Iraqi Journal of Science, 2025, Vol. 66, No. 12, pp: 5361-5372
DOI: 10.24996/ijs.2025.66.12.8

ISSN: 0067-2904

Efficiency of *Dodonaea viscosa* to phytoremediation of heavy metals contaminated soil

Shaimaa Hadi Al-Dulaimi[1]*,Shilan Farhad Mamand[2] ,Ahmed Attalah Hassan Al-Fhdawi[1]

[1]*Al-Karkh First Directorate of Education, Ministry of Education, Baghdad, Iraq.*
[2]*Department of Medical Microbiology, College of Science, Knowledge University, Erbil, Iraq.*

Received: 18/5/2024 Accepted: 10/11/2024 Published: 30/12/2025

Abstract

The study was designed to investigate *Dodonaea viscosa* efficiency in the uptake, translocation, and accumulation of Cadmium, Zinc, and Copper metals from contaminated soils. The phytoremediation of *Dodonaea* was assessed by cultivating the plant in pots. Plants were cultivated in an experiment with an average diameter of 26.5 cm and height of 30 cm for six months under different treatments of Cd, Zn, and Cu . Metals concentrations in soil and plant parts were measured using the XRF instrument. Bioaccumulation factor (BF), translocation factor (TF), and Contamination factor (CF) were values. The results indicated that *D. viscosa* absorbed metals from the soil in the following order: roots > shoots > soil, and three metals are effectively restricted in the root. For BF the order was Zn >Cu > Cd, in which *D. viscosa* absorbed heavy metals from the soil to their roots. TF for the Cd, Zn, and Cu metals were less than one. For CF results, the highest value was recorded under D4 for Cd in root 31.0 ±1.86 mg/kg, and the lowest level was 0.276 ±0.08 mg/kg under D1 for Zn in soil.

Keywords: *Dodonaea*, phytoremediation, Cadmium, Zinc, Copper.

كفاءة *Dodonaea viscosa* في المعالجة النباتية للتربة الملوثة بالمعادن الثقيلة

شيماء هادي حمادي الدليمي [1] *,شيلان فرهاد مامند[2] , احمد عطاالله حسن الفهداوي[1]

[1] تربية الكرخ الاولى , وزارة التربية العراقية ، بغداد, العراق.

[2]قسم الاحياء المجهرية الطبية ،كلية العلوم، جامعة نولج ،اربيل ،العراق.

الخلاصة

صممت هذه الدراسة للتحقق من كفاءة نبات الدودونيا في امتصاص ونقل وتراكم معادن الكادميوم والزنك والنحاس من التربة الملوثة بهذه المعادن. ولتقييم المعالجة النباتية لنبات الدودونيا ، تمت زراعة النباتات في اصص بلاستيكية تجريبية قطرها 26.5 سم والارتفاع 30 سم لمدة ستة أشهر تمت معاملة التربة بتراكيز مختلفة من الكادميوم والزنك والنحاس. تم قياس تراكيز المعادن في التربة وأجزاء النبات باستخدام جهاز XRF. تم تحديد عدد من المؤشرات ، مثل عامل التراكم الحيوي (BF)، وعامل النقل (TF)، وعامل التلوث (CF). أشارت النتائج إلى ان نبات الدودونيا يمتص المعادن من التربة بالترتيب التالي: الجذور > البراعم > التربة وتحتجز المعادن الثلاث بشكل فعال في الجذر. بالنسبة لعامل التراكم الحيوي للمعادن كان اخذها من

*Email: dw.msr@atu.edu.iq

التربة الى اجزاء النبات يتبع التسلسل التالي: Zn >Cu > Cd. كما أن عامل النقل للمعادن كان أقل من واحد. بالنسبة لنتائج عامل التلوث تم تسجيل أعلى القيم تحت المعاملة الرابعة للكادميوم في الجذر $mg.kg^{-1}$ (31.0 ±1.86) وأقل المستويات كانت $mg.kg^{-1}$ (0.276 ±0.08) تحت المعاملة الاولى للزنك في التربة.

Introduction

The use of plants to remediate contaminated soil is known as phytoremediation, and also is an exciting ecofriendly approach [1]. Phytoremediation has garnered significant interest as a low-cost technique [2]. It is a non-disruptive, efficient, and clean technique for the environment. It is a less expensive, non-invasive, and socially acceptable method of addressing environmental contamination cleanup[3]. This approach includes many procedures that can result in the removal of pollutants by phytoremediation (phytoextraction, phytovolatilization, phytodegradation, immobilization or phytostabilization). It can be used for a wide range of contaminants [4].

Plant and soil characteristics, such as physical and chemical soil parameters, metal bioavailability, plant and microbial exudates, and the ability of plants to "absorb, store, transport, isolate, and neutralize metals," are important considerations in deciding the efficacy of phytoremediation [5,6]. This approach is incredibly effective at accumulating harmful quantities of heavy metals using specific wild species of plants [7]. These plants are commonly referred to as accumulators. Despite growing under identical circumstances, hyperaccumulators produce no outward symptoms and accumulate heavy metals at quantities over a hundred times higher than non-hyperaccumulators [8]. Areas with low levels of metal, nutrients, organic material, or pollution contamination can be cleaned up with the help of phytoremediation. According to Nagaraju and Karimulla [9], a number of plants, including *Jatropha curcas* (Euphorbiaceae), *Dodonaea viscosa* (Sapindaceae), and *Cassia auriculata* (Fabaceae), may regenerate soils polluted with a wide range of metals and trace elements. [10]. *Dodonaea viscosa* has developed extremely specialized and effective systems to extract vital micronutrients from their surroundings, even at low parts per million concentrations. Plant roots can dissolve and assimilate micronutrients from exceedingly low levels in the soil, including nearly insoluble precipitates. This is achieved through the assistance of chelating agents produced by plants, as well as pH alterations and redox reactions induced by plants [11].

It is possible to classify heavy metals (HMs) as either non-essential or essential to biological processes [12]. Important metals that play physiological functions in plant growth and development include iron, nickel, copper, manganese, and zinc [13]. Lead, cadmium, arsenate, and mercury are superfluous because they do not affect plant physiology in any way [14]. Additionally, some of these HMs, like zinc, copper, and nickel, are necessary micronutrients that must be present in tiny amounts because they function as cofactors for several different enzymes. At greater concentrations, however, these metals become hazardous. Other metals used in pesticides, including lead and cadmium, have no useful purpose and become harmful when their amounts are a particular threshold [15].

Heavy metal pollution is mostly caused by the natural weathering of parent materials and volcanic activity [16]. Heavy metal contamination of previously uncontaminated soils is mostly caused by human activities such as mining, fertilizer, pesticide, and sewage applications, as well as the extensive development of asphalt roads. This endangers ecosystems and human health while also influencing the food chain [17].Furthermore, both microbes and larger species are poisonous to them. Basically, a number of metals have a direct impact on a number of physiological and biochemical functions, which reduce growth, block respiration and photosynthesis, and cause the primary cell organelles to degenerate [18]. Also, when a tissue of a plant has more heavy metals than it should, it either stores the metals in certain parts of its root or stem or transforms them into other, non-toxic forms that it may repurpose for other metabolic activities [19].

Minerals such as Cu, Fe, Zn, Ca, K, Mg, and Na are typically present in soil solutions, which are essential for plant growth and development. Along with these useful elements, plants also absorb inert ones, including Cd, As, Cr, Al, and Pb [10]. This study aims to investigate *Dodonaea viscosa* efficiency in uptake, translocation, and accumulation of metals from contaminated soils.

Materials and Methods

Pot experiment

The Central Plant Nursery of Erbil, situated in the Erbil Governorate in Northern Iraq, is where the current study was conducted in October of 2022. To assess the effectiveness of phytoremediation for Cd, Zn, and Cu, the evergreen plant species *Dodonaea viscosa* L. was chosen due to its rapid growth and tolerance to pollution [20].

Efficiency of Dodonaea viscosa

To assess the phytoremediation efficiency of *Dodonaea viscosa* L for Cd, Zn, and Cu in contaminated soil, a factorial randomized experiment with three replications was conducted in a plastic pot with an average diameter of 26.5 cm and height of 30 cm filled by 16kg of soil . Distinct concentrations of Cd, Zn, and Cu (0,25,75 and 100 mg/kg^1) were made using laboratory-grade $CdCl_2$ from Sigma Company, U.S.A. for Cd, $CuSO_4$ $5H_2O$ for Cu, and $ZnSO_47H_2O$ for Zn. Thirty-six experimental pots were evaluated in three replications for each of the twelve combination treatments. After being screened through a 4-mm sieve, each pot was filled with 16 kg of air-dried soil. A portion of this soil was subsampled and subjected to physical and chemical examination using the techniques described by Pansu and Gautheyrou [21]. The soil was sandy-loamy and had an electric conductivity of 0.41 $dS.m^{-1}$, moisture content of 4.50%, a low organic matter content of 0.61%, total nitrogen (N) of 0.11%, and total phosphorus (P) of 23 $mg.kg^{-1}$. It also had a slightly alkaline pH of 7.56. Also, the following quantities of heavy metals: Cd 2.36 mg/kg-1, Cu 21.2 mg/kg^{-1}, and Zn 23.3 mg/kg^{-1} were used as a reference (control soil). In every container, three plants were planted. When necessary, weeding was done, and plants were watered to keep soil moisture levels close to field capacity using weighted techniques.

Soil and plant samples collection and analysis

Using a core sampler that was 23 cm high and 4 cm in diameter at the base of each uprooted plant, soil samples were obtained. The samples were then placed into appropriately labeled plastic bags. Samples were sieved and stored in tiny containers until analysis after being oven-dried for 24 hours at 105 °C. Six months after they began to grow; the plants were harvested. Every plant was carefully collected and placed in individual plastic bags, each one labeled correctly. The plant samples were meticulously dried in an oven at 70 °C for 24 hours, following a rinse and cleaning with tap water. The next step was to reduce them to a powder and keep them in airtight containers until examination. Furthermore, both the wet and dry weights of the root system and shoots were measured. Chlorophyll levels have been measured using a chlorophyll-meter (SPAD). Additionally, measurements have been taken for plant length, as well as leaf length and width. The XRF instrument (Genius 5000 XRF) was utilized to quantify the levels of Cd, Zn, and Cu in the soils and plant parts [22].

Pollution quantification accumulation factors**:**

Plant bioaccumulation factor (BF), translocation factor (TF), and pollution factor (CF) were used to quantify the quantity of pollution.

The capacity of a plant to uptake and accumulate metals concentrations is known as thebioaccumulation factor (BF). It is calculated as the ratio of contaminants from the plant's root and shoot to soil [23,24].
The formula below is used to determine the bioaccumulation factor (BF):

$$BF = \frac{\text{Conc.(shoot)}}{\text{Conc.(soil)}} \quad \text{.........................(1)}$$

Where:
Conc. shoot is the metal concentration in $mg.kg^{-1}$ in shoot dry weight, Conc. soil is the total metal concentration in $mg.kg^{-1}$ in the soil.
The translocation factor (TF) is a measure of the capacity of a plant to move chemicals from its roots to its shoots. It is calculated as the ratio of the concentration of contaminants in the shoots to those in the roots [25].

The following formula is used to compute the translocation factor (TF):

$$TF = \frac{\text{Conc. (shoot)}}{\text{Conc. (root)}} \quad \text{........................ (2)}$$

Where:
Conc. root is the concentration of metals in plant roots ($mg.kg^{-1}$).
Contamination Factor (CF)
Simex and Helz [26] introduced the Contamination Factor (CF) as a normalization technique to evaluate the metal content [27]. This formula is used to determine the CF:

$$CF = \frac{\text{M (sample)}}{\text{M (background)}} \quad \text{...................... (3)}$$

Where:
For each given soil sample, we divide the metal concentration by the background or undisturbed value of the same element to get the contamination factor (CF). According to Kabata-Pendias and Pendia's study [28], the metal background values are derived from it.

Statistical analysis

The SAS (2018) software was utilized to estimate the impact of variance variables on the study parameters. To compare means significantly, the least significant difference (LSD) test and analysis of variation, or ANOVA, were employed. The correlation coefficient estimates every variable [29].

Results and Discussion

Morphological effect of heavy metals

After six months of plant treatment with different doses of Cd, Zn, and Cu metals. Tables 1, 2, and 3 exhibited some vegetative characteristics of *Dodonaea viscosa*, such as leaf length, leaf width, and plant length, which were significantly impacted by Cd doses at $p \leq 0.05$. However, the variations in Cd doses have no obvious effect on chlorophyll. Nonetheless, Zn and Cu doses had a significant impact ($p \leq 0.05$) on all of the aforementioned vegetative characteristics. The results showed that the highest values for chlorophyll in Cu in (D2), leaf length and width in Zn (D3), and plant length in Zn (D1 (control)) were (68.0 ±3.55), (12.1 ±0.76 cm), (3.3 ±0.24 cm), and (96.5 ±5.20 cm), respectively. Nonetheless, the lowest values for chlorophyll, leaf length, and plant length in Cu (D4 and D1) were (45.8 ±2.17), (6.5 ±0.37 cm), and (75.7 ±3.29 cm), respectively. Conversely, the Leaf Width in Cd (D4) was (1.8 ±0.04 cm).

In terms of morphological characteristics, the results showed that *D. viscosa* plants could grow in soil polluted with Cd, Zn, and Cu in D (1) and D (2). The plant's growth rate, however, decreased linearly with increasing heavy metal concentrations and peaked in D (4). The result indicates that Cd doses reduce the characteristics of plants. Because it interferes with the activity of certain enzymes, cadmium is thought to be hazardous to plants. They also mentioned that plants treated with Cd showed inhibition of the production of anthocyanin and chlorophyll pigments. These findings are consistent with those reported by Monni *et al*. [30], who propose that inhibition of the enzymes involved in chlorophyll production may be the cause of the reduced chlorophyll concentration linked to heavy metal stress. Furthermore, recent findings showed that high amounts of Zn and Cu reduced some vegetative characteristics. Nevertheless, excessive amounts of these metals can have detrimental effects on cells [31]. Our results are in agreement with those of Nofal *et al*. [32], who found that different development characteristics of *D. viscosa* declined gradually with increasing concentrations of heavy metals (Pb, Cd, and Ni). When compared to the control group, the T4 combination showed the lowest values for the following traits: stem diameter, root length, number of branches and leaves per plant, leaf area, and plant height. In addition, Chaignon and Hinsinger [33] found that higher copper concentrations can retard root growth before shoot development and accumulate in the roots without substantially increasing the amount of copper in the aerial parts.

Table 1: Morphological characteristics of *Dodonaea viscosa* under exposure to different concentrations of Cd for 6 months period.

Cd doses $mg.kg^{-1}$	Chlorophyll SPAD	Leaf Length(cm)	Leaf Width(cm)	Plant Length(cm)
D1(0)	59.9 ±2.66	10 ±0.52	2.3 ±0.11	78.5 ±3.73
D2(25)	63.1 ±3.05	12 ±0.75	2.1 ±0.08	94.0 ±4.95
D3(75)	59.3 ±2.72	8.2 ±0.49	3.1 ±0.16	93.1 ±5.02
D4(100)	60.3 ±2.89	8.0 ±0.45	1.8 ±0.04	80.4 ±4.15
LSD value	5.027 NS	2.894 *	1.045 *	8.253 *
* ($P \leq 0.05$).				

Table 2: Morphological characteristics of *Dodonaea viscosa* under exposure to different concentrations of Zn for 6 months period

Zn doses $mg.kg^{-1}$	Chlorophyll SPAD	Leaf Length(cm)	Leaf Width(cm)	Plant Length(cm)
D1(0)	57.2 ±2.67	9.5 ±0.62	2.3 ±0.19	96.5 ±5.20
D2(25)	55.1 ±2.31	7.8 ±0.50	1.8 ±0.08	94.6 ±4.76
D3(75)	65.1 ±3.48	12.1 ±0.76	3.3 ±0.24	87.7 ±4.25
D4(100)	55.2 ±2.76	10.9 ±0.66	2.0 ±0.13	80.7 ±4.38
LSD value	6.823 *	2.748 *	0.966 *	7.905 *
* ($P \leq 0.05$).				

Table 3: Morphological characteristics of *Dodonaea viscosa* under exposure to different concentrations of Cu for 6 months period

Cu doses mg.kg-1	Chlorophyll SPAD	Leaf Length(cm)	Leaf Width(cm)	Plant Length(cm)
D1(0)	58.3 ±2.78	6.5 ±0.37	1.8 ±0.08	75.7 ±3.29
D2(25)	68.0 ±3.55	10.5 ±0.72	2.2 ±0.15	82.3 ±4.08
D3(75)	60.3 ±2.94	10.3 ±0.67	2.3 ±0.17	87.7 ±4.32
D4(100)	45.8 ±2.17	9.4 ±0.58	1.9 ±0.08	83.2 ±3.91
LSD value	7.027 *	2.855 *	0.604 NS	7.317 *
* (P≤0.05).				

Effect of different doses of Cadmium, Zinc, and copper concentrations (mg/kg) in soil and plant parts.

From outcomes of *Dodonaea viscosa* plants absorbing heavy metals through the phytoremediation process, there was a noticeable rise in the concentration of heavy metals in various plant organs. Concerning the heavy metal Cd (Figure 1), it was noted that there was a notable rise (P≤0.05) in the Cd levels found in the soil, root, and shoot. In the D4 (100 mg.kg^{-1}) Cd soil treatment, the plant roots had the highest concentration value at 6.2 ±0.38 mg.kg^{-1}, while the roots of the control D1(0) had a concentration of 2.4 ±0.19 mg.kg^{-1}. In addition, the D4 (100 mg.kg^{-1}) soil treatment showed the highest concentrations of soil and shoot, with measurements of 3.2 ±0.24 mg.kg^{-1} and 3.4 ±0.24 mg.kg^{-1}, respectively. The soil under D1(0) treatment had a significantly lower accumulation of Cd, with a value of 1.7 ±0.12 mg.kg^{-1}, compared to the other treatments.

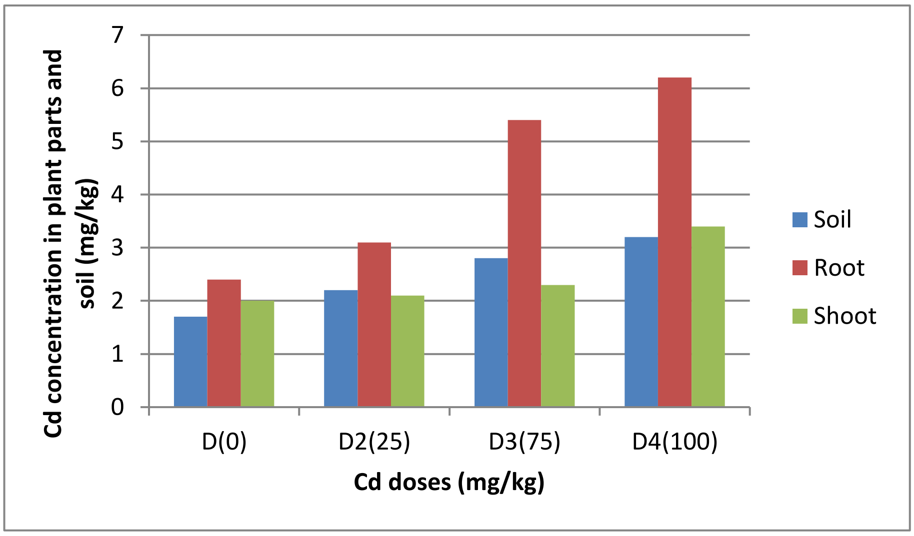

Figure 1: Concentrations of Cd (mg/kg) in soil and *D. viscosa* plant parts in soil treated with 0,25,75 and 100 Cd mg.kg^{-1} soil.

The Zn heavy metal (Figure 2) showed a significant increase at (P≤0.05) in the soil, shoot, and root. The highest concentration values were (79.7 ±3.92), (57.0 ±2.69), and (57.3 ±2.46) mg.kg^{-1} in the root, shoot, and soil, respectively, under the D4 (100 mg.kg^{-1}) Zn soil treatment. The amount of accumulated Zn in the soil under (D1 control) soil treatment was significantly lower than in the other treatments, with a value of 17.1 ±1.08 mg.kg^{-1}.

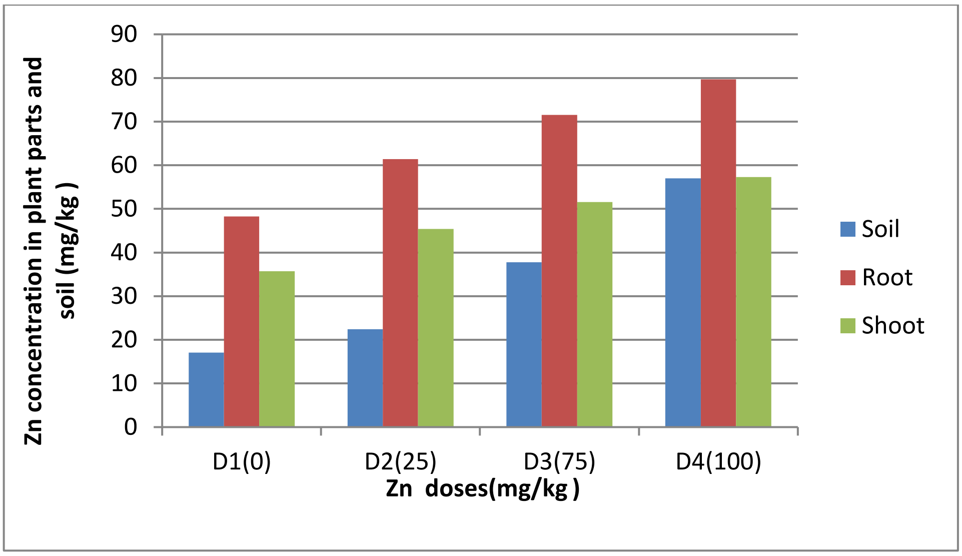

Figure 2 : Concentrations of Zn(mg/ kg) in soil and *D. viscosa* plant parts in soil treated with 0,25,75 and 100 Zn mg/ kg soil

With increases in Cu content, a significant increase at ($P \leq 0.05$) was noted in the soil, root, and shoot of *Dodonaea viscosa* plants for Cu absorption through the phytoremediation mechanism, as shown in Figure 3. In root, shoot, and soil, the maximum concentration values were (62.0 ±3.02), (44.8 ±2.19), and (41.7 ±2.42) $mg.kg^{-1}$, respectively. With a value of 15.3 ±0.74 $mg.kg^{-1}$, Cu soil under (D1) soil treatment was significantly lower than in other treatments.

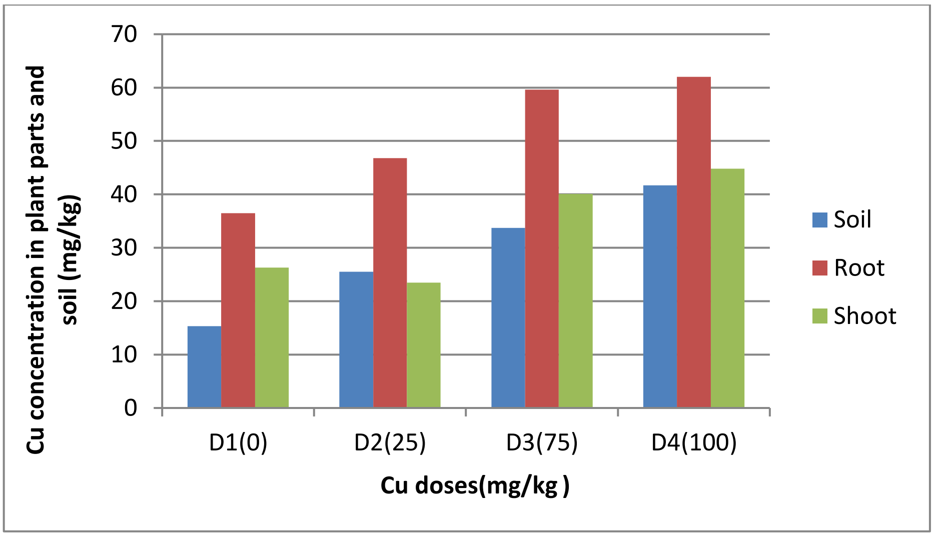

Figure 3: Concentrations of Cu(mg/ kg) in soil and *D. viscosa* plant parts in soil treated with 0,25,75 and 100 Cu mg/ kg soil.

Additionally, Table 5 lists the correlation coefficients for all treatments between the concentrations of heavy metals in soil and the different parts of the *D. viscosa* plant.

Table 5: Correlation coefficient between soil mineral concentrations and plant mineral concentrations

Minerals		Correlation coefficient	P-value
Cd: Soil	Cd: Root	-0.44 *	0.046
Zn: Soil	Zn: Root	-0.52	0.033
Cu: Soil	Cu: Root	-0.42 *	0.049
Cd: Soil	Cd: Shoot	-0.28 NS	0.362
Zn: Soil	Zn: Shoot	0.47 *	0.042
Cu: Soil	Cu: Shoot	0.02 NS	0.943
Cd: Soil	Cd: Plant	-0.36 NS	0.205
Zn: Soil	Zn: Plant	-0.06 NS	0.827
Cu: Soil	Cu: Plant	-0.29 NS	0.198
* (P≤0.05), NS: Non-Significant.			

For Cd and Cu treatments, a significant negative correlation was detected for root only with values (r= -0.44 and -0.42, respectively). While for Zn treatment, a significant positive correlation was detected for soil only with a value of 0.47.
According to the data above, the capacity of *D. viscosa* to absorb Cd, Zn, and Cu increases as soil treatments containing these three metals reach higher concentrations. Nonetheless, *D. viscosa* plants absorbed both necessary and non-essential metals from the soil in the following order: root > shoot > soil. In addition, three metals are effectively trapped in the root, with the root and shoot being considered the primary sites for metal accumulation. Several studies have indicated a correlation between the presence of heavy metals in the surrounding environment and their subsequent accumulation in plant tissue [34]. A key component in influencing absorption is the availability of metals, which is affected by both soil-associated and plant-associated variables. In the polluted region, the roots meticulously investigated the metals. There was a strong correlation between increased metal extraction and the roots' thorough examination of elements present in the contaminated soil. Metals tend to build up in the shoots of various plant species or ecotypes that are associated with soils containing high levels of heavy metals. These plants can draw metals out of the ground and store them in their biomass that grows above ground. Hence, they can be employed to restore regions polluted by metals [35]. In a study conducted by Castañeda-Espinoza *et al*.[36], *D. viscosa* showed that plant tissues in the roots and leaves were an effective accumulator of Cu, Cd, Fe, Pb, and Zn. Also, the effectiveness of three different native plant species, including *D. viscosa*, in extracting mercury (Hg) from contaminated soil was investigated by Zeki *et al*.[37].

Pollution indices in D. viscosa as a response to different doses of Cadmium, Zinc, and Copper

Results illustrated in Table 6 demonstrated how different doses of Cd, Zn, and Cu significantly ($p \leq 0.05$) affected the mean values of the following pollution indices: bioaccumulation factor (BF), translocation factor (TF), and contamination Factor (CF) for soil, root, and shoot. In terms of BF, the Zn under D1 (control) had the highest mean value of 2.088 ±0.17 $mg.kg^{-1}$, while the Cd under D3 (75 $mg.kg^{-1}$) had the lowest mean value of 0.821 ±0.12 $mg.kg^{-1}$. Zn >Cu > Cd was the order in which *D. viscosa* absorbed heavy metals from the soil, going from higher to lower amounts. Additionally, the findings showed that the Cd under D1 (control) had the highest mean value of TF at 0.833 ±0.12 mg.kg^{-1}, while the Cd under D3 (75 mg.kg^{-1}) had the lowest mean value at 0.426 ±0.06 mg.kg^{-1}. When TF values are below one, these plants tend to accumulate metals mostly in their roots and rhizomes rather than in their shoots or leaves, suggesting ineffective metal transport. On the other hand, Yoon *et al*. [38] proposed that heavy metal transfer is only successful when the transfer factor (TF) values are more than one. Results showed that phytoremediation was an efficient mechanism for heavy metal removal by *D. viscosa*, including Cd, Zn, and Cu. As seen by the TF values being near to one, this process entails the plant concentrating the metals in its roots. Treatment with increasing quantities of Cd, Zn, and Cu resulted in an increasing value of CF. For Cd in root, the maximum value was found at 31.0 ±1.86 mg.kg^{-1}, with D4 (100 mg.kg^{-1}). On the other hand, CF for soil Zn levels was found to be the lowest at 0.276 ±0.08 mg.kg^{-1} under D1 (control). Factors such as bioaccumulation factor (BF) and translocation factor (TF) can be used to estimate the plant's phytoremediation capability [39]. The values of bioaccumulation and translocation factors demonstrate the efficiency with which plants can store and distribute heavy metals within their tissues, depending on the presence of metals in the soil and their absorption by plants [40]. Once the roots can no longer stabilize or store the heavy metals, the accumulated heavy metals start moving from the roots to the shoots [41]. Castañeda-Espinoza *et al.*[36], found a clear pattern in the significant impact of certain metals on micro-morphological and size features. The order of the elements in terms of their relative reactivity is as follows: Fe, Cd, Cr, Pb, Cu, Zn. *D. viscosa* has a remarkable ability to accumulate Cu, Cd, Fe, Pb, and Zn in its root and leaf tissues. In general, the metal translocation factors of the exposed *D. viscosa* plants followed a consistent pattern: Zinc is greater than copper, which is greater than cadmium. Current findings indicated that *D. viscosa* can extract and stabilize metals (Cd, Zn, and Cu) from polluted soils and relocate them to their appropriate sites in plants.

Table 6: Effect of different doses of Cd, Zn, and Cu (mg.kg^{-1}) in soil and *D. viscosa* parts on some pollution indices.

Does mg.kg^{-1}	Metals	BF	TF	CF soil	CF root	CF Shoot	LSD value
D1(0)	Cd	1.765 ±0.10	0.833 ±0.12	1.545 ±0.18	12 ±0.45	10 ±0.39	3.084 *
	Zn	2.088 ±0.17	0.739 ±0.10	0.276 ±0.08	0.84 ±0.06	0.621 ±0.17	0.552 *
	Cu	1.719 ±0.14	0.721 ±0.08	1.093 ±0.12	2.92 ±0.15	2.104 ±0.19	0.603 *
D2(25)	Cd	0.955 ±0.08	0.677 ±0.11	2.0 ±0.16	15.5 ±0.74	10.5 ±0.54	2.692 *
	Zn	2.027 ±0.14	0.739 ±0.12	0.361 ±0.07	1.068 ±0.04	0.790 ±0.10	0.674 *
	Cu	0.922 ±0.15	0.502 ±0.07	1.821 ±0.27	3.744 ±0.24	1.88 ±0.10	0.791 *
D3(75)	Cd	0.821 ±0.12	0.426 ±0.06	2.545 ±0.17	27.0 ±1.07	11.5 ±0.64	2.704 *
	Zn	1.365 ±0.18	0.722 ±0.12	0.609 ±0.13	1.243 ±0.12	0.897 ±0.07	0.488 *
	Cu	1.189 ±0.08	0.673 ±0.08	2.407 ±0.18	4.768 ±0.27	3.208	1.051 *
D4(100)	Cd	1.063 ±0.12	0.548 ±0.07	2.909 ±0.14	31.0 ±1.86	17.0 ±1.05	2.757 *
	Zn	1.005 ±0.07	0.719 ±0.11	0.919 ±0.08	1.386 ±0.09	0.997 ±0.13	0.395 *
	Cu	1.074 ±0.12	0.723 ±0.09	2.979 ±0.18	4.96 ±0.35	3.584 ±0.20	1.026 *
* (P≤0.05).							

Conclusion

According to pollution indices in *D. viscosa* (root, shoot) and soil as a response to different doses of Cadmium, Zinc, and Copper in this study, *D. viscosa* plants have enormous phytoremediation potential when it comes to heavy metal removal. In comparison to more conventional ways of soil cleaning, phytoremediation has shown to be an efficient and cost-effective strategy for heavy metal management .

Acknowledgement

The authors are thankful to Central Plant Nursery of Erbil / Erbil Governorate, Northern Iraq, for support.

Conflict of Interest: The authors declare that they have no conflicts of interest.

References

[1] BY. Zhang, JS. Zheng and RG. Sharp, "Phytoremediation in engineered wetlands: Mechanisms and applications," *Procedia Environmental Sciences*, vol.2, pp.1315-1325, 2010

[2] R. Al-Anbari, , A.H. Al-Obaidy and T.J. Al-Amari, "Phytoremediation of chromium contaminated soils by using Catharanthus roseus," *Mesopotamia Environmental Journal*, vol. 2, no.4, pp.32-40, 2016.

[3] J. P. Schwitzguebel, J. Kumpiene, E. Comino and T. Vanek, "From green to clean: a promising and sustainable approach towards environmental remediation and human health for the21st century,"*Agrochimica*, vol. 53, pp. 1-29,2009.

[4] R .Naza, M. S. Khana , A. Hafeez , M. Fazila , M. N. Khana, B. Ali , M. A. Javedd , M. Imrana , A. A. Shatie , M. Y. Alfaifie , S. E. I. Elbehairie and A. E. Ahmedg, “Assessment of phytoremediation potential of native plant species naturally growing in a heavy metal-polluted industrial soils," *Brazilian Journal of Biology*,vol.84,pp.1-13,e264473,2022 , https://doi.org/10.1590/1519-6984.264473.

[5] L. Wang, D. Hou, Z. Shen, J. Zhu, X. Jia and Y. S. Ok, “Field trials of phytomining and phytoremediation: A critical review of influencing factors and effects of additives”, *Critical Reviews in Environmental Science and Technology*, vol.50, pp.2724–2774,2020b, doi: 10.1080/10643389.2019.1705724.

[6] J.K. Sharma, N. Kumar, N. P. Singh and A.N. Santa, “ Phytoremediation technologies and their mechanism for removal of heavy metal from contaminated soil: An approach for a sustainable environment”, *Frontiers in Plant Science*,vol.14, 1076876., 2023, doi: 10.3389/fpls.2023.1076876.

[7] J. Brunet, A. Repellin, G. Varrault, N. Terryn and Y. Zuily-Fodil, “ Lead accumulation in the roots of grass pea (Lathyrus sativus L.): a novel plant for phytoremediation systems”, *Comptes Rendus Biologies* ,vol.331,no.11,pp.859-864, 2008.

[8] J. Barceló and C. Poschenrieder, “Phytoremediation: principles and perspectives”, *Contributions in science*,vol.2,no.3,pp.333-344, 2003.

[9] A. Nagaraju and S. Karimulla, “Accumulation of elements in plants and soils in and around Nellore mica belt, Andhra Pradesh, India: a biogeochemical study”, *Environmental Geology*, vol.41,no.7,pp.852-860, 2002

[10] P. Ahmadpour, F. Ahmadpour, T. M. M. Mahmud, M. Arifin Abdu1 Soleimani and F. Hosseini Tayefeh ,“Phytoremediation of heavy metals: A green technology”, *African Journal of Biotechnology*, vol. 11,no.76, pp. 14036-14043, 2012. DOI: 10.5897/AJB12.459.

[11] B. V. Tangahu, S. R. Sheikh Abdullah, H. Basri, M. Idris, M. Anuar and M. Mukhlisin ,“A Review on Heavy Metals (As, Pb, and Hg) Uptake by Plants through Phytoremediation”, *International Journal of Chemical Engineering*, vol.2011,pp.31, 2011. https://doi.org/10.1155/2011/939161

[12] S.L. Zeki and M.J. M-Ridha,“ Phytoremediation Of Synthetic Wastewater Containing Copper By Using Native Plant”, *Iraqi Journal of Agricultural Sciences*,vol.51,no.6,pp.1601-1612, 2020.

[13] V. Gohre and U. Paszkowski,“Contribution of the arbuscular mycorrhizal symbiosis to heavy metal phytoremediation”, *Planta*, vol. 223, pp.1115–1122, 2006.

[14] E. Azab and A.K. Hegazy,"Monitoring the Efficiency of Rhazya stricta L. Plants in Phytoremediation of HeavyMetal-Contaminated Soil", *Plants* ,vol.9,pp.1057,2020. doi:10.3390/plants9091057

[15] A.A. Hamad, Kh. H. Alamer and H.S. Alrabie ," The Accumulation Risk of Heavy Metals in Vegetables which Grown in Contaminated Soil", *Baghdad Science Journal*, vol. 18,no.3,pp.471-479, 2021. DOI: http://dx.doi.org/10.21123/bsj.2021.18.3.0471

[16] C. Li, K. Zhou, W. Qin, C. Tian, M. Qi, X. Yan and W. Han ,"A review on heavy metals contamination in soil: Effects, sources, and remediation techniques", Soil and Sediment Contamination: *An International Journal*,vol.28,pp.380–394,2019. https://doi.org/10.1080/15320383.2019.1592108

[17] G.-G. Ying ," Remediation and mitigation strategies. In Integrated Analytical Approaches for Pesticide Management", Maestroni, B., Cannavan, A., (eds.), Academic Press: Cambridge, MA, USA, 2018.

[18] C. Garbisu, and N. Alkorta ," Phytoextraction: A cost-effective plant-based technology for the removal of metals from the environment", *Bioresource Technology*, vol.77,no.3,pp.229-236, 2001.

[19] H. N. Abdul-Alghaffar and A. S. Al-Dhamin," Phytoremediation of Chromium and Copper from Aqueous Solutions Using Hydrilla verticillata",*Iraqi Journal of Science*, Vol.57,no.1A,pp.78–86 ,2023.

[20] USDA, United States Department of Agriculture. Natural Resources Conservation Service, 2019.

[21] M. Pansu and J. Gautheyrou,"Mineralogical separation by selective dissolution", Handbook of Soil Analysis: Mineralogical, Organic and Inorganic Methods pp.167-219, 2006.

[22] S.N. Khudhur, M.S. Khudhur and N.I. Ahmad ,"An Assessment of Heavy Metal Soil Contamination in a Steel Factory and the Surrounding Areain Erbil City", *Jordan Journal of Earth and Environmental Sciences*, vol.9,no.1,pp.1- 11,2018 .

[23] S. F. Mamand, N. S. Khudhur and D. A. Darwesh ,"Phytoremediation efficiency of some evergreen plant genera for lead polluted soil. *Zanco J Pure Appl Sci*, vol.32,no.5,pp.174-178 ,2020.

[24] A.O. Fayiga, L.Q. Ma, X. Cao and B. Rathinasabapathi ,"Effects of heavy metals on growth and arsenic accumulation in the arsenic hyperaccumulator *Pteris vittata* L", *Environmental Pollution*, vol.132,no.2,pp. 289-296, 2004.

[25] Y. Sun, Q. Zhou, Y. Xu, L. Wang and X. Liang ,"The role of EDTA on cadmium phytoextraction in a cadmium-hyperaccumulator *Rorippa globosa*", *Journal of Environmental Chemistry and Ecotoxicology*, vol.3,no.3,pp.45-51,2011.

[26] S.A. Simex and G.R. Helz,"Regional geochemistry of trace elements in Chesapeake Bay", *Environmental Geology*, vol.3,no.6,pp.315-323 , 1981.

[27] E.A.M. Salah, T.A. Zaidan and A.S. AL-Rawi,"Assessment of heavy metals pollution in the sediments of Euphrates River, Iraq", *Journal of Water Resource and Protection*, Vol.4,No.12,pp.1-15, 2012. DOI: 10.4236/jwarp.2012.412117

[28] A. Kabata-Pendias and H. Pendias," Trace elements in soils and plants", 3rd edn CRC Press. *Boca Raton, FL, USA.* , 2001.

[29] (SAS) Statistical Analysis System, User's Guide. Statistical. Version 9.6th ed. SAS. Inst. Inc. Cary. N.C. USA.2018

[30] S. Monni, C. Uhlig, O. Junttila, E. Hansen and J. Hynynen,"Chemical composition and ecophysiological responses of *Empetrum nigrum* to aboveground element application", *Environmental Pollution*, vol.112,no.3, pp.417-426,2001.

[31] A.J.M. Baker and R.R. Brooks,"Terrestrial higher plants which hyperaccumulate metallic elements a review of their distribution, ecology and phytochemistry", *Biorecovery*, vol. 1,pp. 81–126 , 1989.

[32] E. M. S. Nofal, S. M. SHahin, A. M. A. EL-Tarawy and S. H. M.Omar,"The effect of some heavy metal combinations on growth and chemical composition of some ornamental shrubs common in Egypt No1. – Hop bush (*Dodonaea viscasa* L.) ", *Applied Ecology And Environmental Research*, vol. 20,no.5,pp.4339- 4350 , 2022. DOI: http://dx.doi.org/10.15666/aeer/2005_43394350

[33] V. Chaignon and P. Hinsinger,"A biotest for evaluating copper bioavailability to plants in a contaminated soil", *Journal of Environmental Quality*, vol.32,pp. 824-833. ,2003.

[34] Y. Cui, Q. Wang and P. Christie,"Effect of elemental Sulphur on uptake of Cadmium, Zinc, and Sulphur byoilseed Rape growing in soil contaminated with Zinc and Cadmium", *Communications in Soil Science and Plant Analysis*, vol. 35, pp.2905-2916, 2004.

[35] K. Peng, X. Li, C. Luo and Z. Shen ," Vegetation composition and heavy metal uptake by wild plants at three contaminated sites in Xiangxi area, China", *Journal of Environmental Science and Health Part A*, vol.40, pp.65-76, 2006.

[36] J. Castañeda-Espinoza, D. Salinas-Sánchez, P. Mussali-Galante, M. Castrejón-Godínez, A. Rodríguez, M. González-Cortazar, A. Zamilpa-Álvarez, E. Tovar-Sánchez,"Dodonaea viscosa (Sapindaceae) as a phytoremediator for soils contaminated by heavy metals in abandoned mines ", *Environmental Science and Pollution Research*,vol.30,no.2,pp.2509-2529,2023.doi: 10.1007/s11356-022-22374-5.

[37] H.F. Zeki, R.N. Ajmi and E.M. Ati,"Phytoremediation Mechanisms of Mercury (Hg) between some plants and soils in Baghdad City", *International Journal of Agricultural Science*, vol.4, PP.2367-9026,2019.

[38] J. Yoon, X. Cao, Q. Zhou and L.Q. Ma,"Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site*", Science of The Total Environment* ,vol, 368,pp. 456–464,2006.

[39] K.Usman, M.A. Al-Ghouti and M.H. Abu-Dieyeh," The assessment of cadmium, chromium, copper, and nickel tolerance and bioaccumulation by shrub plant Tetraena qataranse", *Scientific Reports*, vol. 9,pp. 5658,2019.

[40] A.S.S. AL- Wotaify and Z.A.S. Al-Mamuri," Bioaccumulation for some heavy metals on the impact of irrigating soil and plant with wastes of Al-Muamirah station", *Euphrates Journal of Agriculture Science*,vol.11.no.1,pp. 22 - 32 ,2019.

[41] A.K. Hegazy, N.T. Abdel-Ghani and G.A. El-Chaghaby," Adsorption of phenol onto activated carbon from Rhazya stricta: Determination of the optimal experimental parameters using factorial design", *Applied Water Science*, vol. 4, pp.273–281,2014.