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Macrophytes in Phytoremediation of Heavy Metal Contaminated Water and Sediments in Pariyej Community Reserve, Gujarat, India

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Abstract

A phytoremediation study was carried out at Pariyej reservoir, an internationally important wetland listed in Asian Directory of Wetlands, designated as a “Wetland of International Importance” and a proposed community reserve of Gujarat State, India, to ascertain the degree of heavy metal contamination. The study focused on assessment of heavy metal accumulation in certain aquatic macrophytes used as biomonitors, in comparison with water and sediments (abiotic monitors) for phytoremediation. Roots, stems and leaves of native aquatic plants (biomonitors) represented by seven species: *Ipomoea aquatica* Forsk, *Eichhornia crassipes*, (Mart.) Solms, *Typha angustata* Bory & Chaub, *Echinochloa colonum* (L.) Link, *Hydrilla verticillata* (L.f.) Royle, *Nelumbo nucifera* Gaerth. and *Vallisneria spiralis* L. along with surface sediments and water, were analyzed for Cd, Co, Cu, Ni, Pb and Zn contamination. The greater accumulation of heavy metals was observed in *Nelumbo nucifera* and the poor content in *Echinochloa colonum*. Based on the concentration and toxicity status observed in the lake's vegetation, the six heavy metals are arranged in the following descending order: Zn > Cu > Pb >Ni > Co > Cd compared with the standard, normal and critical toxicity range in plants. The detected values of Cd and Pb fall within normal range, while that of Co and Ni were within the critical range. However, Zn and Cu showed the highest accumulation with alarming toxicity levels, which are considered as one of the most hazardous pollutants in Pariyej reservoir. Species like *Typha angustata* and *Ipomoea aquatica* are also proposed as bioremediants, which are the two most useful plant species in phytoremediation studies due to their ability to accumulate heavy metals in high concentration in the roots. The results showed the significant differences in accumulation of metals like Zn, Cu and Pb in different plant organs, in roots than that of stems and leaves. High positive correlation between combinations of different metal pairs in plant’s root, stem or leaf system was established. The potential use of these wetland plants in phytoremediation is also discussed.

Key words: freshwater macrophytes, heavy metals, lake contamination, phytoremediation, Pariyej Community Reserve (PCR), Gujarat, India.

Introduction

Direct discharge or wet and dry depositions of contaminants increase the concentration of trace elements in aquatic systems, thus resulting in their accumulation in sediments (Dunbabin and Bowmer, 1992; Sinicrope *et al.*, 1992). Aquatic plants absorb elements through roots and/or shoots (Pip and Stepaniuk, 1992; Jackson, 1998). Various species show different behaviour regarding their ability to accumulate elements in roots, stems and/or leaves. Therefore, it is useful to identify the plant organ that absorbs the greatest amount of trace elements (St-Cyr and Campbell, 1994; Baldantoni *et al.*, 2004). In aquatic systems, where pollutant inputs are discontinuous and pollutants are quickly diluted, analyses of plant components provide time-integrated information about the quality of the system (Baldantoni *et al.*, 2005).

Phytoremediation has several advantages and is the most significant one in study of sub-lethal levels of bioaccumulated contaminants within the tissues / components of organisms, which indicate the net amount of pollutants integrated over a period of time (Lovett-Doust *et al.*, 1994). Biomonitoring of pollutants using some plants as accumulator species, accumulate relatively large amounts of certain pollutants, even from much diluted solutions without obvious noxious effects (Ravera *et al.*, 2003). It may be performed in two ways, based on the kind of sampled organisms: I) ‘endemic’, or native, organisms (passive biomonitoring) and ii) introduced organisms (active biomonitoring) (Chaphekar, 1991). The metal pollution load (Siegel *et al.*, 1994) and its biomonitoring in aquatic plants (Ramdan, 2003) were intensively investigated in Manzala lake of Nile delta, Egypt. Similarly, Ravera *et al.* (2003) studied trace element concentration in freshwater macrophytes. Moreover, macro and microelement accumulation in *Typha angustata* and *Phragmites australis* was assessed in relation to spatial gradients of lake by Baldantoni *et al.* (2004; 2005).

Rana and Nirmal Kumar (1988) observed heavy metal accumulation through Energy Dispersive Analysis of X-Rays (EDAX) in certain sediments in Central Gujarat and noticed that Fe content was found the highest in sediments of Undeva pond, followed by the presence of Si and Al. Nirmal Kumar *et al.* (1989)

have investigated elemental composition of certain aquatic plants by EDAX and found high level of heavy metals such as Al, Si, Mn and Fe being found accumulated in *Vallisneria spiralis*, *Hydrilla verticillata* and *Azolla pinnata*. Phytoaccumulation of heavy metals by selected freshwater macrophytes was also studied to assess the phytoremediation of six heavy metals in Nal Sarovar Bird Sanctuary (Nirmal Kumar *et al.*, 2006). Therefore, it is necessary to carry out phytoremediation of heavy metal contaminated water and sediments by selected aquatic macrophytes viz. *Eichhornia crassipes*, *Ipomoea aquatica*, *Typha angustata*, *Hydrilla verticillata* and *Vallisneria spiralis* in Pariyej Community Reserve, Gujarat, India.

Materials and Methods

Pariyej Community Reserve (PCR)

PCR is located on 22°33′ N latitude and 72°38′ E longitude, falls in 4B Gujarat-Rajwara biotic province of the semiarid lands of Central Gujarat, India (Figure 1). The reservoir occupies 500 ha area, 15 m ASL (Above Sea Level), and is the principal source of food, drinking, irrigation and fishing for local dependent communities of peripheral five villages. It carries household sewage at certain extent and agricultural run-off from surrounding village pockets at northern and western boundaries. No industrial effluent enters into the lake. The temperature rises up to 37°C during the month of May and falls below 14°C in January. The average rainfall is about 800 mm concentrated in July to September. The water regime of the reservoir supports more than 160 species of aquatic birds with an average density of around 28,000 waterfowl during peak winter months (Van Der Ven, 1987). The population estimation of the recorded waterfowl clearly signifies the lake as an internationally important wetland (Koning and Koning-Raat, 1975; Scott, 1989) and 'Wetland of National Importance' (MoEF, 2005). Besides, it is known to support dominant growth of aquatic vegetation of *Hydrilla*, *Ipomoea* and *Typha* spp. and others. Accordingly, it is one of the proposed Community Reserved by GSFD (2005) and is also identified as one of the important wetlands for evolving management action plan by the National Wetland Committee. Due to human interference, considerable changes occurred in its geomorphology, hydrological regime and biotic composition in recent past.

Water and Sediment Sampling

Surface water and composite sediment samples were collected at random from different areas of the lake, covering all directions. Soon after collection, the water samples were filtered through 0.45 µm (pore size) Millipore filter and preserved in plastic bottles by the addition of a few drops of nitric acid, while sediment samples were preserved in air-dry plastic bags. The samples were labeled carefully and brought to the laboratory for further analysis (Allen, 1989).

Plant Sampling

Seven native aquatic macrophytes from the lake were selected as passive biomonitors for estimating the toxicity status induced by six heavy metals (Cd,

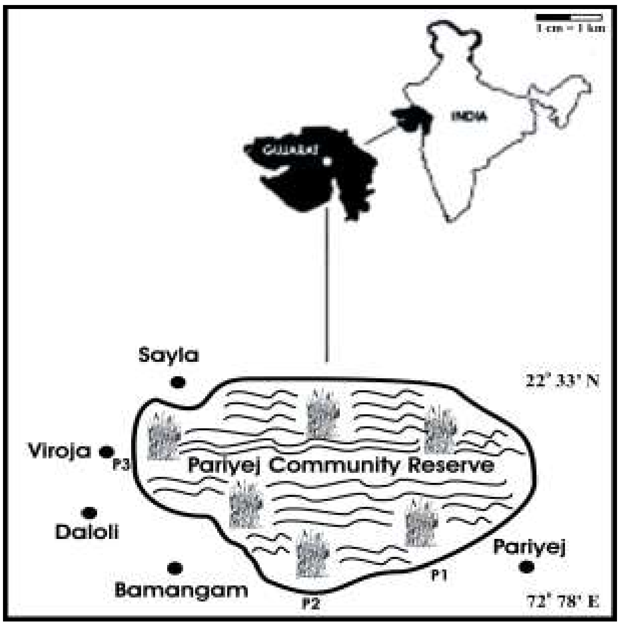

Figure 1. Location map of Pariyej Community Reserve (PCR).

Co, Cu, Ni, Pb and Zn) and were collected during November 2004. The plant species selected were: *Eichhornia crassipes* (Mart.) Solms, *Ipomoea aquatica* Forsk., *Echinochloa colonum* (L.) Link, *Typha angustata* Bory & Chaub, *Hydrilla verticillata* (L.f.) Royle, *Nelumbo nucifera* Gaerth., and *Vallisneria spiralis* L. Healthy aquatic plants were collected by hand, washed with lake water to remove periphyton and sediment particles. The collected plant species were placed in plastic bags, labeled carefully and brought to the laboratory. Polythene tools were used in sampling and storing the collected matrices to avoid the metal contamination. Plant species were identified according to Shah (1978a, 1978b).

Chemical Analysis of Water, Sediment and Plant Samples

Sediment samples were air-dried, sieved through 2 mm governorates sieve and kept for analyses. Each aquatic plant species sorted into different parts: roots, stems and leaves. The 50 gm of each fresh sample dried at 800°C in hot air oven for 48 h. The samples of water, sediment and plant-parts were chemically analyzed for detection of heavy metals (Cd, Co, Cu, Ni, Pb and Zn). Accurately 0.5 gram of dry powder of each sample was weighed, and digested with con. HNO_3, H_2SO_4 and H_2O_2 (2:6:6) as prescribed by Saison *et al.* (2004). The blanks were run with set, and the samples were analysed in Inductive Coupled Plasma Analyzer (ICPA) (Perkin-Elmer ICP Optima 3300 RL, U.S.A.) at Sophisticated Instrumentation Center for Applied Research and Testing (SICART), Vallabh Vidyanagar, Gujarat. The concentration of heavy metals such as Cd, Co, Cu, Ni, Pb and Zn were represented in ppm. Mean values of duplicate sub-samples of the water, sediment and plant samples were considered.

Data Analysis

The mean values of heavy metals were calculated for water, soil and plant samples. The unilateral F-test was carried out between heavy metal contents in roots, stems and leaves to check if significant differences exist between the accumulation rate of each metal and different plant parts. Pearson correlation coefficient analysis was done between metal-pairs in plants to check if differences exist between different metal combinations in either root, stem or leaf system. The products of the correlation coefficient (r) were evaluated (Norusis, 1993) as follows:

0–0.3: No correlation;
0.3–0.5: Low correlation;
0.5–0.7: Medium correlation;
0.7–0.9: High correlation;
0.9–1.0: Very high correlation

The comparison of the concentration of an element in an aquatic organism with that of the same element in the water in which the organism lives is the ratio between the concentration of the element in the organism and that in the water, which is known as Concentration Factor (De Bortoli *et al.*, 1968). The Concentration Factor (C.F.) was also calculated. When the C.F. value is at equilibrium, the release rate of the element from the organism is equivalent to its intake rate, so that the element concentration in the organism is fairly constant.

Results

The concentrations of heavy metals were higher in the sediments than those calculated for the same heavy metals in the lake water. Of the analyzed heavy metals, Zn was the most abundant in sediments (2114.82 ppm) and water (160.70 ppm), followed by Cu with a concentration of 105.78 ppm in the sediments and 19.67 ppm in the water. Other metals like Ni, Co, Pb and Cd exhibited the receding trend in both sediments and water. The values of the ratio between element concentrations in the sediments and those in the water were lower (1.55-13.16 ppm) for Pb, Cd, Cu, Ni and Zn, whereas that of Co was observed high (19.81 ppm) (Table 1, Figure 2).

Macrophytes

Table 2 shows the mean values of concentration of six elements in seven species of macrophytes. The mean concentration values of the elements in the plants decrease according to this sequence: Zn > Cu > Pb > Ni > Co > Cd. The highest mean concentration value was recorded in *N. nucifera* (343.54 ppm), followed by *E. crassipes* (136.46 ppm), *V. spiralis* (82.42 ppm), *H. verticillata* (81.89 ppm), *I. aquatica* (74.81 ppm), *T. angustata* (70.51 ppm) and *E. colonum* (65.19 ppm). Among all studied metals, the lowest Cd content was recorded in *H. verticillata* (0.15 ppm), while the greatest amount of Zn was observed in *E. crassipes* (709.07 ppm).

The concentration of individual metal also varies from species to species. The content of Cd ranged from 0.15 to 23.83 ppm in *H. verticillata* and *I. aquatica*, respectively. The Co content was found low in *V. spiralis* (3.09 ppm) and high in *E. crassipes* (25.75 ppm). On the other hand, *H. verticillata* showed low amount of Cu (16.32 ppm), while high amount of the same was recorded in *N. nucifera* (1617.21 ppm). The Ni content fluctuates from 4.10 to 28.83 ppm in *V. spiralis* and *E. crassipes*, respectively. Besides, low concentration of Pb was registered in *I. aquatica* (4.47 ppm), while high concentration of the same was observed in *V. spiralis* (82.40 ppm). The minimum concentration of Zn was recorded in *E. colonum* (253.25 ppm), while maximum content of the same was registered in *E. crassipes* (709.07 ppm).

Table 1. Heavy metal concentration in sediments and water and ratios between the concentration in the sediments and that in the water

Metal	Sediment (ppm)	Water (ppm)	Sediment / Water
Cd	1.27	0.74	1.70
Co	34.88	1.76	19.81
Cu	105.78	19.67	5.38
Ni	58.08	10.13	5.73
Pb	9.47	6.11	1.55
Zn	2114.82	160.70	13.16

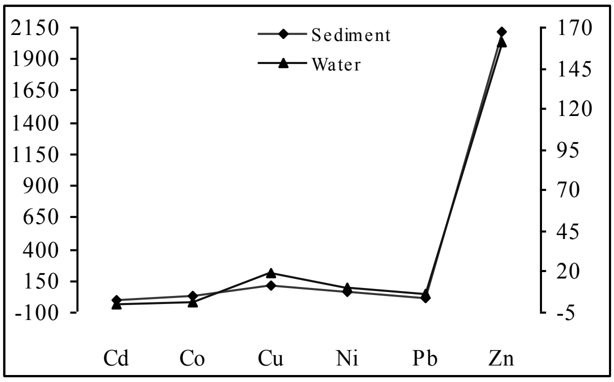

Figure 2. Mean concentration (ppm) of six heavy metals in water and sediment samples of PCR.

Table 2. Mean heavy metal concentration (ppm) in macrophyte species

Element / Taxon	Cd	Co	Cu	Ni	Pb	Zn	Mean
E. colonum	0.56	8.16	113.32	11.06	4.81	253.25	65.19
E. crassipes	0.79	25.75	44.50	28.83	9.81	709.07	136.46
H. verticillata	0.15	5.19	16.32	4.81	7.16	457.68	81.89
I. aquatica	23.83	23.72	54.73	14.38	4.47	327.73	74.81
N. nucifera	0.35	6.76	1617.21	5.13	8.12	423.66	343.54
T. angustata	1.44	14.11	104.21	20.26	6.92	276.13	70.51
V. spiralis	0.83	3.09	26.84	4.10	82.40	377.29	82.42
Mean	3.99	12.40	282.45	12.65	17.67	403.54	
SD	8.76	9.11	589.72	9.28	28.60	153.81	

Table 3 gives mean values of Concentration Factor (C.F.) for each species and element. The mean C.F. value of the elements in the plants decreases according to this sequence: Cu > Zn > Pb > Cd > Ni > Co. This sequence (which is rather different from that of the mean concentrations of elements in the plants) reflects the capacity of the macrophytes to accumulate elements independently from their concentration in the water that is the regulation capacity of the plants. Mean concentration factors for the various elements calculated for *N. nucifera* are generally rather high (56.58 ppm), followed by *V. spiralis* (14.70 ppm), *E. crassipes* (12.55 ppm), *I. aquatica* (9.28 ppm) and *T. angustata* (8.32 ppm), while those for *E. colonum* and *H. verticillata* are lower than those of the other species i.e. 7.68 ppm and 7.27 ppm, respectively. Of all metals, the lowest C.F. value of Cd was observed in *H. verticillata* (0.09 ppm), while the highest value of Cu was recorded in *N. nucifera* (300.60 ppm).

The low concentration of Cd was recorded in *H. verticillata* (0.09 ppm), while maximum content of the same was registered in *I. aquatica* (14.02 ppm). On the other hand, minimum concentration of Co was registered in *V. spiralis* (0.16 ppm), while high amount of the same was observed in *E. crassipes* (1.30 ppm). The Cu content fluctuates from 3.03 to 300.60 ppm in *H. verticillata* and *N. nucifera*, respectively. Besides, *V. spiralis* showed low amount of Ni (0.72 ppm), while greater amount of the same was recorded in *E. crassipes* (5.03 ppm). The Pb content was found less in *I. aquatica* (2.88 ppm) and high in *V. spiralis* (53.16 ppm). The content of Zn ranged from 19.24 to 53.88 ppm in *E. colonum* and *E. crassipes*, respectively. The principal source of contamination in PCR is agricultural run-off coming through several drains along with washing and bathing activities by local inhabitants and cattle wading at peripheral villages at north-west boundary.

Heavy metals are the most dangerous contaminants since they are persistent and accumulate in water, sediments and in tissues of the living organisms, through two mechanisms, namely 'bio-concentration' (uptake from the ambient environment) and 'bio-magnification' (uptake through the food chain) (Chaphekar, 1991). The results of the present study include assessment of six heavy metals (Cd, Co, Cu, Ni, Pb and Zn) and evaluation of their toxicity status in different plant parts of seven native aquatic plant species (Figures 3, 4, 5).

Heavy Metal Accumulation in Plant Components

The mean values of six heavy metals fluctuate in roots of aquatic macrophytes. Plants like *T. angustata*, *E. crassipes* and *N. nucifera* have great amount of heavy metals such as Zn, Cu and Ni, Co and Cd, and Pb, respectively. However, poor amount of heavy metals was recorded in *E. colonum* (Figure 3).

The mean concentration of heavy metal of stems of five aquatic plants varies from species to species. The higher values of Zn and Cu were observed in *N. nucifera* and *I. aquatica*, respectively, compared to other studied metals. On the other hand, stems of *E. crassipes* showed high amount of Ni, Pb, Co and Cd in a recessive manner (Figure 4). The accumulation of heavy metals in leaves of five native aquatic macrophytes is exhibited by high accumulation of Zn, Cu and Cd in *E. crassipes*, *E. colonum* and *I. aquatica* and low accumulation of metals in *T. angustata* and *N. nucifera* (Figure 5). The order of the accumulation of heavy metals in various parts of aquatic species is given below:

Table 3. Concentration factor calculated for the various species and heavy metals

Element / Taxon	Cd	Co	Cu	Ni	Pb	Zn	Mean
E. colonum	0.33	0.41	21.06	1.93	3.10	19.24	7.68
E. crassipes	0.46	1.30	8.27	5.03	6.33	53.88	12.55
H. verticillata	0.09	0.26	3.03	0.84	4.62	34.78	7.27
I. aquatica	14.02	1.20	10.17	2.51	2.88	24.90	9.28
N. nucifera	0.21	0.34	300.60	0.90	5.24	32.19	56.58
T. angustata	0.85	0.71	19.37	3.54	4.46	20.98	8.32
V. spiralis	0.49	0.16	4.99	0.72	53.16	28.67	14.70
Mean	2.35	0.63	52.50	2.21	11.40	30.66	
SD	5.15	0.46	109.61	1.62	18.45	11.69	

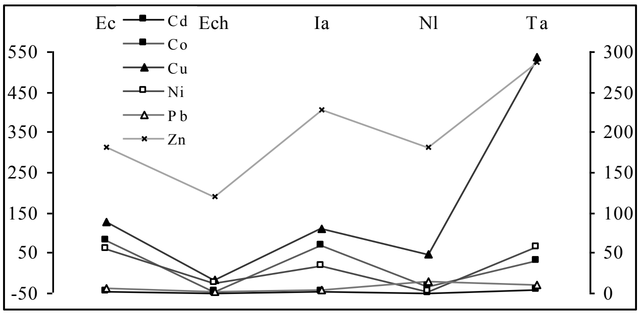

Figure 3. Mean concentration (ppm) of six heavy metals in roots of five plant species from PCR.
(Ec= *Eichhorniacrassipes*, Ech= *Echinochloa colonum*, Ia= *Ipomoea aquatica*, Nl= *Nelumbo nucifera*, Ta= *Typha angustata)*

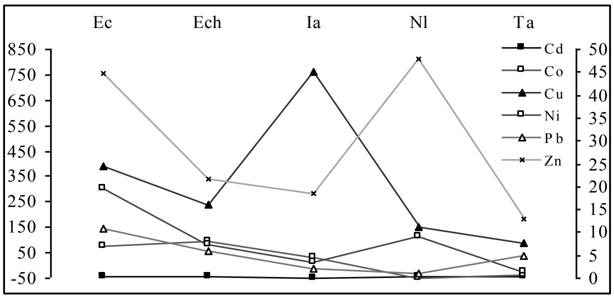

Figure 4. Mean concentration (ppm) of six heavy metals in stems of five plant species from PCR.
(Ec= *Eichhornia crassipes*, Ech= *Echinochloa colonum*, Ia= *Ipomoea aquatica*, Nl= *Nelumbo nucifera*, Ta= *Typha angustata)*

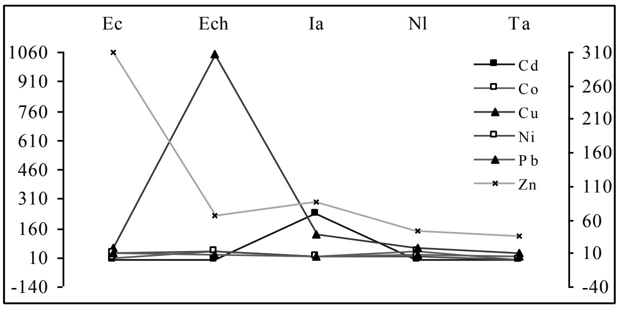

Figure 5. Mean concentration (ppm) of six heavy metals in leaves of five plant species from PCR.
(Ec= *Eichhornia crassipes*, Ech= *Echinochloa colonum*, Ia= *Ipomoea aquatica*, Nl= *Nelumbo nucifera*, Ta= *Typha angustata*)

Root heavy metal accumulators: *T. angrustata*, *I. aquatica*, *N. nucifera*
Stem heavy metal accumulators: *E. crassipes*, *I. aquatica*, *N. nucifera*
Leaves heavy metal accumulators: *E. crassipes*, *I. aquatica*, *E. colonum*

Heavy Metal Accumulation in Plants

The heavy metal analysis of roots, stems and leaves of aquatic native plants: *E. crassipes*, *E. colonum*, *I. aquatica*, *N. nucifera* and *T. angustata* from PCR were carried out. Besides *H. verticillata* and *V. spiralis* were analysed intact without sorted into different parts due to their incoherent phenophases. Compared to the standard, normal and critical toxicity range of metals (Kabata-Pendias and Pendias, 1992) in selected plants, the accumulation of Cd and Pb were observed within normal ranges, while that of Co and Ni were registered within the critical range. However, Zn and Cu showed the greater accumulation with alarming toxicity levels, which is considered to be the hazardous pollutants in PCR (Table 4).

Comparing with standard normal ranges in plants, the mean concentrations of Cd and Pb fall within the normal range. All values of Cd (0.15-23.83 ppm) and Pb (4.47-82.40 ppm) fall within the standard normal range in studied plants, whereas Co (3.09-25.75), Ni (4.10-28.83 ppm), Cu (16.32-1617.21 ppm) and Zn (253.25-709.07 ppm) were recorded within critical ranges. Compared with the standard critical range of Zn, a critical amount was encountered in roots of *E. crassipes* (522.61 ppm), in stems of *N. nucifera* (812.29 ppm) and in leaves of *E. crassipes* (1059.67 ppm). Thus, Zn seems to be hazardous metal in PCR, since it reached considerable high concentration.

Applying unilateral F-test on the accumulation of each metal separately in roots, stems and leaves, it is clearly evident that the accumulation of heavy metals is more significant for Zn followed by Cu, Pb, Ni, Co and Cd.

Metal:	Zn	Cu	Pb	Ni	Co	Cd
F-value:	0.579	0.132	0.030	0.002	0.001	0.001

Gradient of Heavy Metals in Root, Stem and Leaf Systems

The output of Pearson correlation coefficient (r) analysis on combinations of different metal-pairs which are present together in either roots, stems or leaves of the tested plant species showed medium correlation (r = 0.5-0.7) between only a single metal pair (Cu and Co) and high correlation (r = 0.7-0.9) between Ni and Zn, Zn and Pb, Cu and Ni, and Ni and Co metal pairs (Table 5). Thus, results indicate that both roots and stem systems may have a kind of natural controlling mechanism regarding the quantity of specific metals taken from the ambient environment, but they don't have controlling mechanism to suppress the combination between specific metal pairs in their tissues / components (Ravera *et al.*, 2003).

Study revealed the transport mechanism of metals from abiotic environment (sediment) to biotic environment (macrophytes) and their accumulation in various parts. The transport mechanism and accumulation pattern of heavy metals can be elaborated as follows: Sediment > Root system > Stem system > Leaf system (Figure 6).

The accumulation of heavy metals by various species in order is as follows:

Zn – *E. crassipes* > *H. verticillata* > *N. nucifera*
Cu – *V. spiralis* > *T. angustata* > *N. nucifera*
Pb - *V. spiralis* > *T. angustata* > *N. Nucifera*

Discussion

The present study exhibited different heavy metal concentrations in aquatic plants, depending on the plant organ. Roots of aquatic plants absorb heavy metals from the sediments and accumulate high concentrations (Baldantoni *et al.*, 2004). Similarly our findings revealed the high accumulation of heavy metals registered in roots of *T. angustata* and *I. aquatica*. The stems and/or leaves of submerged plants accumulated lower concentrations of trace elements than roots, which is well substantiated with the findings of Baldantoni *et al.* (2005). Thus, among the selected plant species, *T. angustata* and *I.*

Table 4. Ranges of heavy metals contents and toxicity status in the tested plant species, compared with normal and critical ranges in plants

Metal	Mean Range in tested plants (ppm)	Normal range in plants (ppm)*	Critical range in plants (ppm)*	Toxicity status
Cd	0.15-23.83	0.1-2.4	10-30	Normal
Co	3.09-25.75	0.75-1.07	1-8	Critical
Cu	16.32-1617.21	7.53-8.44	25-90	Critical
Ni	4.10-28.83	0.89-2.04	10-50	Critical
Pb	4.47-82.40	0.2-20	30-300	Normal
Zn	253.25-709.07	1-400	100-400	Critical

* Data after Kabata-Pendias and Pendias (1992)

Table 5. Correlation coefficient between concentrations of heavy metal-pairs in root, stem and leaf systems of plant species

Analysis metal-pair	Correlation Coefficient (r)		
	Root system	Stem system	Leaf system
Zn x Cd	0.860	0.411	-0.111
Cu x Cd	0.987	-0.360	-0.171
Ni x Cd	0.791	0.713	-0.179
Ni x Zn **	0.635	0.798	0.479
Co x Cd	0.422	0.151	-0.059
Pb x Cd	0.136	0.851	-0.422
Zn x Cu	0.887	-0.140	-0.200
Zn x Co	0.512	-0.063	-0.291
Zn x Pb **	0.392	0.175	0.873
Cu x Ni **	0.719	0.023	0.742
Cu x Co *	0.349	0.400	0.617
Cu x Pb	0.284	-0.047	-0.119
Ni x Co **	0.822	0.441	0.497
Ni x Pb	-0.103	0.708	0.521
Co x Pb	-0.100	0.631	0.050

* Medium Correlation (r = 0.5 - 0.7), ** High Correlation (r = 0.7 - 0.9).

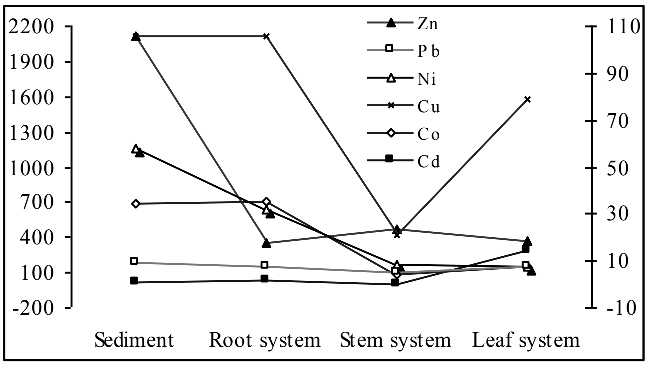

Figure 6. Mean concentration (ppm) of six heavy metals in sediment and plan parts from PCR.

aquatica appear to be the best monitoring species due to their availability in PCR.

The accumulation of heavy metals (in sediments and plant components) could be arranged in descending order as follows: Zn > Cu > Pb > Ni > Co > Cd, which was based on the degree of toxicity status induced heavy metals in plants as well as sediments: Zn > Cu > Pb. The above sequence agrees with the findings of Ramdan (2003) and Siegel *et al.* (1994) in Lake Manzala, Nile Delta, Egypt. The ratio of heavy metals was two times higher in the sediments than in selected macrophytes. This also agrees with findings of Ramdan (2003). Accordingly, the component systems of aquatic macrophytes in PCR could be arranged in following order based on their accumulation capacity of heavy metals as: Sediment > Root system > Stem system > Leaf system. Similarly, Lovett-Doust *et al.* (1994) reported that the accumulation levels of pollutants in aquatic ecosystems might be higher in sediments than in plants. The high level of Zn and Cu, an important source of contamination in the lake, might be due to agricultural run-off on sediments in the reservoir, carrying various Zn and Cu-based pesticides used in agricultural practices. This largely agrees with findings of Jones *et al.* (1991) in Lake Averno, and Siegel *et al.* (1994) in Ginka sub-basin, south of Lake Manzala.

Hence, it can be concluded that three native aquatic plant species *T. angrustata*, *E. crassipes* and *I. aquaitca* accumulated heavy metals in much higher concentrations. Perhaps, it might be the reason that these three species are more efficient in uptake of heavy metals. Therefore, these macrophytes could be used as 'phytoremediants' compared to other native aquatic macrophyte species.

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References

Allen, S.E. 1989. Chemical Analysis of Ecological Materials. 2nd Ed. Blackwell Scientific Publications. Oxford, 368 pp.

Baldantoni, D., Alfani, A., Di Tommasi, P., Bartoli, G. and De Santo, A. 2004. Assessment of macro and microelement accumulation capability of two aquatic plants, Env. Poll., 130: 149-156.

Baldantoni, D., Maisto, G., Bartoli, G. and Alfani, A. 2005. Analyses of three native aquatic plant species to assess spatial gradients of lake trace element contamination, Aqua. Bot., 83: 48-60.

Chaphekar, S.B. 1991. An overview on bioindicators, J. Env. Biol., 12: 163-168.

De Bortoli, M., Gaglione, P., Malvicini, A. and Polvani, C. 1968. Concentration factors for strontium and caesium in fish of the lakes in the region of Varese (Northern Italy), Giorn. Fisica Sanit. Radioprot., 12: 324-331.

Dunbabin, J.S. and Bowmer, K.H. 1992. Potential use of constructed wetlands for treatment of industrial wastewaters containing metals. Sci. Total Environ., 111: 151-168.

GSFD, 2005. Six wetlands now at par with Chilka. A Proposition by Chief Wildlife Warden, Gujarat State Forest Department, Gandhinagar, Gujarat, India.

Jackson, L.J. 1998. Paradigms of metal accumulation in rooted aquatic vascular plants, Sci. Total Env., 219: 223-231.

Jones, R., Chambers, F.M. and Benson-Evans, K. 1991. Heavy metals (Cu and Zn) in recent sediments of Ilangrose Lake, Wales: non-ferrous smelting, Napoleon and the price of wheat – a plaeoecological study, Hydrobiol., 214: 149-154.

Kabata-Pendias, A. and Pendias, H. 1992. Trace Elements in Soils and Plants. 2nd edition. CRC Press, Boca Raton, Fla.

Koning, F.J. and Koning-Raat, M.J. 1975. IWRB Mission to India. January/February 1975. International Waterfowl Research Bureau, Unpublished Report, Slimbridge, United Kingdom.

Lovett-Doust, J., Schmidt, M. and Lovett-Doust, L. 1994. Biological assessment of aquatic pollution: A review with emphasis on plants as biomonitors, Biol. Rev., 69: 147-186.

MoEF 2005. Gujarat: Six new 'Wetlands of National Importance, Prot. Area Update, 54: 6.

Nirmal Kumar, J.I., Soni, H. and Kumar, R.N. 2006. Biomonitoring of selected freshwater macrophytes to assess lake trace element contamination: A Case Study of Nal Sarovar Bird Sanctuary, Gujarat, India, J. Limnol., 65(1): 9-16.

Nirmal Kumar, J.I., Sreenivas, S. and Rana, B.C. 1989. EDAX- analysis of mud of four ponds from Central Gujarat, Ind. Bot. Cont., 75-76.

Norusis, M.J. 1993. SPSS for Windows Professional Statistics 6.1. SPSS Inc., Chicago.

Pip, E. and Stepaniuk, J. 1992. Cadmium, copper and lead in sediments and aquatic macrophytes in the Lower Nelson River System., Manitoba, Canada, Interspecific differences and macrophyte – sediment relations. Arch. fur Hydrobiol., 124: 337-355.

Ramdan, A.A. 2003. Heavy metal pollution and biomonitoring plants in Lake Manzala, Egypt, Pak. J. Biol. Sci., 6(13): 1108-1117.

Rana, B.C. and Nirmal Kumar, J.I. 1988. Energy Dispersal Analysis of X-rays of certain aquatic macrophytes, Ind. J. Weed Sci., 20: 46-49.

Ravera, O., Cenci, R., Beon, G.M., Dantas, M. and Lodigiani, P. 2003. Race element concentrations in freshwater mussels and macrophytes as related to those in their environment, J. Limnol., 62(1): 61-70.

Saison, C., Schwartz, C. and Morel, J.L. 2004. Hyperaccumulation of metals by *Thlaspi caerulescens* as affected by root development and Cd-Zn/Ca-Mg interactions', Int. J. Phyto., 6(1): 49-61.

Scott, R. 1989. The Asian Directory of Wetlands. IUCN, Switzerland, Glands, 1181 pp.

Shah, G.L. 1978a. Flora of Gujarat State. Vol. I. University Press, S. P. University, Vallabh Vidyanagar, Gujarat, India.

Shah, G.L. 1978b. Flora of Gujarat State. Vol. II. University Press, S. P. University, Vallabh Vidyanagar, Gujarat, India.

Siegel, F.R., Slaboda, M.I. and Stanely, D.J. 1994. Metal pollution loading, Manzalah Lagoon, Nile delta, Egypt: Implications for aquaculture. Env. Geol., 23: 89-98.

Sinicrope, T.L., Langis, R., Gersberg, R.M., Busnardo, M.J. and Zedler, J.B. 1992. Metal removal by wetland mesocosms subjected to different hydroperiods, Ecol. Eng., 1: 309-322.

St-Cyr, L. and Campbell, P.G.C. 2000. Bioavailability of sediment-bound metals for *Vallisneria americana* Michx, a submerged aquatic plant, in the St. Lawrence River, Canadian J. Fish. Aqua. Sci., 57: 1330-1341.

Van Der Ven, J. 1987. Asian Waterfowl 1987: Midwinter Bird Observations in some Asian Countries. International Waterfowl Research Bureau, Slimbridge, United Kingdom.