RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
57 (4) 1756-1765, 2025
http://doi.org/10.54910/sabrao2025.57.4.42
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

PHYTOREMEDIATION POTENTIAL OF THE WILD PLANTS: A STUDY ON SELECTED SPECIES

R.M. MAHMOOD[1], I.O. SAEED[2*], D.A. DARWESH[3], and B.M.Y. YOUSIF[4]

[1]Department of Biology, College of Education Pure Sciences, Tikrit University, Tikrit, Iraq
[2]Department of Biology, College of Science, Tikrit University, Tikrit, Iraq
[3]Department of Ecology, College of Science, Salaheddin University, Iraq
[4]Nineveh General Directorate of Education, Iraq
*Corresponding author's email: dr.ibrahim1977@tu.edu.iq
Email addresses of co-authors: raghad.ecology@tu.edu.iq, dalshas.darwesh@su.edu.krd

SUMMARY

This study investigated the transport and accumulation of several heavy metals within the lower and upper parts of the wild plants *Typha domingensis, Prosopis farcta,* and *Alhagi maurorum,* belonging to the Al-Kasak and Al-Qayyarah sites in Iraq, which were collected in autumn. In the Al-Kasak refinery, results indicated the cadmium (Cd) and nickel (Ni) showed significantly higher bioaccumulation in the root system (392.01 and 658.11 mg/kg, respectively) from dry weight compared with the dry weight of shoots (287.12 and 619.45 mg/kg, respectively). However, the lead (Pb) and manganese (Mn) exhibited higher bioaccumulation in the shoot system (280.23 and 80.95 mg/kg dry weight, respectively). At the Al-Qayyarah refinery, Ni, Pb, and Mn appeared more accumulated in root parts (668.65, 270.61, and 156.24 mg/kg dry weight, respectively) than in the shoots for each plant (*Prosopis farcta, Alhagi maurorum, and Typha domingensis)*. Meanwhile, Cd bioaccumulation was higher in the shoots (377.31 mg/kg dry weight). Additionally, the roots of *Alhagi maurorum* and *Typha domingensis* revealed higher accumulations of Ni and Mn (778.25 and 235.93 mg/kg dry weight, respectively) compared with the shoot system. At the Al-Kasak site, plants showed a higher bioaccumulation of Pb (13.38 mg/kg dry weight), following the order Pb**>**Ni**>**Mn**>**Cd (13.38>11.14>3.93>1.44 dry weight, respectively). Then again, plants at the Al-Qayyarah site had the highest bioaccumulation of Ni (17.94 mg/kg), with the order of bioaccumulation as Ni>Mn>Pb>Cd (17.94>11.75>3.84>1.07 mg/kg dry weight, respectively). The maximum bioaccumulation of Mn was notable in the plants of *Typha domingensis, Prosopis farcta,* and *Alhagi maurorum* (28.86, 146.68, and 419.86 mg/kg dry weight, respectively).

Communicating Editor: Dr. Gwen Iris Descalsota-Empleo

Manuscript received: January 09, 2025; Accepted: March 03, 2025.

Citation: Mahmood RM, Saeed IO, Darwesh DA, Yousif BMY (2025). Phytoremediation potential of the wild plants: A study on selected species. *SABRAO J. Breed. Genet.* 57(4): 1756-1765. http://doi.org/10.54910/sabrao2025.57.4.42.

Keywords: Wild plants, heavy metals, phytoremediation, bioaccumulation, biotranslocation

Key findings: At the Al-Kasak site in Iraq, the bioaccumulation of Ni, Cd, and Pb was higher in roots than in shoots, while the bioaccumulation of Pb and Mn was higher in shoots of wild plants. However, at the Al-Qayyarah site, the bioaccumulation of Ni, Pb, and Mn was greater in roots, while the bioaccumulation of Ni was superior in shoots of wild plants.

INTRODUCTION

Mineral resources naturally occur in the soil, and exploitation of these resources is highly beneficial for nations in the advancements in science, technology, economy, and development. However, the increasing demand for mineral resources through geological, industrial, and agricultural activities has led to severe environmental problems. Soil bioaccumulation is one of the most prominent issues, particularly with heavy metals released into the environment.

The soil metals' bioaccumulation is dependent on their chemical and physical properties, such as pH, electrical conductivity (EC), cation exchange capacity (CEC), organic matter, and total mineral content, particularly clay fraction. These heavy metals pose significant risks to both plants and human life, causing carcinogenic effects, mutations, and other toxic outcomes, as they do not degrade naturally into non-toxic types. Thus, remediation is an essential technology for reducing their harmful effects (Chen *et al*., 2022).

For treating the soils contaminated with various heavy metals and oils, various chemical and physical techniques are applicable. These techniques can be time-efficient, with multiple drawbacks, such as high costs, energy requirements, and potential environmental harm. For instance, chemical methods like oxidation, filtration, and chemical precipitation involve adding organic solvents and chemicals to the contaminated soils to stabilize pollutants and reduce their toxicity. However, these methods may result in harmful residues and do not completely remove contaminants from the soil (Kour *et al*., 2022; Wang *et al.,* 2022).

Bioremediation utilizes bacteria to break down hydrocarbons and convert toxins into less harmful byproducts, such as water vapor and carbon dioxide, with the said method preferred in waste management and in the treatment of contaminated soils. Similarly, phytoremediation uses different plants to remove and stabilize the pollutants through mechanisms like phytoextraction and phytodegradation (Liu *et al.,* 2020; Ahmad *et al.,* 2020). In the last decade, a huge amount of heavy metals from various sources, such as industrial and agricultural applications to soil, have shown considerable damaging effects on environmental health. Thus, the presented study aimed to quantify the percentage of some heavy metals in soil and plants, as well as identify the hyperaccumulated wild plants.

Tolerance and accumulation of heavy metals can be beneficial to plant stability. The biotransfer factor (TF) and bioaccumulation factor (BAF) can be effective to estimate the plant's capacity for phytoremediation. Measuring the ability of a plant to transport metals from the roots to the leaves uses TF, which is defined as the ratio of the metal concentration in the leaves to that in the roots (Yoon *et al.,* 2006). Estimating the ability of a plant to accumulate metals from the soil can also apply the BAF, with the definition as the ratio of the metal concentration in the roots to that in the soil. Phytoextraction generally requires the transport of heavy metals to parts of the plant that can be easily harvested, i.e., the leaves. By comparing BAF and TF, we can compare the ability of different plants to absorb metals from the soil and transport them to the leaves. Plants that are hyperaccumulators actively absorb and transport metals into their aboveground biomass. Slow accumulators tend to have restricted transport of metals from the soil to the roots and from the roots to the leaves, and thus, accumulate much less of them in their biomass. Enrichment occurs when a contaminant absorbed by a plant does not rapidly degrade, leading to its accumulation in the plant (Fitz and Wenzel, 2002).

MATERIALS AND METHODS

Description of study sites

The Al-Kasak refinery is an affiliate of the Northern Refineries Company, established in the eighties of the last century, with a location at the northwest of the city of Mosul, about 40 kilometers from the center of Mosul. In the Al-Kasak area, a small village located in the Al-Jazeera region near Tal Afar, the refinery produces the following petroleum derivatives: light and heavy naphtha, kerosene, diesel, and black oil. It contains oil tanks that may be a cause of soil pollution as a result of accidental spills causing the accumulation of oil ponds and thus, soil pollution with heavy elements. It also has oil-refining furnaces that may be a source of environmental pollution as a result of the combustion of hydrocarbons. This could lead to the emission of gases, such as carbon dioxide (CO_2), lead (Pb), and cadmium (Cd). in addition to industrial water waste polluted with heavy elements that lead to soil pollution. Natural plants, such as *Prosopis farcta, Alhagi maurorum, and Typha domingensis,* are prevalent in the area.

Al-Qayyarah Refinery, also affiliated with the Northern Refineries Company, sits in the Al-Qayyarah district, which is about 60 kilometers from the center of Mosul City in Nineveh Governorate. The Al-Qayyarah oil refinery enjoys great economic importance because it supplies many Iraqi governorates with their needs of asphalt and gas oil. The importance of this refinery increased with the rehabilitation of the railways and their reconnection to the ports of Basra in Southern Iraq. It is one of the specialized refineries to produce asphalt used in street paving works, as well as the 125 used in mastic and flancote factories. The secondary product of the refinery is heavy gas oil as fuel for stations. The refinery carries out the process of refining crude oil extracted from the oil wells attached to the processing plant, which contains a large percentage of sulfur, constituting one of the major problems for this refinery.

Collection of samples

Plant samples and preparation of plant powder

Plant samples of the *Prosopis farcta*, *Alhagi maurorum,* and *Typha domingensis,* collected from the polluted sites of Al-Kasak Refinery and Al-Qayyarah Refinery, Iraq, had distances of 50, 150, and 300 meters from the source of contamination, with the samples collected once in autumn. The vegetative parts of these plants, as separated from their roots, had both parts' types weighed at the site by an electric balance. The samples' placement in paper bags included the identification information to be used for further study after being transferred to the laboratory (Ikiriko and Chukwumati, 2023).

The shoot and root parts, digested separately, underwent estimation of the bioaccumulation of heavy metals using the atomic absorption spectrophotometer. The study took 0.5 g of dry matter and placed them in a digestion tube, then added nitric, sulfuric, and perchloric acids with a ratio of 2:1:1. Afterward, the samples' digestion continued by increasing the temperature gradually for a period of 2–4 h. The samples' filtration in 50 ml volume followed, completing the solution with distilled water (APHA, 1998). The collection of soil samples at each site and under each plant also occurred for heavy metals determination.

Determination of heavy metals

The standard curve for each of the metals, prepared earlier, estimated the bioaccumulation of heavy metals (Cd, Pb, Ni, and Mn). The bioaccumulation of heavy metals used the expression in mg/kg dry weight (APHA, 1998).

Determination of the bioaccumulation factor (BAF) and the translocation factor (TF)

After determining heavy metals in plant samples, the estimation of bioaccumulation factors (BAF) and the transfer factor (TF) ensued (Ghosh and Singh, 2005; Bitterli *et al*., 2010).

Bioaccumulation factor (BAF)

Calculating the ratio of the element's bioaccumulation in the roots to its bioaccumulation in the soil will estimate the plant's efficiency in accumulating heavy elements in the roots and determine the plant's ability to process them. The bioaccumulation efficiency calculation used the following equation (Yoon *et al*., 2006).

$$BAF = \frac{\text{Matel concentration Plant}}{\text{Matel concentration Soil}} \quad \ldots\ldots\ldots\ldots\ldots 1$$

The bioaccumulation of heavy metals in plant roots refers to the amount of heavy metals absorbed by the roots, while the bioaccumulation in the soil represents the amount of heavy metals found in the soil.

Translocation factor (TF)

The ability of plants to transport heavy metals from roots to shoots attained computation by the transport factor (TF). A TF value > 1 indicates the plant is efficiently transporting metals from the root to the shoot. The transport factor's calculation used the formula below (Mattina *et al.,* 2003).

$$TF = \frac{\text{Matel concentration in the shoot}}{\text{Matel concentration in the Root}} \quad \ldots\ldots\ldots\ldots\ldots 2$$

Statistical analysis

All the recorded data's analysis utilized the SPSS Statistical Package. The averages of the heavy metals in the different wild plants and in the soil samples of the study sites incurred comparison using the Duncan Multiple Range Test (DMRT) by the one-way analysis of variance at the probability level of $p \leq 0.05$ (Prescott *et al*., 2005).

RESULTS AND DISCUSSION

Heavy metals bioaccumulation

The highest bioaccumulation of cadmium (Cd) and nickel (Ni) resulted in the roots of *Alhagi maurorum* at the Al-Kasak site, with values of 367.73 and 875.42 mg/kg dry weight, respectively. In contrast, the lowest bioaccumulation of these elements was evident in the roots of *Typha domingensis*, with values of 287.20 mg/kg dry weight for Cd and 472.87 mg/kg dry weight for Ni (Table 1). The bioaccumulation of Cd and Ni was significantly higher in the roots than in the green mass (shoots) of both *Alhagi maurorum* and *Typha domingensis*, with values of 291.97 and 216.90 mg/kg dry weight, respectively. In the green mass of *Prosopis farcta* and *Typha domingensis*, the bioaccumulation of Ni reached 747.93 and 545.97 mg/kg dry weight, respectively. This can be due to the ability of *Alhagi maurorum and Typha domingensis* to bioaccumulate Cd and Ni in their roots through absorption from the soil. The premier bioaccumulation of manganese (Mn) was notable in the vegetative system (shoots) of *Typha domingensis* (207.22 mg/kg dry weight), compared with its roots (162.81 mg/kg dry weight). Conversely, the lowest Mn bioaccumulation appeared in the vegetative system of *Alhagi maurorum* (17.7 mg/kg dry weight), compared with its roots (7.20 mg/kg dry weight). This suggests that *Typha domingensis* can better biotransport Cd and Ni between its roots and shoots.

The soils near tailings emerged highly polluted with Cd and Ni and moderately polluted with Mn and Pb (Shi *et al.*, 2023). The maximum accumulation values of Ni and Cd in plants exceeded permissible limits. In *Ammophila breviligulata*, the Mn and Cd contents in the roots were lower than those in the shoot system, which could be due to the strong capacity for the bioconcentration (BAF) of heavy elements (Mn, Ni, and Pb). This highlights the ability of plants to immobilize heavy elements in the soil. The order of heavy element bioaccumulation in plants, from

Table 1. The interaction between the two sites (AL-Kasak and AL-Qayyarah) with the plant effects on heavy metal concentrations.

Sites	Cd		Pb		Mn		Ni	
	Leaves	Root	Leaves	Root	Leaves	Root	Leaves	Root
S1P1	352.50[b]	332.10[b]	209.56[a]	198.43[a]	28.48[b]	17.638[c]	747.937[a]	626.04[b]
S1P2	291.97[c]	367.73[a]	420.60[a]	217.47[a]	7.17[c]	7.20[c]	564.44[b]	875.42[a]
S1P3	216.90[b]	287.20[c]	210.53[a]	207.60[a]	207.22[a]	162.81[b]	545.97[b]	472.87[c]
S2P1	355.73[b]	368.90[a]	202.50[a]	210.97[a]	1.60[c]	2.84[c]	536.09[b]	681.08[b]
S2P2	351.00[b]	332.10[b]	209.56[a]	189.43[a]	6.30[c]	156.81[b]	576.96[b]	681.08[b]
S2P3	425.20[a]	355.87[a]	383.37[a]	402.43[a]	32.99[a]	309.06[a]	755.67[a]	643.78[b]

*****Similar letters mean no significant differences, S1P1, S1P2, and S1P3 represent *Prosopis farcta*, *Alhagi maurorum,* and *Typha domingensis* plants for Al-Kasak site, S2P1, S2P2, and S2P3 represent *Typha domingensis*, *Prosopis farcta,* and *Alhagi maurorum* plants for Al-Qayyarah site.

highest to lowest, was Mn > Ni > Pb > Cd, which exceeds the normal range of heavy elements in plants. At the Al-Qayyarah site, the vegetative mass of *Typha domingensis* and *Alhagi maurorum* showed a biotransfer of nickel (755.67–536.09 mg/kg dry weight) compared with the roots (681.08–643.78 mg/kg dry weight) (Table 1). However, the lowest and highest biotransfer values of cadmium were between 425.20 and 351.00 mg/kg dry weight for the vegetative mass of *Prosopis farcta* and *Alhagi maurorum* compared with the roots of both plants (355.87 and 332.10 mg/kg dry weight, respectively). The roots of *Typha domingensis* and *Alhagi maurorum* bioaccumulated manganese between 309.06 and 2.84 mg/kg dry weight. Heavy metals can accumulate between soil and plants compared with the green plant parts of both *Typha domingensis* and *Alhagi maurorum* P3, with bioaccumulation of 32.99–1.60 mg/kg dry weight. Abbas *et al*. (2019) mentioned the gradual increase of cadmium levels in the soil of the *Prosopis farcta*, irrigated with water rich in heavy metals, as the highest BAF accumulation was for cadmium, lead, nickel, and cobalt, respectively, with the movement of element ions from roots to shoots calculated as the transfer factor (TF) T5 for Cd and T2 for Pb>Ni, respectively.

The plant's exposure to cadmium led to a decrease in plant growth and an increase in the bioaccumulation of cadmium in the leaves and roots, and then a linear decrease in the plant shoots and roots. Past studies revealed the bioaccumulation rate of nickel was 1.54 (Githuku *et al*., 2018; Taher and Said, 2021). Other findings showed the *Typha latifolia* can remove heavy metals efficiently and in the order of Pb < Cd. *Alhagi maurorum* has a higher tolerance to cadmium in the root than in the stem and contaminated soil, as affected by cadmium toxicity, while the biotransport factor (TF) for cadmium had a value of TF > 1, while the bioaccumulation factor (BAF) had a value of BAF < 1. Cadmium accumulation in the roots of *Alhagi maurorum* was higher than its accumulation in the stem (Alotaibi *et al*., 2023).

The superiority of cadmium and nickel elements was prominent at the site of the cuscus by their accumulation in the root system with average bioaccumulations of 392.01 and 658.11 mg/kg dry weight, found significantly higher than their accumulation in the vegetative system (Figure 1). Most of the heavy elements entering the plant had first retention in the root cells, which significantly reduced the displacement of the organ to the ground and protected leaf tissues from damage resulting from heavy metal toxicity (Chitimus *et al.,* 2023). The maximum values of lead and manganese elements occurred in the root system with a bioaccumulation ratio of 280.23 and 80.95 mg/kg dry weight, due to the difference in the tissues of the roots and vegetative parts. Ikiriko and Chukwumati (2023) believe that, with increasing levels of crude oil pollution, the content of cadmium, nickel, and lead significantly decreased in the roots and shoots.

At the Al-Qayyarah site, the detection of bioaccumulation of nickel, lead, and manganese with higher values resulted in the

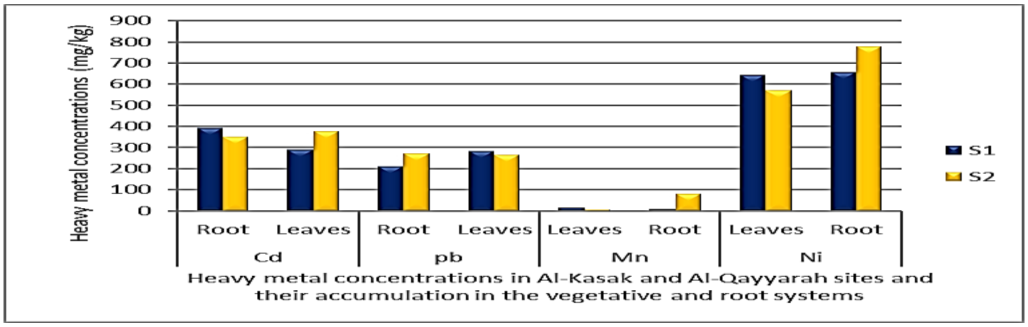

Figure 1. Comparison of the heavy metals' bioaccumulation in terms of their accumulation in the shoot and root systems of plants at the sites of Al-Kasak (S1) and Al-Qayyarah (S2) site.

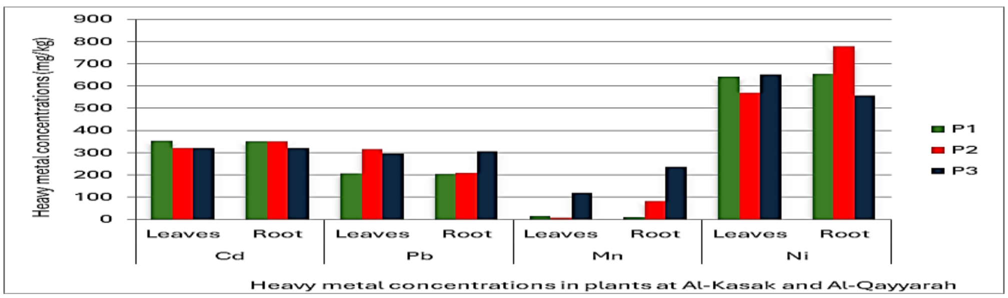

Figure 2. Heavy metals' bioaccumulation in the vegetative and root systems of Al-Kasak and Al-Qayyarah sites.

*S1P1, S1P2, and S1P3 represent *Prosopis farcta, Alhagi maurorum,* and *Typha domingensis* plants for Al-Kasak site, and S2P1, S2P2, and S2P3 represent *Typha domingensis, Prosopis farcta,* and *Alhagi maurorum* plants for Al-Qayyarah site.

roots (668.65, 270.61, and 156.24 mg/kg dry weight, respectively) compared with the vegetative group, while the cadmium element appeared more accumulated in the vegetative parts than in the roots (377.31 mg/kg dry weight) due to the efficiency of plants in biotransport from the roots to the vegetative group. The differences in bioaccumulation between plant tissues were substantial, and this depends upon the amount of bioaccumulation in the tissues and on the type of organ where the heavy elements accumulate. The rate of transfer within the plant depends on the type of heavy metals and the plant. Azizi *et al.* (2020) reported the distribution of heavy elements was Ni > Cd in contaminated soils, and *Typha latifolia* has a higher bioaccumulation capacity (BAF) and efficiency in removing heavy elements from the ecosystem. The amount of bioaccumulation in tissues depends on the type of element and the organ in which the heavy elements accumulate. Amare and Workagegn (2022) concluded that *Typha latifolia* can remove heavy elements from polluted sites, and the results showed a higher bioaccumulation of heavy elements in *Typha latifolia* than in the samples of the compound plants, especially samples at different sites. The bioaccumulation of heavy metals in the root system was higher than in the vegetative system for the *Typha latifolia*.

The average bioaccumulation of cadmium and lead has not shown a significant difference for the root and vegetative parts of all plants at both study sites (Figure 2). The remarkable superiority of manganese was evident in the roots of *Typha domingensis* at the Al-Kasak site and the roots of *Alhagi maurorum* at the Al-Qayyarah site compared

Table 2. Comparison of bioaccumulation factor (BAF) and translocation factor (TF) of heavy metals in the soil and plants at the Al-Kasak and Al-Qayyarah sites.

Sites	Heavy metals (mg/kg)				BAF				TF			
	Cd	Pb	Mn	Ni	Cd	Pb	Mn	Ni	Cd	Pb	Mn	Ni
S1	470.68	166.36	36.49	114.69	1.44	13.38	3.93	11.14	0.73	1.35	1.29	0.94
S2	491.74	139.61	14.46	72.01	1.48	3.84	11.75	17.94	1.07	0.98	0.09	0.93

* S1 represents the location of Al-Kasak, and S2 represents the location of Al-Qayyarah.

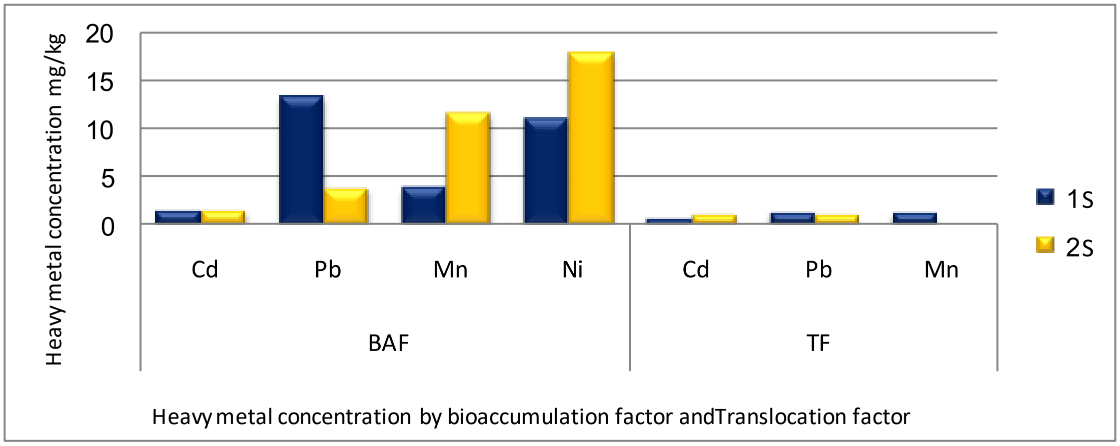

Figure 3. Heavy metals concentration as per the bioaccumulation factor (BAF) and translocation factor (TF) for the soil and plants at the Al-Kasak and Al-Qayyarah sites.

with the vegetative group, with an average bioaccumulation of 235.93 mg/kg dry weight. The roots of *Alhagi maurorum* and *Prosopis farcta* at the Al-Kasak and Qayyarah sites showed a noteworthy increase in nickel versus the vegetative parts, with a bioaccumulation of 778.25 mg/kg dry weight. The distribution of nickel in the roots and vegetative systems indicates that nickel accumulates mainly in the roots, unlike other heavy metals. Plants exposure to cadmium led to a decrease in their growth due to an increase in the bioaccumulation of cadmium in the buds and roots. Then, the weight of the leaves and roots decreased linearly with the increase in the cadmium content in the roots and leaves. The *Prosopis farcta* was more capable of transporting cadmium from the roots to the buds, and the natural accumulation of cadmium was under a gradual increase in these elements in the soil (Gishini *et al*., 2020). Shi *et al*.'s (2023) findings revealed that *Ammophila breviligulata* can greatly accumulate heavy metals due to the bioaccumulation factor (BAF). Ikiriko and Chukwumati (2023) concluded that the content of cadmium and lead in the shoots was higher than in the roots in plants grown on different contaminated soils, while the content of nickel in the roots was higher than in the shoots.

The maximum bioaccumulation value at the site of Al-Kasak was for lead (13.38 mg/kg dry weight), and for nickel at the site of Al-Qayyarah, it was 17.94 mg/kg dry weight because of the presence of oil reservoirs and oil product combustion furnaces (Table 2, Figure 3). This reflects the efficiency of the roots of the plants *Prosopis farcta, Alhagi maurorum,* and *Typha domingensis* and their ability to bioaccumulate heavy elements from the soil into the roots. The bioaccumulation of heavy metals at the two study sites reached BC > 1, and the bioaccumulation factor for heavy metals at the site of Al-Kasak was Cd < Mn < Ni < Pb, while in Al-Qayyarah, it was Cd < Pb < Mn < Ni. The results further showed that the highest biotransfer value for lead and manganese appeared at the site of Al-Kasak (1.35 and 1.29 mg/kg dry weight) for *Prosopis farcta, Alhagi maurorum,* and *Typha domingensis.* Abbas *et al*. (2019) observed the gradual increase of cadmium levels in the soil of *Prosopis farcta*, irrigated with water rich in heavy metals. The *Prosopis farcta* plant can absorb cadmium from contaminated soils, and the cadmium can biotransport from the roots to the shoots. Hence, the *Prosopis farcta* has a natural accumulation of cadmium and can be effective in phytoremediation. Waris *et al*. (2022) reported that *Alhagi maurorum* has the ultimate capacity to accumulate cadmium in roots and aerial parts (1.02 and 0.65 μg g^{-1}), and *Alhagi maurorum* has the highest capacity for bioaccumulation (BAF) and biotransfer (TF). It is also efficient in absorbing cadmium and lead from contaminated soils. The absorption of heavy metals by the *Typha domingensis* plant increases with the rise in the bioaccumulation of heavy metals. Past studies enunciated that the biotransport factor (TF) of leaves was higher than in root parts (Pb > Ni > Cd) (Soudani *et al*., 2022).

The manganese element recorded the supreme bioaccumulation for *Typha domingensis* at the Al-Kasak site and for *Prosopis farcta* at the Al-Qayyarah site (419.89 mg/kg) (Table 3, Figure 4). This revealed that the *Typha domingensis* and *Prosopis farcta* can efficiently accumulate metal pollutants inside the roots. The results further revealed that the highest biotransfer emerged from lead for *Alhagi maurorum* and *Prosopis farcta* (1.52 mg/kg) compared with the rest of the heavy metals. It indicates the ability of *Alhagi maurorum* and *Prosopis farcta* to transfer mineral elements between the root and the vegetative systems. *Typha latifolia* can biotransport nickel and manganese from roots to leaves (TF > 1) (Ramos *et al*., 2019). The *Typha domingensis* can be beneficial in the

Table 3. Comparison of the bioaccumulation factor (BAF) and translocation factor (TF) of heavy metals for plants at the Al-Kasak and Al-Qayyarah sites.

Distances	Cd	Pb	Mn	Ni	BAF				TF			
P1	704.62	410.73	25.28	1295.58	1.46	1.94	28.86	11.34	1.01	1.01	1.47	0.98
P2	671.40	523.**03**	88.74	1348.96	1.42	3.08	146.68	13.04	0.92	1.52	0.08	0.73
P3	642.59	601.97	356.04	1209.16	1.34	3.70	419.86	8.13	1.00	0.97	0.51	1.17

*****P1, P2, and P3 represent the *Prosopis farcta*, *Alhagi maurorum,* and *Typha domingensis* plants at Al- Kasak site, respectively and P1, P2, and P3 represent *Typha domingensis*, *Prosopis farcta,* and *Alhagi maurorum* plants at Al-Qayyarah site, respectively***.***

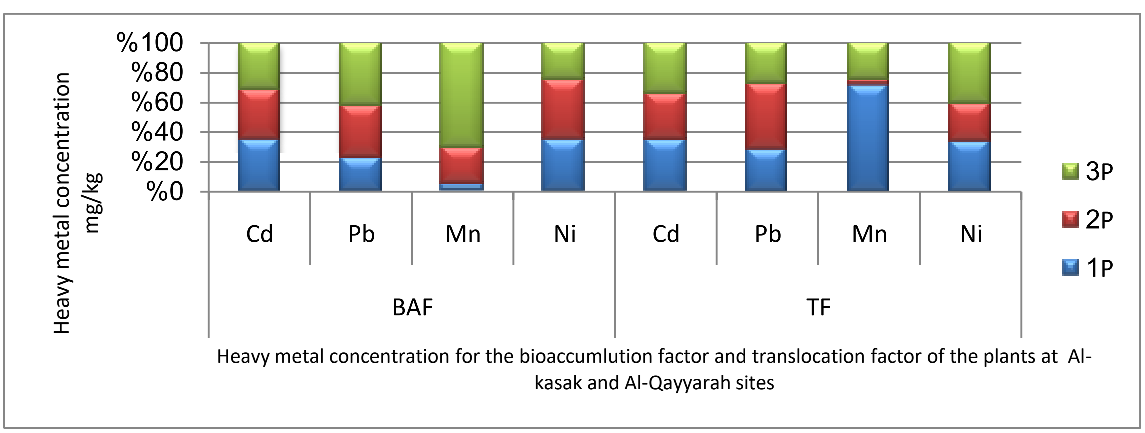

Figure 4. Comparison of the bioaccumulation factor (BAF) and the translocation factor (TF) of plants at Al-Kasak and Al-Qayyarah sites.

phytoremediation of heavy metals in polluted environments, as the plant's absorption of heavy metals through different plant tissues increases with the boost in the concentration of heavy metals. The roots of *Typha domingensis* had the highest values of the bioaccumulation factor (BAF) Pb > Ni > Cd compared with the leaves, while the biotransport factor (TF) of the leaves was higher than the root parts (Pb > Ni > Cd) (Compaore *et al*., 2020; Soudani *et al*., 2022). Previous findings indicated that *Typha domingensis* showed bioaccumulation factors of Mn > Ni > Pb, while *C. zizanioides* showed bioaccumulation factors of Mn > Pb. Meanwhile, the translocation factor of *C. zizanioides* was higher than that of *Typha domingensis* due to a higher biomass production.

CONCLUSIONS

Nickel, lead, and manganese showed higher bioaccumulation in the roots than in the shoots, except for cadmium, which had a higher concentration in the shoots than in the roots. The plants *Typha domingensis, Prosopis farcta, and Alhagi maurorum* in the Al-Kasak site exhibited higher bioaccumulation of lead than the rest of the elements, while the highest bioaccumulation was evident in the plants in the Al-Qayyarah site for nickel. The transfer factor for lead in the Al-Kasak site was better than the other elements, while cadmium emerged with the highest transfer factor compared to the rest of the elements in the Al-Qayyarah site.

REFERENCES

Abbas AM, Abdulmabood SK, Al-Ashry SM, Suleiman WS, Al-Tayeh N, Castillo JM (2019). Invasive tree capacity *Prosopis glandulosa* Torr. for the treatment of treated soil with sewage sludge. *Sustainability* 11(9): 2711. https://doi.org/10.3390/su11092711.

Ahmad AA, Muhammad I, Shah T, Kalwar Q, Zhang J, Liang Z, Mei D, Juanshan Z, Yan P, Zhi DX, Rui-Jun L (2020). Remediation methods of crude oil contaminated soil. *World J. Agric. Soil Sci.* 4(3): 8. doi: 10.33552/WJASS.2020.04.000595.

Alotaibi MO, Ghoneim AM, Eissa MA (2023). Cd uptake and translocation by camelthorn (*Alhagi maurorum* Medik): A promising approach for phytoremediation of Cd-contaminated soils. *Environ. Sci. Pollut. Res.* 30(24): 65892-65899. doi:10.1007/s11356-024-33771-3.

Amare TA, Workagegn KB (2022). Phytoremediation: A novel strategy for the removal of heavy metals from the offshore of Lake Hawassa using *Typha latifolia* L. *Soil Sediment Contamin.* 31(2): 240–252. https://doi.org/10.1080/15320383.2021.1924619.

APHA (1998). American Public Health Association (APHA), Standard Method for Water and Wastewater Inspection, 20 1015 Fifteenth Street, Northwest, Washington DC, USA.

Azizi A, Krika A, Krika F (2020). Heavy metal bioaccumulation and distribution in *Typha latifolia* and *Arundo donax*: Implication for phytoremediation. *Caspian J. Environ. Sci.* 18(1): 21–29. https://doi.org/10.22124/CJES.2020.3975.

Bitterli C, Bañuelos GS, Schulin R (2010). Use of transfer factors to characterize uptake of selenium by plants. *J. Geochem Explor.* 107:206–216. https://doi.org/10.1016/j.gexplo.2010.09.009.

Chen Ch, Shi Z, Ni Sh, Cheng L (2022). Characteristics of soil pollution and element migration associated with the use of coal in Hutou Village, Yunnan Province, China. *Ecol. Indicators.* 139: 108976. https://doi.org/10.1016/j.ecolind.2022.108976.

Chitimus D, Nedev F, Musnigoto E, Parsan N, Iremiah O, Nidev F (2023). Studies on the accumulation, transfer and fertilization of soil capacity and plant species *Phragmites australis* (common reed) with heavy metals. *Sustainability* 15(11): 8729. https://doi.org/10.3390/su15118729

Compaore WF, Dumoulin A, Rousseau DB (2020). Mineral absorption by spontaneously cultivated *Typha domingensis* and introduction of *Chrysopogon zizanioides* into constructed wetlands that address the leakage of the gold mine tailings storage facility. *Environ. Eng.* 158: 106037. https://doi.org/10.1016/j.ecoleng.2020.106037.

Fitz WJ, Wenzel WW (2002). Arsenic transformations in the soil-rhizosphere-plant system: Fundamentals and potential application to phytoremediation. *J. Biotechnol.* 99(3): 259–278.

Ghosh M, Singh SP (2005). A review on phytoremediation of heavy metals and utilization of its by products. *Asian J. Energy Environ.* 6(4): 18.

Gishini MFS, Azizian A, Alemzadeh A, Shabani M, Amin S, Hildebrand D (2020). Response of *Prosopis farcta* to copper and cadmium stress and potential for accumulation and translocation of these heavy metals. *Bio Rxiv* 2020-11. https://doi.org/10.1101/2020.11.02.365619

Githuku CR, Ndambuki JM, Salim RW, Badejo AA (2018). Treatment potential of *Typha latifolia* in removal of heavy metals from wastewater using constructed wetlands. 41st WEDC International Conference, Egerton University, Nakuru, Kenya.

Ikiriko ME, Chukwumati JA (2023). Phytoremediation potential of *Ficus benjamina* on soils contaminated with crude oil in Rivers State, South-South Nigeria. *World J. Agric. Soil Sci.* 8(4): 1–6. http://dx.doi.org/10.33552/WJASS.2023.08.000693.

Kour D, Khan SS, Kour H, Kaur T, Devi R, Rai PK, Judy C, Mcquestion C, Bianchi A, Spells S (2022). Microbe mediated bioremediation: Current research and future challenges. *J. Appl. Biol. Biotechnol.* 10(2): 6–24. https://doi.org/10.7324/JABB.2022.10s202

Liu H, Tan X, Guo J, Liang X, Xie Q, Chen S (2020). Bioremediation of oil-contaminated soils by combining soil conditioner with microorganisms. *J. Soil Sediment.* 20: 2121–2129. https://doi.org/10.1007/s11368-020-02591-6.

Mattina M, Lannucci-Berger W, Musante C, White JC (2003). Simultaneous plant absorption of heavy metals and pops from soil. *Environ. Pollut.* 124(3): 375–378. https://doi.org/10.1016/S0269-7491(03)00060-5.

Prescott LM, Harley JB, Klein DA (2005). Microbiology, Sixth Edition, McGraw-Hill International Edition, New York, USA.

Ramos ASA, Lopez MS, Rivera SL, Gonzalizmondragón E, de la CLM, Velázquez MJ (2019). Phytotherapy of landfill leaching using vetiver (*Chrysopogon zizanioides*) and cattail (*Typha latifolia*). *Appl. Ecol. Environ. Res.* 17(2). http://dx.doi.org/10.15666/aeer/1702_26192630.

Shi J, Qian W, Jin Z, Zhu Z, Wang X, Yang X (2023). Assessment of heavy metal soil pollution and phytoprocessing potential of copper and nickel mine tailings basins. *PLOS One* 18(3): E0277159. https://doi.org/10.1371/journal.pone.0277159.

Soudani A, Gholami A, Roozbahani M, Sabzalipour S, Mojiri A (2022). Heavy metal phytoremediation of aqueous solution by *Typha domingensis*. *Aquatic Ecol.* 56(2): 513–523. https://doi.org/10.1007/s10452-022-09945-x

Taher AM, Said EA (2021). Bioremediation of soils contaminated with hydrocarbons and heavy metals in some areas of Salah-Al-Dhayn and Nineveh governorates. M.Sc. Thesis, Department of Biology. Faculty of Science. Tikrit University, Iraq.

Wang Y, Liang LY, Chen XY, Zhang Y, Zhang FB, Xu F, Zhang T (2022). The Effect of river sand mining on lead and cadmium refilling in sediments – a case study of Jialing River. *Ecotox. Environ. Saf.* 246: 114–144. https://doi.org/10.1016/j.ecoenv.2022.114144.

Waris M, Page JA, Talpur FN, Kazee TJ, Afridi HI (2022). Environmental field assessment of soil quality and phytotherapy of toxic metals from saline soils by selected halophytes. *J. Environ. Health Sci. Eng.* 20(1): 535–544. https://doi.org/10.1007/s40201-022-00800-7.

Yoon J, Cao X, Zhou Q, Ma LQ (2006). Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. *Sci. Total Environ.* 368(2-3): 456–464.