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Phytoremediation of Toxic Heavy Metals by Potamogeton Pectinatus (L.) Plant from Alasfar Lake Polluted with Wastewater in Al-Ahsa, Saudi Arabia

Salim M. Al-Gahtani Ibrahim[1],
Mohamed A. Elsheikh[1]
[1]Department of Botany and Microbiology,
College of Science, King Saud University,
Riyadh. Saudi Arabia

Samir G. Al-Solaimani[2]
[2]Department of Arid Land Agriculture,
King Abdulaziz Universitay, Jeddah,
Saudi Arabia

***Abstract*—The wetland plant Potamogeton pectinatus (L.) of the family (Potamogetonaceae) accumulated the heavy metals (Cr, Fe, Mn, Zn, Cd and Pb) at concentrations of 300.86, 1782.31, 1777, 146.79, 0.38, 6.85 ppm respectively in the different plant parts at levels above their concentrations in Lake Alasfar waste water and its soil, and above the permissible standards suggested by world Organizations (FAO/WHO, 2007). Also the plant accumulated P in its parts at rates above the permissible level (P=2000 mg/kg). The transfer factor (TF) for heavy metals and elements from soil to the different plant parts was high for P, Cr, Mn, Zn, Cd and Pb, and also the transfer ratio (TR) between the different plant parts was high from root to stem and leaves in K, Mn, Zn, and from soil to stem in Na. There was positive correlation as regard concentrations of heavy metals and nutrients between the soil, water and the different plant parts as follows: soil - leaves in P, Cr, Zn, Fe, Mn, Ca, soil - stem in Zn, Pb, Fe, P, Ca, soil - root in, Zn, Pb, Fe, P, Cr, water – root in Pb and water – leaves in Ca. All heavy metal and element concentrations in the soil are lower than that in the plant parts except Cu and Na, and their contents in water is also less than in the plant parts except Cu, Na, Mg and Ca. Potamogeton pectinatus is recommended as phytoremediator for heavy metals removal from wastewater of Lake Alasfar, and the species contains high concentrations of heavy metals so animals should be kept away from grazing on it.**

Keywords*—*Phytoremediation, Potamogeton pectinatus, heavy metals, nutritional element

I. INTRODUCTION

The presence of heavy metals in water and soil even in trace amounts, can cause serious problems to all organisms, and heavy metal bioaccumulation, especially in the food chain, can be highly dangerous to human health (Islam et al., 2007). Plant roots take up metal contaminants and/or excess nutrients from growth substrates through rhizofiltration process, the adsorption, or, precipitation onto plant roots or absorption into the roots of contaminants that are in solution surrounding the root zone. This process is for metals, excess nutrients, and radionuclide contaminants in groundwater, surface water, and wastewater medium (Li et al., 2010; Kahkonen and Manninen, 1998). Plants through several natural biophysical and biochemical processes, such as adsorption, transport and translocation, hyperaccumulation or transformation and mineralization, can remediate pollutants (Meagher, 2000). Mechanisms of toxic metal removal by plant roots depend of different metals. Biological processes, like intracellular uptake, vacuolar deposition and translocation to the shoot, are responsible the removal of metals (Salt et al., 1995).

Potamogeton spp. (*Potamogetonaceae*), submerged macrophyte of world-wide distribution, produces large quantities of biomass and can remove such toxic metals as Cd, and Hg from wastewater (Demirezen and Aksoyo, 2007). *P. pectinatus* can be regarded as a pioneering, eurytopic species able to tolerate a wide range of nutrient concentrations as it quickly colonizes polluted waters, areas that have been interfered with or have become newly flooded, or environments unsuitable for other species (Fritioff and Greger,2003). The use of submerged aquatic macrophyte *P. pectinatus* for wastewater treatment may be useful, *P. pectinatus*, like most submerged vascular plants, is ecologically adapted to grow with its roots in sediments that have low oxygen levels. *Potamogeton pectinatus* significantly accumulated significant amount of metals in their tissues, which resulted in reduction of heavy metals Fe, Cu, Zn and Pb from the wastewater showing its phytoremediation potential for the metals (Sing et al., 2016). *P. pectinatus* tends to accumulate notable amounts of Cu, Cr, Pb, As and Cd according to their concentrations as follows: 8.2 μg g^{-1} dw, 0.97 μg g^{-1} dw, 6.04 μg g^{-1}dw, 2.52 μg g^{-1} dw and 0.34 μg g^{-1} dw, respectively (Norouznia and Hamidian, 2015).

The aim of present study is to assess treatability potential of submerged macrophyte *Potamogeton pectinatus* plant (Sago pond weed), family (*Potamogetonaceae*) as a phytoremediator for heavy metals in the wastewater of Lake Alasfar wetland in the eastern part of Saudi Arabia.

II. MATERIALS AND METHODS

Alasfar Lake Region is in Al-Ahsa Province in the southern eastern corner of the eastern region of Saudi Arabia, 13 km east of Al-Ahsa and extends between Latitudes 25^0 05' and 25^0 40' north and between Longitudes 49^0 10' and 49^0 55' east , and rises about 109 m above sea level (Al-Taher,

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1999). It is one of the shallow lakes with moistened soils and of most importance in the eastern region of Saudi Arabia. Its water is polluted by heavy metals, and a number of water plant species dominate its water, of which is *Potamogeton pectinatus* (L.). Maintaining the Integrity of the Specifications

Analysis of heavy metals in plant, water and soil

Four plant samples were collected from each of the three sites chosen, and were separated into the roots, the stems and the leaves. Washed thoroughly with distilled water, and dried and ground, and plant extracts were made out of it. Then the concentration of heavy metals was determined from each of these three plant parts (roots, stems and leaves) using the absorption spectroscopy and was estimated as ppm. Soil samples were collected from three pits in each plant site, dried, digested and heavy metals were determined. Samples of water were collected from the same plant sites chosen, and heavy metal concentrations were determined. The heavy metals and nutrients determined are Fe, Cu, Pb, Mn, Cd, Cr, Na, Ca, K, Mg and P, using the absorption spectroscopy as ppm, and P was determined using An Inductively Compelled plasma-atomic emission spectrophotometer IL-Plasma 200 according to method of (Allen et al., 1974).

Estimation of the Transfer Factor (TF) and Transfer Ratio (TR) for heavy metals

Heavy metals transferred from the soil to the different plant parts were estimated according to (Chamberlin, 1983) equation.

$$TF = \frac{\text{Concentration of an element in the plant body (ppm)}}{\text{concentration of the same element in the soil at the same site}}$$

The TR is estimated to determine whether the plant is capable in transferring nutrients and heavy metals from the root to the shoot according to (Kim et al., 2003).

$$TR = \frac{\text{Concentration of an element in the shoot (ppm)}}{\text{concentration of the same element in the root (}}$$

III. RESULTS

Heavy metals and nutritional elements in the different parts of the plant P. pectinatus and in soil and Lake water

The results in table (1) and figure (1) shows significant differences of all heavy metals and elements between the different plant parts and soil and water. The soil is characteristically high in contents of Na, Mg and CA reaching 3994.20, 33454.92 and 17956.36 ppm respectively, and with low values in P, Cr, Cd and Pb reaching 4.57, 0.05. 0.04 and 30.87 ppm respectively. In lake water Cu is high (254.79 ppm) and low values of K, Mn and Zn giving 172.9, 2.32 and 10 ppm respectively, and the lower parts values are high in each of P, Cr, Fe, Cd and Pb giving 4432.31, 300.86, 1782.31, 0.38 and 6.85 ppm respectively. Stem accumulations are high in K and Mn with 3555.55 and 1776.68 ppm respectively, and low in Fe and Cu with 270.10 and 11.86 ppm respectively. Leaves are high in contents of Zn= 146.79 ppm, and low in Na, Mg and Ca with 498.11, 1877.46 and 398.46 ppm respectively.

Averages of Transfer factor (TF) and Transfer ratio (TR) in P. pectinatus

The results of (table 2) showed that metals of P, Cr, Mn, Zn, Cd, K and Pb gave TF more than one between all plant parts and the soil, and as is known TF is the division of the concentration of the element in the plant part by its concentration in the soil. As for the TR which is the division of the metal concentration in the stem by that in the root, K, Mn and Zn gave high values in their transference from root to stem i.e., K, Mn and Zn accumulate more in the stem than in the root.

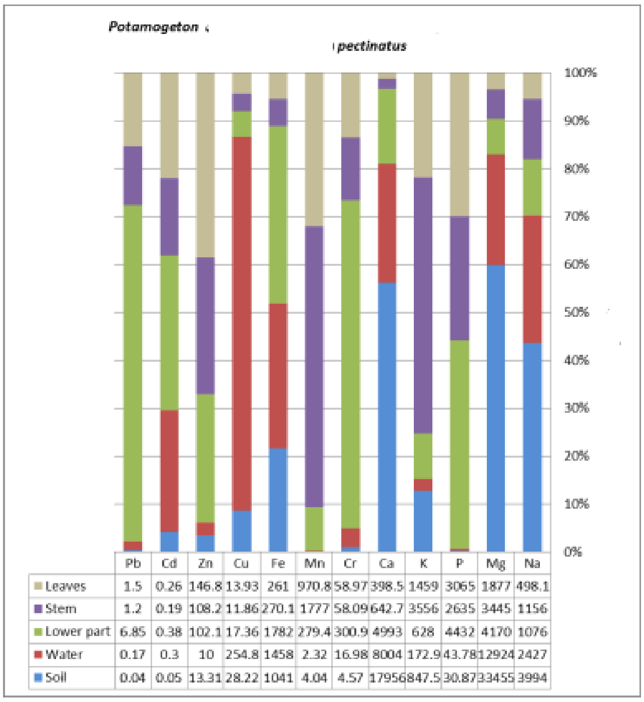

Fig. 1. Values of heavy metals and nutrient elements in plant parts of P. pectinatus and in water and soil samples.

Correlation between contents of heavy metals and elements in leaves and water

The results in Table (3) of Pearson simple linear correlation coefficient (r) between heavy metals and elements in water and leaves illustrated a negative significant correlation for Ca (Ca=0.823**).

Correlation between contents of heavy metals and elements in stem and water

The results in Table (4) of Pearson simple linear correlation coefficient (r) showed no significant correlation between heavy metals and elements in water and stem.

Correlation between contents of heavy metals and elements in plant parts below soil surface and water

The results in Table (5) of Pearson simple linear correlation coefficient (r) between heavy metals and elements in plant parts below soil surface and water illustrated a negative significant correlation for Pb (0.702*).

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Correlation between contents of heavy metals and elements in plant leaves and soil

The results in Table (6) of Pearson simple linear correlation coefficient (r) between heavy metals and elements in soil and leaves illustrated a positive significant correlation for P (P=0.930**), Ca (Ca=0.958**), Cr (Cr=0.851**), Mn (Mn=0.804**), Fe (Fe=0.903**) and Zn (Zn=0.936**).

Correlation between contents of heavy metals and elements in plant stem and soil

Table (1): Means of concentrations of heavy metals and nutrients of water and soil samples and *P. pectinatus* plant parts (first line) and standard error ± (second line) and F-Value based on ANOVA.

Element ppm	Soil	Water	Lower part	Stem	Leaves	F-Value
Na	3994.20	2427.42	1076.37	1155.89	498.11	38.145***
	±748.75	±1278.29	±241.44	±231.62	±68.98	
Mg	33454.92	12924.01	4170.27	3444.64	1877.46	350.685***
	±4456.90	±674.51	±920.14	±966.90	±431.65	
P	30.87	43.78	4432.31	2635.05	3065.19	55.503***
	±8.12	±21.51	±1035.40	±926.17	±1067.89	
K	847.53	172.90	627.96	3555.55	1458.93	308.820***
	±297.82	±65.09	±115.45	±358.92	±145.47	
Ca	17956.36	8003.96	4992.77	642.74	398.46	400.045***
	±1495.28	±1742.44	±712.19	±153.72	±161.02	
Cr	4.57	16.98	300.86	58.09	58.97	561.246***
	±0.59	±3.10	±30.39	±11.30	±11.06	
Mn	4.04	2.32	279.37	1776.68	970.82	1352.262***
	±0.66	±1.24	±30.83	±100.22	±91.91	
Fe	1040.75	1457.69	1782.31	270.10	260.98	40.775***
	±313.09	±379.01	±527.38	±38.36	±39.57	
Cu	28.22	254.79	17.36	11.86	13.93	40.576***
	±2.50	±111.62	±3.68	±4.16	±1.11	
Zn	13.31	10.00	102.13	108.22	146.79	286.516***
	±2.63	±5.29	±11.12	±12.42	±16.64	
Cd	0.05	0.30	0.38	0.19	0.26	4.392**
	±0.03	±0.19	±0.19	±0.06	±0.28	
Pb	0.04	0.17	6.85	1.20	1.50	34.814***
	±0.02	±0.05	±3.08	±0.64	±0.54	

Table (2): Values of TF and TR in P. pectinatus plant

	TF			TR	
ppm	Leaves	Stem	Lower part	Leaves	Stem
Na	0.12	0.29	0.27	0.46	1.07
Mg	0.06	0.10	0.12	0.45	0.83
P	99.29	85.36	143.58	0.69	0.59
K	1.72	4.20	0.74	2.32	5.66
Ca	0.02	0.04	0.28	0.08	0.13
Cr	12.90	12.71	65.83	0.20	0.19
Mn	240.30	439.77	69.15	3.48	6.36
Fe	0.25	0.26	1.71	0.15	0.15
Cu	0.49	0.42	0.62	0.80	0.68
Zn	11.03	8.13	7.67	1.44	1.06
Cd	5.20	3.80	7.60	0.68	0.50
Pb	37.50	30.00	171.25	0.22	0.18

The results in Table (7) of Pearson simple linear correlation coefficient (r) between heavy metals and elements in soil and stem illustrated a positive significant correlation in each of P (P=0.964**), Ca (Ca=0.835**), Pb (Pb=0.831**), Fe (Fe=0.825**) and Zn (Zn=0.681*).

Table (3): Pearson correlation coefficient (r) between heavy metals and elements in leaves P. pectinatus and water. Significant correlation p ≤ 0.05* p ≤ 0.01** p ≤ 0.001***

P. pectinatus		Leaf (ppm)							
		P	Ca	Cr	Mn	Fe	Cu	Zn	Pb
Water (ppm)	Mg	-.863**	-.525	-.787*	.817**	-.516	.044	-.717*	-.727*
	P	-.134	-.053	-.044	-.100	-.151	.665	-.122	-.040
	K	-.671*	-.716*	-.614	.319	-.795*	.479	-.687*	-.290
	Ca	-.541	-.823**	-.507	.217	-.758*	-.135	-.482	-.306
	Fe	-.163	-.484	.107	-.258	-.530	.701*	-.276	-.168

Correlation between contents of heavy metals and elements in plant parts below soil surface and soil

The results in Table (8) of Pearson simple linear correlation coefficient (r) between heavy metals and elements in plant parts below soil surface and soil illustrated a positive significant correlation for P (P=0.915**), Cr (Cr=0.670*), Pb (Pb=0.826*), Fe (Fe=0.877**) and Zn (Zn=0.894**).

Table (4): Pearson correlation coefficient (r) between heavy metals and elements in stem of P. pectinatus and water. Significant correlation p ≤ 0.05* p ≤ 0.01** p ≤ 0.001***

Potamogeton pectinatus		stem (ppm)								
		P	Ca	Cr	Mn	Fe	Cu	Zn	Cd	Pb
Water (ppm)	Na	-.247	.260	-.730*	.383	-.008	.072	-.401	.038	-.382
	Mg	-.873**	-.448	-.551	.376	-.676*	-.329	-.367	-.043	-.384
	K	-.660	-.536	-.216	.059	-.489	.006	-.773*	.284	-.709*
	Mn	-.272	-.047	.000	-.277	-.188	.691*	-.637	.766*	-.709*
	Fe	-.301	-.726*	.676*	-.589	-.559	.402	-.398	.768*	-.514
	Cu	-.519	-.510	-.438	.685*	-.520	-.162	.011	-.227	-.170
	Zn	-.388	-.366	.185	-.325	-.391	.610	-.640	.847**	-.852**
	Pb	-.109	.016	.059	-.186	-.006	.782*	-.543	.697*	-.617

IV DISCUSSION

The results of the study on *Potamogeton pectinatus* plant (Sago pond weed), family (*Potamogetonaceae*) in table (9) showed that *P. pectinatus* plant accumulated in its lower parts (roots) heavy metals of (Cr=300.9 mg/kg), (Zn=102.1 mg/kg), (Cd=0.38 mg/kg) and (Pb=6.85 mg/kg), and in its stem (Cr=58.09 mg/kg), (Mn=1777 mg/kg), and (Zn=108.2 mg/kg), and in its leaves (Cr=58.97 mg/kg), (Zn=146.8 mg/kg) and (Cd=0.26 mg/kg) and all these heavy metal concentrations are above the permissible levels suggested by the Food and Agriculture Organization and the World Health Organization (FAO/WHO, 2007) table (9). These metals are considered harmful according to the Agriculture and Food Organization, and the main source of these heavy metals is lake Alasfar wastewater which is polluted with concentrations of heavy metals of Cr=16.98 mg/kg, Mn=2.32 mg/kg, Fe=1458 mg/kg, Zn=10 mg/kg, Cd=0.3 mg/kg and Cu=254.8 mg/kg and all these concentrations are above the permissible levels put forward by (FAO, 1985). It is observed that the plant accumulated P in its leaves at rates above the permissible level (P=2000 mg/kg), and this is mostly due to presence of some soil fungi like mycorrhizal fungi that enhances P absorption by the plant. Also it is observed that the transfer factor (TF) of elements from soil to the different plant parts was high as regards P, Cr, Mn, Zn, Cd and Pb, and stem and leaves indicated high absorption rate for K. Also the transfer ratio (TR) was high between the different plant parts, it is high for K, Mn, Zn from the root to the stem and leaves, and high TR of Na from soil to stem, and this is as indicated by (Al-Wihaibi, 2007) is because some elements are movable and move from roots to stem and leaves and some are immovable and remain in the roots.

From table (10) can be seen that there is correlation between water, soil and the different plant parts in concentration of heavy metals and elements. There is a positive correlation between soil - stem in P, Ca, Fe and Pb, and soil - leaves in P, Ca, Cr, Fe and Zn, and soil – root in P, Cr, Fe, Zn and Pb, and between water – leaves in Ca, and water – root in Pb.

As regards soil it can be seen that all heavy metal and element concentrations in the soil except Cu and Na are lower than that in the plant parts which indicates its transfer to these parts from the soil, and their contents in water is also less than in the plant parts except Cu, Na, Mg and Ca. It is clear that heavy metals accumulate in the lower plant parts at a higher levels, a fact which agrees with results of other researchers (Vymazal et al.,2007 and with Mazej and Germ, 2009 who said that P. pectinatus practices filtration to many heavy metals. Consideration of P. pectinatus as a phytoremediator for heavy metals agrees with the findings of (Sing et al.,2016) that *Potamogeton pectinatus* accumulated significant amount of

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metals in its tissues, which resulted in reduction of heavy metals Fe, Cu, Zn and Pb from the wastewater showing its phytoremediation potential for the metals. Also with the findings of (Norouznia and Hamidian, 2015) that P. pectinatus tends to accumulate notable amounts of Cu, Cr, Pb, As and Cd according to their concentrations as follows: 8.2 µg g-1 dw, 0.97 µg g-1 dw, 6.04 µg g-1dw, 2.52 µg g-1 dw and 0.34 µg g-1 dw, respectively.

Table (5): Pearson correlation coefficient (r) between heavy metals and elements in lower parts below soil surface of P. pectinatus and water. Significant correlation $p \leq 0.05$* $p \leq 0.01$** $p \leq 0.001$***

Potamogeton pectinatus		**Lower part (ppm)**							
		Mg	**P**	**Ca**	**Mn**	**Cu**	**Zn**	**Cd**	**Pb**
Water (ppm)	**Na**	.494	-.425	.303	-.719*	-.080	-.255	-.059	-.377
	Mg	.107	-.588	.134	-.080	-.220	-.688*	-.103	-.274
	K	.754*	-.710*	-.025	-.085	.141	-.648	.758*	-.778*
	Ca	.830**	-.754*	-.438	-.026	-.177	-.434	.310	-.565
	Mn	.484	-.470	-.152	-.214	.670*	-.497	.177	-.713*
	Fe	.231	-.345	-.688*	.700*	.632	-.506	.607	-.544
	Zn	.583	-.553	-.379	.070	.680*	-.573	.407	-.805**
	Pb	.609	-.382	-.152	-.228	.662	-.287	.268	-.702*

Table (6): Pearson correlation coefficient (r) between metals and elements in P. pectinatus leaves and soil. Significant correlation $p \leq 0.05$* $p \leq 0.01$** $p \leq 0.001$***

Potamogeton pectinatus		**Leaf (ppm)**									
		Na	**Mg**	**P**	**K**	**Ca**	**Cr**	**Mn**	**Fe**	**Zn**	**Pb**
Soil (ppm)	**Na**	.304	.714*	.828**	.659	.434	.743*	-.831**	.425	.653	.704*
	Mg	.260	.664	.861**	.642	.496	.774*	-.835**	.486	.697*	.727*
	P	-.079	.147	.930**	.357	.871**	.829**	-.690*	.877**	.921**	.733*
	Ca	-.311	-.073	.835**	-.009	.958**	.697*	-.356	.943**	.715*	.523
	Cr	.093	.461	.940**	.534	.689*	.851**	-.798*	.674*	.817**	.787*
	Mn	-.377	-.781*	-.760*	-.670*	-.332	-.679*	.804**	-.321	-.575	-.676*
	Fe	-.205	.025	.921**	.299	.921**	.840**	-.642	.903**	.904**	.737*
	Cu	.675*	.495	-.614	.066	-.883**	-.603	.228	-.854**	-.603	-.299
	Zn	-.076	.066	.896**	.355	.872**	.809**	-.679*	.862**	.936**	.805**
	Cd	.663	.939**	.061	.552	-.471	.035	-.393	-.458	-.146	.105
	Pb	-.345	-.183	.844**	.155	.962**	.774*	-.509	.940**	.868**	.663

CONCLUSION

Lake Alasfar wastewater is contaminated with the heavy metals of Cr, Mn, Fe, Cu, Zn and Cd and the concentration of all these heavy metals are far above the standards put forward by (FAO, 1985). *Potamogeton pectinatus* plant accumulated in its roots (lower parts) heavy metals of Cr, Zn, Cd, Pb, and in its stem Cr Mn, Zn, and in its leaves Cr, Zn, Cd, and all these heavy metal concentrations are above the permissible levels suggested by the Food and Agriculture Organization and the World Health Organization (FAO/WHO, 2007) table (12). The main source of these heavy metals is lake Alasfar polluted water where all these meta concentrations are above the permissible levels put forward by (FAO, 1985). It is

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Table (7): Pearson correlation coefficient (r) between heavy metals and elements in P. pectinatus stem and soil. Significant correlation p ≤ 0.05* p ≤ 0.01** p ≤ 0.001***

Potamogeton pectinatus		**stem (ppm)**					
		Mg	**P**	**Ca**	**Fe**	**Zn**	**Pb**
Soil (ppm)	**Na**	.392	.828**	.420	.644	.275	.327
	Mg	.328	.864**	.461	.681*	.319	.383
	P	-.223	.964**	.688*	.830**	.659	.718*
	K	.679*	-.227	-.451	-.327	-.435	-.249
	Ca	-.305	.867**	.835**	.892**	.540	.733*
	Cr	.092	.958**	.579	.769*	.484	.575
	Mn	-.491	-.761*	-.339	-.575	-.208	-.247
	Fe	-.345	.950**	.708*	.825**	.640	.787*
	Cu	.764*	-.603	-.663	-.605	-.471	-.694*
	Zn	-.286	.936**	.618	.787*	.681*	.797*
	Cd	.930**	.030	-.242	-.073	-.356	-.461
	Pb	-.527	.877**	.716*	.787*	.661	.831**

Table (8): Pearson correlation coefficient (r) between heavy metals and elements in P. pectinatus lower parts and soil. Significant correlation p ≤ 0.05* p ≤ 0.01** p ≤ 0.001***

Potamogeton pectinatus		**Lower part (ppm)**						
		Mg	**P**	**K**	**Cr**	**Fe**	**Zn**	**Pb**
Soil (ppm)	**Na**	.010	.494	.257	.637	.601	.627	.168
	Mg	-.062	.554	.201	.651	.647	.669*	.231
	P	-.598	.915**	-.247	.568	.865**	.895**	.693*
	K	.682*	-.561	.567	.036	-.321	-.380	-.516
	Ca	-.668*	.865**	-.311	.565	.839**	.775*	.726*
	Cr	-.308	.732*	-.008	.670*	.770*	.790*	.461
	Fe	-.699*	.946**	-.363	.591	.877**	.868**	.745*
	Cu	.939**	-.832**	.752*	-.440	-.629	-.550	-.745*
	Zn	-.653	.935**	-.285	.533	.883**	.894**	.736*
	Cd	.819**	-.415	.774*	.171	-.191	-.141	-.628
	Pb	-.830**	.971**	-.509	.519	.860**	.834**	.826**

observed that the plant accumulated P in its parts at rates above the permissible level (P=2000 mg/kg), and this is mostly due to presence of some soil fungi like mycorrhizal fungi that enhances P absorption by the plant. The transfer factor (TF) or absorption of heavy metals and elements from soil to the different plant parts was high as regards P, Cr, Mn, Zn, Cd and Pb, and stem and leaves indicated high absorption rate for K. Also the transfer ratio (TR) between the different plant parts was high, it is high for K, Mn, Zn from root to the stem and leaves, and high TR of Na from soil to stem. There was correlation between the different plant parts and water and soil. There is a positive correlation between soil and leaves for concentration of P, Cr, Zn, Fe, Mn, Ca, and between soil and stem in Zn, Pb, Fe, P, Ca, and between soil and root in, Zn, Pb, Fe, P, Cr. All heavy metal and element concentrations in the soil are lower than that in the plant parts except Cu and Na, which indicates its transfer to these parts from the soil, and their contents in water is also less than in the plant parts except Cu, Na, Mg and Ca. *Potamogeton pectinatus* is recommended as phytoremediator for heavy metals removal from wastewater of Lake Alasfar, and the species contains high concentrations of heavy metals so animals should be kept away from grazing on it.

Table (9): Rate of concentration of nutrient elements and heavy metals in P. pectinatus in (mg/kg) and the standards permissible by (WHO/FAO, 2007), and the toxic limits for water (in mg/L) suggested by (FAO, 1985) and soil (in mg/kg) and toxic limits by (EU, 2002).

Elment	Water ASafer lake	FAO standard Cytotoxi Range (Mg/l)**	Soil ASafer lake	Eu Standard s Cytotoxi Rang (Mg/Kg)* **	Leaf	Stem	Lower part	FAO standard Cytotoxi Rang (Mg/kg) *
Na	2427	-	3944	-	498.1	1156	1076	-
Mg	12924	-	33455	-	1877	3445	4170	-
P	43.78	-	30.87	-	3065	2635	4432	2000
K	172.9	-	847.5	-	1459	3556	628	10000
Ca	8004	-	17956.4	-	398.5	642.7	4993	-
Cr	16.98	0.1	4.57	150	58.97	58.09	300.9	5
Mn	2.32	0.2	4.04	-	970.8	1777	279.4	1000
Fe	1458	5	1041	-	261	270.1	1782	-
Cu	254.8	0.2	28.22	140	13.93	11.86	17.36	40
Zn	10	2	13.31	300	146.8	108.2	102.1	50
Cd	0.3	0.01	0.05	3	0.26	0.19	0.38	0.2
Pb	0.17	0.5	0.04	300	1.5	1.2	6.85	5

Table (10): Pearson correlation coefficient (r) between heavy metals and elements in soil and water and different parts of P. pectinatus. Significant correlation $p \leq 0.05$* $p \leq 0.01$** $p \leq 0.001$***

	Leaf (ppm)	Stem (ppm)	Lower part (ppm)
Water (ppm)	Ca		Pb-
Soil (ppm)	Ca, P, Mn, Cr, Zn, Fe	Ca, P, Zn, Fe, Pb	Cr, P, Zn, Fe, Pb
Leaf (ppm)	-	Mg, Na, Ca, P, Cu, Fe, Pb, Zn	Cr, P, Na, Zn, Cu, Fe
Stem (ppm)	-	-	Zn, Cu, Fe, Ca,P, Mg, Na

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