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Biotransportation of Heavy Metals in *Eichhornia crassipes* (MART.) Solms. Using X-Ray Fluorescence Spectroscopy

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ABSTRACT

Biomonitoring study of heavy metals was done at pilgrimage freshwater ecosystems of Central Gujarat, India, to ascertain the degree of 17 metals. The study focused on the assessment of available metals in *Eichhornia crassipes* (Mart.) Solms., collected from sacred palustrine habitat (Dakor Sacred Wetland – DSW) of Gujarat, to be used as a biomonitor (active) species, in comparison with sediment (abiotic monitor) for metal pollution. The results were obtained by analyzing elemental composition of rhizome, tuber, stem and leaves of native aquatic freshwater macrophyte (*Eichhornia crassipes*) along with bottom sediments for 17 heavy metals (Ti, Cr, Mn, Fe, Ni, Cu, Zn, Br, Rb, Sr, Y, Zr, Nb, Ba, Pb, Sm, Ir) using Wavelength Dispersive X-Ray Fluorescence (WD-XRF) (Omania Software). The highest concentrations were observed in rhizome (12) in assay species of aquatic macrophyte, followed by tuber and stem (10 each), and least content was observed in leaf (8). Toxic heavy metals (Ti, Mn, Fe, Zn, Br, Sr, Zr, Pb) were detected, prone to cardiac, respiratory, musculo-skeletal and hepatic interferences in indigenous human clusters in and around studied wetland. *Eichhornia crassipes* was proved to be the best phytoaccumaltor species for heavy metals, exhibited by highest translocation factor for Zn, Sr, Zr, and Pb, and bioaccumulation factor for Mn, Rb, Sr and Fe metals. Present research indicates that *E. crassipes* (Mart.) Solms. is better remediator species for mobility of Pb, Zr and Sr metals. Thus, *Eichhornia crassipes* can be used for an effective abatement of contaminated aquatic sites.

Key words: Eichhornia crassipes; Elemental composition; Translocation factor; Bioaccumulation factor; Mobility index.

INTRODUCTION

Aquatic macrophyte are aquatic plants growing in or near shores; extremely important components of biotic communities; essential for oxygen production, nutrient cycling, water quality control, and sediment stabilization. They provide favourable habitats and shelters for aquatic life; considered as efficient accumulators of heavy metals and minerals (Vardanyan and Ingole, 2006). Due to these characteristics, such plants can be used successfully as biological monitors and accumulators of aquatic environments contaminated with metals. Metal pollution is very stern problem due to their non-biodegradable and hazardous nature, having momentous bioaccumulation capacity in living tissues of plants and animals (Tsekova, 2010). Point and non-point deposits of contaminants magnify the concentrations of meager elements in aquatic bodies, resulting in their sporadic accretion in sediments (Dunbabin and Bowmer, 1992). Aquatic macrophytes accumulate elements in roots and shoots (Pip and Stepaniuk, 1992; Jackson, 1998). Aquatic plants exhibit diverse behavior in context of their ability to mount up the elements in roots, stems, and leaves. In aquatic ecosystems, pollutant loads are erratic and are rapidly diluted, plant tissue analysis provides time-integrated information about the quality of the ecosystem (Baldantoni *et al*., 2005). Now-a-days, various types of methods are used to lessen the unwarranted heavy metals from aqueous environ, which are sometimes unproductive or costly when heavy metals exist in momentous concentration (Ahluwalia and Goyal, 2007). Phytoremediation (biomonitoring) is an effectual, inexpensive, and preferred clean-up method to be used at moderately contaminated habitats; using selective aquatic plant species for gradient accumulation of heavy metals (Szymanowska *et al*., 1999; Demirezen and Aksoy, 2004; Deng *et al*., 2004; Vardanyan and Ingole, 2006). The increase of environmental problems and paucity of heavy metal pollution studies make the important asset to find autochthonous species capable of cleaning up aquatic environments contaminated by metals.

In past, researchers carried out biomonitoring study of heavy metals uptake by aquatic macrophytes at selected freshwater ecosystems of Gujarat (Nirmal *et al*., 2006; 2007; 2008; 2012). Moreover, previous studies focusing on profile of abiotic and biotic components of Dakor Sacred Wetland (DSW) was investigated by Soni and Thomas (2013 abcde; Thomas and Soni, 2013). However, the present study site (DSW) has not been focused to study elemental profile and biomonitoring of heavy metals and minerals in aquatic macrophyte (*E. crassipes*) yet. Hence, an attempt was made to assess the potential of *E. crassipes* to accumulate available heavy metals (17) in different plant-parts, using Wavelength Dispersive X-Ray Fluorescence Spectroscopy (WD-XRF, AxiosMAX, PANalytical, Netherland).

MATERIALS AND METHODS

Study Area

Dakor Sacred Wetland (DSW), District Anand, Central Gujarat, India (22.75^0 N, 73.15^0 E), falls in 4-B Gujarat-Rajwara, the semi-arid lands of Gujarat (Rodgers and Panwar, 1988). Average elevation of area is 49 meters (~160 feet) above msl; temperature ranges from lowest 12 ^{0}C (Winter) to highest 34 ^{0}C (Summer). According to 2001 census, the human population of Dakor is around 23,784 with an average literacy rate of 76%. More than 70-80 lakh devotees visit the shrine every year (Figure 1, Table 1).

Water and Sediment Sampling

Surface water and composite sediment samples were taken from transactional regime of the study area in the month of October, 2014. Surface water samples were samples in pre-cleaned polyethylene bottles (two litres), filtered using 0.45µ filters, preserved by addition of few drops of Conc. HNO_3, and stored in icebox at -4 ^{0}C, brought to the laboratory for analysis. Composite sediment samples were taken from the pond using grab sampler,

Table 1: Site fidelity of Dakor Sacred Wetland (DSW), Gujarat, India

Site fidelity of Dakor Sacred Wetland (DSW), Gujarat, India	
Coordinates	22.75^{0}N, 73.15^0 E
Biotic Province	4-B Gujarat-Rajwara (Semi-Arid Ecosystem)
Area (ha)	232
Wind Direction	South-East
Shape	Ovo-ellispoidal
Maximum Depth (ft)	28
Average Depth (m)	18
Mean Temperature (^{0}C)	27
Average Rainfall (cm)	95
Wind Velocity (kmh^{-1})	5
Average Humidity (%)	43
Phytoplankton	75*
Zooplankton	52*
Aquatic Macrophyte	18*
Waterfowls	88#
Fish	12#
Herpetofauna	14#
Mammals	10#
Significance	Renowned Hindu Pilgrimage Spot
Recreational Activities	Fishing, Boating, Horse Riding
Anthropogenic Threats	Cutting, Uprooting, Lopping, Thatching, Roofing, and Trading of Aquatic Plants Hunting and Poaching of Indian Flap Shell Turtle *Lyssemis punctata*)

* Soni and Thomas (2013 ac); # Singh *et al*. (2002)

preserved on-site in air-dried polyethylene bags, labeled carefully, and brought to the laboratory (Trivedy and Goel, 1986; Maiti, 2003; APHA, 2012).

Plant Sampling

For the present study, the native aquatic macrophyte *Eichhornia crassipes* (Mart.) Solms. was selected as an active biomonitor species for the elemental composition (Ti, Cr, Mn, Fe, Ni, Cu, Zn, Br, Rb, Sr, Y, Zr, Nb, Ba, Pb, Sm, Ir) in different plant-parts (rhizome, tuber, stem, leaves). Healthy aquatic plant individuals were collected from 0.5-1.0m depth, washed with pond water to remove unwanted elements. The plant-parts were kept in zipped air-tight moisture-ridden polyethylene bags, and analyzed in laboratory for elemental composition (Figures 2ab). To avoid metal contamination in collected samples, polythene objects were used (Allen, 1989). Plant species was identified on-site, and were further authenticated referring standard published literature (Shah, 1962; Biswas and Calder, 1994).

Laboratory Work

Chemical Analysis of Water, Sediment, and Plant

Sediment samples were air-dried, sieved using 2 mm sieve, and analyzed in WD-XRF, AxiosMAX, PANalytical, Netherland. The selected plant species was cleaned using double ionized water, and sorted into different plant-parts: rhizomes, tuber, stem, and leaves. The 50g of each fresh sample was dried at 80 ^{0}C in hot air oven for 48 hrs. The samples of sediment and plant-parts were analyzed for detection of heavy metal concentrations (as listed earlier). For this, five grams of dry powder of both samples was weighed. Before analysis, samples were treated by preparing a mixture of powdered samples and Boric Acid (H_3BO_3). Later, treated samples were converted into powder pellets using high pressure of 20 tones for 20 seconds with the help of hydraulic pressure. The elements were analyzed using Wavelength Dispersive X-Ray Fluorescence Spectroscopy (WD-XRF, AxiosMAX, PANalytical, Netherland), embodied with scintillation and flow counter detectors, and ultra-thin X-ray tube

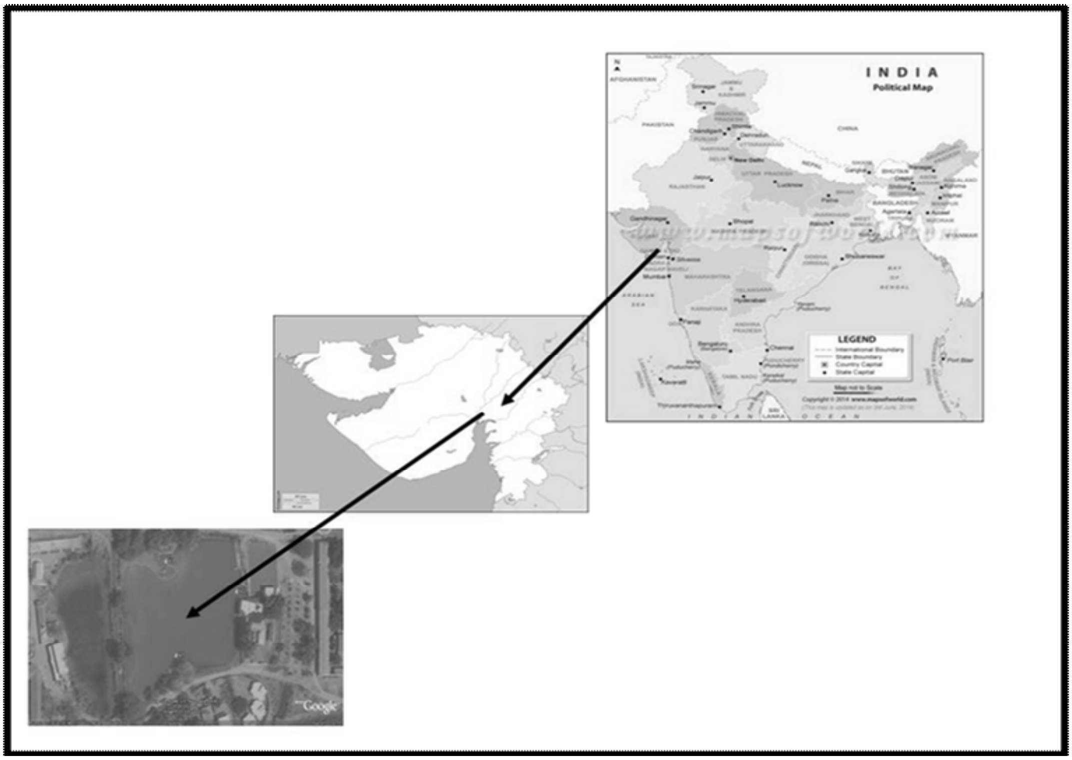

Fig. 1: Holistic View of Dakor Sacred Wetland (DSW), Central Gujarat, India

using Standard Less Omnian Software (Epsilon 3^{X}) at Sophisticated Instrumentation Centre for Applied Research and Testing (SICART)**,** Vallabh Vidyanagar, Gujarat, India. The heavy metals concentration was determined and expressed in percentage (%).

Data Analysis

Elemental composition was ere evaluated for both sediment and plant-parts. Pearson correlation coefficient (r) was derived for plant parts-pairs to speculate the differences between elemental combinations in rhizome, tuber, stem and leaf system. The obtained values were analyzed statistically using Paleontological Statistical Software (PAST, Version 3.04, USA). Furthermore, Translocation factor (TF) [ratio of shoot to root metal concentration] was used as an indicator of the internal metal transport system from root to shoot systems (Deng *et al.*, 2004). TF > 1 indicates the efficiency of plant to translocate the metals from root to shoot (Stoltz and Greger, 2002). Bioaccumulation factor (BAF) [level in root / labile metal level in Near Root Sediment (NRS)]

Fig. 2a: On-field sampling

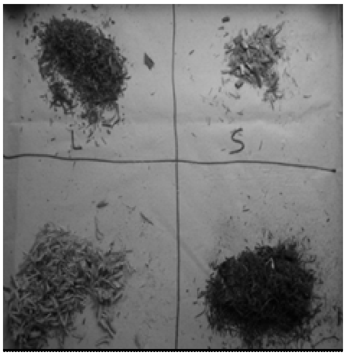

Fig. 2b: Sample preparation

Table 2a: Heavy metals composition in plant-parts of *Eichhornia crassipes*

Heavy Metals	Leaf	Stem	Tuber	Rhizome
Titanium (Ti)	0.050	0.032	0.233	0.192
Chromium (Cr)	-	-	0.006	0.005
Manganese (Mn)	0.028	0.026	0.012	0.186
Iron (Fe)	0.166	0.174	0.108	2.627
Nickel (Ni)	-	-	0.004	-
Copper (Cu)	-	0.026	-	0.009
Zinc (Zn)	0.009	0.140	0.009	0.014
Bromine (Br)	0.003	0.004	0.003	0.005
Rubidium (Rb)	-	-	-	0.006
Strontium (Sr)	0.023	0.047	0.023	0.025
Yttrium (Y)	-	-	-	0.001
Zirconium (Zr)	0.004	0.007	-	0.007
Niobium (Nb)	-	-	0.002	-
Barium (Ba)	-	0.017	-	-
Lead (Pb)	0.127	0.008	0.013	0.008

* Values are expressed in %age

was calculated to evaluate the ability of plant for accumulating metals from the substrate**.** Mobility index (MI) was derived at each level as below:

$$\text{Mobility Index (MI)} = \frac{\text{Concentration of metals in receiving level}}{\text{Concentration of metal in source level}}$$

Mobility index depicts biomobility and transport of heavy metals through plant-parts, and is necessary to understand the transport mechanism of metals and minerals in different plant components (rhizome, stem, leaves) (Kuntal and Reddy, 2014).

RESULTS

Elemental Analysis

To check the elemental composition and biomonitoring of heavy metals, *Eichhornia crassipes* (Mart.) Solms. was selected as an active biomonitor species in studied wetland. Of 17 heavy metals reported in studied macrophyte, 15 were listed in macrophyte, and 11 in sediments. In macrophyte (whole plant), the maximum concentration of Fe (1.537%) was reported, while Y (0.001%) was accumulated in least content. In sediment, Fe (4.371%) showed its maximum concentration, with minimum concentration of Nb (0.004 %). Comparing the results obtained from various plant-parts of studied species, rhizome was found to accumulate the maximum content of heavy metals (12), followed by tuber and stem (10 each), and the least (8) was noticed in leaves. Of the 12 metals in rhizome, maximum amount of Fe (2.627 %) was observed, while Y (0.001%) was accumulated in least content. In tuber and stem, highest concentration was noted in case of Ti (0.233%) and Fe (0.174%), respectively, whereas the lowermost concentration was observed for Nb (0.002%) and Br (0.004%), respectively. In leaves, Fe (0.166%) was accumulated more effectively, with least content of Ti (0.051%). The accumulation trend clearly depicts that Fe is effectively transported through all the plant systems, and *E. crassipes* to be the best candidate for remediation of Fe from the polluted aquatic substrates (Tables 2ab).

Table 2b: Heavy metals composition in *Eichhornia crassipes* and Sediment

Metals	Sediment	Whole Plant
Ti	0.662	0.253
Cr	0.058	0.011
Mn	0.069	0.126
Fe	4.371	1.537
Ni	0.018	0.004
Cu	-	0.0175
Zn	-	0.086
Br	-	0.0075
Rb	0.011	0.029
Sr	0.026	0.0485
Nb	0.004	0.002
Y	-	0.001
Zr	0.032	0.009
Ba	-	0.0175
Pb	-	0.078
Sm	0.039	-
Ir	0.013	-

* Values are expressed in %age

Heavy Metals Analyses (Sediment and Plant)

Of the 17 heavy metals, eight metals were common both in sediment as well studied plant. The content of heavy metals was more (1.032 %) in rhizosphere than freshwater dominant macrophyte (*Eichhornia crassipes*) (0.135 %) in the waters of DSW (Dakor Sacred Wetland), Central Gujarat, India. Overall, eight metals (Ti, Mn, Fe, Zn, Br, Sr, Zr, Pb) were common in whole plant as well as sediment. Of which, three metals (Zn, Br, Pb) were found to be

Table 3: Difference of heavy metals composition in *Eichhornia crassipes* and Sediment

Heavy Metals	Sediment	Whole Plant	Difference
Ti	0.662	0.127	0.535
Mn	0.069	0.016	0.053
Fe	4.371	0.135	4.237
Zn	-	0.721	NA
Br	-	0.008	NA
Sr	0.026	0.020	0.007
Zr	0.032	0.015	0.017
Pb	-	0.039	NA
Mean	1.032	0.135	0.062

* Values are expressed in %age

exclusive elements in *E. crassipes*. Of the reported metals, five metals (Ti, Mn, Fe, Zr, Sr) were found to be common. Among all, the most abundant metal was Zn (0.721%) in macrophyte, with more content of Fe (4.371%) in sediment, while Br (0.008%) was noticed to be minimally concentrated in studied plant, with Sr (0.026%) in sediment. Some metals (Ti, Mn, Zr, Pb) exhibited plummeting trend in both substrates (plant and sediment). Of the reported heavy metals, the overall concentration of heavy metals (0.062%) was more in sediment compared to the studied plant species (Table 3).

Heavy Metals Analyses (Plant-parts)

The metal profile in different plant-parts (roots, stems, leaves) of *Eichhornia crassipes* at DSW was extrapolated. For metal analyses, the studied plant was kept intact (without sorted into plant-parts) as it was in vegetative phase during the post-monsoon period (October, 2014). In total, eight heavy metals (Ti, Cr, Mn, Fe, Zn, Br, Sr, Zr, Pb) were analyzed in plant-parts of studied plant by WD-XRF (Table 4, Figures 3 ab).

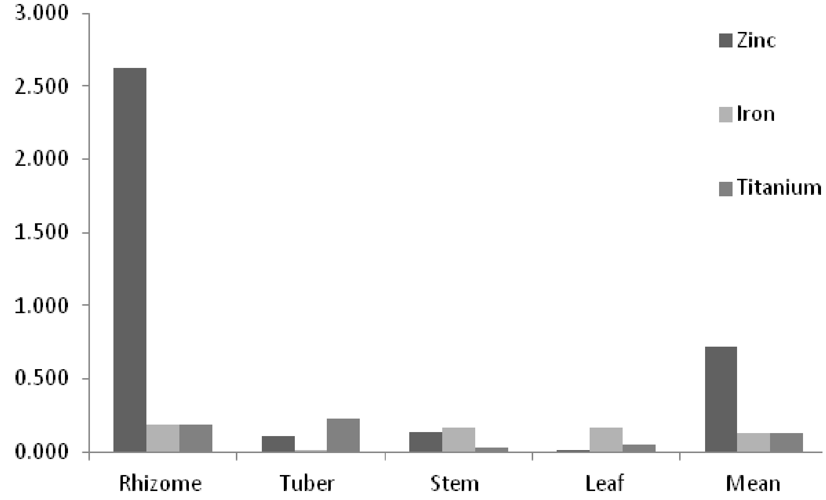

Fig. 3a: Heavy metal concentration in *Eichhornia crassipes*

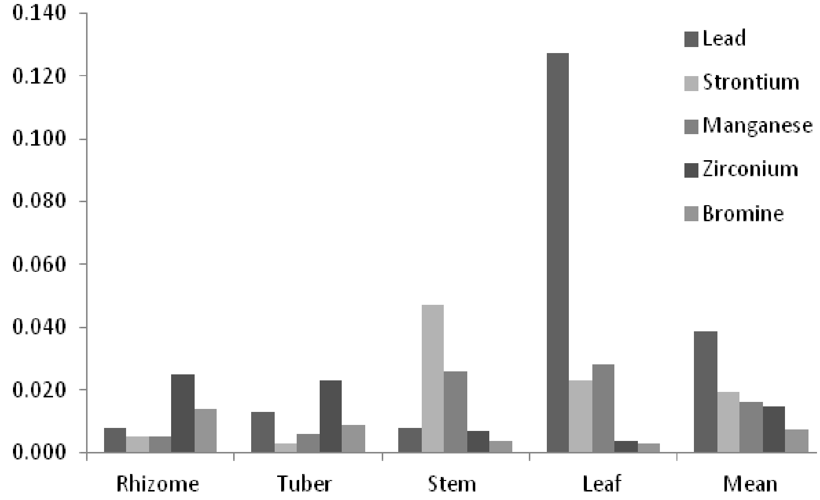

Fig. 3b: Heavy metal concentration in *Eichhornia crassipes*

Overall Chain of Transport Mechanism

Eichhornia crassipes exhibited the maximum positive correlation (*r* = 0.431-0.574) between stem-rhizome (S-R) and stem-leaf (S-L) systems. Metal translocation from rhizome to tuber, and tuber to stem showed moderate positive correlation (r = 0.080-0.339), whereas leaf to tuber (L-T) and leaf to rhizome (L-R) exhibited negative correlation. Thus, the chain of metal transport mechanism in *E. crassipes* is Sediment > Rhizome > Tuber > Stem > Leaf (Table 5).

Translocation of Heavy Metals

The accumulation of heavy metals in root system of *E. crassipes* was more (0.383%) compared to other plant parts. Roots of *E. crassipes* were exhibiting more cumulative and significant association of Zn and Pb. Therefore, the studied macrophyte presents an exclusion strategy for these heavy metals. The gradient of Translocation Factor (TF) of heavy metals in experimental macrophyte was receded as: Zn > Pb > Mn > Sr > Fe > Zr > Ba > Ti > Cu, indicating contributory role of *E. crassipes* in refining the water quality at source level (Table 6, Figure 4).

Br and Ba concentrations showed congruent symmetry in shoots (0.007 and 0.017) and roots (0.007 and 0.018), their Translocation Factor (TF) signifies a transference of metals from underground (root system) to aboveground (shoot system) tissues. Br and Ba ions are readily taken up by roots, and translocated into leaves in many plant species (Demirezen and Aksoy, 2004).

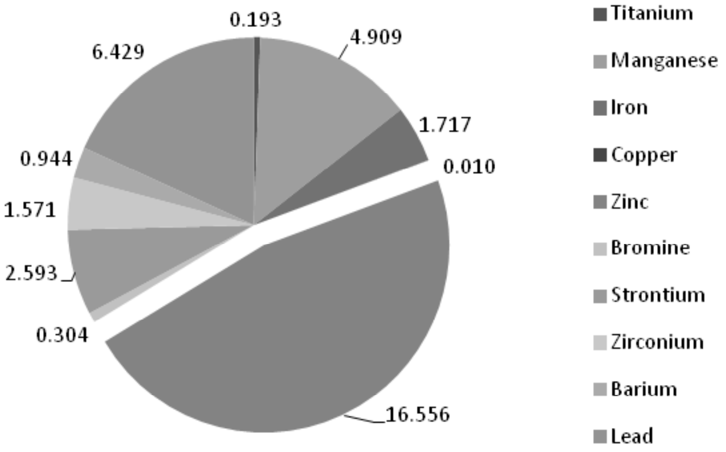

Fig. 4: Translocation factor (TF) in *Eichhornia crassipes*

Table 4: Descriptive statistics of heavy metal concentration in *Eichhornia crassipes* (Part-wise)

Metals	Leaf	Stem	Tuber	Rhizome	Mean	Median	S.D.	Skewness
Ti	0.050	0.032	0.233	0.192	0.234	0.192	0.255	1.613
Mn	0.028	0.026	0.006	0.005	0.027	0.026	0.026	1.332
Fe	0.166	0.174	0.012	0.186	0.982	0.174	1.896	2.228
Zn	0.009	0.140	0.108	2.627	0.721	0.124	1.272	1.988
Br	0.003	0.004	0.009	0.014	0.008	0.007	0.005	0.738
Sr	0.023	0.047	0.003	0.005	0.021	0.023	0.018	0.619
Zr	0.004	0.007	0.023	0.025	0.018	0.023	0.012	-0.285
Pb	0.127	0.008	0.013	0.008	0.039	0.011	0.059	1.990

* Values are expressed in %age.

Bioaccumulation factor (BAF)

Bioaccumulation factor (BAF) [Metal level in underground tissues / Metal level in Near Root Sediment (NRS)] was pooled to assess the capability of *E. crassipes* for uptake of heavy metals from the surrounding sediment source. BAF of heavy metals in experimental plant showed receding trend as: Mn > Rb > Sr > Ti > Fe > Nb > Zr > Cr. This reflects the tendency of *E. crassipes* to bioconcentrate heavy metals independently and directly from the water.

The value of BAF more than 1 indicates that plants are enriched by particular elements (accumulators), while around 1 indicates a rather indifferent behavior of the plant towards these elements (indicators), and a ratio < 1 clearly shows that the plant exclude these elements from uptake (excluders) (Chamberlain, 1983). In studied plant, the value of BAF was observed (> 1). Thus, *E. crassipes* has been found as a better phytoaccumulator species for toxic heavy metals (Mn, Rb, Sr). Bioaccumulation factor (BAF) less than 1 was observed in case of Cr, Zr, Nb, Fe and Ti, indicating a better excluder for the above stated heavy metals (Table 7, Figure 5).

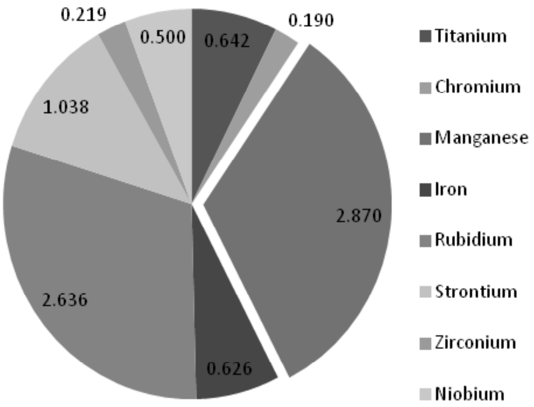

Fig. 5: Bioaccumulation factor (BAF) of *Eichhornia crassipes*

Table 5: Pearson Correlation Coefficient (r) (Part-wise)

Plant-PartsPair	Pearson Correlation Coefficient (r)
Leaf x Stem	0.431
Leaf x Tuber	-0.121
Leaf x Rhizome	-0.233
Stem x Tuber	0.080
Stem x Rhizome	0.574
Tuber x Rhizome	0.339

Mobility of Metals

Mobility index (MI) showed biomobility and translocation of heavy metals at different levels: Level 1 (Sediment-Rhizome), Level 2 (Rhizome-Tuber), Level 3 (Tuber-Stem) and Level 4 (Stem-leaf) in *E. crassipes.* This becomes essential to apprehend the transport mechanism of heavy metals in macrophyte components of underground and aboveground systems. Present findings revealed that Level 1 (Sediment-Rhizome) was enriched with high mobility rate of Zr (0.781%). In case of Level 2 (Rhizome-Tuber) and Level 4 (Stem-leaf), maximum mobility rate of Pb (1.625% and 15.875%, respectively) was noticed, indicating Pb to be readily and easily remediated by *E. crassipes*. Sr (15.667) was remediated more after entering Level 3 (Tuber-Stem). Thus, higher mobility gradient of heavy metals among various levels can be expressed as: Pb > Sr > Fe > Mn > Ti > Zr > Br > Zn. (Table 8, Figure 6).

Causative Factors of Health Hazards

Five commonly available toxic heavy metals (Ti, Mn, Fe, Zr, Sr) were detected in both the

Table 6: Translocation factor (TF) of heavy metals in *Eichhornia crassipes*

Heavy Metals	Translocation factor(TF)
Ti	0.193
Mn	4.909
Fe	1.717
Cu	0.010
Zn	16.556
Br	0.304
Sr	2.593
Zr	1.571
Ba	0.944
Pb	6.429

* Values are expressed in % age

substrates (plant and sediment), which adversely affect the health of local inhabitants residing nearby localities of DSW due to their erratic and persistent presence in abiotic as well as biotic components of aquatic body. Zn interferes with the gastro-intestinal, haematological and respiratory tract functioning, Ti deteriorates Respiratory system, Mn affects cardiovascular, hepatic, neurological and respiratory mechanisms, Pb interferes with body mechanisms; impairs heart, bones, intestines, kidneys, reproductive and nervous systems; obstructs the development of nervous system, and toxic in children, causing learning and behavioral disorders. The minute concentration of Sr adversely affects the musculo-skeletal systems of the human body (ATSDR, 1995; 1996).

Table 7: Bioaccumulation factor (BAF) of *Eichhornia crassipes*

Heavy Metals	Bioaccumulation factor (BAF)
Ti	0.642
Cr	0.190
Mn	2.870
Fe	0.626
Rb	2.636
Sr	1.038
Zr	0.219
Nb	0.500

* Values are expressed in %age

DISCUSSION

In the present work, the studied aquatic macrophyte *Eichhornia crassipes* (Mart.) Solms. Was found to exhibit heavy metal concentrations in plant-parts (Rhizome, Tuber, Stem, Leaf). Roots of *E. crassipes* absorb heavy metals from the water, and acquire high contents (Baldantoni *et al*., 2005). The current findings depict the high amount of heavy metals in rhizome of *E. crassipes*, and the least contents in leaves. Similar results (low metal concentrations in leaf system) were obtained by Nirmal *et al*. (1989) and Baldantoni *et al*. (2005). Thus, *E. crassipes* was found to be the efficient aquatic species for biomonitoring of heavy metals owing to its availability throughout the year at Dakor Sacred Wetland (DSW). The ratio of overall contents of heavy metals was higher in sediments than macrophyte *E. crassipes* (Ramdan, 2003). Accordingly, the gradient of heavy metals concentration is Sediment > Root system > Stem system > Leaf system. These results reflect that both underground and upper ground systems have natural controlling mechanism for the specific metals absorbed from the proximate environment (Ravera *et al*., 2003). Negative correlation indicates that re-translocation of metals from shoot to root system in *E. crassipes* is not feasible, and the metals absorbed are retained in its plant-parts. This also highlights the overall chain of transport mechanism and accumulation of different metals along the abiotic factor (sediment) and the biotic component (plant).

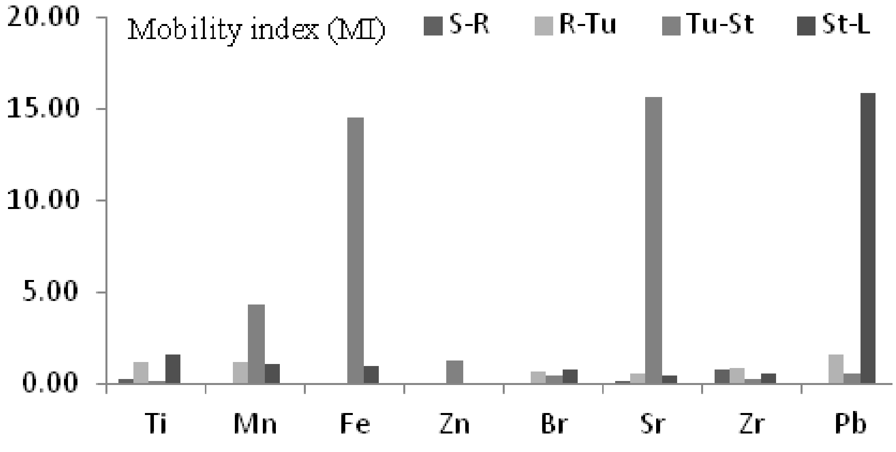

Fig. 6: Mobility index (MI) of *Eichhornia crassipes*

Table 8: Mobility index (MI) ***of Eichhornia crassipes***

Mobility index	S-R	R-Tu	Tu-St	St-L
Ti	0.290	1.214	0.137	1.563
Mn	0.072	1.200	4.333	1.077
Fe	0.043	0.065	14.500	0.954
Zn	BDL	0.041	1.296	0.064
Br	BDL	0.643	0.444	0.750
Sr	0.192	0.600	15.667	0.489
Zr	0.781	0.920	0.304	0.571
Pb	BDL	1.625	0.615	15.875

* S: Sediment; R: Rhizome; Tu: Tuber, St: Stem; L: Leaf

Translocation of heavy metals in different plant-parts clearly indicated that root system of *E. crassipes* accumulates more metals than the above-ground tissues (Dunbabin and Bowmer, 1992; Deng *et al*., 2004), which could be a metal tolerant capacity of the plant (Deng *et al*., 2004), and plants with such capacity are designated as non-accumulator species. Although Br and Ba are not essential for plant (Demirezen and Aksoy, 2004), the present findings depict the translocation and mobility of these metals too effectively by *E. crassipes*. Translocation mechanism of Br and Ba has not been elucidated yet, but its uptake by roots is occurred (probably) *via* a transport system, perhaps with another essential divalent micronutrient (possibly Zn). Bromine (Br) and Barium (Ba) is a chemical analogue of Zn; perhaps the plant could not distinguish between these two ions (Kirkham, 2006). Although *E. crassipes* is a perennial, floating hydrophyte, exhibiting dry phenophase during winter-summer period, it experiences deciduous phenomenon especially in case of shoots. Ba accumulated in the shoot tissues is incorporated to sediments, which could be a detoxification mechanism of plant *E. crassipes*. Thus indicates its more tendency to accumulate the affinity metals (Mn, Rb, Sr), which may be due to high physiological requirement of Mn by the studied plant (Mergler *et al*., 1994; Boucher and Watzin, 1999; Doyle *et al*., 2003). Present research work indicates that *E. crassipes* (Mart.) Solms. could be a better remediator species for uptake of Pb, Zr and Sr. It reveals that sometimes roots act as hurdle to transfer the toxic metals through soil-plant system (Jones and Clement, 1972). Jarvis and Robson (1982) observed the accentuated amount of Zr in root system. Low metal concentration was detected in roots due to high mobility of heavy metals from soil to roots. This indicates the propensity of roots to retain rich amount of metals from soil, and very little is transferred to the above ground system. The results exhibited the conformity with Jarvis *et al*. (1976) and Leita *et al*. (1991). The indigenous species may become lenient to such heavy metals for their metabolize and secretion (Abdel Moati, 1985). The concentrations of heavy metals were much lower in plant tissues of the native aquatic species than sediments. Thus, it is recommended that pollution at Dakor Sacred Wetland (DSW) can be abated effortlessly by preventing the excessive anthropogenic loads through point and non-point sources, and the implementation of sophisticated water purification treatments on the drainage points. On-ground wetland management action plans (WPAPs) should be executed by involving local inhabitants, and with managerial assistance from government and non-government nodal agencies within intensive rehabilitation programs for an effective and effectual management of DSW at regional grass-roots level (Payne, 1991). Owing to the sacred significance contriving with human pressures, rare and threatened biotic components should immediately be saved for preservation of its sanctity. Moreover, the DSW should be declared as a *Sanctum sanctorum* to revive and rejuvenate its prevailing biodiversity not to be deteriorated by momentous anthropogenic interventions.

CONCLUSION

Present study clearly illustrates that *Eichhornia crassipes* (Mart.) Solms. can be signified as the key species (phytoaccumulator and bioaccumulator) for an effective remediation of toxic elements into aquatic environment. Thus, the studied aquatic macrophyte could be used as an active biomonitor plant species to cleanse the contaminated wetlands as it can significantly accumulate, translocate and remediate the perilous heavy metals like Zn, Pb, Mn, Rb, Sr, Fe, Nb, Zr, Ba, Ti, Cu and Cr, thereby aiding in absolute abatement of toxic and obnoxious elemental contamination of aquatic ecosystem.

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