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(RESEARCH ARTICLE)

Heavy metals accumulation and translocation by *Typha elephantina* roxb. and *Typha domingensis* pers. in an arid habitat: perspectives for phytoremediation

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Abstract

The present study investigated the ability of two emergent macrophytes *Typha elephantina* and *Typha domingensis* for accumulation of six heavy metals in an arid habitat in Saudi Arabia. Plant samples (aboveground shoot and belowground root and rhizome) as well as sediment samples were collected and analyzed. Regarding the variation in sediment characters, PH, EC, Cu, Ni, Pb and Zn concentrations of the *T. elephantina* sites were significantly higher than those of the *T. domingensis* sites; while Fe and Mn concentrations of the *T. domingensis* sites were significantly higher than those of the *T. elephantina* sites. *T. elephantina* allocated approximately 57.8% of its total biomass to leaves, 5.9% to flowers, 7.0% to peduncles, 18.7% to rhizomes and 10.6% to roots. The total above-ground biomass was 2.4 times that of the total below-ground biomass. *T. domingensis* allocated approximately 61.3% of its total biomass to leaves, 8.6% to flowers, 11.3% to peduncles, 9.8% to rhizomes and 9.0% to roots. The total above-ground biomass was 4.3 times that of the total below-ground biomass. Significant variations in Mn was recorded between *T. elephantina* and *T. domingensis*, while significant variations in Fe, Ni and Pb were recorded between the different organs. All heavy metals concentrations were significantly higher in belowground organs as compared to other plant organs. The heavy metal contents of *T. elephantina* and *T. domingensis* organs differed significantly between different plant organs. All the investigated species were characterized by a bioaccumulation factor > 1.0 for all heavy metals. In the present study, the translocation factor varied among plant species, among organs and among heavy metals. Finally, *T. elephantina* and *T. domingensis* could be regarded as a good candidates as phytoremediator for mitigating heavy metals pollution.

Keywords: Heavy metals; Green technology; Soil pollution; Macrophytes

1. Introduction

The contamination of the aquatic ecosystems with heavy metals is the common environmental problem all-over the world [1] and is a serious dilemma that threatens aquatic ecosystems, agriculture and human health [2]. These heavy metals originate from metals smelting and refining, electroplating, corrosion, and the use of pesticides, fertilizers, sewage sludge and municipal compost [3]. These heavy metals are serious pollutants in natural environments and cannot be degraded by microbial or chemical process and they may cause significant injury to ecosystems [4]. The accumulation of heavy metals in the environment has become a concern due to the health risks to humans and animals. The transfer and accumulation of heavy metals in the animal and human bodies over the food chain cause DNA damage, carcinogenic effects and induction of mutations [2, 5].

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Phytoremediation is a biological, cost-effective and eco-friendly clean-up methodology that uses plants and their associating micro-organisms to degrade, remove or remediate contaminants from soil and water [6] and for the restoration of the water and soil properties [7]. It is already considered as a green alternative solution to the problem of heavy metal pollution, with great possibility, since over 400 plant species have been specified as prospective phytoremediators [8]. Phytoremediation can be achieved through different methods like phytoextraction, rhizofiltration, phytostabilization and phytotransformation or phytodegradation (see [9]. The effectiveness of a phytoremediation process depends on the selection of appropriate plants for particular environment [10, 11]. Using native plants for phytoremediation is significant, since these plants are more efficient in terms of survival, fast growth, and reproduction under environmental stress than introduced plants [12]. In addition, the information on the accumulation potential of aquatic plants can help in choosing appropriate plants for phytoremediation of aquatic ecosystems [13]. Moreover, it has long been known that aquatic plants are heavy metal accumulators and therefore, their use for removal of these metals from contaminated water has gained high interest [1, 7, 12].

Typha species (cattails) are a rhizomatous perennial that forms dense, nearly monospecific stands through vigorous vegetative growth; a tightly-packed advancing front of ramets excludes other plants (phalanx strategy, *sensu* [14]. Vegetative growth is through under-ground lateral rhizomes which apices grow upward to form the aerial shoot. The unit of vegetative growth is the ramet. In *Typha* species, the ramet consists of the submerged rhizomes, associated roots and shoot. The shoot can exceed 2 m in height and may or may not develop an apical flowering spike [15]. Although sometimes considered an invasive weed [16, 17], *Typha* species are now attracting attention for their usefulness in various ecological fields such as purification of polluted water [7, 18, 19, 20, 21], bank protection against boat wash [22], wetlands diversity restoration [16, 23, 24], mitigation strategies [25] and the influence of the vegetation on greenhouse gas emissions from wetlands [26, 27]. According to the authors' knowledge, so far no studies have been carried out on the accumulation of heavy metals by two macrophytes *T. elephantina* and *T. domingensis* grown under arid habitats like that in Saudi Arabia. Thus, this research addresses the issue of heavy metals accumulation by *T. elephantina* and *T. domingensis* in the context of their usefulness for phytoremediation. Hence, the present study aims to: (1) assess and compare the accumulation and translocation of six heavy metals in different organs of *T. elephantina* and *T. domingensis*, (2) investigate the extent of heavy metals mobility from the sediment to below-ground organs and within these two macrophytes, and (3) assess the possibility of using these two species for phytoremediation purpose.

2. Material and methods

2.1. Study area

Saudi Arabia extends over approximately 16º degrees of latitude, from 16º 22′ at the borders with Yemen in the south; to 32 º 14′ at the Jordanian border in the north, and between longitudes 34º 29′ E and 55º 40′ E (Fig. 1). Taif region is located in the central foothills of the western mountains at an altitude up to 2500 m above sea level. It is an important place for the people due to its scenic views and fertile valleys, which support the growth of a favorable fruits and vegetables. Agriculture had been the prime economic income in Taif. Historically the tribes of Taif grew wheat, barley and fruits such as lemon, apricot, orange, olive, peaches, pomegranate, watermelons, grapes, almonds and dates. However, the agricultural development has to pay a heavy price for the natural vegetation of Taif region. Over the years, vast areas of virgin lands have turned into agricultural lands, which resulted in the disappearance of many wild species including medicinal plants [28].

The climate of the study area is typically tropical and arid. The monthly mean of climatic variables that recoded in Taif meteorological station (1997 – 2009) indicated that the monthly average of minimum and maximum ambient air temperatures ranged from 7.9±1.2 to 23.4±0.8°C and 22.9±1.1 to 36.3±0.8°C, respectively with a total monthly mean of 23.2±5.1°C (Table 1). The mean maximum temperature (± SD) was 30.6 ± 4.8°C, while the average values of minimum temperature was 15.8 ± 5.5°C. The mean monthly humidity was 40.6±14.8%. The data from the last 10 years showed considerable inter-annual variation in the monthly amount (range 4.3±5.7-294.1±383.8 mm mo^{-1}) and timing of rainfall. The monthly amount of rainfall ranges from 4.3±5.7 mm mo^{-1} in December to 294.1±383.8 mm mo^{-1} in September.

2.2. Sampling design

Sampling was carried out through four sampling sites representing the growth of *T. elephantina* and *T. domingensis* populations (Fig. 1). At each sampling site, the aboveground parts were collected from three randomly distributed quadrats (0.5 × 0.5 m), while the belowground parts (roots and rhizomes) were excavated from the same quadrats at a depth of 0.5 m, since > 90% of these parts are located in this depth [29]. Plant materials were separated into leaves, flowers, peduncles, rhizomes and roots; and were carried in polyethylene bags to the laboratory. Tap water was used to wash the collected plant samples in the laboratory using a 4-mm mesh sieve to avoid material loss, and then the samples were oven dried at 85 °C for one week. Gram dry matter per square metre (g DM m−2) was used to determine the biomass. Afterwards, plant materials of each organ were ground using a metal-free plastic mill, then they were mixed to form one composite sample for each sampling site and kept for heavy metals analysis.

2.3. Sediment sampling and analysis

At each sampling site, three sediment samples were collected from the same sampling quadrats of the plant samples as a profile of 0-50 cm. The sediments were air dried and then passed through a 2 mm sieve to remove gravel and debris, and then they were mixed to form one composite sample for each sampling site. Soil-water extracts of 1:5 were prepared for the determination of pH and EC (electric conductivity) using pH- and EC- meters. Heavy metals in sediment and plant samples were extracted using a mixed-acid digestion method. The concentrations of Cu, Fe, Mn, Ni, Pb and Zn were determined by atomic absorption spectrophotometer (Shimadzu AA-6300; Shimadzu Co. Ltd., Japan). All these procedures are outlined by [30].

2.4. Data analysis

The most common method to model the transfer of heavy metals from sediment to plant is the use of empirical bioaccumulation factor (BAF), which is based on the assumption of a linear relationship between plant and soil metal concentrations. The BAF is used to evaluate the potentiality of plants for accumulating metals in their roots, while the translocation factor (TF) is used to estimate the potential to transfer metals from the root to the rhizome and aerial shoot. The BAF was calculated according to [12] as follows: BAF = element concentration in the root (mg kg^{-1}) / concentration of element in the sediment (mg kg^{-1}), while the $TF_{rhizome}$ = element concentration in the rhizome (mg kg^{-1}) / concentration of element in the root (mg kg^{-1}), TF_{leaf} = element concentration in the leaf (mg kg^{-1}) / concentration of element in the root (mg kg^{-1}), TF_{flower} = element concentration in the flower (mg kg^{-1}) / concentration of element in the root (mg kg^{-1}), and $TF_{peduncle}$ = element concentration in the peduncle (mg kg^{-1}) / concentration of element in the root (mg kg^{-1}). The heavy metal contents (mg m^{-2}) of the leaves, rhizomes, roots, flowers and peduncles were calculated by multiplying the heavy metal concentrations (mg kg^{-1}) by the biomass of the respective organs (g DM m^{-2}). Before performing two-way analysis of variance (ANOVA-2), the data were tested for their normality of distribution and homogeneity of variance, and when necessary, the data were log-transformed. Biomass and heavy metals data for these two plant species were subjected to a two-way ANOVA to identify the interactions in the independent variables (species and organs). The significance of variation in sediment quality parameters between *T. elephantina* sites and *T. domingensis* sites was assessed using paired *t*-test. Statistical analyses were carried out using Statistica 7.1 [31].

3. Results

Regarding the variation in sediment characters, pH, EC, Cu, Ni, Pb and Zn concentrations of the *T. elephantina* sites were significantly higher than those of the *T. domingensis* sites; while Fe and Mn concentrations of the *T. domingensis* sites were significantly higher than those of the *T. elephantina* sites (Fig. 1). Heavy metals concentrations in the soil of the *T. elephantina* and *T. domingensis* sites had the following sequence: Mn > Cu > Fe > Zn > Pb > Ni.

Regarding the two plant species, biomasses were significantly affected by plant species, and by plant organs (Fig. 2). *T. elephantina* allocated approximately 57.8% of its total biomass to leaves, 5.9% to flowers, 7.0% to peduncles, 18.7% to rhizomes and 10.6% to roots. The total above-ground biomass was 2.4 times that of the total below-ground biomass. *T. domingensis* allocated approximately 61.3% of its total biomass to leaves, 8.6% to flowers, 11.3% to peduncles, 9.8% to rhizomes and 9.0% to roots. The total above-ground biomass was 4.3 times that of the total below-ground biomass.

Significant variations in Mn was recorded between *T. elephantina* and *T. domingensis*, while significant variations in Fe, Ni and Pb were recorded between the different organs (Fig. 3). All heavy metals concentrations were significantly higher in belowground organs as compared to other plant organs (Fig. 3). It is worth mentioning that *T. elephantina* and *T. domingensis* showed Fe concentrations >1000 mg kg^{-1} in the roots and rhizomes. The heavy metal contents of *T. elephantina* and *T. domingensis* organs differed significantly between different plant organs (Fig. 4).

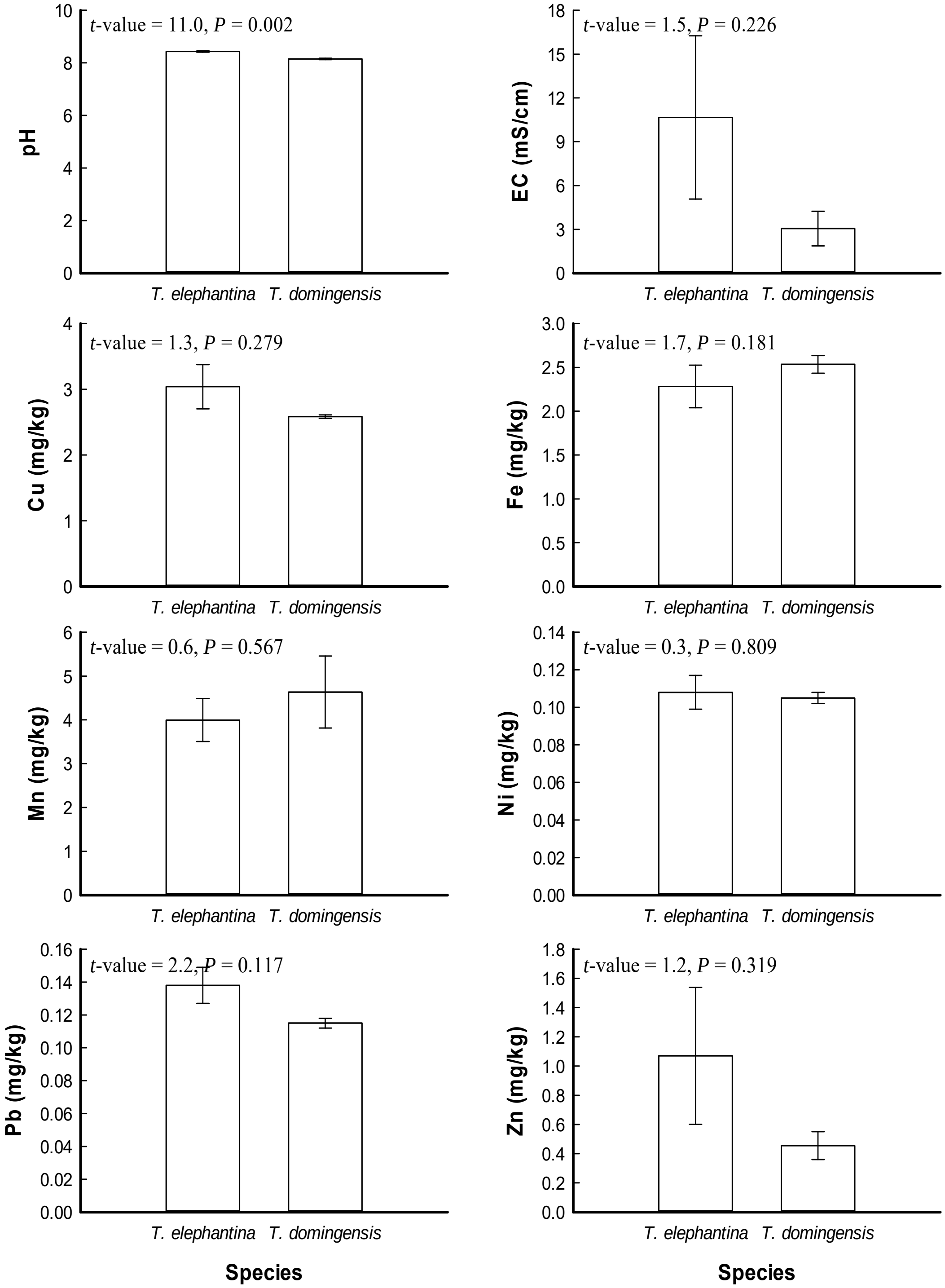

Figure 1 Variation in pH, electric conductivity (EC) and the concentrations of six heavy metals in the sediment supporting the growth of *Typha elephantina* and *Typha domingensis*. Vertical bars indicate the standard errors of the means (*n* = 4). *t*-values represent the paired *t*-test.

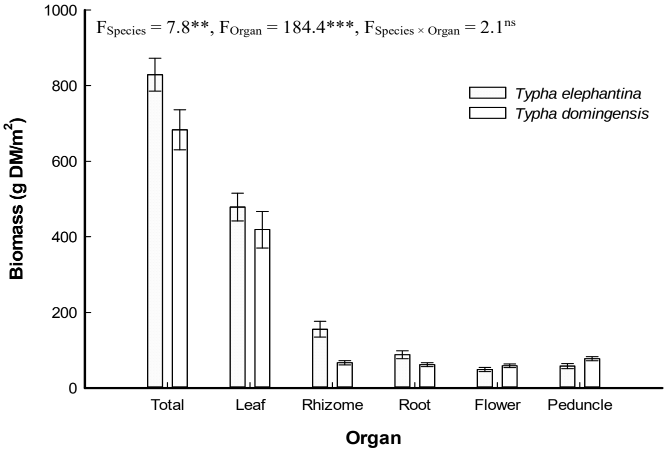

Figure 2 Variation in organ biomass of *Typha elephantina* and *Typha domingensis*. Vertical bars indicate the standard errors of the means ($n = 12$). *F*-values represent the two-way analysis of variance, **: $P < 0.01$, ***: $P < 0.001$, *ns*: not significant (i.e., $P > 0.05$).

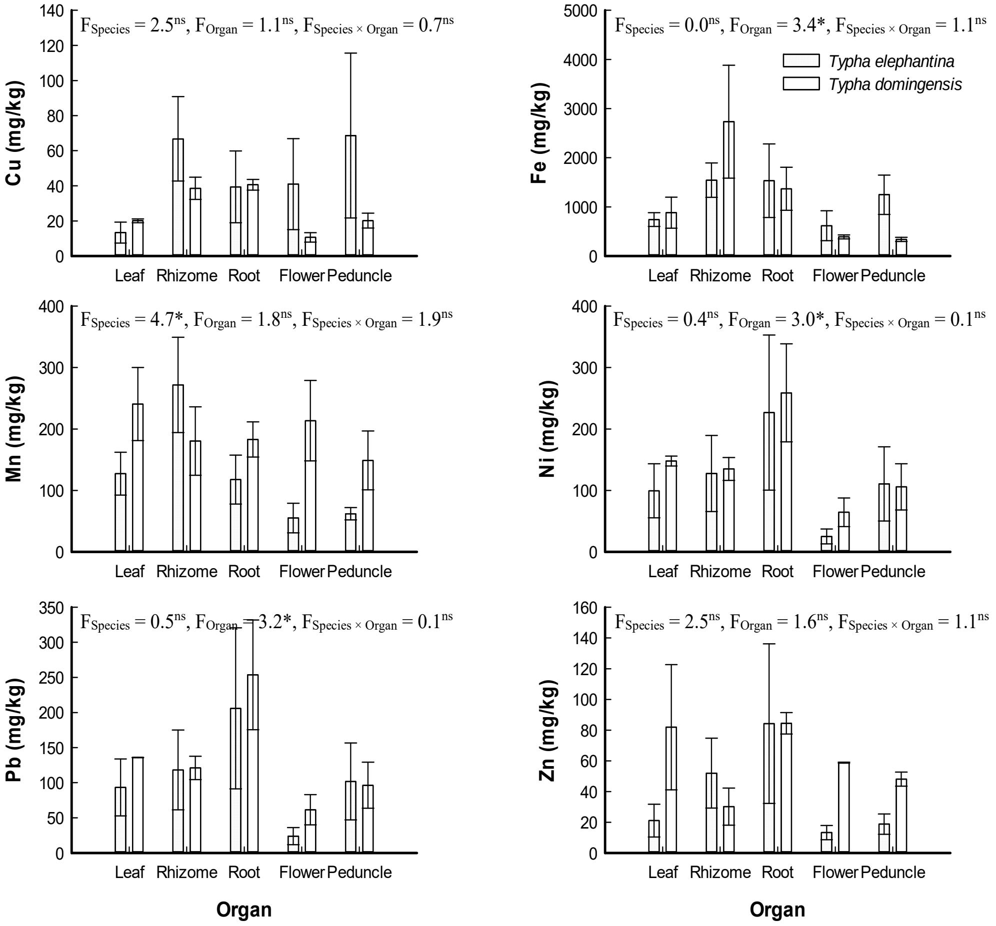

Figure 3 Variation in the concentrations of six heavy metals in the organs of *Typha elephantina* and *Typha domingensis*. Vertical bars indicate the standard errors of the means ($n = 4$). *F*-values represent the two-way analysis of variance. *: $P < 0.05$, *ns*: not significant (i.e., $P > 0.05$).

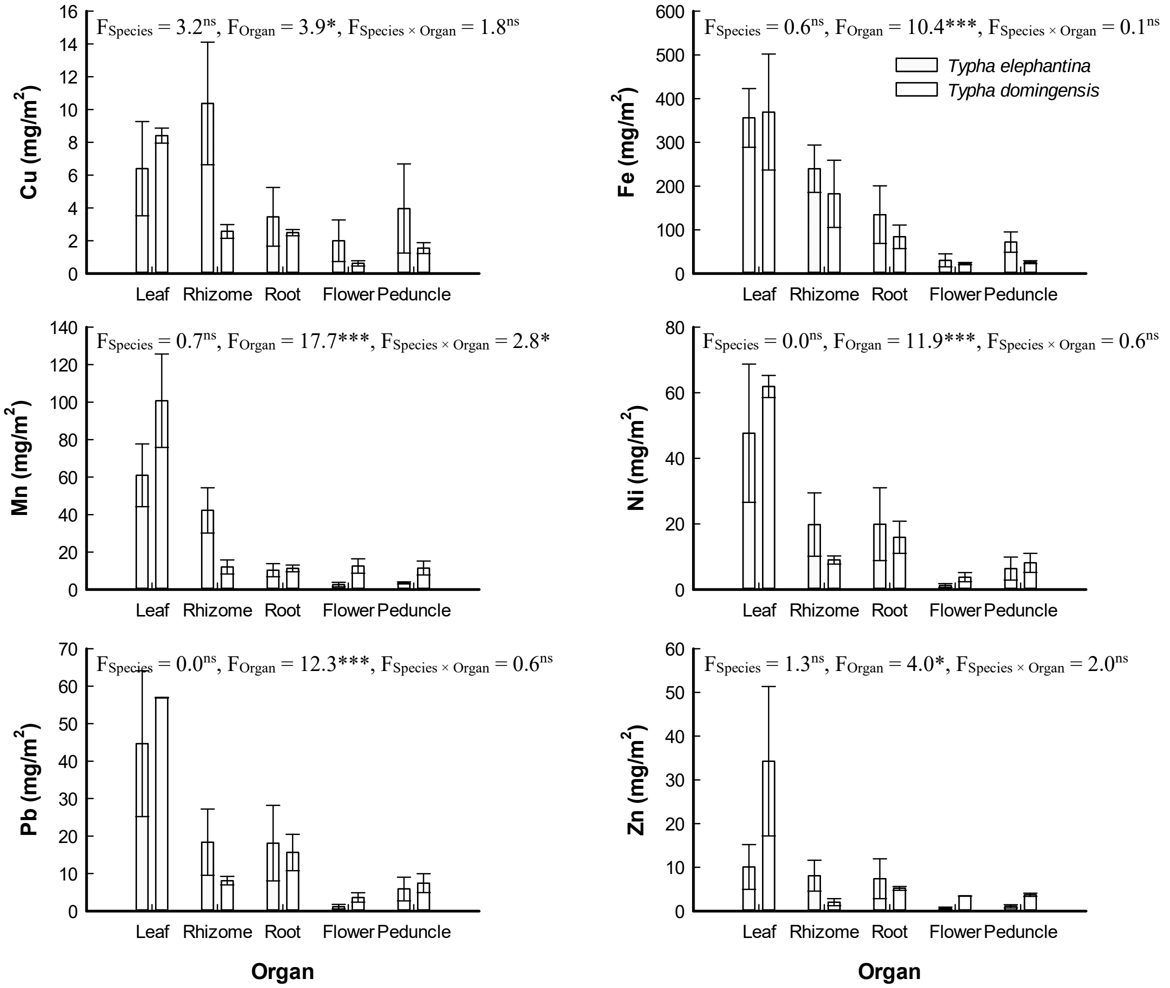

Figure 4 Variation in the heavy metal contents in *Typha elephantina* and *Typha domingensis* organs. Vertical bars indicate the standard errors of the means (n = 4). F-values represent the two-way analysis of variance. *: $P < 0.05$, ***: $P < 0.001$, ns: not significant (i.e., $P > 0.05$).

All the investigated species were characterized by a bioaccumulation factor (BAF) > 1.0 for all heavy metals (Table 2). BAF was generally higher for Ni, followed by Pb, Fe, Zn, Mn and Cu. Among these two plant species grown, *T. domingensis* showed higher BAF values for Ni (2533.6 mg kg^{-1}), Pb (2260.7 mg kg^{-1}), Zn (202.5 mg kg^{-1}), Mn (40.0 mg kg^{-1}) and Cu (15.7 mg kg^{-1}), while *T. elephantina* showed higher BAF value for Fe (740.9 mg kg^{-1}). In the present study, the translocation factor (TF) varied among plant species, among organs and among heavy metals (Table 1). For some heavy metals, TFs were < 1.0. *T. elephantina* had the highest TF for all heavy metals.

Table 1 Monthly variation in air temperature (°C), relative humidity (RH), wind speed (WS) and rainfall (RF) as recorded at Taif meteorological station. The data are long term averages from Climatological Normals for KSA from 1997 to 2007 (Anonymous, 2008). The F-value for each variable are calculated (ANOVA), ***:P≤0.001.

Month	Temperature (ºC)			RH	WS	RF
	Max.	Min.	Mean	(%)	(km hr^{-1})	(mm mo^{-1})
Jan.	22.9±1.1	7.9±1.2	15.4±1.0	58.7±5.6	5.5±0.5	12.1±12.0
Feb.	25.8±1.3	10.1±1.4	17.9±1.1	52.2±4.7	6.7±0.6	283.0±392.2
Mar.	27.5±0.9	12.0±1.2	19.8±0.7	46.5±7.1	7.2±0.9	22.5±23.7
Apr.	30.8±1.0	15.3±0.9	23.0±0.7	43.2±4.5	6.7±0.6	93.5±227.8
May	34.1±1.2	18.4±0.7	26.3±1.2	33.1±7.4	6.2±0.8	97.9±227.9
Jun.	36.3±0.8	22.2±0.9	29.4±0.6	19.6±4.2	8.3±0.6	141.8±314.4
Jul.	35.6±1.0	23.2±0.9	29.1±0.9	21.8±4.6	10.6±1.2	73.7±233.5
Aug.	36.3±0.5	23.4±0.8	29.5±0.4	27.5±4.4	9.7±0.9	92.8±229.2
Sep.	35.3±0.6	20.3±0.9	28.0±0.4	29.6±4.1	6.2±0.4	294.1±383.8
Oct.	31.2±0.7	15.3±0.6	23.5±0.6	39.7±7.9	5.0±0.4	88.0±231.8
Nov.	27.2±1.0	12.0±1.1	19.6±0.5	55.5±8.4	5.1±0.3	155.6±308.1
Dec.	24.4±1.4	9.3±1.0	16.7±1.1	60.0±6.0	5.1±0.7	4.3±5.7
Total mean	**30.6±4.8**	**15.8±5.5**	**23.2±5.1**	**40.6±14.8**	**6.9±1.9**	**113.3±257.4**

Table 2 Mean ± standard error (n = 4) of bioaccumulation factors (BAF) from soil to roots; translocation factors (TF) from roots to rhizomes, leaves, flowers and peduncles of heavy metals in *Typha elephantina* and *Typha domingensis*.

Species		Heavy metal					
		Cu	Fe	Mn	Ni	Pb	Zn
T. elephantina	BAF	15.0 ± 8.4	740.9 ± 380.9	32.6 ± 12.1	1950.2 ± 1108.5	1334.5 ± 721.9	129.8 ± 73.5
	TF$_{Rhizome}$	3.04 ± 1.12	1.60 ± 0.41	2.65 ± 0.36	2.27 ± 1.72	2.16 ± 1.54	14.27 ± 13.25
	TF$_{Leaf}$	0.93 ± 0.49	1.41 ± 0.97	1.73 ± 0.74	0.83 ± 0.33	1.01 ± 0.47	2.72 ± 2.43
	TF$_{Flower}$	3.34 ± 2.01	0.90 ± 0.39	0.88 ± 0.48	0.78 ± 0.57	0.78 ± 0.52	18.95 ± 18.85
	TF$_{Peduncle}$	33.94 ± 33.44	2.31 ± 1.33	1.40 ± 0.99	5.73 ± 3.29	6.22 ± 3.73	44.36 ± 44.21
T. domingensis	BAF	15.7 ± 1.0	521.8 ± 151.9	40.0 ± 0.9	2533.6 ± 829.3	2260.7 ± 737.0	202.5 ± 27.0
	TF$_{Rhizome}$	1.00 ± 0.23	1.72 ± 0.29	1.22 ± 0.49	0.64 ± 0.12	0.58 ± 0.12	0.33 ± 0.12
	TF$_{Leaf}$	0.51 ± 0.07	0.61 ± 0.04	1.25 ± 0.13	0.76 ± 0.20	0.75 ± 0.23	1.11 ± 0.58
	TF$_{Flower}$	0.28 ± 0.09	0.37 ± 0.09	1.08 ± 0.19	0.47 ± 0.23	0.45 ± 0.22	0.71 ± 0.06
	TF$_{Peduncle}$	0.53 ± 0.15	0.32 ± 0.07	0.75 ± 0.14	0.76 ± 0.38	0.70 ± 0.35	0.60 ± 0.10

4. Discussion

Phytoremediation has a great role in improving the environment through ecological restoration and recovery processes [32]. Heavy metals uptake by aquatic plants depends on various factors such as species, plant age, generation time, pH, temperature, salinity, organic matter and levels of other associated elements [22, 33, 34]. In the present study, the investigated heavy metals were accumulated in the below- rather than the above-ground organs of *T. elephantina* and *T. domingensis* and this is in accordance with the behavior of many emergent plants such as *Phragmites australis* [35, 36]; *T. domingensis* [7, 37]; *Echinochloa stagnina* [38]; *Arundo donax* [39] and *Vossia cuspidata* [40]. Distribution of metals in different plant organs depends on their form, water transport and plant species [41]. The variations in heavy metal concentrations in various parts of plants have been ascribed to compartmentalization and translocation through the vascular system [42]. According to [34], aquatic plants may accumulate high levels of heavy metals in their belowground parts due to their high internal detoxification potential. In addition, [43] reported that heavy metals concentration in the root exceeding those in the shoot may reflect high phytoavailability of these metals in the sediment.

The bioaccumulation factor (BAF) was used to assess the relationship of heavy metal concentration between the sediment and plant tissues [40]. Generally, it shows the movement of heavy metals from the sediment to the plant root, which indicates the uptake potential of available metals from the environment giving an idea whether this plant is an excluder, accumulator or indicator [13]. The BAF of all heavy metals was greater than 1, which means that *T. elephantina* and *T. domingensis* implies a bioaccumulation process based on high concentrations in the below-ground organs. These results agreed, to a great extent, with [40] on *V. cuspidata*; [39, 44] on *A. donax*; and [7, 37] on *T. domingensis*. According to [45], aquatic plants are root accumulators for heavy metals, and this will confirm the findings of the present study that *T. elephantina* and *T. domingensis* had a phytoremediation potential for heavy metals.

In the current study, for some heavy metals, TFs were < 1.0. Similar findings were reported by [7, 37] on *T. domingensis*. According to [46], emergent plants have lesser mobility and translocation of heavy metals from below- to above-ground tissues. As reported by [47], the TF > 1 indicates metal accumulating plants, while TF < 1 denotes metal excluding plants. Therefore, leaves of *T. elephantina* is suitable for Fe, Mn, Pb and Zn phytoextraction, and the remaining metals exclusion. In addition, leaves of *T. domingensis* is suitable for Mn and Zn phytoextraction, and the remaining metals exclusion. Moreover, the high BAF and low TF of most investigated metals indicate the potential of *T. domingensis* for these metals phytostabilization.

5. Conclusion

In conclusion, the current study tried to quantify the role of *T. elephantina* and *T. domingensis* for the phytoremediation of six heavy metals in an arid habitat in Saudi Arabia. Based on our results, both these two macrophytes could be used as a green filter for the extraction of heavy metals to reduce the pollution load reaching the wetland habitats, if the *T. elephantina* and *T. domingensis* are harvested at their maximum total biomass during May. Considering values for peak total biomass of *T. elephantina* and *T. domingensis* in May, as much as 263.0 g ha−1 Cu, 8.334 kg ha−1 Fe, 1.198 kg ha−1 Mn, 950.0 g ha−1 Ni, 883.0 g ha−1 Pb, and 273.0 g ha−1 Zn could be theoretically removed from the wetlands by harvesting *T. elephantina* and 157.0 g ha−1 Cu, 6.853 kg ha−1 Fe, 1.485 kg ha−1 Mn, 988.0 g ha−1 Ni, 916.0 g ha−1 Pb, and 487.0 g ha−1 Zn by harvesting *T. domingensis* in May. The harvested materials could be used as substrate for biogas production, carbonization to make charcoal or could be ashed and packed in a safe place. The accumulated HMs could also be recovered for commercial use if so desired.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no any interest of conflict between the authors of this piece of research work. The authors agreed and assigned in hand to all matter arise to this piece of research work.

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