Some Aquatic Macrophytes and their Metal Accumulation Potentiality

Jamshed Zaidi[1], A. H. Khan[2], Amit Pal[1]*

[1]Institute of Environment and Development Studies, Bundelkhand University, Jhansi – 284128, Uttar Pradesh, India; apu13@rediffmail.com
[2]CSIR-Indian Institute of Toxicology Research, Lucknow – 226001, Uttar Pradesh, India

Abstract

The present study analyses the potential capacity of aquatic macrophytes to accumulate heavy metals from contaminated waters of three different aquatic bodies namely Mahil Talab, Sumera Talab and Kothi Talab (lake). Four different macrophytes taken for study due to their abundance, are named as *Eichhornia crassipes* (Mart.), *Hydrilla verticillata* (L.F.), *Chara spp.* (L.) and *Lemna minor* (L.) Samples for the analysis of heavy metals were collected from these ponds during the period of October 2015 to September 2016. Five heavy metals named as Fe, Cd, Cu, Cr, Pb and Ni were analyzed in water, sediments and selected plant species which were abundant in water. The amount of metals and their accumulation status recorded in the studied macrophytes are arranged in the given sequence Fe>Pb>Cd>Cr>Cu>Ni. On the basis of metal concentration in different aquatic plants, water bodies and sediment, Pb and Cd was found to be target metal for the removal from the selected water bodies. The present experiments were carried out in the laboratory to analyze the Pb and Cd uptake capacity by above mentioned aquatic macrophytes. From the aspect of phytoremediation in present research, out of the four different macrophytes as above *E. crassipes and Chara spp*. may be considered as more affective for remediation of contaminated water bodies of Bundelkhand region especially for Pb and Cd removal.

Keywords: Aquatic Macrophytes, Bundelkhand Region, Heavy Metals, Toxicity

1. Introduction

During the last millenarian year large number of lakes/ponds were made in peninsular and western India (Sengupta et al., 2010). Majority of our water bodies are gradually becoming contaminated due to the introduction of external materials from the surrounding areas. These included agricultural runoff that contains heavy metal based fertilizers, pesticides effluents released by industrial and domestic sewage. All these adds up large amount of heavy metals and inorganic ions in water bodies and their sediments (ECDG, 2002). Heavy metal is one of the toxic pollutant which causes serious impact on the all organisms of aquatic ecosystem. However treatment of heavy metals has achieved highest significance over the last couple of decades. The lakes are considered to be the complex and delicate ecosystem as they do not possess self cleaning capability and therefore can easily accumulate pollutant. Bioremoval treatment practices are found to be highly effective in lowering down the concentration of heavy metals and in the use of in expensive biosorbent materials (Wild & Bennemann, 1993). Cynobacteria are the organism which can be readily isolated from a solution by filtration method and are self immobilized, hence are used as a bio film on a porous support such as poly urethane foam (Inthorn et al., 2005) and therefore effectively utilized in remediation process. Aquatic plants can be considerably used in pollution control, specifically the application of aquatic macrophytes in the accumulation of heavy metal ion from the water (Ray & White, 1979; Dietz, 1973). The concentration of metals may vary with plant species (Low et al., 1984; Sawidis et al., 1991; Abo Rady, 1980), with different parts of plant (Chen et al.,

*Author for correspondence

1990; Dinka, 1986; Nir et al., 1990), and with the kind of metals and its concentration in growth media (Lee et al., 1981; Taylor and Growder, 1993b; Mortimer, 1985).

In this context present study has been undertaken for monitoring of water quality in selected aquatic bodies of Bundelkhand region of Uttar Pradesh, India and recognizes the major contaminants for polluting our water bodies and how these water bodies can be remediated by using existing plant communities which is economically as well as eco friendly also (Zaidi and Pal, 2017).

2. Materials and Methods

2.1 Study Area

The Bundelkhand is one of the historical regions of India; it plays an important role in 1857 revolution for the independence of country. It occupied 7080 thousand hectares and is situated between $23^020'$ to $26^020'$ N latitude and $78^020'$ to $81^040'$ E longitude. The region spared across 13 districts: seven in Uttar Pradesh - Jalaun, Jhansi, Hamirpur, Lalitpur, Banda, Mahoba and Chitrakut, and six in Madhya Pradesh - Tikamgarh, Datia, Chattarpur, Sagar, Damoh and Panna.

2.2 Selection of Site

Three aquatic bodies of three districts of distinct zone of this region namely Lalitpur (Sumera Taalab), Jalaun (Mahil Pond) and Chitrakoot (Kothi Tallab) respectively has been selected for present study (Fig. 1). Samples were collected quarterly from these water bodies during the period of October 2015 to September 2016, and each water bodies have been divided into five distinct sampling sites.
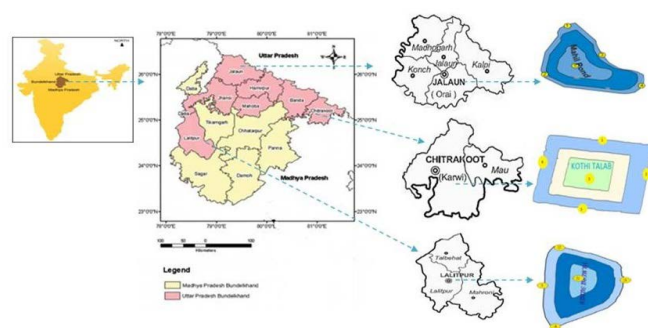

Fig-1: Map of study area

Figure 1. Map of study area.

2.3 Water Sampling

From the given sampling sites water samples were collected by using pre cleaned 1 Liter plastic bottle for physico-chemical parameter and 0.5 Liter plastic bottle used for the analysis of heavy metals. Heavy metal samples were preserved by adding of 2 ml concentrate HNO_3 and DO (Dissolved oxygen) fixed also at sites. The temp and pH of the water were measured on site by using pH meter.

2.4 Sediment Sampling

From the selected water bodies the sediment samples were collected by using a trowel at a depth of 5 cm. The collected samples were kept inside the labeled polythene bags which were placed in ice-box and then transported to laboratory for further metal analyses.

2.5 Plant Sampling

The plant species *Eichhornia crassipes* (Mart.) Solms, *Hydrilla verticillata* (L.F.), *Chara spp.* (L.), and *Lemna spp.* (L.) have been selected for the study of heavy metal content on the basis of their dominance in the selected water bodies. Separate healthy aquatic plants from collected plant samples, first it is washed with tab water then after distilled water to remove periphyton and sediment particles.

2.6 Analytical Design

The techniques of samples preservation and analysis were based on standard method of American Public Health Association (APHA, 2005).

2.7 Calculation of Water Quality Index (WQI)

The proposed method for comparing the water quality of various water sources is based upon eight water quality parameters such as temperature, pH, turbidity, dissolved oxygen, biochemical oxygen demand, total phosphates, nitrates and total solids (Brown et al., 1970; Kumar et al., 2009). The water quality data are recorded and transferred to a weighting curve chart, where a numerical value of Qi is obtained. The data was calculated by online NSF WQI software. The mathematical expression for NSF WQI is given as-

$$WQI = \sum_{i=1}^{n} = QiWi$$

Where, Qi = sub-index for ith water quality parameter;

Wi = weight associated with ith water quality parameter;

n = number of water quality parameters.

For this NSFWQI method, the ratings of water quality have been presented below.

2.8 Sodium Absorption Ratio (SAR)

The sodium or alkali hazard in the use of water for irrigation is determined by absolute and relative concentration of cation and is expressed in term of Sodium Absorption Ratio (SAR) and it can be estimated by formula (Singh, 2002).

$$SAR = Na / \sqrt{\left[\frac{Ca + Mg}{2}\right]}$$

Percentage of sodium has been calculated by following formula-

$$\%Na = \frac{Na \times 100}{Ca + Mg + Na + K}$$

Classification of water for irrigation use based on TDS, SAR and % Na are tabulated in **Table 1.**

2.9 National Sanitation Foundation Water Quality Index (NSFWQI)

- If WQI value between 91-100 water quality will be Excellent.
- If WQI value between 71-90 water quality will be Good.
- If WQI value between 51-70 water quality will be Medium.
- If WQI value between 26-50 water quality will be Bad.
- If WQI value between 0-25 water quality will be very bad.

Table 1. Classification of water for irrigation use based on TDS, SAR and % Na

Classification	Excellent	Good	Fair	Unsuitable
TDS (ppm)	< 200	200-500	500-1500	>1500
SAR	<10	10-18	18-26	>26
Na%	<20	20-40	40-60	>26

Total Dissolved Solid (TDS); Sodium Absorption Ratio (SAR)

2.9.1 Heavy Metals in Water Samples

The Water samples were mixed together by shaking continuously. Then after, a 50 ml aliquot of water sample was pipetted out into the clean digestion flask. Combination of Conc nitric acid and sulphuric acid was used in the process of digestion. 3 ml conc nitric acid was added and the mixture was boiled gradually on a hot plate, allowing it to evaporate to about 15 ml, while controlling the temp of about 70°C on the other hand. Then 3 ml conc nitric acid and 5 ml conc sulphuric acid was added while continuing heating until the solution becomes clear and brown fumes were no longer visible. Upon cooling, digested samples were filtered through using 0.45 μm filter paper and then topped to the mark with de-ionized water. The digest thus obtained was then further analyzed for heavy metal using Atomic Absorption Spectrophotometer (Perkin Elmer 200).

2.9.2 Heavy Metals in Sediment Samples

Sediment samples were kept in sun light and then dried completely after that it is put in hot air oven at 50°C for 24 hours. After that dried sediment were crushed into small particles and allowed to be passed through a 2 mm sieve. 1.0 gm of sieved sample was transferred into a conical flask, mixed with 5 ml of conc. HNO_3 and shook constantly for 2 minutes, and then 2 ml of conc. HCl was added while continuing shaking. The sample was then transferred to a hot plate and subjected to heating for about 2 hours until brown fumes were no longer visible with controlling temperature at 70°C. The solution was then cooled, filtered into a 50 ml flask. The filtrate was made upto the mark with distilled water.

2.9.3 Heavy Metals in Plant Sample:

Heavy metals were analyzed in harvested plants which were thoroughly washed with distilled water, and dried in an oven at 80°C for 48 hr. Dried plant tissue (1gm) were digested in HNO_3 (70%) and $HClO_4$ (70%) (3:1). Heavy metals in aquatic plants species was determined by using atomic absorption spectrophotometer.

2.9.4 Experimental Design

The plants were thoroughly cleaned under running tap water then with distilled water and thus all the soil and sediment particles were removed. The experiment was set up in a glasshouse at 22±3⁰C, equipped with supplementary lighting (day lights); the light period was 17 hr. The

plants were cultured in plastic buckets the way as follows. One plant was cultured in each bucket containing 7 L 0.1% Hoagland solution. After three days the nutrient medium was changed and plants were grown in different concentration solution of Pb and Cd (0.5, 1.0, 1.5 and 2.0 mg/l) for 24, 48 and 72 hr. Plant grown in 10% nutrient solution without lead (Pb) and Cadmium (Cd) served as controls.

3. Results and Discussion

For present study following Ponds e.g., Kothi Talab , Sumera Talab, and Mahil Talab from three different districts of Bundelkhand region have been selected. The observations and the results are shown in following heads and respective tables

Table 2. Physico-chemical properties of water of selected water bodies

Sl. No.	Parameters	Kothi Talab	Sumera Talab	Mahil Pond	IS 10500:2012
1.	Temp	23.3 ± 0.021	23.1 ± 0.031	22.9 ± 0.013	……..
2.	pH	7.66 ± 0.020	7.84 ± 0.025	7.93 ± 0.012	6.5-8.5
3.	EC	731 ± 6.523	934 ± 9.762;	681.7 ± 3.23	2250
4.	TH	203 ± 1.432	222 ± 0.87	131.475 ± 0.92	200
5.	NO_3	22 ± 0.060	27.49 ± 0.04	12.97± 0.03	45
6.	DO	7.32 ± 0.01	5.85 ± 0.031	7.13 ± 0.01	6
7.	Mg	20.3 ± 0.04	23.24 ± 0.07	24.3 ± 1.12	30
8.	TDS	425 ± 2.01	637 ± 4.13	431 ± 2.32	500
9.	PO_4	0.54 ± 0.02	0.75 ± 0.02	0.717 ± 0.015	……
10.	SO_4	18.0 ± 0.01	23.7 ± 0.04	18.4 ± 1.73	200
11.	BOD	3.37 ± 0.025	3.42 ± 0.017	2.925 ± 0.08	3
12.	COD	180 ± 0.856	143 ± 0.573	35.25 ± 1.31	250
13.	Na	253 ± 1.93	236 ± 1.14	251.5 ± 1.43	…..
14.	K	43.3 ± 0.03	35.7 ± 0.07	34.25 ± 1.14	……
15.	Ca	44.5 ± 0.20	52.0 ± 0.08	43.575 ± 0.08	75
WQI		34.45(BAD)	32.82(BAD)	34.70 (BAD)	……..
SAR		44.48	38.47	43.08	………
%Na		70.06	68.02	71.12	……….

Temperature (Temp.); Electrical conductivity (EC); Total Hardness (TH) ; Nitrate (NO_3) ; Dissolved Oxygen (DO) ; Magnisium (Mg); Total dissolved Solid (TDS) ; Biochemical oxygen demand (BOD); Chemical oxygen Demand (COD); Sodium (Na) ; Potassium (K); Calcium (Ca); Sulphate (SO4); Phosphate (PO4); Water Quality Index (WQI); Sodium Absorption Ratio (SAR); Indian Standard (IS).
Values are Mean ± SE (n = 3); Units: - Concentration in mg/l, except pH; Temperature (ºC); EC (µS/cm).

Table 3. Average metals concentrations in water of selected water bodies

Sl. No.	Metals	Kothi Talab	Sumera Talab	Mahil Pond	Indian Standard
01.	Cd	0.045 ± 0.0003	0.064 ± 0.0005	0.031 ± 0.0001	.01
02.	Cr	0.0038 ± 0.007	0.0161 ± 0.013	ND	.05
03.	Cu	0.0020 ± 0.008	ND	0.0016 ± 0.001	.05
04.	Fe	1.297 ± 0.011	1.304 ± 0.005	0.812 ± 0.012	.3
05.	Pb	0.412 ± 0.024	0.787 ± 0.001	0.274 ± 0.002	.05
06.	Ni	ND	0 .013± 0.001	0.021±0.001	.02 *

Cd (Cadmium) ; Cr (Chromium) ; Cu (Copper) ; Fe (Iron) ; Pb (Lead) ; Ni (Nickel)
Values are Mean ± SE (n = 3); Unit: - concentration in mg/l, ND = not detected *WHO Standard

Table 4. Average Metals concentrations in sediment of selected water bodies

Sl. No.	Metals	Kothi Talab	Sumera Talab	Mahil Pond
01.	Cd	0.85 ± 0.005	1.04 ± 0.0005	0.72 ± 0.0001
02.	Cr	0.080 ± 0.009	0.0732 ± 0.013	ND
03.	Cu	0.090 ± 0.006	ND	0.046 ± 0.001
04.	Fe	3.297 ± 0.020	2.112 ± 0.005	3.013 ± 0.012
05.	Pb	0.912 ± 0.014	0.987 ± 0.001	0.804 ± 0.002
06.	Ni	ND	0 .052± 0.001	0.071±0.001

Cd (Cadmium) ; Cr (Chromium) ; Cu (Copper) ; Fe (Iron) ; Pb (Lead) ; Ni (Nickel)

All values are µg/g (DW), ND = not detected

Table 5. Average metals concentration in selected aquatic macrophytes grown in the study areas

Sl. No.	Metals	Eichhornia crassipes	Lemna minor (L.)	Chara spp. (L.),	Hydrilla-verticillata
01.	Cu	0.135±0.001	0.082±.001	0.112±0.003	0.096±0.001
02.	Fe	27.12±0.002	8.176±0.003	19.83±0.002	15.952±0.001
03.	Cr	0.321±0.001	0.091±0.002	0.126±0.001	0.056±0.001
04.	Cd	0.821±.004	0.224±.002	0.53±.001	0.3135±.002
05.	Pb	6.29±.006	2.619±.006	4.754±.002	3.125±.002
06.	Ni	0.153±0.002	0.023±.006	0.052±.002	0.061±.001

Cd (Cadmium) ; Cr (Chromium) ; Cu (Copper) ; Fe (Iron) ; Pb (Lead) ; Ni (Nickel)

All values are µg/g (DW), ND = Not Detected

3.1 Physico-Chemical Properties in Different Water Bodies

The results of physico-chemical properties of study areas are tabulated in the **Table 2**. It may be concluded on the basis of fifteen physico-chemical parameters and WQI (Water Quality Index) that Kothi Talab is more contaminated, followed by Sumera Talab and Mahil Talab respectively. Kothi Talab and Sumera Talab are received domestic and small scale industries discharge directly through the inlets. Mahil Talab is less polluted because it is properly maintained by Municipal Corporation.

3.2 Metal Concentration in different Water Bodies

Heavy metal concentration in three different water bodies (Kothi, Sumera and Mahil Pond) are tabulated in the **Table 3.** Among six metals, except Fe, Pb and Cd all are found within the limit of Indian standards. Presence of Pb and Cd in water may be recognized more harmful for all organisms. The average concentration of lead and cadmium was significantly higher (0.787 mg/l to 0.06 mg/l) respectively in Sumera Talab and followed by Kothi Talab

and Mahil Talab. Source of cadmium is pesticides which come from domestic and agricultural sources. Several researcher viz. Tiwari *et al.* (2015), Sharma *et al.* (2014) and Suneela *et al.* (2008) also observed the similar trend in their respective study at Bhilai Lakes, Laxmi Tal and Husain sagar.

3.3 Metal Concentration in Sediment

The investigated heavy metals show higher concentration in the bottom sediments of lakes than in the lake water. The concentration (mean±SD) of heavy metals in sediment samples are given in **Table 4.** Fe concentration levels in sediment were consistently higher than other analyzed metals. The highest mean levels of Cd (1.04±0.0005 µg/g), Cr (0.085±.009 µg/g), Cu (.090±0.006 µg/g), Fe (3.29±0.020 µg/g), Pb (0.987±0.001) and Ni (0.071±0.001) were found in respective selected water bodies.

3.4 Metal Concentration in different Macrophytes

In natural conditions, the heavy metals concentrations in selected macrophytes named as *E.crassipes, Chara spp.,*

Table 6. Accumulation of lead and cadmium in different macrophytes at different dose and time interval

Time Interval	Lead (Pb) Concentration				Aquatic Macrophytes	Cadmium (Cd) Concentration				Control (Cd)	Control Pb
	0.5 mg/l Dose	1 mg/l Dose	1.5 mg/l Dose	2 mg/l Dose		0.5 mg/l Dose	1 mg/l Dose	1.5 mg/l Dose	2 mg/l Dose		
24 hrs	23.3±2.45	87±7.8	145±11.4	205±12.23	E.Crassipes	1.2±0.02	1.7±0.01	2.2±.002	2.4±.014	0	0
	11±1.51	44±6.4	36±9.8	22±8.32	L. minor	0.72±0.01	0.54±0.001	0.51±.001	0.49±.01	0	0
	14± 2.22	53±3.5	102±12.3	146±8.81	H. verticillata	0.87±0.012	1± 0.001	1.3±.001	1.41±.011	0	0
	18±1.83	68±7.3	118±10.5	171±16.2	Chara spp.	0.9± 0.014	1.2± 0.012	1.37±.001	1.6±.012	0	0
48 hrs	47.3 ±4.2	107±12.3	173±15.5	240±7.7	E.Crassipes	1.6±0.021	2.0±0.011	2.3±.012	2.8±.01	0	0
	23±3.2	78±9.7	55±9.8	60±8.3	L. minor	0.84±0.01	0.74± 0.01	.61±.013	0.58±.001	0	0
	31±3.31	83±5.4	135±11.8	179±12.4	H. verticillata	0.97± 0.012	1.3±.02	1.42±0.014	1.56±.02	0	0
	35±3.12	91±7.4	142±13.5	195±13.2	Chara spp.	1.1±0.01	1.5±.01	1.72±0.012	1.93±.01	0	0
72 hrs	76.4±12.11	125±16.6	207±15.6	262±16.7	E.Crassipes	1.8±0.021	2.3±.01	2.6±.011	3.1±.01	0	0
	31±2.03	84±7.5	62±11.8	67±10.8	L. minor	1.12±0.002	1.03±.02	1.0±.013	0.9±.011	0	0
	47± 6.43	95±8.8	171±13.8	193±11.5	H. verticillata	1.2±0.003	1.6±.013	1.69±.001	1.81±.018	0	0
	53±5.32	102±12.2	192±17.6	238±12.3	Chara spp.	1.3±0.002	1.8±.001	1.92±.013	2.12±.011	0	0

All values are μg/g (DW), Values are Mean ± SE (n = 3)

L.minor and H. verticillata are summarized in the **Table 5**. *In these macrophytes, c*oncentration of heavy metals namely Cadmium (Cd), Chromium (Cr), Iron (Fe), Lead (Pb), Copper (Cu) and Nickel (Ni) have been estimated. Concentration of heavy metals was recorded in the given sequence Fe, Pb, Cd, Cr, Cu and Ni in all selected marcophytes in decreasing order as *E.crassipes >Chara spp.> H. verticillata> L. minor.*

3.5 Accumulation of Heavy Metals in Aquatic Macrophytes

In present investigation, different concentrations of dose of Pb and Cd viz. 0.5mg/l, 1.0 mg/l , 1.5 mg/l and 2.0 mg/l given to selected macrophytes *E. crassipes, Chara spp., L. minor and H. verticillata,* separately with control for 24 hr, 48 hr and 72 hr. The data of accumulation of metal concentrations by aquatic macrophytes are presented in **Table 6**.

Lead accumulation: except *L. minor* (at 1mg/l dose) accumulation of lead was recorded higher in all selected species at 2.0 mg/l for 72 hrs in *E. Crassipes* (262 μg/g), *H. verticillata* (193 μg/g) *Chara spp.* (238 μg/ g) and *L. minor* (84 μg/g) respectively.

Cadmium accumulation: *L. minor* was recorded maximum (1.12 μg/g) Cd accumulation at 0.5 mg/l dose and other selected plants were found higher at 2.0 mg/l for 72 hrs, in *E. crassipes* (3.1 μg/g), *H. verticillata* (1.81 μg/g) and *Chara spp. (2.12 μg/g)* and lowest amount was recorded in *L. minor* (0.49 μg/g) at 2.0 mg /l dose for 24 hrs and minimum was observed in *E. crassipes* (1.2 μg/g), *H. verticillata* (0.87 μg/g) and *Chara spp.* (0.9 μg/g) respectively. Our finding also supported by studies of Garg *et al.* (1997), Alka *et al.* (2012) , Saygideger *et al.* (2013), Ekta *et al.* (2014), Goswami *et al.* (2010), Clabeauxt *et al.* (2011) in *H. verticillata, L. minor*, *E. crassipes* and *Chara spp* respectively .

In the present investigation, comparatively the concentration of lead (Pb) and Cadmium (Cd) was found to be higher in water samples of selected water bodies. Therefore dose of Pb and Cd at different concentrations (0.5 mg/l, 1.0 mg/l, 1.5 mg/l and 2.0 mg/l) had been given to all the four experimental plants, keeping all the external factor under controlled conditions. It was found that *E. crassipes,* and *Chara spp. are* more suitable for the phytoremediation of Pb and Cd contaminated water so it is concluded that among four selected plant spices *E.*

crassipes, and *Chara spp.* could be useful for phytoremediation of Pb and Cd for mitigation of contaminated water bodies.

4. References

1. Abo-Rady, M.D.K. (1980) "Aquatic macrophytes indicator for heavy metals pollution in the river Leine West Germany", *Arch. Fur Hydrobiologie*, **89**, 387–404.

2. Alka, S., Kumar, S.C. and Agarawal A. (2013) Effect of Lead and Cadmium on Aquatic Plant Hydrilla verticillata. *Journal of Environmental Biology*, **34**, 1027-1031.

3. APHA. (2005) *Standard methods for examination of water and waste water 21st ed.* American Public Health Association, Washington.

4. Brown, R.M., McClelland, N.I., Deininger, R.A. and Tozer, R.G. (1970) "Water quality index-do we dare", *Water Sewage Works*, **117**(10), 339-343.

5. Chen, C.Q., Xu, Y.L., Zhang, Q.Z. and Sun, Z.M. (1990) "Absorption of134 Cs by aquatic plants". *Acta Agriculturae Nucleatae Sinica*, **4**(3), 139–144.

6. Clabeauxt, L.B., Divina, A.G., Navrro, Aga. S.D. and Bisson, A.M. (2011) "Cd Tolerance and Accumulation in the Macrophytes,Chara austrulis: Potential use for Clarophytes in phytoremediation", *Environ Sci Technol*, **45,** 5332–335. Crossref

7. Dietz, F. (1973) *The enrichment of heavy metals in submerged plants, in S.M. Jankis (ed.),* Advances in Water Pollution Research, 6, 53-62, Pergamon Press.

8. Dinka, M. (1986) *Accumulation and distribution of elements in cattail species (Typha Iatifolia, T. angestifolia) and common reed (Phragmites australis) (CAV. Trin.ex steudel) living in Lake Balaton,* Proceedings EWRS/AAB 7th Symposium on Aquatic Plant, 81-87.

9. ECDG. (2002) *European Commission DG ENV. E3 Project ENV. E.3/ETU/0058.* Heavy metals in waste. Final report.

10. Ekta, C. and Praveen S. (2014) "Assessment of heavy metal removal efficiency of Lemna minor", *International Journal of Innovative Research and Development*, **3**(6), 176–8.

11. Garg, P, Tripathi, R.D, Rai, U.N., Sinha, S. and Chandra P. (1997) "Cadmium accumulation and toxicity in submerged plant Hydrilla Verticillata (L.F.) Royl", *Environmental Monitoring and Assessment,* **47**, 167–73. Crossref

12. Goswami, R., Thakur, R. and Sarma, K.P. (2010) "Uptake of lead from aqueous solution using Eichhornia crassipes: effect on chlorophyll content and photosynthetic rate", *International Journal of Chem Tech Research*, **2**(3), 1702–5.

13. Inthorn, D., Sombatjinda, S., Wongsirikul, D. and Wantawin C. (2005) "Removal of cadmium by immobilized and free cell of Nostoc poludosum and Rivularia sp. Asian", *J. Microbiol. Biotech. Env. Sc.,* **7**(3), 155-162.

14. Kumar, D. and Alappat, B. (2009) "NSF-Water Quality Index: does it represent the experts opinion", *Pract. Period. Hazard. Toxic Radioact. Waste Manage.*, **13**(1), 75-79. Crossref

15. Lee, C.R., Sturgis, T.C. and Landin, M.C. (1981) "Heavy metal uptake by marsh plants in hydroponic solution cultures", *J. Plant Nutr*, **3**, 139–51. Crossref

16. Low, K.S., Lee, C.K. and Tan, S.H. (1984) "Selected aquatic vascular plants as biological indicators for heavy metal pollution", *Pertanika*, **7**(1), 33–47.

17. Mortimer, D.C. (1985) "Freshwater aquatic macrophytes as heavy metal monitors. The Ottawa river experience", *Environ. Monitoring and Assessment*, **5**, 311–323. Crossref PMid:24258036

18. Nir, R. Gasith, A. and Perry, A.S. (1990) "Cadmium uptake and toxicity to water hyacinth: Effect of repeated exposures under controlled conditions", *Bull. Environ. Contam. Toxicol.*, **44**, 149–157. Crossref PMid:2306532

19. Ray, S.N. and White, W.J. (1979) "Equesitum arvense, and aquatic vascular plant as a biological monitor for heavy metal pollution", *Chemosphere,* **8,** 125-128. Crossref

20. Sawidis, T., Stratis, J. and Zachariadis, G. (1991) "Distribution of heavy metals in sediments and aquatic plants of the river Pinios (Central Greece)", *The Science of the Total Environ*, **102**, 261–266. Crossref

21. Saygideger, S.D., Keser, G. and Dogan, M. (2013) "Effects of lead on chlorophyll content, total nitrogen, and antioxidant enzyme activities in duckweed (Lemna minor)", *Int. J. Agric. Biol.*, **15**, 145-148.

22. Sengupta, M., Gopal, B., Dalwani, R. and Srivastava, S.K. (2010) *Conservation and management of lake an Indian perspective. Ministry of Environment and Forest*, National River Conservation Directorate, Paryavaran Bhawn , New Delhi publication.

23. Sharma, G., Zaidi, J. and Pal, A. (2014) "Remediation of heavy metals through aquatic macrophytes from water bodies of Bundelkhand region of Uttar Pradesh", *J. Eco-Physiol. Occup. Health*, **14**,189-196. Crossref

24. Singh, A.K. (2002) "Quality assessment of surface and subsurface water of Damodar river basin", *Indian J. Environ Hlth*, **44**, 42-46

25. Suneela, M., Krishna, G.R., Krishna, K.V., Sai, V.M., Bhargav, V., Reddy, K.S.S., Srinivas, D.S.S. and Srinivas, J.S. (2008) Proceedings of Taal 2007: The 12th World Lake Conference, 304-306 .

26. Taylor, G.J. and Crowder, A.A. (1983 b) "Uptake and accumulation of copper, nickel and iron by Typha latifolia grown in solution culture". *Can. J. Bot.,* **61**, 1825–1830. Crossref

27. Tiwari, M.K., Bajpai, S., Dewangan, U.K. and Tamrakar, R.K. (2015) "Assessment of heavy metal concentrations in surface water sources in an industrial region of central India", *Karbala Int. J. Mod. Sci,* **1**, 9-14. Crossref

28. Tyagi, S., Sharma, B., Singh, P. and Dobhal, R. (2013) Water quality assessment in terms of Water Quality Index, *American Journal of Water Resources*, **1**(3), 34-38.

29. Wild E.W. and Bennemann, J.R. (1993) Bioremoval of heavy metals by the use of microalgae. *Biotech Adv.*, **1**:781-812. Crossref

30. Zaidi, J. and Pal, A. (2017). Review on the heavy metal pollution in major lakes of India: Remediation through plants. *African J. Environ. Sci. Technol.*, **11**(6), 255-265. Crossref