Shows the mean accumulations of Pb ion in the Plant Parts at the different concentrations.

3.4 Zinc (Zn)

Zn concentrations in the initial and final stages of water samples in the pot experiment for different concentrations (10, 20, 30 & 40) ppm were observed in the range of 9.54-4.74 mgL^{-1}, 17.29-8.24 mgL^{-1}, 24.04-5.34 mgL^{-1}, & 34.54-5.79 mgL^{-1} respectively (Table 4 and Figure 8).

The highest concentration was found in the initial water samples and a decrease in the final water samples. The decrease in concentrations of Zn at the 4th week shows that the metal has been taken up by the hydrophytes. The percentage removal of Zn ion was recorded and presented in Table 4. The average percentage (%) removal of Zinc from the contaminated water was at the different concentrations were (50.31, 52.34, 77.79 & 83.24 %) respectively as shown in Table 4.

Tan and co-worker[30] reported 80.1% for water lettuce and 88% for water hyacinth, Ha and co-worker[31] reported 93% for water hyacinth and (72%),[32] for water lettuce. Akhtar and co-worker[23] reported a lower percentage removal of 55% using CuI–polyvinyl alcohol nano-composite containing bacterial co-cultures.

Table 4. Zinc initial and final concentrations and removal efficiency (%).

		Final concentration and percentage removal							
	Initial	**Wk1**		**Wk2**		**Wk3**		**Wk4**	
Ppm	**mgL^{-1} ± S. D**	**mgL^{-1} ± S. D**	**%**	**mgL^{-1} ± S. D**	**%**	**mgL^{-1} ± S. D**	**%**	**mgL^{-1} ± S. D**	**%**
10	9.54±0.005	9.02±0.005	5.45	7.84±0.008	17.82	5.79±0.004	39.31	4.74±0.007	50.31
20	17.29±0.004	15.54±0.004	10.12	12.27±0.012	29.03	9.07±0.006	47.54	8.24±0.003	52.34
30	24.04±0.004	20.84±0.004	13.31	17.32±0.005	33.53	12.34±0.004	48.67	5.34±0.004	77.79
40	34.54±0.005	15.99±0.003	53.71	15.79±0.004	54.28	7.4±0.006	78.58	5.79±0.006	83.24

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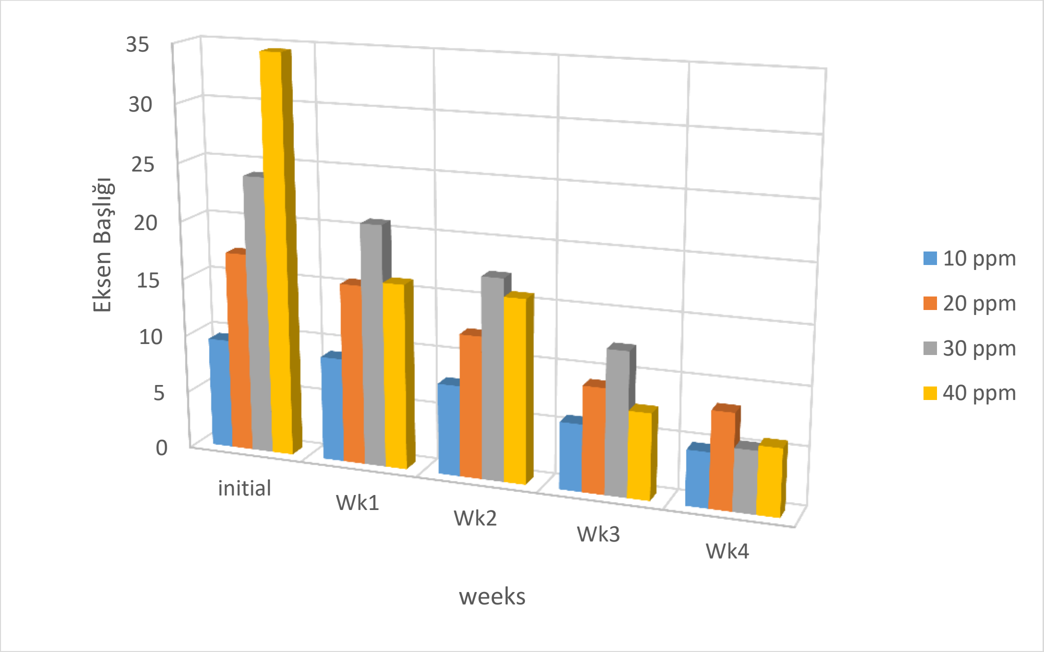
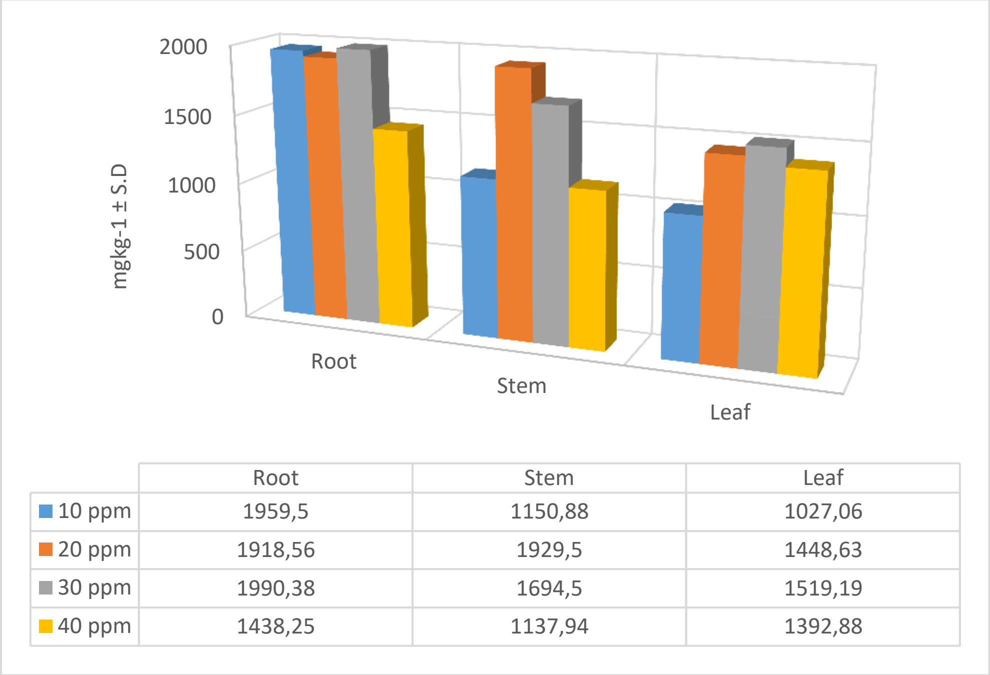


Figure 8. Zn concentrations in water (mgL^{-1}).

Figure 9, shows the results of zinc ions accumulations in the root, stem & leaves of *L. decurrens.* At 10 ppm, the accumulations in the root, stem & leaves were, 1959.50, 1150.88 & 1027.06 $mgkg^{-1}$ respectively. It was observed that root had the highest accumulations followed by stem and leaf. This is similar compare to the report of[33] that the highest average of Zn accumulation was detected in the root part of *L. minor* plant (97.8 $mgkg^{-1}$). The same trend of higher accumulation of zinc in the root is observed for all the concentrations. The concentrations did not have significant difference in the uptake of Zinc by the hydrophyte.



	Root	Stem	Leaf
🟦 10 ppm	1959,5	1150,88	1027,06
🟧 20 ppm	1918,56	1929,5	1448,63
⬜ 30 ppm	1990,38	1694,5	1519,19
🟨 40 ppm	1438,25	1137,94	1392,88

Figure 9. The mean accumulations of Zn ion in the Plant Parts at the different concentrations.

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3.5 Bio-concentration and Translocation factors

Bio-concentration factor (BCF) is a crucial parameter in phytoremediation to measure the potential of the plant in accumulating contaminants (metals) from the environment.[14] The concentration of metal present in the water was a key factor influencing the efficiency of metal uptake. A general trend was observed, where an increase in metal concentration in the water led to a corresponding increase in metal accumulation in plants.[14] However, this was accompanied by a decrease in the bioconcentration factor (BCF), indicating that the plant's ability to concentrate metals from the water decreased at higher metal concentrations.[34]

When considering the phytoremediation potential of a given species, BCF is a common factor, the BCF for the four metals (Cd, Cr, Pb & Zn) were determined using their concentrations in the water medium (Table 5). This is done for the plant parts (root, stem & leaf) using equation 2. Bio-concentration factors decrease with increasing heavy metal concentration. This study was in agreement with that,[35] examined that the BCF of *E. crassipes* are high for Cu, Se, Cd, and Cr at low concentration.

The hydrophyte was able to deplete metals from the solution. The plant showed accumulation of substantial quantity of metals as BCF was mostly greater than 10 but not a good hyperaccumulator. For a plant to be considered a good accumulator or hyperaccumulator, the BCF value must be greater than 1000,[36] thus *L. decurrens* cannot be considered as a good accumulator of the metals. Yadav and co-worker[37] showed BCF in root of *Azolla caroliniana* growing in a fly ash pond ranging from 1.7 to 18.6.

Table 5. Bio-concentration factors BCF of study metals at the plant parts.

Heavy metal	Plant Part	10 ppm	20 ppm	30 ppm	40 ppm
Cd	Root	29.76	13.32	4.71	2.42
	Stem	13.16	11.42	6.33	3.76
	Leaf	19.93	9.29	7.08	1.81
Cr	Root	180.64	89.40	40.26	27.39
	Stem	85.89	62.42	35.86	37.92
	Leaf	178.31	71.37	48.32	39.79
Pb	Root	60.74	24.23	13.27	10.02
	Stem	56.56	31.24	17.29	11.65
	Leaf	52.11	16.16	14.95	7.08
Zn	Root	205.40	110.96	82.79	40.47
	Stem	120.64	111.60	70.47	32. 02
	Leaf	107.66	83.74	63.19	39.17

Most of the Translocation factors (TF) of metals as shown in Table 6, were less than 1 indicating that the hydrophyte accumulated them in the root compartment, thus suggesting it to be good for phytostabilization processes.[38]

Pandey and co-worker[39] reported TF (root-stem) in the range of 0.26 to 3.33 and TF (stem-leaf) in the range of 0.03 to 2.90 for *Ipomea carnea, Lantana camara, Solanum surattense* growing on a fly ash dumpsite, which is consistent with this study, the findings indicate that aquatic plants tend to accumulate higher concentrations of metal ions in their roots compared to other plant parts. This pattern of metal deposition suggests that roots play a primary role in metal uptake and sequestration, serving as a barrier to prevent metal translocation to the rest of the plant.[40] The translocation of metal-containing sap from roots part to shoots part is primarily governed by two key processes: root pressure and leaf transpiration. However, certain metals are retained in the roots, likely due to physiological barriers that restrict their transport to aerial parts.[41] These barriers prevent excessive metal accumulation in shoots, highlighting the root's role in regulating metal distribution within the plant. As shown in the results, total metal content in the roots and shoots showed significant differences on the distribution. Throughout most of the experimental stages, metal accumulation was significantly higher in the roots compared to the shoots, indicating a preferential retention of metals in the root tissue.

Table 6. Translocation factors (TF) of metals at the Stem & Leaf.

Heavy metal	Plant Part	10 ppm	20 ppm	30 ppm	40 ppm
Cd	Stem	0.44	0.86	1.34	1.55
	Leaf	0.67	0.70	1.50	0.75
Cr	Stem	0.48	0.70	0.89	1.38
	Leaf	0.99	0.80	1.20	1.45
Pb	Stem	0.93	1.29	1.30	1.18
	Leaf	0.86	0.67	1.13	0.72
Zn	Stem	0.59	1.01	0.85	0.79
	Leaf	0.52	0.75	0.76	0.97

There was a clear decreasing trend in Cd accumulation as the concentration increases from 10 ppm to 40 ppm concentrations with a significant value of $p < 0.05$ Cd accumulation exhibited an inverse relationship with concentration, where greater accumulation occurred at lower Cd concentrations compared to higher concentrations. There was no statistical significant difference in Cr accumulation across the different concentrations, with a significant value of $p > 0.05$. This implies that Cr accumulations was not substantially affected by the difference in metal concentrations. As the concentrations increases from 10 – 30 ppm, there was a decrease in Pb accumulations at the plant parts with a slight increase at 40 ppm concentration ($p< 0.05$). Zn accumulation displayed an inverse relationship with concentration, where greater accumulation occurred at lower concentrations compared to higher concentrations ($p < 0.05$). The study demonstrates that different treatment levels significantly affect the accumulation of Cd, Pb and Zn in plant roots, while Cr accumulation remains relatively unaffected within the studied range. The Metal-Specific Responses of Cd and Pb, show decreased accumulation with increasing treatment levels, suggesting possible inhibitory effects or adaptive plant responses at higher treatments. While zinc (Zn) show high accumulation at lower treatments indicates essential uptake, but significant reduction at the highest treatment level may prevent toxicity. Also, chromium (Cr) is consistent accumulation across treatments suggests a need for targeted strategies to manage chromium (Cr) uptake.

4. CONCLUSION

In conclusion, the study provides valuable insights into how varying treatment levels influence heavy metal accumulation in *L. decurrens* over a controlled period of time. The hydrophyte (*L. decurrens)* effectively removed the heavy metals (Cd, Cr, Pb & Zn) from the contaminated water, Cd had the highest percentage removal. From the results, it was observed that *L. decurrens* efficiently removed heavy metals from contaminated water and the removal performance was in order of Cd> Pb> Cr >Zn. Most of the translocation factor values are less than one (1), this shows that the root part of the plant, *L. deccurens*, retained most of the metal ions absorbed from the contaminated water. *Ludwigia decurrens*-based phytoremediation is a viable, eco-friendly, and cost-effective technology for removing heavy metals from polluted water, offering a promising solution for environmental remediation.

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Conflict of Interest

The authors declare that they have no conflict of interest

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