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Harnessing Phytodiversity for Decontamination of Aquatic Pollutants in Freshwater Lakes

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The metal phytoextracting ability of aquatic macrophytes is being widely exploited for phytoremediation of contaminated wetland ecosystems. A study was carried out in Vellayani wetland ecosystem comprising a fresh water lake and surrounding polders lying 8° 24' 09" to 8° 26' 30" N latitude and 76° 59' 08" to 76° 59' 47"E longitude at an elevation of 29 m above mean sea level. Water, sediment and plant samples were collected from 15 geocoded sites during different seasons, biomass was recorded and analysed for various chemical constituents. Fourteen dominant species were identified within the ecosystem. Highest number of plant species was found during pre-monsoon and the lowest during monsoon season. *Panicum repens* was the most abundantly distributed macrophyte. The biomass production was highest for *Pistia stratiotes*. Water and sediment properties were significantly influenced by the seasons. Water properties *viz.*, acidity, EC, BOD, COD, NH_4-N, NO_3-N, Fe, Al, Cd, and Pb contents were at their lowest during monsoon season and highest during pre-monsoon season except for NH_4-N. Sediment also showed almost similar trend with exceptions for NH_4-N, Cd and Pb. With regard to water pollution in Vellayani lake, the entire lake was contaminated with Al and at two sites with Fe, six sites with Cd and eight sites with Pb. Among tested macrophytes, *Eichhornea crassipes* was the best phytoextractor for Fe and *Dryopteris erythrosora* and *Eichhornea crassipes* for Al and *Nelumbo nucifera* for Cd and *Nymphaea odorata*, *Nelumbo nucifera* and *Pistia stratiotes* for Pb.

(***Key words***: *Phytoremediation, bioconcentration, phytoextractor*)

Availability of good quality water for all forms of lives, from micro-organisms to man, is a serious problem today, because all water resources have been reached to a point of crisis due to unplanned urbanization, unscientific agricultural practices and industrialization (Singh *et al.,* 2004). The extent of pollution faced by the fresh water ecosystems is very severe, far exceeding their assimilative capacity and this will have a direct impact on human and animal health.

Kerala, a relatively small state comprising an area of 38864 km^2 is criss–crossed by 44 rivers and several lakes and lagoons. Out of the 34 lakes in Kerala, only seven are fresh water lakes and the most prominent fresh water lakes are Sasthamkotta, Vellayani and Pokkode. These lentic water bodies which contribute significantly to the ecological and economic sustainability of the region are currently subjected to acute pressure of rapid developmental activities and indiscriminate utilisation resulting various kinds of pollution (Kumar, 2005). Vellayani lake, which is the major drinking water source of the State capital Thiruvananthapuram is being subjected to both organic and inorganic contamination (Meera, 2017; Sobha *et al.,* 2011, 2009; Radhika *et al.*, 2004). Since the anthropogenic pressure being quite high, a constant monitoring of this water body is highly essential to prevent further deterioration of lake water quality.

Several remediation technologies are being attempted for the restoration of degraded lakes. Most of the conventional remediation approaches do not provide acceptable solutions to this catastrophe. Phytoremediation, a cost effective plant based technology which mainly relays on the metal hyperaccumulation ability of plants was found ideal for the cleanup of the contaminated lakes. Aquatic macrophytes are capable of removing heavy metals from water and accumulate them in plant parts. *Eichhornea crassipes, Hydrilla vertisilata, Typha angustata, and Ipomea aquatica* removed heavy metals like Zn, Cu, Pb, Ni and Cd from lakes and maintain water quality (Thampatti and Beena, 2014; Kumar *et al.,* 2008). Each ecosystem contains several plants having phytoremediation capacity, which may act as the cleaners of the system. They have to be identified and can be exploited for restoration and preservation of the ecosystems.

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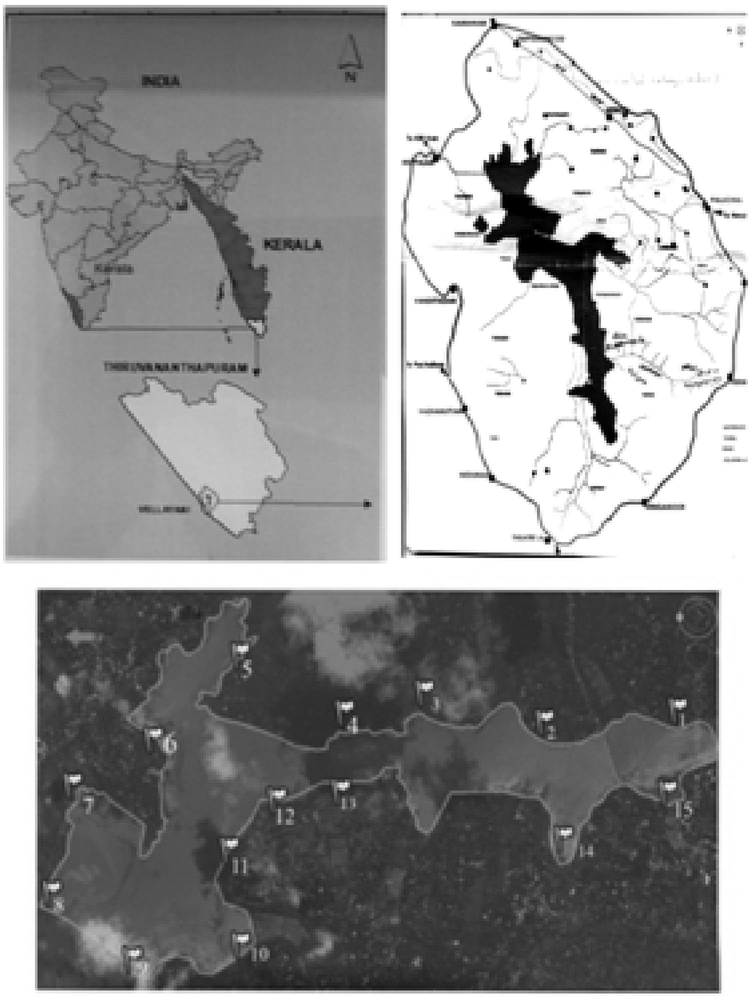
Aquatic macrophytes have paramount significance in removing metals and inorganic contaminants from wetlands which can do much in the field of phytosanitization, restoration and maintenance of water quality and commercial water purification systems like constructed wetlands. The present paper explores the seasonal impact on the water and sediment quality of the Vellayni fresh water lake along with the exploration on the phytodiversity of native aquatic macrophytes and their phytoextraction ability for toxic contaminants.

MATERIALS AND METHODS

Vellayani wetland ecosystem comprising a fresh water lake and surrounding polders lies between 8°24′ 09″ to 8°26′ 30″ N latitude and 76° 59′ 08″ to 76°59′47″ E longitude at an elevation of 29 m above mean sea level (Fig. 1). The area enjoys a humid tropical climate with two distinct monsoons viz., south west and north east, receiving more than 2300 mm rainfall annually. Currently the lake experienced a drastic reduction in its area and water quality. The lake area has reduced to less than 240 ha (Job *et al*., 2014) from 750 ha in 1926. Deterioration water quality was also reported by several researchers. (Meera., 2017; Kamal, 2011; Sobha *et al*., 2009; Radhika and Devi, 2007; Radhika *et al*., 2004).

To study the seasonal impact on lake water quality, water and sediment samples were collected from 15 geocoded sites representing the entire lake during pre-monsoon (April), monsoon (Sep) and post monsoon (Dec) seasons. Grab samplers were used for the collection of sediment from the lake bottom and polyethylene dippers for collecting water samples. Water samples were drawn from 50 cm depth. Actively growing native macrophytes were collected from the above sites from one square meter area during the three seasons and



1-Panangode, 2- Kizhur-manalivila, 3-Kakkamoola, 4-Manamukku, 5-Reservoir bund, 6- Pallichalthodu, 7-Palapoor, 8-Karithalaykkal, 9-Aaratukadavu RB, 10-Valiyavilagam 11-Kulangara, 12- Mannamvarambu, 13-Kochukovalam, 14-Venniyoor, 15-Kattukulam

Fig. 1. *Location map of Vellayani lake showing the study area*

their fresh weight was recorded to determine the plant density. They were separated into shoot and root, dried and recorded their dry weight. The water, sediment and plant samples were analyzed as per standard procedures as outlined below.

The pH and EC of sediments were determined from the sediment water suspension in 1:2.5 ratio using pH meter (Cyber Scan PC510, EuTech Instruments, Singapore) and EC-TDS Analyzer (CM 183, Elico, India) respectively as described by Jackson (1973). For lake water samples direct measurement of pH and EC were done using the above equipments.

Organic carbon of the sediment was determined by wet digestion method using sulfuric acid and potassium dichromate (1N) and titration with standard ferrous ammonium sulphate (Walkley and Black, 1934). NH_4-N and NO_3-N were determined from 2M KCl extract of sediment (1:10) by Kjeldahl macro distillation (Bremner and Keeney, 1965). Available Fe, Al, Pb and Cd of sediment were estimated from 0.1N HCl extract in 1:10 ratio (O"Connor (1988) using Inductively coupled plasma emission spectroscopy (ICP OES Optima 8000, PerkinElmer Inc., USA). For water samples, direct estimation of Fe, Al, Pb and Cd was done using Inductively coupled plasma emission spectroscopy (Wei and Yang, 2010).

BOD of the water samples was estimated by determining the dissolved oxygen content of water on the first day and five days after incubation in a BOD incubator by modified Winkler's method (Incubation followed by titration) as described by APHA (2012). COD also was determined by the APHA (2012) method by refluxing the water sample on a hot water bath for 2 hours after the addition of 0.25 N potassium dichromate and titration with standard ferrous ammonium sulphate using ferroin as indicator. Fe, Al, Pb, Cd contents of plant sample were estimated from the nitric-perchloric acid (9:4) digest of plant samples (Piper, 1966) by Inductively coupled plasma emission spectroscopy (ICP OES Optima 8000, PerkinElmer Inc., USA).

The bioconcentration factor and translocation index for each element were worked out using the formula (Chaney *et al*., 1995) given below.

$$\text{Bioconcentration factor (BCF)} = \frac{\text{Metal concentration in plant part}}{\text{Metal concentration in growing medium}}$$

$$\text{Translocation index (TI)} = \frac{\text{Metal concentration in shoot}}{\text{Metal concentration in root}}$$

RESULTS AND DISCUSSIONS

Impact of spatial and seasonal variation on occurrence and distribution of macrophytes

The dominant aquatic macrophytes present in Vellayani lake, their distribution pattern and plant density are presented in Table 1. Fourteen species were identified as the most dominant aquatic macrophytes in Vellayani wetland ecosystem. They are *Pistia stratiotes, Ipomea aquatica, Eleocharis dulcis, Nelumbo nucifera, Brachiaria mutica, Colocasia esculenta, Scirpus grossus, Echinocloa colona, Eichhornea crassipes, Nymphaea odorata, Dryopteris erythrosora, Nymphoides indicus, Ipomea aquatica and Limnocharis flava.*

Highest number of plant species was found during pre-monsoon and the lowest during monsoon season. The increased water levels during monsoons have drowned most of the macrophytes and severe turbulence during this season might have prevented their easy emergence. *Panicum repens* was the most abundantly distributed macrophyte followed by *Dryopteris erythrosora* and *Nelumbo nucifera.* No definite relation was observed between the spread of macrophytes and location since the macrophytes found in a location at one season may not be present there in the next season. Removal of macrophytes by human intervention may be the major reason for this erratic occurrence of plants in the lake. *Nelumbo nucifera*, *Panicum repens*, *Nymphaea odorata, Nymphoides indicus* and *Eleocharis dulcis* were found throughout the year. A general observation was that rather than having a mix of different species, one species dominate in an area and another one in another area.

Perusal of the data on biomass production per unit area revealed that the biomass (Table 1) was highest for *Pistia stratiotes* during pre-monsoon and monsoon and *Nelumbo nucifera* during post monsoon season.

Impact of seasonal variation on water characteristics

The mean values and range of different water quality parameters for pre-monsoon, monsoon and post-monsoon seasons are presented in Table 2. All the parameters were significantly influenced by the season. Lake water was acidic with very little salinity throughout the year. Water pH was highest during monsoon season, definitely due to the dilution effect of increased quantity of water received and low evaporation rates. A reverse trend was observed in the case of EC. The large volume of water present might have diluted the salt concentration of the lake water leading towards low EC values (Radhika *et al*., 2004).

***Table 1**. Distribution of aquatic macrophytes in Vellayani Lake during different seasons*

	Scientific name	No. of species present			No. of sites where the species is present			Plant density($g\ m^{-2}$)					
								Wet weight			Dry weight		
		I	II	III	I	II	III	I	II	III	I	II	III
1	*Brachiaria mutica*	1	NF	NF	15	NF	NF	155	NF	NF	15.2	NF	NF
2	*Colocasia esculenta*	2	NF	NF	9,15	NF	2	252	NF	NF	22.7	NF	NF
3	*Scirpus grossus*	3	1	1	1,2,6	6	2	200	252	205	20.8	26.2	21.3
4	*Echinocloa colona*	1	NF	NF	1,14	NF	NF	101	NF	NF	11.31	NF	NF
5	*Eichhornea crassipes*	NF	1	1	9	NF	NF	156	NF	NF	14.9	NF	NF
6	*Dryopteris erythrosora*	4	NF	1	1,12,14,15	NF	12	100	NF	148	11.1	NF	16.4
7	*Limnocharis flava*	1	NF	NF	1	NF	NF	253	NF	NF	22.26	NF	NF
8	*Nelumbo nucifera*	3	4	2	7,10,15	1,9,10,15	7,10,15	155	202	210	19.4	25.3	26.3
9	*Panicum repens*	7	2	3	1,4,5,9,11,12,13	4,13	4,11,12	202	151	152	28.9	21.6	21.7
10	*Pistia stratiotes*	1	1	NF	14	NF	NF	303	302	NF	27.9	27.8	NF
11	*Nymphaea odorata*	1	2	3	13	13,14	1,12,13	104	172	123	11.8	19.4	13.9
12	*Nymphoides indicus*	1	3	2	3	2,3,7	2,13,14	158	250	102	15.5	24.5	10.0
13	*Eleocharis dulcis*	1	1	2	8	8	2,13	203	155	205	19.3	14.7	19.5
14	*Ipomea aquatica*	NF	1	1	NF	5	5	NF	302	281	27.2	23.2	25.3

I= Pre monsoon, II=Monsoon, III = Post Monsoon; NF= Not found

1-Panangode, 2- Kizhur-manalivila, 3-Kakkamoola, 4-Manamukku, 5-Reservoir bund, 6- Pallichalthodu , 7-Palapoor, 8-Karithalaykkal, 9-Aaratukadavu RB, 10-Valiyavilagam 11-Kulangara, 12- Mannamvarambu, 13-Kochukovalam, 14- Venniyoor, 15-Kattukulam

Both BOD and COD were at their lowest values during monsoons and highest during pre- monsoon season. Low values of BOD and COD during monsoon may be due to the receipt of large quantities of fresh water on receipt of monsoon showers. After the cessation of monsoon showers, the receipt of fresh rain water recedes and the drainage from surrounding agricultural fields increases which may reach the lake finally. This might enhance the nutrient level in lake water and initiate eutrophication. Thus as the oxidisable organic matter increases, there will be a corresponding increase in the oxygen demand of water. The decrease in lake water volume and the presence of partially decomposed organic residues enhanced the oxygen demand during pre and post -monsoon periods. The major factor that reduced BOD and COD during monsoon season is mainly the large volume of fresh water that reaches the lake through the canals and springs.

In water, N is present mainly in the form of ammonia and nitrate with small quantities of nitrite. The rate of oxygenation decides the transformation of ammonia to nitrate. NH_4-N was highest during post-monsoon and lowest during monsoon season. Agriculture together with municipal waste water is the most important source of anthropogenically derived ammonia and nitrate to surface waters (Moore, 1991). The residues from N fertilisers reaching the lake water might be responsible for the increase in NH_4-N during post-monsoon season which coincides with the peak vegetable cultivation season. The NO_3-N content was highest during pre-monsoon season and was undetectable in most of the sites during the monsoon season. The continuous receipt of monsoon showers might have reduced the nitrification process and even facilitate denitrification. NO_3-N was more during the pre monsoon season probably due to better oxidation status of water.

Fe content was highest during post-monsoon season and was below detectable level during the monsoon season. The receipt of large quantity of fresh water in response to the monsoon showers has improved the water quality considerably. Fe residues in surface waters are extremely variable and the oxidation- reduction cycle controls the fate of Fe. The cycle varies seasonally depending on the availability of oxygen resulting, the absence of Fe in water due to deposition of insoluble Fe^{3+} in sediments.

The Al content was highest during pre-monsoon and lowest during monsoon season. Al content of lake water ranged from 5.35 to 5.61 mg L^{-1}. Relatively large amount of Al was found in surface water in dissolved form due to

***Table 2**. Chemical properties of water and sediment during different seasons*

Parameters	Water			CD (0.05)	Sediment			CD (0.05)
	I	II	III		I	II	III	
pH	6.3 4.4 - 6.9	6.8 6.5-7.3	6.6 6.1-6.7	0.067	5.8 3.5-6.6	6.6 6.1-7.5	5.8 5.0-6.8	0.088
EC microS cm^{-1}	110 91 – 119	103 89-117	114 51-162	2.41	121 68-213	95 51-178	121 65-192	8.195
BOD mg L^{-1}	16 6 - 39	4 0-15	10 2 - 26	0.584	–	–	–	–
COD mg L^{-1}	65 13 - 126	28 4 -47	51 8 - 103	1.23	–	–	–	–
NO_3-N mg L^{-1}	3.06 0.32-12.4	0.71 00.1-3.760	2.92 0.33-9.80	0.767	66 40.1-94.7	13 5.6-43.5	6 940.4-95.8	1.387
NH_4-N mg L^{-1}	9.5 1-27.5	0.96 0.1-2.7	11 1.35-44.3	0.273	68.8 17-130	97.3 49.5-254	70.8 39-138	2.244
Fe mg L^{-1}	0.25 0.18-0.67	–	0.26 0.19-0.71	0.008	16.6 14.8-19.8	15.5 13.5-16.7	15.7 14.2-16.8	0.113
Al mg L^{-1}	5.61 5.29-5.91	5.35 4.43-5.90	5.57 4.8-5.89	0.179	41.3 34.1-48.2	40.8 33.5-48	43.06 33.2-49.2	0.881
Cd mg L^{-1}	0.008 0.0001-0.025	0.003 0.0001-0.01	0.007 0.0001-0.03	0.001	0.12 0.0001-0.025	0.013 0.0001-0.10	0.009 0.0001-0.02	0.0023
Pb mg L^{-1}	0.106 0.0001-0.25	0.009 0.0001-0.02	0.089 0.0001-0.215	0.012	0.425 0.001-1.20	0.308 0.04-0.715	0.037 0.001-1.04	0.0018

I= Pre monsoon, II=Monsoon, III=Post monsoon

the acidic pH of surface water (Goenaga and Williams, 1988). Dissolved Al is highly toxic to crop plants, animals and human beings. At all seasons the Al content of water was much above the maximum permissible limit (MPL) of 0.2 mg L^{-1}, indicating chances for severe threat from Al toxicity.

Vellayani lake water showed the presence of Cd and Pb in small concentrations with lowest values during monsoon season, evidently due to the dilution effect of heavy monsoon showers. In the pre-monsoon season the Cd and Pb contents were highest which might be due to the concentrating effect in response to the increased rate of evaporation. The change in volume of lake water is the major factor that controls the level of Cd and Pb in water. The average Cd and Pb contents of lake water were below MPL (0.01and 0.1 mg L^{-1} respectively) at all seasons, but individual pockets exceeded these values, expressing the threat of Cd and Pb contamination.

Impact of seasonal variation on sediment characteristics

Electrochemical properties viz., pH and EC (Table 2) showed season wise variation which was significant. With regard to the pH it showed an increase towards the monsoon season and there after a decrease and electrical conductivity showed a reverse trend. The high pH and low EC were definitely due to the dilution effect of large volume of water added by monsoons. NH_4-N content of sediment showed an increasing trend towards the monsoon season might be due to the low nitrification rate during monsoon season, as the water level is high and prevalence of continuous anaerobic condition. The data on NO_3-N also support this observation (Table 2).

The contents of available Fe, was highest during the pre-monsoon season, mainly due to the decrease in volume of lake water in this season, compared to other seasons. While Al content in the sediment was at its highest during the post monsoon season. The increase in pH might have reduced the solubility of Al which is directly related to the soil pH (van Mensvoort *et al.,* 1985).

The Cd content of sediment was very low, but Pb was present in sizeable amounts. Available Pb content was also highest during pre-monsoon season, definitely due to the high evaporation rate. Pb continues to be used in large amounts in storage batteries, metal products, pigment, chemicals and hydro carbon fuels (Abbasi *et al.,* 1998). The Pb released by such materials might have reached the lake, contaminating the water. The different aquatic systems of Thiruvananthapuram showed a Pb content ranged from 21.1 to 99.4 mg kg^{-1} during post monsoon season and from 0.4 to 29.4 mg kg^{-1} during pre monsoon season (Sobha *et al.,* 2009).

Extent of pollution in lake water

According to Indian standards (IS: 2296), the maximum permissible pH for drinking water is 8.5 and minimum pH is 6.5. The water of Vellayani lake comes within the limit only at the monsoon season. In other two seasons, some of the sites showed high acidity, exceeding the maximum permissible limit (MPL). During those seasons, the water from such sites cannot be used for drinking and even domestic purposes. For electrical conductivity, the MPL for domestic purposes as well as for irrigation is 0.75 dS m^{-1} (Ayers and Westcot, 1985). As per the above criteria, the lake water is safe for use. Regarding BOD, the MPL for drinking water is 2 mg L^{-1} and 3 mg L^{-1} for domestic purposes. The different locations of Vellayani lake recorded values ranging from 0 to 39 mg L^{-1}. During both pre and post monsoon seasons the BOD for all the sites was above the MPL. During monsoon season though the mean value was above the MPL, there were seven sites showing lower values than MPL. This indicated that the lake water is highly contaminated with organic load.

NH_4-N content of the area ranged from 0.1 to 44.3 mg L^{-1}. The permissible maximum concentration for NH_4-N is 16 mg L^{-1} in water and a concentration above this is lethal to the marine lives like fish and prawn (Sebastian, 1994). During the monsoon season, there is no threat of contamination by NH_4-N. But during pre monsoon and post monsoon periods, three sites recorded NH_4-N content above this limit. This might be due to the leachate of N fertilisers from these sites which were intensively cultivated with vegetables. N content as nitrates should not exceed 45 mg L^{-1} for drinking and for other domestic purposes. In all the three seasons, NO_3-N content of lake water was below the above limit and can be safely used.

The mean Al content of water did not vary much during different seasons but with locations a range of 4.43 to 5.89 mg Al L^{-1} was observed. As per WHO (1971) standards, permissible limit is up to 0.2 mg L^{-1} only. The entire lake water is unfit for drinking purpose as per the above criteria. Remediation measures for reducing the Al level in water should be advocated.

For Fe, the permissible limit is 0.3 mg L^{-1}. Fe was absent in all the sites during the monsoon season. In the pre monsoon and post monsoon season, only one site exceeded the MPL. Otherwise the water is safe with regard to its Fe content (Table 2). With regard to Cd, the MPL is 0.01 mg L^{-1}. The lake water exceeded this limit at six sites. Two locations were contaminated with Cd throughout the year. Hence decontamination treatments should be advocated. In the case of Pb the MPL is 0.1 mg L^{-1}. During monsoon season, the entire locations recorded values below this limit. But during pre-monsoon season, 9 sites and during post monsoon 8 sites exceeded the MPL. Hence Vellayani lake water is contaminated with Pb at several locations and proper treatments have to be undertaken to remove Pb from water since it is highly toxic to human beings, aquatic organisms and macrophytes.

On evaluating the extent of aquatic pollution in Vellayani lake, it was observed that the water is contaminated with organic residues. With regard to the heavy metals, one location is contaminated with Fe, six locations with Cd and eight locations with Pb. During monsoon season, the water quality was generally good. But in the case of Al, the whole area is above the MPL. In general Al is mainly responsible for the degradation of the ecosystem. Fe, Pb and Cd are contributing to it, creating further aggravated conditions.

Suitability of macrophytes as hyperaccumulators/ phytoremediators

Hyperaccumulator plants can take up large amounts of metals in their shoots without showing significant signs of toxicity and can accumulate pollutants at high concentrations in their shoots and can grow in soils containing high concentrations of metals (Thampatti *et al*., 2016; Thampatti and Beena, 2014; Prasad *et al*., 2005; Cunningham *et al.,* 1997). This ability of plants is widely exploited under phytoremediation for the cleanup of environment.

Evaluation of the macrophytes for their metal extraction revealed that *Eichhornea crassipes* had highest phytoextraction ability for Fe in shoot and *Eichinocloa colona* for root. The Fe phytoextraction ability of *Eichhornea crassipes* was already reported by several workers (Rai and Singh, 2016; Padmapriya and Murugesan, 2012; Jayaweera *et al*., 2008). Though both these species had removed large quantity of Fe, their translocation index (TI) was below 1.0 definitely due to high concentration of Fe in their roots (Table 3), but their

Table 3. *Fe, Al, Cd and Pb extraction by aquatic macrophytes during different seasons*

Sl No	Scientific name	Shoot (mg kg^{-1})				Root (mg kg^{-1})				Translocation index			
		Fe	Al	Cd	Pb	Fe	Al	Cd	Pb	Fe	Al	Cd	Pb
1	*Brachiaria mutica*	1727	115	2	15	445	105	0.09	5.4	3.88	1.10	22.22	2.78
2	*Colocasia esculenta*	928	622	0.9	5	1249	396	2	6.0	0.74	1.57	0.45	0.83
3	*Scirpus grossus*	1304	555	NIL	4.1	1549	396	1.4	5.5	0.84	1.40	–	0.75
4	*Eichinocloa colona*	1404	470	1.5	10	2630	368	0.04	8	0.53	1.28	37.50	1.25
5	*Eichhornea crassipes*	2060	725	2.6	7.8	2512	605	2.5	10.5	0.82	1.20	1.04	0.74
6	*Dryopteris erythrosa*	1233	769	0.04	2.8	2047	524	1.0	3.7	0.60	1.47	0.04	0.76
7	*Limnocharis flava*	1865	346	NIL	12	750	257	0.01	4.6	2.49	1.35	–	2.61
8	*Nelumbo nucifera*	1147	721	3.2	14.2	473	658	3.3	8.1	2.42	1.10	0.97	1.75
9	*Panicum repens*	1067	511	1.1	7.3	584	352	0.5	5.9	1.83	1.45	2.20	1.24
10	*Pistia stratiotes*	1101	586	NIL	22.0	2007	422	NIL	12.2	0.55	1.39	–	1.80
11	*Nymphaea odorata*	1283	618	2.4	22.4	1042	439	1.0	9.2	1.23	1.41	2.40	2.43
12	*Nymphoides indicus*	1001	581	2.1	20.8	754	304	1.1	7.5	1.33	1.91	1.91	2.77
13	*Eleocharis dulcis*	1445	312	3.5	3.1	1922	279	1.4	1.5	0.75	1.12	2.50	2.07
14	*Ipomea aquatica*	810	550	1.7	2.0	702	408	0.7	0.8	1.15	1.35	2.43	2.50

DM = Dry matter

Table 4. *Bioconcentration quotients for Fe, Al, Cd and Pb for aquatic macrophytes*

	Scientific name	Fe		Al		Cd		Pb	
		Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
1	*Brachiaria mutica*	104	27	3	3	6.7	0.3	22.2	18.0
2	*Colocasia esculenta*	59	80	15	9	3.0	6.7	10.0	20.0
3	*Scirpus grossus*	79	92	13	9	0.0	4.7	0.0	18.3
4	*Eichinocloa colona*	83	155	10	8	5.0	0.1	16.7	26.7
5	*Eichhornea crassipes*	137	166	125	104	8.7	8.3	28.9	35.0
6	*Dryopteris erythrosa*	91	57	21	14	0.1	3.3	0.4	12.3
7	*Limnocharis flava*	108	45	7	5	0.0	0.0	0.0	15.3
8	*Nelumbo nucifera*	73	30	18	16	10.7	11.0	35.6	27.0
9	*Panicum repens*	66	36	12	8	3.7	1.7	12.2	19.7
10	*Pistia stratiotes*	66	121	115	83	0.0	0.0	0.0	40.7
11	*Nymphaea odorata*	80	43	16	11	8.0	3.3	26.7	30.7
12	*Nymphoides indicus*	60	45	13	7	7.0	3.7	23.3	25.0
13	*Eleocharis dulcis*	92	122	9	8	11.7	4.7	38.9	5.0
14	*Ipomea aquatica*	51	44	15	11	5.7	0.3	18.9	2.7

bioconcentration quotients (BQ) were high viz., 107 and 83 respectively (Table 4). Most of the selected macrophytes showed a Fe concentration above 1000 mg kg^{-1}. The TI was highest for *Limnocharis flava* which had a high Fe concentration in shoot compared to root. Its BQ for shoot was 108 and 45 for root. Comparing their biomass production and Fe extraction ability, they can be rated as hyper accumulators of Fe and can be recommended for phytomining of Fe from iron toxic ecosystems. Anning *et al*. (2013) also reported the phytoremediation potential of *Limnocharis flava. Eichhornea crassipes* had removed highest quantity of Fe. BQ was also highest for the same plant. This has clearly indicated the suitability of *Eichhornea crassipes* for the cleanup of the water/sediment contaminated beyond the toxic levels with Fe. Similar result has been already reported for removing Fe from water bodies of Kuttanad (KAU, 2009).

Regarding the phytoextraction of Al, *Dryopteris erythrosora* recorded the highest value for shoot and *Nilumbo nucifera* for root, followed by *Eichhornea crassipes*. All the selected macrophytes showed a TI >1, clearly indicating better ability of translocation of Al from root to shoot. The highest TI was for *Nymphoides indicus.* But the BCF was highest for *Eichhornea crassipes* followed by *Pistia stratiotes*. The hyperaccumulation ability of *Eichhornea crassipes* and *Pistia stratiotes* for Al has been already confirmed (KAU, 2009). According to Yetneberk *et al*. (2013) wide variation in Al accumulation was noticed even within the closely related species indicating the species as well as site wise preference in phytoextraction of Al. Thus the above plants, though they are noxious weeds are doing a favour to the nature by maintaining water quality by the removal of potentially toxic elements. Meera (2017) also reported the phytoextraction potential of *Nilumbo nucifera*, *Nymphoides indicus, Eichhornea crassipes and Pistia stratiotes* for Al from fresh water lakes.

Except *Pistia stratiotes* all the selected macrophytes showed phytoextraction ability for Cd. For *Scirpus grossus*, it was accumulated in root only and not translocated to shoot. Similar result was reported by KAU (2009). *Nelumbo nucifera* recorded the highest Cd content followed by *Eichhornea crassipes, Nymphaea odorata* and *Nymphoides indicus*. All the above macrophytes showed higher values for BQ with the highest value for *Eleocharis dulcis.* TI was highest for *Eichinocloa colona* (37.0), indicating its very high translocation ability for Cd. Hence the above five species can be suggested for the removal of Cd from lake water through phytoremediation. Cd phytoextraction ability of *Eichinocloa colona, Eichhornea crassipes, Nymphaea odorata* and *Nymphoides indicus* was reported by Meera (2017).

All the selected macrophytes showed phytoextraction ability (Table 3 and 4) for Pb with *Nymphaea odorata* (shoot) and *Pistia stratiotes* (root) recording the highest values. But *Nelumbo nucifera* recorded the highest BQ followed by *Eichhornea crassipes.* For the above plants TI was also >1. Even with very small concentration of Pb in water/sediment, these plants were able to extract Pb and translocate it to different plant parts.

Among tested macrophytes, *Eichhornea crassipes* was the best phytoextractor for Fe, *Dryopteris erythrosa* and *Pistia stratiotes* for Al and Pb, *Nymphaea odorata* was found to phytoextract Cd and *Nymphoides indicus* for Cd and Pb.

Evaluating the seasonal impact on the water and sediment quality of the Vellayni fresh water lake it was found that the water quality was poorest during pre-monsoon season since the water quality parameters like acidity, EC, BOD, COD, NH_4-N, NO_3-N, Fe, Al, Cd, and Pb contents were at their highest except for NH_4-N. Sediment also showed almost similar trend with exceptions for NH_4-N, Cd and Pb. The entire lake faces the problem of Al contamination and few sites with Fe, Cd and Pb contamination. Evaluating the phytoextraction ability of native aquatic macrophytes it was observed that among tested macrophytes, *Eichhornea crassipes* was the best phytoextractor for Fe, *Dryopteris erythrosa* and *Pistia stratiotes* for Al and Pb, *Nymphaea odorata* was found to phytoextract Cd and *Nymphoides indicus* for Cd and Pb.

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