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RESEARCH ARTICLE

POTENTIALS OF AQUATIC MACROPHYTE SPECIES FOR BIOREMEDIATION OF METAL CONTAMINATED WASTEWATER

[1]Shingadgaon, S. S., [1]Jadhav, S.L., [1]Thete-Jadhav, R.B., [2]Zambare, N.S., [3]Daspute-Taur, A.B., [4]Babare, M.G. and [5]Chavan, B.L.

[1]Department of Environmental Science, School of Earth Sciences, Solapur University, Solapur-413255, INDIA
[2]St.Gonsalo Grasia College, Vasai, Dist. Palghar, 401201, MS, India
[3]S.B.E.S. College of Science, Aurangabad-431004, MS, India
[4]Arts, Commerce and Science College, Naldurga, Dist. Osmanabad, 413602 MS, India
[5]Department of Environmental Science, Dr. Babasaheb Ambedkar Marathwada University, Aurangabad-431004 MS, India

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ABSTRACT

The potential ability of aquatic plants naturally grown in marshlands and wetlands receiving municipal sewage from Solapur city were sampled. These macrophytes were exposed to a mixed test bath of metals and examined to know their potentialities to accumulate heavy metals for judging their suitability for phytoremediation technology. Potentialities for metal absorption, accumulation, magnification and enrichment were found to be dependent on the plant species and metal types. The studies were conducted from June 2014 to June 2018. The plant species tested in present investigation for accumulation of heavy metals were *Eichhornia crassipes, Eichhornia azurea, Lemna gibba, Lemna minor, Salvinia molesta, Chara vulgaris, Salvinia auriculata, Pistia stratiotes* and *Ipomoea aquatic* from the group of floating macrophytes, *Ceratophyllum demersum, Potamogeton crispus, Potamogetor pectinatus, Potamogetor perfoliatus, Sagittaria sagittifolia L.* and *Colocasia esculenta* from the group of Submerged macrophytes and *Cyperus esculentus, Typha domingensis, Phragmites australies, Cyprus alopecnroide, Cyperus longus, Echinochloa stagninum, Typha angustifolia L., Typha lotifolia* and *Iris pseudacorus* from the group of Emergent macrophytes. Metals in all species were higher in roots than shoots. The highest level of Fe phyto-absorption was 1475.9 µg/g in *Salvinia auriculata* and 1134.6 µg/g in *Eichhornia crassipes* in the roots whereas the measured lowest level of 0.06 µg/g was observed in the leaves of *Cyprus alopecnroide* species.

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INTRODUCTION

Heavy metal contaminated water is the major environmental problem in most of the areas. It has been increasing with the discharge of wastewater from industries, trade centers and runoff from mining sites in untreated or partially treated forms. They drastically affect health of human being, fauna and flora from the natural ecosystems including agro-ecosystems. Many conventional methods are available, most of these are very expensive, laborious and energy intensive. They don't provide the efficient treatments reducing the desirable pollutants and do not give acceptable results. Phytoremediation can serve as an ecological alternative to the conventional mechanized treatment systems. In recent years, it has gained increased attention of scientific and industrial communities since last decade as an emerging, sustainable, cheaper and simple technology for efficient treatments. The cost effective and environment friendly technology of phytoremediation uses suitable plants to remove heavy metals from wastewater or to it renders them harmless (Wani *et al*., 2017). Phytoremediation is a sustainable, cost effective and novel technique and it is an integrated multidisciplinary approach for the treatment of contaminated wastewaters from any of the sources which provides a great potential to treat such polluted wastewaters in wetland systems using aquatic macrophytes. Therefore, it is essential to assess the potentials of these macrophytes for the screening them to prefer in the treatment technologies efficiently and effectively to meet the treatment needs. The present studies are the efforts in same directions.

EXPERIMENTAL METHODOLOGY

A survey study was undertaken to measure heavy metal contents of various aquatic plant species in Four major water

Corresponding author: **Shingadgaon, S. S.,**
Department of Environmental Science, School of Earth Sciences, Solapur University, Solapur-413255, INDIA

tanks located in and around Solapur city as well as the municipal sewage at Degaon-adjoining area of Solapur, Maharashtra where sewage is perennially available in ponds and is used to irrigate the grass fields after receiving the agricultural runoff water from nearby fields occasionally. Samples of species of aquatic plants which are dominant in Solapur regions were selected according to their availability from major water bodies and wetlands receiving the city sewage. They were water hyacinth *(Eichhornia crassipes),* duck weed *(Lemna gibba),* coontail *(Ceratophyllum demersum),* curly leaf pond weed *(Potamogeton crispus),* cattail *(Typha domingensis),* common reed *(Phragmites australis),* matsedge *(Cyprus alopecuroide),* nutesedge *(Cyprus longus)* and barnyardgrass *(Echinochloa stagninum).* Identification of plant samples was done as described elsewhere on various internet sources. The healthy macrophyte plant samples were collected from Solapur region and adjacent Naldurga of Marathwada region (40 Km from Solapur) in a fresh green condition so that each sample consists of at-least 5 healthy and well grown plants and immediately replanted for acclimatization for adequate period in the rectangular test chambers having the size of 1meter by 1meter with the depth of 10cm of mixed test bath keeping 2 cm free board for floating macrophytes, the same size of experimental set up for emergent for and without leaving the free board for submerged macrophytes by adjusting the volume using addition of sand at the bottom flower. The macrophytes were rarified by the removal of un-healthy and non-acclimatized macrophyte plants. The healthy and acclimatized macrophytes were exposed for the sufficient period till they attain their full growth, preferably of 1 month in a metal-mixed synthetic wastewater test bath of metals using stock standards of concentrations of 100 ppm (mg/L) which was freshly prepared to contaminate the tap water to prepare the synthetic wastewater test bath. The metal salts like $CuS0_4.8H_2O$, PbO, $FeSO_4.7H_2O$, $CdSO_4.8H_2O$ and NH_4SO_4 .$NiSO_4$. $6H_2O$ etc. were used as per known standard procedures (AOAC, 1975; APHA, 1980; Echem, 2014; Smith, 1983). These macrophyte plants were then harvested and examined to know their potentialities to accumulate heavy metals for judging their suitability for phytoremediation technology.

The collected plant materials were rinsed with water, packed in polyethylene bags and these were taken to the laboratory where they were washed with tap water again and rinsed with double distilled water. The macrophyte samples were air dried and cut with stainless steel scissors for separating their shoots and roots in case of *Eichhornia crassipes, Typha domingensis*, Cyprus *alopercuroide* and *Cyprus longus* and roots, stems and leaves as per needs in case of *Phragmites australis*. Samples of other species like *Ceratophyllum demersum*, *Potamogeton crispus* and *Echinochloa stagninum* were composed of only the leafy portion of the macrophyte, with the exception of *Lemna gibba* which has one root suspended in the water. All samples were oven-dried to constant weight at 60°C, powdered in pestle and mortar to get homogenized contents and stored for analysis. For the analysis of metal contents, 500 mg plant material was digested using H_2O_2 and H_2SO_4 and the digested aliquot was analyzed for various heavy metals using suitable methods. Heavy metals from the prepared aliquot were analyzed on AAS or otherwise using different methods from authentic internet sources of research publications owing to suitability and availability of facilities for analysis including methods such as Cobalt by cobaltous pyridine method as described by Nicolaysen (1941) , Iron (Fe) by Dichromate method, Zinc (Zn) by EDTA Complexometry-Back Titration method (Tazul and Ahemad, 2013), Manganese (Mn) by Volhard's method, Copper (Cu) by Sodium Thiosulphate titration method with confirmation by Spectrophotometric method (Ahmed and Zannat, 2012), Lead (Pb) by EDTA Complexometric method, Manganese (Mn) by Periodate Oxidation Method, Chromium by with Diphenylcarbazide Spectrophotometric method (IBM, 2012) Cd by spectrophotometric method (Ahamed and Chowdhury, 2004), Chromium (Cr) by Diphenylcarbazide Method (Yarbro, 1976), Cobalt (Co) by colorimetric method (Hobart ,1920) and were confirmed by random cross check with known Standard methods for analytical simplicity and accuracy as described elsewhere (Bendix and Grabenstetter, 1943; Kimura and Murakani, 1951; Sandall, 1965; Hackley etal., 1968; Loftberg,1969; Rubeska, 1969; Baker *et al*., 1971; James and MacMohan, 1971; Song *et al*., 1976; Sarma *et al*., 2005; Soomro and Menon, 2009; Ahemad and Roy, 1969; Soomro and Shar, 2014, Wei, 2014). Following is the list of macrophytes studied in the present investigation;

A. Floating macrophytes

1. *Eichhornia crassipes,*
2. *Eichhornia azurea*
3. *Lemna gibba*
4. *Lemna minor*
5. *Salvinia molesta*
6. *Chara vulgaris*
7. *Salvinia auriculata*
8. *Pistia stratiotes*
9. *Ipomoea aquatic*

B. Submerged macrophytes

1. *Ceratophyllum demersum*
2. *Potamogeton crispus*
3. *Potamogetor pectinatus*
4. *Potamogetor perfoliatus*
5. *Sagittaria sagittifolia L.*
6. *Colocasia esculenta*

C. Emergent macrophytes

1. *Cyperus esculentus*
2. *Typha domingensis*
3. *Phragmites australies*
4. *Cyprus alopecnroide*
5. *Cyprus longus*
6. *Echinochloa stagninum*
7. *Typha angustifolia L.*
8. *Typha lotifolia*
9. *Iris pseudacorus*

Chemicals and reagents

All chemicals, reagents and solvents used were of analytical reagent grade or having the highest purity and were made freshly available. Doubly distilled water was used throughout. Glass vessels were cleaned by soaking in acidified solutions of $KMnO_4$ or $K_2Cr_2O_7$, followed by washing with concentrated HNO_3 and rinsed several times with double distilled water. Calibration curves as the standard curves of the solutions at the known concentrations for respective metals were prepared. These calibration curves were later used in order to determine the concentrations of the substance(s) of the unknown samples. The obtained calibration curves of heavy metals were used for the analysis of the concentration of the test samples.

EXPERIMENTAL RESULTS

Many heavy metals reach to the toxic levels as their concentrations become bio-magnified through the food chains and food webs. This has attracted the attentions of many researchers and warranted a focus on developing the methods for removing these metallic pollutants from the environment. Phytoremediation of heavy metals is an eco-friendly and innovative method for removing these toxic metals from aquatic environment. This investigation has been conducted to know the capacity of aquatic plants to absorb Cd, Cr, Co, Cu, Fe, Ni, Pb and Zn using the Plant samples naturally grown in wetlands receiving water or sewage from Solapur city of western region in Maharashtra. These macrophyte species belong to various families, and are floating, submerged or emergent and are available in the Solapur region naturally. As evidenced from vast published literature (Hinchman *et al.*, 1995; Burken and Schnoor, 1996; Erdei *et al.*, 2005; Bhattacharya *et al.*, 2006), these plants have a relatively high ability to absorb these metals. Uptake of one of these metals by any plant is generally highly correlated with the uptake of the others. Roots tend to absorb more metals than stems, which in turn absorb more metals than shoot or stem and leaves is described in these referred literatures. Table 1 (A, B and C) shows the concentration of various heavy metals in aquatic plants collected from sewage ponds, marshlands and sewage irrigated fields near Solapur city. The different plants sampled were grouped into three groups, representing floating (Table 1A), submerged (Table 1B) and emergent (Table 1C) macrophyte species.

Phyto-absorption potentials of macrophytes

Phyto-absorption is also referred as phytosequestration. Phytoextraction term includes phytoaccumulation, phytose questration, phytoabsorption, and phytomining with the use of

Table 1. Heavy metal concentration in various species of aquatic plants

Table 1 A. Heavy metal concentration (µg/g) in Floating macrophyte species

Macrophyte	Heavy metal contents (µg/g) in plant/plant parts							
Species and plant parts	Cd	Cr	Co	Cu	Fe	Mn	Ni	Pb	Zn
Eichhornia crassipes (Roots)	7.5	27.5	38.6	18.4	1134.6	343	732	27.7	184
(Shoots)	1.2	5.62	12.3	6.8	198.1	151	345	12.3	59
Eichhornia azurea (Roots)	8.95	11.9	2.98	14.4	421.3	876	7.96	6.33	212
(Shoots)	4.19	5.45	0.93	11.25	127.6	794	5.34	2.91	94.4
Lemna gibba									
(whole plant)	7.1	9.1	1.1	6.7	235.2	143	550	21.6	103
Lemna minor									
(whole plant)	0.19	0.26	0.34	4.59	109.2	345	3.1	3.001	17.7
Salvinia molesta									
(Roots)	0.24	2.20	4.1	2.21	59	64.2	84.2	3.85	24.0
(Shoots)	0.11	1.05	2.03	1.50	32	32.4	60.8	2.96	14.3
Chara vulgaris									
(whole plant)	0.14	2.1	3.2	0.94	1.2	22.0	20.0	12.1	3.9
Salvinia auriculata									
(Roots)	0.2	22	17.4	10.2	1475.9	1256.1	4.09	23.6	128
(Shoots)	0.15	6.9	2.41	7.9	710.3	139.4	2.98	4.13	47.9
Pistia stratiotes									
(Roots)	23.9	22.8	8.64	16.46	863.4	332.1	6.11	10.3	253
(Shoots)	12.7	13.3	2.13	10.96	476.8	95.7	4.93	6.32	173
Ipomoea aquatic									
(Roots)	12.6	42.1	52.7	105	328.7	50.3	64.1	7.64	210
(Shoots)	6.4	19.7	34.2	64.5	118.2	31.3	47.3	4.21	103
(Leaves)	7.8	31.6	41.6	84.3	217.3	42.3	52.1	6.19	165

Shoots are the total of aerial parts with stem & leaves, except specially mentioned

Table 1 B. Heavy metal concentration (µg/g) in Submerged macrophyte species

Macrophyte	Heavy metal contents (µg/g) in plant/plant parts								
Species and plant parts	Cd	Cr	Co	Cu	Fe	Mn	Ni	Pb	Zn
Cerartophyllum demersum									
(Whole plant)	6.0	34	8.0	16.5	1060	902	600	18	184.0
Potamogeton crispus									
(Roots)	0.42	64.8	9.3	3.09	1255	145	354	13.27	41.01
(Shoots)	0.09	23.7	5,4	2.33	853	96	135	4.63	2.41
Potamogetor pectinatus									
(Roots)	1.23	4.4	8.4	18.53	123	23.21	41.93	19.34	174
(Shoots)	0.62	2.7	3.6	4.54	86	5.49	9.51	6.42	26.7
Potamogetor perfoliatus									
(Roots)	2.97	3.12	8.32	16.22	56.2	368	28.05	15.24	394
(Shoots)	1.33	1.44	5.22	7.23	22.6	137	7.52	5.35	142
Sagittaria sagittifolia L.									
(Roots)	18.53	16.32	17.26	15.41	560	194	72.4	59.36	312
(Shoots)	4.94	8.15	9.75	11.12	322	123	42.5	27.12	145
Colocasia esculenta									
(Roots)	33.2	63.2	97.4	92.6	1196.5	297	67.2	11.03	203
(Shoots)	21.4	42.6	72.6	63.2	733.2	185	44.5	6.96	127

Shoots are the total of aerial parts with stem & leaves, except specially mentioned.

Table 1 C. Heavy metal concentration (µg/g) in Emergent macrophyte species

Macrophyte	Heavy metal contents (µg/g) in plant/plant parts								
Species and parts	Cd	Cr	Co	Cu	Fe	Mn	Ni	Pb	Zn
Cyperus esculentus									
(Roots)	66	524	637	157	2396	344	122	347	99
(Shoots)	53	69	183	120	1738	196	76	59	54
(Leaves)	38	32	91	88.5	1134	171	46	23	31
Typha domingensis									
(Roots)	5.21	41.7	13.5	138	7891	243	548	14.3	236
(Leaves)	2.86	16.4	4.27	19.5	2211	136	353	7.28	92
Phragmites australies									
(Roots)	8.5	52	19.5	32.1	1272	2346	401	14.5	252
(Shoots)	2.9	6.5	1.78	8.89	359	154	131	6.22	99.7
(Leaves)	2.5	22.4	0.61	5.14	721	107	61	4.08	82.7
Cyprus alopecnroide									
(Roots)	2.81	8.11	N.DN.	16.1	2562	65	48.0	12.0800	143.0
(Shoots)	1.42	1.43	D	5.33	832	39	19.8	61.23	47.5
(Leaves)	1.52	3.12	N.D	8.23	1346	53	25.9		63.2
Cyprus longus									
(Roots)	7.51	52.5	14.04	24.6	1105	189	87	22.7	137
(Leaves)	4.13	11.66	3.13	14.4	885	134	36	12.9	34
Echinochloa stagninum									
(Whole Plant)	6.7	77.5	1.15	27.5	2125	49.5	387	23.14	231
Typha angustifolia L.									
(Roots)	6.2	8.6	15.7	24.8	9989	1332	153	14.75	141
(Shoots)	BDL	2.1	9.3	6.1	1475	921	94	6.3	61
(Leaves)	3.3	3.8	11.8	12.3	1686	1174	123	11.61	14
Typha lotifolia									
(Roots)	6.2	8.4	3.12	24	42.5	194	26.2	19.3	81
(Shoots)	3.7	5.1	2.0	4.3	16.3	83.3	7.4	5.2	14
Iris pseudacorus									
(Roots)	2.2	3.2	22.1	36.4	7964	643	164	21.7	12
(Shoots)	0.9	1.1	14.2	17.9	732	313	91	12.7	2

BDL= Below Detectable Limit, N.D.=Not Detected. Shoots are the total of aerial parts with stem & leaves, except specially mentioned.

certain plants to transport metals and heavy metals from the media like soil and concentrate them in the different parts of the plants like into the roots and aboveground shoots. One or a suitable combination of these plants can be selected and planted at a heavy metal polluted site based on the type of metals present and other site-specific conditions. After the plants have been allowed to grow for several weeks or months, they are harvested and either incinerated or recycled just like metal ore. Phytoextraction for the contaminated sites can be preferred for remediating the site contaminated with metals like e.g., Ag, Cd, Co, Cr, Cu, Hg, Mn, No, Ni, Pb, and Zn), metalloids like As and Se, radionuclides ^{90}Sr, ^{137}Cs, ^{234}U, and ^{238}U, and also to the nonmetals like B for which the knowledge of phyto-absorption capacities of aquatic plants plays very crucial role. Therefore, to know the natural potential of heavy metal absorption in aquatic macrophytes, the present investigation was carried out so as to use them in phytoremediation technique for the treatment of sewage, trade effluents and industrial waste waters. In the present investigation, the macrophytes are studied for such screening which showed varied phyto-absorption potentials for various metals when exposed to the mixed synthetic bath.

Cadmium phyto-absorption: Phyto-absorption of cadmium (Cd) was highest (23.9 µg/g) in the roots of Pista stratiotes, followed by Ipomoea aquatic roots (12.6 µg/g) and *Eichhornia azurea* roots (8.95 µg/g). It was lowest (0.11 µg/g) in the shoots of *Salvinia molesta* among the floating macrophytes. The maximum content of cadmium in submerged macrophyte species was recorded in the roots of *Colocasia esculenta* (33.2 µg/g) followed by roots of *Sagittara sagittifolia* (18.53 µg/g) and lowest in the shoots of *Potamogetor pectinatus* (0.09 µg/g). It was highest (66 µg/g) in the roots of *Cyperus esculentus* followed by its shoots (53 µg/g) and leaves (38 µg/g) and lowest in the shoots of *Iris pseudacorus* (0.9 µg/g) among the emergent macrophytes. The cadmium content in *Typha angustifolia* was below detection limit.

Chromium phyto-absorption: The chromium (Cr) content absorbed was highest (524 µg/g) in the roots of emergent macrophyte *Cyperous esculentus L.*, followed by 77.5 µg/g and 64.8 µg/g in the roots of *Echinochloa stagninum* (emergent) and *Potamogeton pectunatus* (submerged) respectively. Chromium in *Ipomoea aquatic* roots was 42.1 µg/g followed by its leaves (31.6 µg/g) and was lowest absorbed in the *Lemna minor* (0.26 µg/g) as observed in its whole plant analysis among the floating macrophyte species. The highest bioaccumulation of chromium was noticed in the roots of *Potamogeton crispus* (64.8 µg/g) followed by roots of *Colocasia esculentus* (63.2 µg/g) and minimum level was 2.7 µg/g in the shoots of *Potamogetor pectinatus* among the submerged macrophyte species. *Cyperus esculentus* roots absorbed 524 µg/g of chromium followed by its shoots (69 µg/g) indicated it as best macrophyte for Cr absorption and lowest absorption was noticed in the shoots of *Iris pseudacorus* (1.1 µg/g) among the emergent macrophyte species.

Cobalt Phyto-absorption: The cobalt (Co) content absorbed in the roots of *Ipomoea aquatic* was highest (42.1 µg/g) followed by its leaves (31.6 µg/g) and lowest in the whole plant of *Lemna minor* (0.26 µg/g) among the floating macrophytes. Cobalt phyto-absorption observed was 97.4 µg/g in the roots of *Colocasia esculenta* which was highest. It was followed by 72.6 µg/g in the shoots of same plant and minimum phyto-absorption was in the shoots of *Potamogetor pectinatus* (3.6 µg/g) among the submerged macrophytes. The *Cyperus esculentus* showed highest phyto-absorption of cobalt (637 µg/g) in its roots followed by the shoots of same plant species (183 µg/g) and minimum level of cobalt was recorded in the shoots of *Phragmites australies* (0.61 µg/g) among the emergent macrophyte species tested. The cobalt content in *Cyprus alopecnroide* was not detected.

Copper Phyto-absorption: The highest copper (Cu) content was observed in the roots of *Ipomoea aquatic* (105 µg/g) which was followed by its shoots (64.5 µg/g) and leaves (84.3 µg/g) of the same macrophyte species and minimum phyto-absorption was in *Chara vulgaris* (0.94 µg/g) among the floating macrophytes. The roots and shoots of *Colocasia esculenta* showed phyto-absorption level of 92.6 µg/g and 63.2 µg/g respectively which was followed by the roots of *Potamogetor pectinatus* (18.53 µg/g) and minimum copper was absorbed in the shoots of *Potamogeton crispus* (2.33 µg/g) among the submerged macrophyte species. About 157 µg/g of copper was absorbed in the roots of *Cyperus esculentus* followed by 138 µg/g of copper absorption in the roots of *Typha domingensis* among the emergent macrophyte species with the minimum phyto-absorption of 4.3 µg/g in the shoots of *Typha lotifolia*.

Ferrous Phyto-absorption: The iron (Fe) content was found more absorbed in almost all plants studied as compared to the other metals. The highest level of phyto-absorption and accumulation was 328.7 µg/g in the roots of *Ipomoea aquatic*, which was highest among the metals it absorbed. It was 1475.9 µg/g in the roots of *Salvinia auriculata* and 1134.6 µg/g in the roots of *Eichhornia crassipes* with the lowest level of 1.2 µg/g in the whole plant of *Chara vulgaris* in the category of floating macrophytes studied. The *Cerartophyllum demersum* (whole plant) showed the absorption level of about11965µg/g followed by 1060 µg/g in the roots of *Colocasia esculenta* and minimum level of 22.6 µg/g in the shoots of *Potamogetor pectinatus* in the group of submerged macrophytes studied. The emergent macrophyte *Phragmites australies* absorbed 1272 µg/g in the roots, followed by the roots of *Cyprus longus* (1105 µg/g) and highest in the roots of *Typha angustifolia* (9989 µg/g). The macrophyte *Cyperus esculentus* showed the phyto-absorption level of 2396 µg/g in its roots, 1738 µg/g in the shoots and 1134 µg/g in its leaves. The minimum level of absorption of 16.3 µg/g was noticed in *Typha lotifolia* shoots.

Manganese Phyto-absorption: The phyto-absorption of manganese (Mn) was highest in the roots of *Savinia molesta* was 1256.1 µg/g followed by the absorption in *Eichhornia azurea* (876 µg/g) and it was absorbed up to 343 µg/g in *Eichhornia crassipes* and minimum of it was 22 µg/g observed in the whole plant of *Chara vulgaris* in the category of floating macrophytes. The manganese content was highest in the whole plant of *Cerartophyllum demersum* (902 µg/g) followed by the roots of *Potamogetor perfoliatus* (368 µg/g) and minimum of 5.49 µg/g in the shoots of *Potamogetor pectinatus* macrophyte species in the category of submerged macrophytes. The highest level of manganese in the roots of *Phragmites australies* (2346 µg/g) was followed with the roots of roots of *Typha angustifolia* (1332 µg/g) and the level of manganese was minimum in the whole plant of *Echinochloa stagninum* (49.5 µg/g) among the emergent macrophyte species.

Nickel Phyto-absorption: The macrophyte *Eichhornia crassipes* was capable to absorb 732 µg/g of nickel (Ni) in its roots and 345 µg/g in its shoots which was followed by the whole plant of *Limna gibba* (550 µg/g) and least level of 2.98 was noticed in shoots of *Salvinia auriculata* species of macrophyte among the group of floating macrophytes. Upto 600 µg/g of nickel was noticed in the whole plant of *Certophyllum demersum* followed by 354 µg/g in the roots of *Potamogeton crispus* roots and minimum level of 7.52 µg/g was observed in the shoots of *Potamogetor perfoliatus* macrophyte in the group of submerged macrophyte species tested. The nickel content was highest (548 µg/g) in the roots of *Typha domingensis* followed by 401 µg/g in the roots of *Phragmites australies* and 387 µg/g in the whole plant of *Echinochloa stagninum*. The minimum level of nickel was 7.4 µg/g in *Typha lotifolia* macrophyte in the group of emergent species.

Lead Phyto-absorption: Lead (Pb) phyto-absorption was highest (27.7 µg/g) in the roots of *Eichhornia crassipes* followed by roots of *Salvinia auriculata* (23.6 µg/g) and minimum level (2.91 µg/g) was noticed in the shoots of *Eichhornia azurea* in the floating macrophyte species. The level of lead absorption was maximum (59.36 µg/g) in the roots of *Sagitara sagittifolia* followed by the level in the whole plant of *Ceratophyllum demersum* (18 µg/g) and minimum (7.52 µg/g) in *Potamogetor perfoliatus* among the submerged macrophyte species. Lead concentration was 347 µg/g in the roots of *Cyperus esculentus* which is comparatively highest and is followed by its shoots (59 µg/g) and (23.14 µg/g) in the whole plant of *Echinochloa stagninum*. The minimum phyto-absorption was 0.06 µg/g in the leaves of *Cyprus alopecnroide* in the category of emergent macrophytes.

Zinc Phyto-absorption: Phyto-absorption of zinc (Zn) was highest (253 µg/g) in the roots of *Pistia stratiotes* followed by the roots of *Eichhornia azurea* (212 µg/g) and *Ipomoea aquatic* (210 µg/g) and least (3.9 µg/g) in *Chara vulgaris* whole plant among the all floating macrophytes studied. Phyto-absorption of 394 µg/g was recorded in the roots of *Potamogetor perfoliatus* followed by 312 µg/g in the roots of *Sagitara sagittifolia* and it was minimum (2.41 µg/g) in *Potamogeton crispus* macrophyte in the group of submerged macrophytes. The highest phyto-absorption of 252 µg/g was noticed in *Phragmites australies* followed by 231 µg/g in the whole plant of *Echinochloa stagninum* macrophyte and least (2 µg/g) phyto-absorption was in the shoots of *Iris pseudacorus* species in the group of emergent macrophyte species.

DISCUSSION

The present studies on metal absorption potential of plants carried out would help in the selection of the suitable aquatic plants for absorption of specific heavy metals from polluted water by phytoremediation process using constructed wetlands. Through the analysis of metal concentration in aquatic plants, the scrutiny for the proper selection of plants can be done for phytoremediation. The high concentration of heavy metals in aquatic plants indicates that such species could accumulate high level of metals and may be preferred for remediation and eco-restoration of water bodies, even when the concentration of metal in the water is not particularly high. We still lack in a full understanding of the mechanisms, forms and pathways by which these aquatic plants absorb and accumulate heavy metals in their various parts. The capacity of aquatic plants to absorb heavy metals, the mechanisms by which such uptake occurs, and the effects of heavy metal accumulation in various parts of aquatic plants may be different from the capacity, mechanisms, and effects in non-aquatic plants. Similar studies have been reported by various researchers on heavy metal removal potentials as well as pollutant reduction potentials.

Costa and Henry (2010) conducted studies to determine the phosphorus, nitrogen, and carbon contents of aquatic macrophyte species during two periods of the year in the land-water transition zone of three lakes lateral to the Paranapanema River (Sao Paulo) and observed that the highest phosphorus and nitrogen concentrations during the dry period were observed for Cyperus esculentus L. Similar carbon contents were found for both Cyperus. esculentus and Eichhornia azurea but not similar trend of change in phosphorus and nitrogen. During the rainy period, Cyperus esculentus and E. azurea had the highest nitrogen concentration. All the aquatic macrophyte species presented similar carbon contents, but varied reductions in phosphorus and nitrogen. The highest phosphorus concentration was in that of Cyperus esculentus.

Lee and others (1976) conducted hydrophonic studies on heavy metal uptake by selected marsh plant species and concluded that C. esculentus is one of the suitable macrophytes which have more potential for heavy metal uptake than the other species. C esculentus is recommended due to its ability to take up and accumulate heavy metals such as zinc, cadmium, nickel, and mercury from dredged material under varying laboratory and field conditions. Comparison of the two floating species i.e. *Eichhornia crassipes* and *Lemna gibba* indicated that the concentration of all heavy metals were higher in *Eichhornia crassipes* than in *Lemna gibba*. *Eichhornia crassipes*. As for the two submerged species i.e. *Ceratophylum demersum* and *Potamogeton crispus,* the comparison between them showed that the concentration of Mn and Co in *Ceratophyllum demersum* was much higher than that in *Potamogeton crispus*. On the other hand, *Potamogeton crispus* accumulated higher amount of Fe, Cu, Cr and Pb than did the *Ceratophyllum demersum*. The two species however, were almost equally effective in removing Zn, Cd, and Ni from the metal polluted synthetic bath wastewater. A glance at the table also showed that the five emergent species i.e. *Typha domingensis, Phragmites australies*, *Cyprus alopecuroid*, *Cyprus longus*, and *Echinochloa stagninum* contained considerable amounts of Fe, Zn, Co, Cd and Pb, In the contrast, *Phragmites australies* accumulated the highest amount of Mn, *Typha domingensis* the highest amount of Cu, while *Echinochloa stagninum* was the most effective in accumulating Ni.

Conclusion

The overall studies conducted reveal that the phyto-absorption of metals in aquatic macrophytes is species specific and plant-part specific. Therefore, for the removal of specific metal or metals, specific plant or plants having high absorption potential are scrutinized. It is concluded that using the suitable species of floating, submerged or emergent macrophytes which have high potential of phyto-absorption are preferable for the treatment of metal polluted wastewaters. The macrophytes having high absorption capacities can be employed for efficient treatment in the suitable wetland systems.

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