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Phytoremediation Potential of Native Plants Growing in Industrially Polluted Soils of Al-Qassim, Saudi Arabia

Saud S. Aloud [1], Khaled D. Alotaibi [1], Khalid F. Almutairi [2,*] and Fahad N. Albarakah [1]

[1] Soil Science Department, College of Food and Agriculture Sciences, King Saud University, Riyadh 13362, Saudi Arabia
[2] Plant Production Department, College of Food and Agriculture Sciences, King Saud University, Riyadh 13326, Saudi Arabia
* Correspondence: almutairik@ksu.edu.sa

Abstract: Rapid industrialization has resulted in the release and subsequent accumulation of heavy metals (HMs) in various environmental matrices, which poses serious health threats globally. Utilizing native plant species to extract such HMs from soil may be an efficient and cost-effective remediation approach. Thus, HM accumulation in soil and native plant species in the industrial area of Al-Qassim province, Saudi Arabia, was investigated in this study, and the phytoremediation potential of the native plant species was assessed. Briefly, 30 surface soil samples and 10 native plants samples were collected from 10 different locations in the studied area. Soil samples were analyzed for physiochemical characteristics and HM contents, while the plant samples were digested and HM concentrations were determined. The results showed that Fe was highest in concentration from soil samples (3900–19,600 mg kg^{-1}), followed by Mn, Zn, Ni, Pb, Cr, Cu, and Cd. Similarly, Fe concentration was also higher in plant samples (432 mg kg^{-1}), followed by Mn (70.2 mg kg^{-1}) and Zn (38.1 mg kg^{-1}). Enrichment factor revealed that 90% of the samples were extremely enriched with Cd, while 20% were highly enriched with Pb. Similarly, contamination factor (5.0–46.9) was also the highest for Cd. Higher bioaccumulation factor (>1) of *Phrgmites australis* and *Chenopodium marale* for Cd and Cu, *Chenopodium album, Lactuca serviola, and Chenopodium marale* for Cu, and *Pulicaria crispa* for Mn suggested that these native plants can be effectively used for phytoremediation of HMs in soil.

Keywords: bioaccumulation; phytoremediation; industrial pollution; soil contamination

1. Introduction

Industries are rapidly evolving into a much larger scale globally due to the increasing population the past few decades. The continiously growing demand of goods has pushed anthropogenic activities even further in manufacturing and processing of various kinds of products, subsequently resulting in more waste production and release into the environment [1,2]. Heavy metals (HMs) are among the most toxic environmental pollutants being released into the environment regularly, consequently posing serious threats to the flora and fauna of the ecosystem. Therefore, it is an urgent need of time to restore such HM-polluted soils for the sustainable health of human beings and animals.

Various remediation technologies including soil flushing, electrokinetic extraction, surface capping, adsorption, solidification, verification, and phytoremediation have been used by different researchers to restore HM-contaminated soils [2]. However, most of such technologies are either expensive or inefficient for complete removal of HMs [3]. Phytoremediation is a promising solution as it is the most effective, cost-efficient, and certainly environment-friendly process for HM-contaminated soil remediation [4]. According to Chappell [5], the cost of phytoremediation is ten times less than that of other technologies. However, the efficiency of phytoremediation is dependent on the type of plant, type of HM, as well as the climatic and environmental conditions [6].

Saudi Arabia is comprised of an arid environment with lack of rainfall throughout the year. Most of the soils in Saudi Arabia contain a higher calcium carbonate and pH level [7]. Therefore, the plants able to tolerate such conditions may be used to accumulate HMs through phytoremediation in HM-contaminated areas of Saudi Arabia. According to Antosiewicz et al. [8] and Yoon et al. [9], native plants should be chosen for phytoremediation as they frequently outperform other plants in tolerating different stresses. Identification of potential native plants to remediate heavy metal-contaminated soil could sustain the environment and ecosystem in Saudi Arabia. For instance, *Malva parviflora* is a native plant in Saudi Arabia and has the potential to accumulate HMs in arid ecosystems. In general, this plant can absorb almost all kinds of HMs, such as Pb, Cd, Zn, Cu, and Ni, and therefore, could potently be used in phytoremediation programs. Ibrahim et al. [10] reported that *Malva parviflora* plant can absorb around 2 to 80 mg kg^{-1} of HMs from soil. Similarly, *Sisymbrium irio* is another native plant in Saudi Arabia that is commonly found in industrial areas with the ability to accumulate various types of HM ions, especially Cr and Cu [11]. Previously, it has been reported by Aloud et al. [11] that *Sisymbrium irio* has a higher potential to absorb Cr and Cu from soil.

Although the use of hyperaccumulator plants in phytoremediation of the HM-contaminated industrial serve as an effective and cost-effective solution, the efficiency of such techiques is heavily influenced by the soil and climatic conditions. For instance, the survival of hyperaccumulator plants is difficult in arid-region soils with higher pH, EC, and calcium carbonate contents on top of HM soil pollution. Therefore, native accumulator plants can survive and grow well in such conditions and can effectively remediate the polluted soil. Identification of the native accumulator plants for absorbing specific types of metals is of critical importance. Application of native plants in phytoextraction of HMs could potentially increase the performance of phytoremediation, as these plants are adapted to the natural conditions of the contaminated area. According to some of the reports, naturally growing plant species performed far better in extracting HMs from polluted soils as compared to those introduced from other areas to the contaminated sites for phytoremediation purposes [9]. However, according to the best of our knowledge, very little is known about the accumulator plants native to Saudi Arabia for phytoremediation of HMs. The current study was performed to investigate the extent of HM pollution in the industrial areas of Al-Qassim province in Saudi Arabia. Furthermore, the potential of native plant species growing in these areas to absorb HMs from soil was explored in this research.

2. Materials and Methods

2.1. Study Area

Al-Qassim province is the central region of Saudi Arabia and is located about 400 km northwest of Riyadh. The geographical location of Al-Qassim region is at the coordinates of 26°12′ N, 44°05′ E, and it is located 600–750 meters above sea level. The region faces extreme weather conditions with a hot climate and very low precipitation rate. The average winter temperature of Al-Qassim is noted to be 17 °C, while that of summer reaches 46 °C. Al-Qassim is known as the "food basket" of Saudi Arabia due to the rich argriculture industry. Since the establishment of Saudi Authority for Industrial Cities and Technology Zones (MODON) in 2001, around 36 industrial cities have been developed. As part of the industrialization process, two industrial zones have been established in Al-Qassim region i.e., First Industrial City (156 industries and services) and Second Industrial City (38 industries and services) (Figure 1). These industries include food, metal plating, aluminum products, fertilizers, and pharmaceuticals [12]. The operation of such a large number of industries may generate hazardous pollutants including HMs, subsequently contaminating various environmental matrices (air, water, and soil).

Figure 1. Geographical map of the First Industrial City in Al-Qassim (Numeric values on the map represent the sampling locations in the study area).

2.2. Sample Collection and Processing

Surface soil samples and plant tissue samples were randomly collected from 10 sites located in the First Industrial City of Al-Qassim Province, Saudi Arabia as shown in Figure 1. Overall, 30 soil and 10 plant samples were collected from different locations in the studied area. Three surface soil samples were collected from the top 0–20 cm soil layer with the help of wooden auger, and one composite sample was prepared for each site. Likewise, leaf and root samples of 10 dominant plant species (Table 1), which were naturally grown in the study area, were collected from those 10 different sites of the selected locations. Briefly, three individual samples of either roots or leaf from each species were collected to make one composite sample. Collected samples were brought to the laboratory for further analysis [11]. The soil was dried in air, crushed for more homogeneity, sieved using a 2-mm screen, and subjected to physio-chemical analysis. The plant samples were washed with EDTA followed by deionized water to remove dust and entrapped HMs [13]. Thereafter, the plant samples were oven dried at 65 °C until a constant weight was achieved. The plant leaf and root samples were grinded with a mechanical grinder and subject to further analysis.

Table 1. The details of 10 plant species along with their family names and classification, collected in this study from the First Industrial City of the Al-Qassim region.

Sr. No.	Family	Species	Classification
1	Malvaceae	*Malva parviflora*	Annual or perennial
2	Polygonaceae	*Rumex vesicarius*	A perennial plant
3	Solanaceae	*Solanum nigrum*	Short-lived perennial shrub
4	Asteraceae	*Lactuca serriola*	Annual or biennial
5	Amaranthaceae	*Chenopodium murale*	Annual
6	Brassicaceae	*Sisymbrium irio*	Annual or winter-annual
7	Asteraceae	*Pulicaria crispa*	Annual or perennial
8	Poaceae	*Phrgmites australis*	Annual or perennial
9	Amaranthaceae	*Chenopodium album*	Annual plant
10	Brassicaceae	*Brassica tournefortil*	Annual plant

2.3. Soil and Plant Analyses

Soil pH and electrical conductivity (EC) were determined in 1:1 ratio of soil with deionized water using a pH meter and EC meter, respectively. Soil particle size distribution was analyzed with help of the hydrometer method, and soil texture was estimated by using the USDA textural triangle [14]. The lime contents ($CaCO_3$) were analyzed by using the calcimeter method [15]. The Walkley–Black method was used to estimate the contents of soil organic matter [16]. Total soil HMs were extracted by wet-digestion method, and the concentrations of the metals in the digestates were measured by using ICP-OES (PerkinElmer Optima 4300 DV, USA). The dried and powdered plant samples were digested using mixture of acids (HNO_3 + $HClO_4$, and aqua regia). The digestates were used to analyze the concentrations of HMs in plant tissue samples (root and leaf) with the help on an ICP-OES [17].

2.4. Data Precision and Accuracy

For the standards, firstly, stock solutions containing 1000 mg L^{-1} of the HMs were made in deionized water, working standards with multi-elements were prepared through diluting the stock solutions in deionized water with 8% addition of concentrated nitric acid. The calibration curve was constructed for each heavy metal element to be analyzed by using least square fitting.

2.5. Soil Heavy Metals Contamination Assessment

2.5.1. Soil Enrichment Factor (EF)

Enrichment factor (EF) was calculated to evaluate the influences of natural and anthropogenic sources on HM contents in soil by comparison with a non-contaminated background reference [18,19]. In this study, Fe was used as the background metal to estimate metal contamination extent. The concentration of Fe in the Earth's crust was used as background reference considering that Fe concentrations are not affected by anthropogenic activities in the Earth's crust [20]. The EF was calculated using Equation (1).

$$EF = \frac{C_{metal}/C_{normalizer}\,[soil]}{C_{metal}/C_{normalizer}[control]} \tag{1}$$

where C_{metal} represents metal concentration and $C_{normalizer}$ shows normalizer concentration in sediment and in non-contaminated control. It has been established that EF < 2 is designated as minimal or deficient enrichment, EF = 2−5 is considered as medium enrichment, EF = 5−20 is significant enrichment, EF = 20−40 represents very high enrichment, and EF > 40 is considered to represent extremely high enrichment [21].

2.5.2. Soil Contamination Factor (CF)

The ratio of concentration of HMs in the soil (C_m) and its concentration in background reference (C_b), which is generally the average concentration of a particular heavy metal in the Earth's crust, is known as contamination factor (CF). The CF was calculated by using Equation (2).

$$CF = \frac{C_m}{C_b} \tag{2}$$

The level of HMs contamination can be categorized into six different levels depending on the resultant CF values. The CF value of 0 represents no contamination, while 1 shows none to medium, 2 represents moderate, 3 shows moderate to strong, 4 shows strongly contaminated, 5 represents strong to very strong, and 6 shows very strong [22].

2.5.3. Estimation of Pollution Load Index (PLI)

The severity of pollution and its variation in all studied areas was estimated by calculating the PLI. The PLI is considered a rapid tool to compare the level of contaimination of different locations in the study area and as a comprehensive technique to compare the extent of pollution in a particular area due to HMs [23,24]. The PLI can be calculated by using Equation (3).

$$\text{PLI} = (\text{CF}_1 \times \text{CF}_2 \times \text{CF}_3 \times \cdots \times \text{CF}_n)^{1/n} \tag{3}$$

where CF stands for contamination factor and n is number of metals and world average concentration of metals as background values.

2.5.4. Plants Bioaccumulation Factor (BF) Calculation

The ability of the plant to accumulate HMs from soil into its body is termed the bioaccumulation factor (BF). The BF is the hyperaccumulation efficiency of a particular plant and the ratio of the concentration of a heavy metal in plant to the concentration of the same HMs in soil [25,26]. BF can be calculated using Equation (4).

$$\text{BF} = \frac{C_1}{C_2} \tag{4}$$

where C_1 stands for the average concentrations of a metal in plant and C_2 is the average concentration of metal in soil.

2.6. Statistical Analyses

The acquired data were arranged and descriptive statistical analyses including mean, minimum, maximum, standard deviation (SD), and coefficient of variance (CV) were performed using SPSS (IBM Corp., New York, NY, USA) and Microsoft Excel. The figures were drawn using Microsoft Excel program. Comparison of the mean of HMs in plants across all sites was made with Statistical Package for Social Studies (SPSS; IBM Corp., New York, NY, USA) using least significant difference at the risk level of 5% [27].

3. Results and Discussion

3.1. Soil Physicochemical Characterization

The physiochemical properties of collected soil samples are presented in Table 2. The particle size distribution results showed that the collected samples contained an average 81% of sand, 10% silt, and 9% of clay particles. Therefore, the average soil texture for the collected soil samples was loamy sand. Soil pH results showed that most of the soils were alkaline, with average pH of 8.23, while the EC was in the range of 3.3 to 8.1 dS m^{-1}, with an average value of 5.7 dS m^{-1}. Most of the soil were deficient in organic matter. The average contents of soil organic matter were 0.84%, ranging from 0.58% to 1.3%. The contents of CaCO$_3$ % were in the range of 5.9% to 14.4% with a mean value of 9.7%. Overall, the soils of the studied area were slighlty saline, with alkaline pH. The higher pH of the soil indicates possible precipitation of HMs within the top layer of soil. Moreover, the presence of higher lime contents could further aid the precipitation and fixation of HMs in soils. Therefore, higher pH and lime content could potentially reduce the availability of HMs to the plants in studied area.

Table 2. Chemical and physical properties of the soil samples collected from the First Industrial City of Al-Qassim region.

Soil Properties	Min	Max	Mean	SD [a]	CV
Sand %	79	84	81	1.55	1.9
Silt %	8	12	10	1.62	16
Clay %	7	11	9	1.34	15
pH (1:1)	8.1	8.4	8.2	0.12	1.4
OM % [c]	0.58	1.3	0.8	0.18	21
EC (1:1) dS/m [b]	3.3	8.1	5.7	1.41	25
CaCO$_3$ %	5.9	14.4	9.7	2.64	27

[a] Standard deviation, [b] electrical conductivity, and [c] soil organic matter.

3.2. Soil Heavy Metal Concentrations

Table 3 represents the concentration of measured HMs (Fe, Mn, Pb, Cr, Zn, Cu, Cd, and Ni) in the soil samples collected from the studied area. The results showed that the concentrations of HMs were increased in order of: Cd < Cu < Cr < Pb < Ni < Zn < Mn < Fe. The average value of Ni was found as 27.9 mg kg^{-1} with a range of 15.8 to 55.5 mg kg^{-1}. The average value of Cd was found 9.8 mg kg^{-1} with a range of 3.5 to 32.8 mg kg^{-1}. The average of Cu was found as 13.7 mg kg^{-1} with a range of 6.0 to 29.5 mg kg^{-1}. Zn was found in the range of 41.5 to 177.8 mg kg^{-1} with an average of 93.4 mg kg^{-1} while Cr was found in the range of 5.9 to 25 mg kg^{-1} with an average of 15.6 mg kg^{-1}. The average value of Pb was found 20 mg kg^{-1} in a range of 8.3 to 49.8 mg kg^{-1}, while Mn was found in range of 68.5 to 280 mg kg^{-1} with an average value of 165 mg kg^{-1}. The highest average value was found for Fe as 8223 mg kg^{-1} in a range of 3900 to 19,600 mg kg^{-1}. Soil characteristics (chemical and physical) affect the mobility and fate of HMs in the environment [28]. The soil used in the following study contains a pH level 8.2 with 35% CaCO$_3$ which could result the precipitation of HMs in the topsoil ultimately indicating the decreased mobility and bioavailability of HMs. The soil is situated in an industrial area where stones and cement from factories could contaminate a large area crossing the standard limits. Moreover, chemicals, gases, and dust from the cementing industry as well as transport vehicles contribute to the pollution [29]. The results in Table 3 show that the average concentrations were more than their permissible limits, which indicates contamination by nearby petrochemicals, oil refineries, cement, and batteries factories. Correlation amid soil physiochemical characteristics and HMs is shown in Table 4. Correlation studies showed that Pb and Cu was negatively correlated with sand while Pb and Cu were found to be positively correlated with silt. Moreover, only Pb was also found to be negatively correlated with clay. It was reported by Dragović that silt was positively correlated with Pb at Zlatibor mountains [30]. Electrical conductivity and CaCO$_3$ did not show any significant correlation in the study area of soil.

Table 3. Average concentrations of HMs (mg·kg^{-1}) in soil of study areas (10 site, n = 30) in Al-Qassim province, Saudi Arabia.

	Mean (SD [a])							
Site	Ni	Cd	Cu	Zn	Cr	Pb	Mn	Fe
S1	25.7 (4.1)	5.6 (0.6)	20.9 (2.2)	41.5 (2.7)	12.5 (0.6)	19.6 (2.5)	258.2 (22.8)	7100 (519.6)
S2	28.5 (2.3)	3.5 (0.7)	29.5 (6.0)	59.7 (4.7)	25 (1.6)	23 (2.0)	198.3 (9.9)	3900 (529.1)
S3	55.5 (4.2)	16.2 (0.4)	14 (2.5)	177.8 (15.7)	11.9 (0.5)	49.8 (7.1)	110 (12.8)	6600 (793.7)
S4	44 (4.5)	4.6 (0.5)	15.3 (1.3)	41.5 (4.1)	8.9 (0.3)	21.8 (4.8)	196.5 (10.4)	10,400 (2551.4)
S5	16.8 (0.8)	7.9 (0.4)	13.9 (0.9)	59.7 (4.7)	23.9 (3.3)	8.33 (1.0)	77.3 (5.1)	5990 (770.9)
S6	15.8 (1.5)	4.9 (0.6)	7.1 (1.8)	177.8 (8.5)	5.9 (0.5)	19.9 (4.6)	68.5 (4.9)	5230 (333.0)
S7	36.5 (2.7)	32.8 (2.6)	7.6 (0.9)	41.5 (3.0)	15.9 (1.9)	15.7 (2.6)	75.8 (6.0)	6710 (1712.2)
S8	35.7 (2.6)	10.5 (1.7)	6.0 (1.5)	59.7 (8.0)	12.9 (1.3)	11.5 (2.3)	145 (7.5)	9900 (883.4)
S9	19.3 (1.0)	7.9 (0.4)	16.0 (2.2)	97.3 (6.5)	16.9 (2.3)	15.8 (1.3)	280 (20.4)	6800 (419.0)
S10	16.5 (1.8)	4.3 (0.3)	6.8 (2.0)	177.8 (7.4)	21.9 (2.8)	14.5 (2.1)	240 (23.8)	19,600 (2621.0)

[a] Standard deviation.

Table 4. The Pearson correlation matrix for HMs and soil physicochemical characteristics.

	Sand %	Silt %	Clay %	pH	EC	O.M%	CaCO$_3$ %
Zn	0.486	−0.544	0.326	0.474	−0.486	0.050	0.126
Pb	−0.070	0.611 *	−0.753 **	−0.527	0.475	−0.119	−0.030
Ni	−0.030	−0.127	0.193	−0.086	0.528	−0.449	0.357
Fe	0.362	−0.234	0.016	−0.095	−0.457	−0.241	0.067
Cu	−0.627 *	0.103	0.373	0.447	−0.452	0.157	−0.266
Cr	0.244	−0.373	0.296	0.462	−0.549	0.307	−0.188
Cd	0.195	−0.194	0.099	0.071	−0.035	0.188	0.020

* Correlation is significant at $p = 0.05$. ** Correlation is significant at $p = 0.01$.

3.3. Indices of Pollution

The computed pollution load index (PLI), contamination factor (CF), and enrichment factor (EF) were applied to assess the extent of HMs pollution in studied area. Moreover, bioaccumulation factor (BF) was also utilized and evaluated in the mentioned study.

3.3.1. Soil Enrichment Factor (EF)

Deaccumulation and EF are the common indices which are used to differentiate the influences of anthropogenic activities in originating the metals in comparison with the natural processes affecting the origination of metals. EF was used in this research. The resultant soil EF values of HMs are presented in Tables 5 and 6. The values of EF for HMs ranged from 0.42 to 265.36. Higher EF values represent the presence of HMs due to anthropogenic activities while lower values indicate effects due to natural processes. By considering the contamination classifications, 10% of samples were deficient to minimal enrichment of Ni, 60% were found medium, and 30% samples were significant contaminated. In case of Cd, 10% of samples were significantly contaminated while 90% showed extremely high Cd enrichment, Cu showed 50%, 40%, and 10% deficient, medium, and significant enrichment, respectively. Zn showed 40%, 40%, and 20% deficient, medium, and significant enrichment, respectively, while Cr showed 90% and 10% deficient and medium enrichment, respectively. However, Pb showed 20%, 60%, and 20% medium, significant, and very high enrichment, respectively, while Mn showed 70% and 30% deficient and medium enrichment, respectively. The EF of the soil under consideration was found to be

very high indicating the influence of anthropogenic activities specifically for Ni and Cd from industrial leaks [21,31].

Table 5. Contaminated sample percentages based on the calculated enrichment factor for the soil HMs in Al-Qassim province, Saudi Arabia.

Enrichment Factor	Ni	Cd	Cu	Zn	Cr	Pb	Mn
Minimal to deficient enrichment	10	0	50	40	90	0	70
Medium enrichment	60	0	40	40	10	20	30
Significant enrichment	30	10	10	20	0	60	0
Very high enrichment	0	0	0	0	0	20	0
Extremely high enrichment	0	90	0	0	0	0	0

Table 6. The resultant enrichment factors for the HMs in studied sites (S1–S10) in Al-Qassim province, Saudi Arabia.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Ni	3.44	6.94	7.99	4.02	2.66	2.87	5.17	3.43	2.70	0.80
Cd	42.82	48.72	133.25	24.01	71.60	50.86	265.36	57.58	63.07	11.91
Cu	3.73	9.58	2.69	1.86	2.94	1.72	1.43	0.77	2.98	0.44
Zn	4.44	11.63	20.47	3.03	7.57	25.84	4.70	4.58	10.87	6.89
Cr	0.67	2.44	0.69	0.33	1.52	0.43	0.90	0.50	0.94	0.42
Pb	10.49	22.41	28.67	7.97	5.28	14.46	8.89	4.41	8.83	2.81
Mn	2.30	3.22	1.06	1.20	0.82	0.83	0.72	0.93	2.61	0.78

3.3.2. Pollution Load Index (PLI) and Contamination Factor (CF)

Soil HMs concentrations were used to estimated CF values for the soil samples collected in this research. These values were then compared with the concentrations of HMs in normal soil crust as suggested by Lindsay [20]. The CF values were found in the range of 0.32–1.11 for Ni, 5.0–46.89 for Cd, 0.20–0.98 for Cu, 0.83–3.56 for Zn, 0.06–2.5 for Cr, 0.83–4.98 for Pb, 0.11–0.47 for Mn, and 0.10–0.52 for Fe. The Cd (CF 46.89) in sample S7 was found highest among the other samples; however, on the other side, S3 and S8 were found to be contaminated with Pb (CF 4.98) and Zn (CF 3.56), respectively. The industrial activities might have generated and introduced Cd, Pb, and Zn in the adjacent soils in higher amounts, which has subsequently resulted in higher CF values for aformentioned HMs. Muller et al. [22] reported previously that disposal of these HMs could also be due to vehicle batteries, smelting, and automotive parts [22].

The calculated PLI values are presented in Table 7. The PLI values are generally used for the assessment of pollution level owing to the presence of HMs within soil [32–34]. It compares the means of HMs in the samples which indicates by how many times the metals increased from the natural background concentration level. The PLI ranged between 0.74 and 0.99 with an average of 0.86 for the 10 collected samples from different sites. The lowest PLI value was found for S1 while S4, S8, and S10 showed 0.99 and S2, S3, S5, S6, S7, and S9 showed a PLI value of 0.98. The quality of the site can be evaluated using PLI; if the value of PLI is less than 1 it is perfect, if it is equal to 1 it is primary polluted, and if it is more than 1, it indicates the deterioration of the site [24]. In this case study, the PLI calculated was less than 1, indicating that the soil is not contaminated.

Table 7. Estimated average pollution load index and contamination factor for HMs in soil in the studied sites (S1–S10) of Al-Qassim province, Saudi Arabia.

| Site ID	Contamination Factor								Pollution Load Index
	Ni	Cd	Cu	Zn	Cr	Pb	Mn	Fe	
S1	0.51	8.00	0.70	0.83	0.13	1.96	0.43	0.19	0.74
S2	0.57	5.00	0.98	1.19	0.25	2.30	0.33	0.10	0.98
S3	1.11	23.14	0.47	3.56	0.12	4.98	0.18	0.17	0.98
S4	0.88	6.57	0.51	0.83	0.09	2.18	0.33	0.27	0.99
S5	0.34	11.29	0.46	1.19	0.24	0.83	0.13	0.16	0.98
S6	0.32	7.00	0.24	3.56	0.06	1.99	0.11	0.14	0.98
S7	0.73	46.86	0.25	0.83	0.16	1.57	0.13	0.18	0.98
S8	0.71	15.00	0.20	1.19	0.13	1.15	0.24	0.26	0.99
S9	0.39	11.29	0.53	1.95	0.17	1.58	0.47	0.18	0.98
S10	0.33	6.14	0.23	3.56	0.22	1.45	0.40	0.52	0.99
SD [a]	0.27	12.75	0.25	1.21	0.06	1.14	0.13	0.12	0.08
Range	0.30–1.11	5.0–46.89	0.20–0.98	0.83–3.56	0.06–2.5	0.83–4.98	0.11–0.47	0.10–0.52	0.74–0.99

[a] Standard deviation.

3.3.3. Heavy Metal Concentration in Plants

The contents of HMs present in the local plants are presented in Table 8. The concentration of Fe was found in the range of 126–936.9 mg·kg^{-1}, Mn was found in the range of 31–141.3 mg·kg^{-1}, Pb was found in the range of 0.1–5.2 mg·kg^{-1}, Cr was found in the range of 0.2–7.3 mg·kg^{-1}, Zn was found in the range of 26–53.2 mg·kg^{-1}, Cu was found in the range of 3.8–16 mg·kg^{-1}, Cd was found in the range of 0.47–3.1 mg·kg^{-1}, and Ni was found in the range of 7.7–13.96 mg·kg^{-1}. Figure 2 represents the accumulation of HMs in different native plant species. In the plants samples, Fe and Mn were found highest in all the samples. In all plants species *Malva parviflora, Rumex vesicarias, Solanumnigrum, Lactuca serviola, Chenopodium marale, Sisymbrium irio, Pulicaria crispa, Phrgmites australis,* and *Chenopodium album,* the highest concentration was detected for Fe (594.7, 620.3, 247.3, 126, 229.7, 278.1, 379.5, 176.5, and 607.5 mg·kg^{-1}), whereas the smallest was of Pb (1.12, 0.9, 1.9, 0.12, 2.3, 1.2, 2.1, 2.1, and 0.9 mg·kg^{-1}). The concentration of the Cd was found to be higher than in the data presented by Cardwell et al. [35] in Queensland, Australia. However, the Cd concentration was less than the phytotoxic range (5–700 mg kg^{-1}) presented by Chaney [36]. However, in some species (except *Sisymbrium irio* and *Chenopodium album*), Cd concentration was found less than 2 mg·kg^{-1}, while more than this leads to toxicity in plant species, inhibiting growth and photosynthesis and leading to death. A Cr concentration of more than 2 mg·kg^{-1} also causes plant toxicity [37–39]. A Cr concentration higher than the permissible limit causes risks for human health. A Zn concentration lower than 20 mg·kg^{-1} is categorized as deficient; the Zn concentration was found to be higher than this in all the plant species [40–42]. It can be stated from the results that all the species contained HM concentrations higher than the permissible limits. Previously, Barbafieri et al. [43] reported that native plant species exhibited higher HM concentrations in plant shoots, indicating their suitability for phytoremediation of HM-contaminated soils. Therefore, these native plants species can effectively be used for in situ stabilization of HMs in industrially contaminated soils.

Table 8. Average, minimum, and maximum values of HMs (mg·kg^{-1}) in the tissues of native plants (n = 10) growing in the studied area of Al-Qassim province, Saudi Arabia.

Metals	Minimum	Maximum	Average	SD
Fe	126	936.9	432	191.9
Mn	31	141.3	70.2	38
Pb	0.1	5.2	1.5	0.9
Cr	0.2	7.3	2.4	2
Zn	26	53.2	38.1	9.6
Cu	3.8	16	10.6	3.9
Cd	0.4	3.1	1.2	0.9
Ni	7.7	14	10.3	1.8
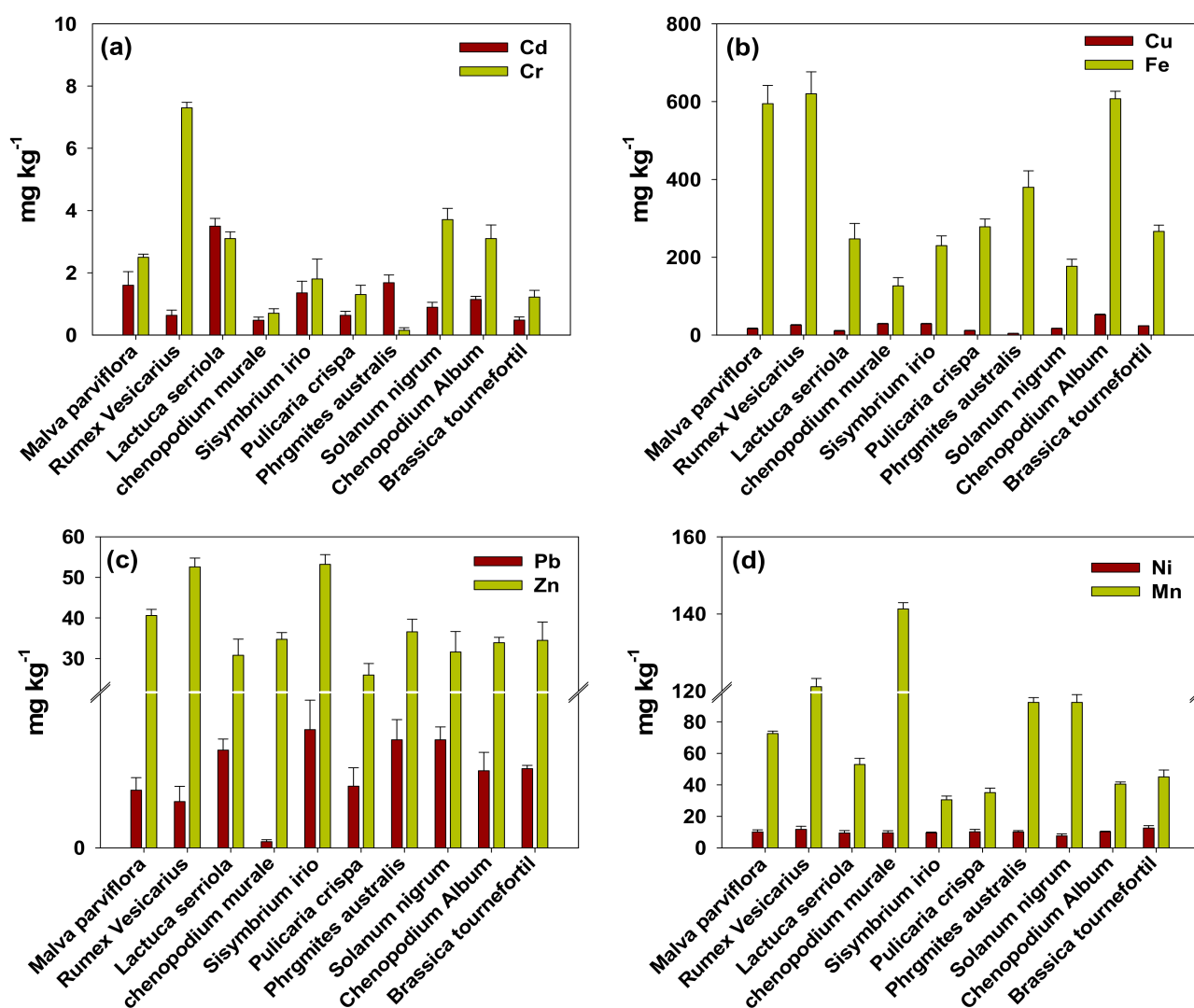
Figure 2. Heavy metal contents (mg kg^{-1}) in various native plant species growing on studied area in Al-Qassim Province, Saudi Arabia. (**a**) Caption of subfigure; (**b**) caption of subfigure; (**c**) caption of subfigure; (**d**) caption of subfigure.

3.3.4. Bioaccumulation Factor (BF)

The calculated values of BF are provided in Table 9. The BF is generally employed to assess the potential of plants to extract and store HMs within its body. BF is calculated by the ratio of HMs in plants to soil [24]. Higher BF values represent more translocation of HMs from soil to that plants parts which can be harvested easily [9]. Therefore, the plants with higher BF values can accumulate more HMs in upper parts (shoots) of plant, which can be harvested later on, and thus can be used in phytoremediation. Overall, the highest BF values were observed for Cu and Cd. Plants species *Chenopodium album* showed the highest BF value of 7.70, followed by *Phrgmites australis* (2.80) for Cu, as compared to all other species. *Phrgmites australis* showed a BF value for Cd of 1.13. Likewise, *Sisymbrium irio* showed a BF value of Cu of 2.14, while *Chenopodium album* indicated a BF value of 7.70 for Cu. BF values for Pb were exhibited as 1.22 by *Pulicaria crispa*. *Sisymbrium irio* showed a BF value of 1.61 for Cu, while *Lactuca serviola* showed a BF value of 1.88 for Cu. Similarly, *Chenopodium marale* exhibited a BF value of 1.36 for Cd and 2.07 for Cu. These results suggest that different HMs were successfully accumulated in different native plant species. This variability of different species to accumulate HMs differently could be due to the variable adaptation of native plants to the contaminated area, depending on the availability of water, soil pH, organic matter, and nutrient availability. Therefore, it proved that these native species could be used for HM extraction from the soil by phytoremediation technique. A BF less than 1 indicates unsuitability of the species for phytoextraction, while the species more than 1 BF are considered potential candidates to be used in phytoextraction from the contaminated site [44]. Thus, native plant species with a BF more than 1 can potentially be used for efficient and cheaper removal of HMs from industrially polluted soils. Barbafieri et al. [43] reported similar results where higher BF values were exhibited by native plants for Zn, Pb, and Cd. Therefore, these native plants can enhance the performance of in situ phytoremediation as they are adapted to the natural and climatic conditions of specific area.

Table 9. Bioaccumulation factor (BF) of heavy metals in plants (n = 10) in the study area in Al-Qassim province, Saudi Arabia.

Plant Species	Ni	Cd	Cu	Zn	Cr	Pb	Mn	Fe
Malva parviflora	0.40	0.32	0.77	0.98	0.20	0.06	0.28	0.08
Rumex vesicarias	0.41	0.11	0.85	0.88	0.29	0.04	0.61	0.16
Solanum nigrum	0.17	0.65	0.71	0.17	0.26	0.04	0.48	0.04
Lactuca serviola	0.22	0.34	1.88	0.84	0.08	0.01	0.72	0.01
Chenopodium marale	0.57	1.36	2.07	0.89	0.08	0.28	0.40	0.04
Sisymbrium irio	0.64	0.03	1.61	0.15	0.22	0.06	0.51	0.05
Pulicaria crispa	0.28	0.32	0.50	0.88	0.01	0.13	1.22	0.06
Phrgmites australis	0.21	1.13	2.80	0.53	0.29	0.18	0.64	0.02
Sisymbrium irio	0.72	0.03	2.14	0.41	0.08	0.33	0.16	0.14
Chenopodium album	0.62	0.08	7.70	0.19	0.14	0.06	0.17	0.03
Range	0.17–0.72	0.03–1.36	0.5–7.7	0.15–0.98	0.01–0.29	0.01–0.33	0.16–1.22	0.01–0.16

4. Conclusions

Heavy metal accumulation in the soil and native plant species collected from the industrial zone of Al-Qassim province, Saudi Arabia was investigated for the assessment of the potential of local plant species as candidates for phytoremediation. All the collected soil and plant samples contained higher Fe concentrations, followed by Mn and Zn. The enrichment and contamination factors indicated that most of the soils were contaminated with the HMs, especially Cd and Pb. Higher accumulation factors (>1) were

observed for *Phrgmites australis* and *Chenopodium marale* for Cd and Cu, *Chenopodium album*, *Lactuca serviola,* and *Chenopodium marale* for Cu, and *Pulicaria crispa* for Mn, which indicates that these native plant species have the potential to extract different HMs from industrially contaminated soils. Therefore, such accumulator native plant could be used to extract various HMs from industrially contaminated soils in order to rehabilitate the polluted soils.

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