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ASSESSMENT OF HEAVY METALS CONTAMINATION IN DRAINS WATER AND AQUATIC PLANTS OF ROHTAK AND BAHADURGARH (HARYANA), INDIA

Sandeep Kumar, Asha Singh, Vishal Panghal and Sunil Kumar*

Department of Environmental Sciences, Maharshi Dayanand University, Rohtak, Haryana, India.

Abstract

Over the past few decades, the rapid growth of population, industrialization and urbanization lead to contamination of heavy metals in surface water along with accumulation in aquatic plants. This study examined the physico-chemical parameters (including heavy metals) in drains water and accumulation of heavy metals content in aquatic plants in various drains of Rohtak and Bahadurgarh. The plants collected from the various sampling sites were *Lepidium didynum, Rumex dentatus, Ranunculus sceleratus, Eichhornia crassipes, Eclipta alba, Typha angustifolia* and *Alteranthera sessilis*. The physico-chemical parameters *viz.,* pH, electrical conductively (EC), total dissolved solid (TDS), total hardness, total alkalinity, sodium (Na), potassium (K) and sulphate (SO_4) were measured. The heavy metals in water and aquatic plants were determined with the help of atomic absorption spectrophotometer (AAS). The physico-chemical parameters of water samples exceeded the permissible prescribed limits of BIS, except pH, Na and K. The biological oxygen demand (BOD) and chemical oxygen demand were found between 24-104 and 95-161 mg L^{-1} respectively. The aquatic plants were noted for having the high concentrations of Cu, Cd, Cr, Pb, Zn and Fe in their different parts. The maximum contamination of heavy metals in aquatic plants was found at Site 3 along with maximum concentration of these heavy metals in the water. The bioaccumulation factor (BAF) was maximum for *Ranunculus sceleratus, Eichhornia crassipes* and *Eclipta alba* for various heavy metals, suggesting that these species are hyperaccumulating in the study area and can be used for phytoremediation of heavy metals.

Key words: Heavy metals, Drains water, Biological Oxygen Demand, Aquatic Plants, Hyperaccumulator.

Introduction

The major sources of wastewater are industries, domestic waste and sewage treatment plants. Due to increasing population, water demand is increasing and in turn lots of wastewater is generated. The massive release of heavy metals in wastewater is due to an explosion in industrialization and urbanization (CPCB, 2008). There are various industries such as electroplating, mining, metal processing, pulp and paper industries, textile, battery manufacturing, petroleum refining, paint and pesticide manufacturing, which generate a large portion of heavy metal contaminated effluents. Heavy metals have major effects on environment and human health because of their persistent, toxic and bioaccumulative nature (Rai *et al.,* 1981; Lokeshwari and Chandrappa, 2007; Chang *et al.,* 2009; Yadav *et al.,* 2009). Heavy metals are the elements that having density above 5 g cm^{-3}. Heavy metals contamination in environment has become serious concern in developed and developing countries. Heavy metals like copper, zinc, iron, chromium, nickel, manganese, lead, cadmium etc. may discharge in water bodies from domestic waste and industrial waste in water.

Aquatic plants are those plants that grow in water or nearby water bodies. These plants have more ability to accumulate nutrients, toxic metals, organic and inorganic pollutants from wastewater. Aquatic plants are more suitable than terrestrial plants for wastewater treatment as they grow rapidly, produce huge amount of biomass, having high capacity of pollutant uptake. As the aquatic plants grow in water, they absorb pollutants and purify the water. Aquatic plants provide shelter to aquatic invertebrates, regulate oxygen balance and nutrient cycle, alter water movement and accumulate heavy metals as these are important for structural and functional aspects of aquatic ecosystem (Srivastava *et al.,* 2008; Dhote and

***Author for correspondence :** E-mail : sunilevs@yahoo.com

Dixit, 2009). There are numerous researchers made efforts to developed technological solutions to reduce the contamination of heavy metals. Various technologies are used for removal of heavy metals contamination such as electro dialysis, adsorption, ion exchange, membrane filtration and precipitation. But all these technologies are not economically cost effective and sustainable solution for metal removal because these technologies generate large concentration of toxic sludge that requires disposal and further treatment. In the developing countries like India, such technologies are not economically affordable due to shortage of land (Singh *et al.,* 1996). Heavy metals cannot be degraded and therefore their effective clean up requires their immobilization to reduce toxicity (Suhag *et al.,* 2011). Heavy metals toxicity can be removed by many methods like Rhizofilteration, Phytoaccumulation, Phytovolatilisation etc. Among them phytoaccumulation for removal of heavy metals draw the attention of community. This is an approach to find out the potential of aquatic plants for phytoremediation of metals.

Phytoaccumulation is an active process and defined as the phenomenon for uptake of heavy metals by living cells and performed by aquatic as well as terrestrial plants by accumulation of pollutants from soils and wastewater (Erakhrumen and Agbontalor, 2007; Erdei *et al.,* 2005). Aquatic plants can uptake large amounts of metals from water and/or sediment through active and passive absorption, with this absorption capacity of metals through different organs such as roots, stems and leaves, making these plants suitable for heavy metal alterations in the aquatic environment (Haraguinteguy *et al.,* 2014; Cai *et al.,* 2018). The aquatic plants like *Eicchornia crassipes* (Kay *et al.,* 1984); *Nasturtium officinale* (Kara *et al.,* 2003); and *Lemna minor* L. (Kara *et al.,* 2004) have accumulated Cd, Cu, Ni, Fe and Pb in higher concentration from the contaminated solutions. This technique is best suited in removal of heavy metal toxicity in diffusely polluted areas, where pollutants occur only at relatively low concentration (Rulkens *et al.,* 1998; Tangahu *et al.,* 2011).

The aim of this research to assess the physico-chemical parameters of wastewater collected from the areas nearer to sewage treatment plants and drains nearer to industrial areas of Rohtak and Bahadurgarh, Haryana. The concentration of six heavy metals (Pb, Cr, Zn, Ni, Cu and Fe) in macrophytic species and bioaccumulation factor were also evaluated.

Materials and Methods

Study area and sampling sites

The contaminated water discharged from various sources such as sewage treatment plant to nearby area and drain carrying domestic and industrial effluents discharge were selected for collection of water samples to measure the physico-chemical parameters. The water samples were collected randomly from polluted sites at Rohtak and Bahadurgarh city. The seven water sampling sites were selected. The identified sites with their description are listed in table 1.

Moreover, 15 aquatic plants of 7 plant species were also collected from nearby of these sites to assess the heavy metal content in these plants to show their accumulation potential. All these plants are listed in table 2.

Sampling and analysis of water

The water samples were collected from various sampling sites in cleaned plastic bottles and transferred to laboratory and preserved at 4°C in ice box. The various physico-chemical parameters like pH, electrical conductivity (EC), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total hardness, chloride, total alkalinity, cations Na^+ and K^{2+}, sulphate and total dissolved solids (TDS) were analyzed in water samples by standard methods as prescribed by American Public Health Association (APHA, 1998). The pH and EC were measured at the sites with the help of systonic water testing kit. The BOD was determined by BOD five day tests. The COD was evaluated by reflux method using ferrous ammonium sulphate as a titrant. The total hardness was measured by titration method using EDTA.

Table 1: Sampling sites with their description.

Site	Description
Site 1	Near STP Jhajjar road, Rohtak
Site 2	Drain No. 8 near Sunariya road, Rohtak
Site 3	New industrial area, Hisar bypass, Rohtak
Site 4	Drain No.8 near STP Singhpura village, Rohtak
Site 5	Sector-17 industrial area, Bahadurgarh
Site 6	Drain, Bahadurgarh
Site 7	STP, Bahadurgarh

Table 2: List of plants collected from nearby sampling sites.

Site	Plant Species
Site 1	*Ranunculus sceleratus, Eclipta alba*
Site 2	*Lepidium didynum, Rumex dentatus, Ranunculus sceleratus*
Site 3	*Eichhornia crassipes, Eclipta alba*
Site 4	*Eichhornia crassipes, Eclipta alba*
Site 5	*Eclipta alba*
Site 6	*Typha angustifolia*
Site 7	*Rumex dentatus, Ranunculus sceleratus, Lepidium didynum, Alteranthera sessilis*

The chloride was measured by argentometric titration using silver nitrate. The alkalinity was determined by titration using HCl. Sodium and potassium were analyzed with the help of Flame Photometer model No. EP 902. The turbidimetric method used to analyzed sulphate. The TDS was indirectly calculated from EC value.

The concentrations of different heavy metals (Pb, Cu, Zn, Cr, Fe and Ni) in water samples were determined by using atomic absorption spectrophotometer (HITACHI, Polarized Zeeman, Atomic Absorption Spectrophotometer, Model No. Z-6100). All chemicals used were of analytical grade. The metals concentration in water was determined after acid digestion. 100 ml water sample was taken in a volumetric flask and evaporated till only 2-3 ml sample remain in the flask. After that digested with HNO_3:$HClO_4$ (3:1 v/v) at 120°C and were cooled at room temperature and volume was make upto 100 ml with distilled water. The concentrations of different heavy metals were determined using AAS.

Sampling and heavy metal analysis of aquatic plants

The aquatic plant samples were collected in plastic bags from nearby wastewater sites and labelled carefully. Different macrophytic plants such as *Eichhornia crassipes, Ranunculus sceleratus, Typha angustifolia*, *Eclipta alba, Lepidium didymum, Rumex dentatus* and *Alternanthera sessilis* were collected to access the heavy metal content. Different heavy metals like Pb, Cu, Zn, Cr, Fe and Ni were estimated in aquatic plants. The selected plants were washed in distilled water and dried at room temperature. Further, the plant samples were dried in oven for 24 h at 80°C. The dried plant samples were grounded. 2 g of plant samples were digested with HNO_3:$HClO_4$ (3:1 v/v) and diluted to 50 ml with de-oinized distilled water. The digested plant samples were analyzed for heavy metals by AAS using standard method of analysis (APHA, 1998).

Bioaccumulation factor (BAF)

Bioaccumulation factor refers to the efficiency of a plant species to accumulate a metal into its tissue from the surrounding environment (Ladislas *et al.,* 2012). BAF of different metals from soil to terrestrial plants, sediment to rooted aquatic plants and water to aquatic plants was calculated on the basis of dry weight of plant samples. It was calculated using the equation given by Wilson and Pyatt (2007).

Bioaccumulation factor (BAF) =

$$\frac{Average\ metal\ conc.in\ whole\ \ plant\ tissue\ (mg\,/\,kg)}{metal\ conc.in\ water\ (mg\,/\,L)}$$

Results and Discussion

Water properties

The results of physico-chemical properties of wastewater are depicted in table 3. The pH, Electrical conductivity (EC), Total Dissolved Solid (TDS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Sodium (Na), Potassium (K), Total Hardness (TH), Chloride, Alkalinity and Sulphate were found between 6.29-7.86, 759-9090µS/cm, 505-6130, 24-104, 95-161, 15-76, 13-91, 334-2127, 16-2657, 272-1527 and 251-1690 mg L^{-1}, respectively. The pH was under permissible limit (6.5-8.5) at all sites. The EC, TDS, Na, total hardness, chloride and COD were found maximum at site 5. The BOD, K and alkalinity were found maximum at site 4. The sulphate was found maximum at site 3. The parameters like alkalinity, sulphate, hardness, BOD were found quite high at all the sites. These parameters were found beyond the permissible limits as recommended by IS 10500:2012 (BIS 2012). The higher value may be attributed to discharge of untreated sewage, domestic waste, contaminated effluent at all sites. The sites 3 (New industrial area, Hisar bypass, Rohtak) and 5 (Sector-17 industrial area, Bahadurgarh) showed the higher values of TDS, clearly indicated that these sites

Table 3: Physico-chemical parameters of water samples at sites.

Site No.	pH	EC (uS/cm)	TDS (mg L^{-1})	BOD (mgL^{-1})	COD (mgL^{-1})	Na (mgL^{-1})	K (mgL^{-1})	Total Hardness (mg L^{-1})	Chloride (mg L^{-1})	Alkalinity (mg L^{-1})	Sulphate (mg L^{-1})
1	7.75±0.04	759±3.5	508±3.6	30±3	125±4	15±1.5	16±0.57	334±4.5	156±1	272±14	251±3.6
2	6.67 ±0.2	1661±5	1114±2.5	43±1.5	101±1.5	21±1.5	13±1.52	600±4.5	123±1	894±1.7	1201±10
3	6.29 ±0.2	4940±9	3312±6	24±0.5	103±4.1	59±3	27±0.57	540±3.5	16±1	1416±12	1690±5
4	7.60± 0.3	2051±9	1360±20	104±5	161±1.5	43±0.5	91±1	580±7	505±2.8	1527±18	1001±8
5	7.55± 0.3	9090±65	6130±124	58±6	156±1.5	76±1	23±1.73	2127±4.9	2657±31	1265±33	1029±24
6	7.86 ±0.1	1936±15	1318±10	27±3	120±3.5	52±0.5	14±1.52	884±4	1081±15	716±6	1215±21
7	7.67±0.01	4779±25	3373±52	41±2	95±1.5	53±2	13±1	888±1.52	1174±8.5	726±4.6	1585±2.08
Mean	7.34	3602	2445	46	123	45	28	850	816	973	1138
Range	6.29-7.86	759-9090	505-6130	24-104	95-161	15-76	13-91	334-2127	16-2657	272-1527	251-1690

were maximum affected by anthropogenic activities. It could be due to clusters of industries are located nearer to these locations. These industries used various type of acids and chemicals and released the untreated effluents. The BOD was found maximum at site 4 (Drain No. 8 near STP Singhpura village, Rohtak), it might be due to discharges of treated and untreated effluent from Singhpura STP. This site located downstream of Singhpura STP in drain No. 8. The BOD value of uncontaminated water has less than 5 mg L^{-1} (WHO, 2011). All the water samples exceeded the WHO criterion given for BOD. However, cations like sodium and potassium were found under permissible limits. The chloride concentration was found above the prescribed limit of BIS (2012) at 4, 5, 6 and 6 sampling sites. While in case of alkalinity and sulphate six samples (86%) were surpassed the BIS (2012) standards, indicating the influence of domestic and industrial activities on these sites. Dutta *et al.,* (2018) also found the higher values of TDS, Cl^{-}, PO_4^{3-}, BOD, COD and Na^{+} in Nag river and associated drains at Nagpur Maharashtra. They revealed that the higher values of physico-chemical parameters could be due to river and drains water contamination by municipal sewage discharge, land runoff, indiscriminate, dumping of solid wastes and low levels of dilution in the pre-monsoon period.

Heavy metals in wastewater

The heavy metal content in wastewater at all the seven sites are shown in Fig. 1. Site 3 was found highly affected with heavy metal content due to discharge from metal plating industries located nearer to this site. This site was nearer to industrial area Hisar bypass in Rohtak and surrounded by various Nut, Bolts and screw manufacturing units. The treated and untreated effluent producing during the metals processing in these industries directly and indirectly discharged in to the drain No. 8. All the heavy metals concentration found higher at this site. The heavy metal content were compared with the IS 10500:2012 (BIS, 2012) standards. The heavy metal like Fe, Pb, Cu and Cr were found beyond the permissible

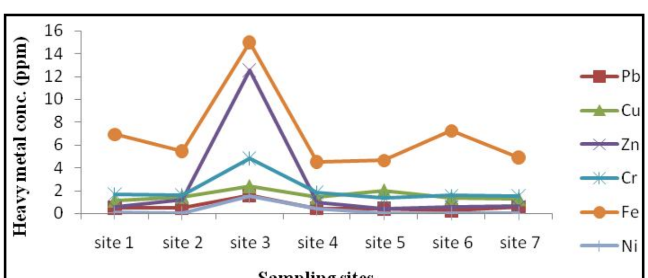

Fig. 1: Heavy metals concentration (mg L^{-1}) in wastewater at different sampling sites.

limits at all the sites. The mean value of heavy metal content varies in the order of Fe>Zn>Cr>Cu>Pb>Ni. Maximum contents of different metals were observed as Fe (15 mg L^{-1}), Zn (12.52 mg L^{-1}), Cr (4.80 mg L^{-1}), Cu (2.37 mg L^{-1}), Pb (1.58 mg L^{-1}) and Ni (1.53 mg L^{-1}) at site 3. Similarly, Bhattacharya *et al.,* (2015) assessed the water heavy metals concentration of Najafgarh drain along with Yamuna River water in Delhi region. They reported that maximum cumulative heavy metals (total of Cu, Zn, Pb, Cr and Ni) concentration was 3.7 mg L^{-1} at Punjabi Bagh in Najafgarh drain. The possible reason for higher heavy metals in Najafgarh drain could be due to the discharge of raw effluent in to sewages by various industries includes battery, printing, chemical electroplating alloy and pickling. These industrial clusters were concentrated along with the Najafgarh drain, some of these industries do not have proper treatment facilities for wastewater. While, in the present study cumulative heavy metals (total of Cu, Zn, Pb, Cr and Ni) concentration was found 22.8 mg L^{-1} at site 3 (drain No. 8 near Hisar bypass). The cumulative heavy metals at site 3 was many fold higher as compared to Najafgarh drain at Punjabi Bagh. It might due to the industrial area on Hisar bypass which is dominated by metal and electroplating processing industries. The heavy metals were used for electroplating, which ultimately become the part of effluents and directly and indirectly discharges to the drain No. 8 upstream to site 3. Furthermore, dilution by domestic wastewater in Najafgarh drain was higher in comparison to the Rohtak drain No. 8, indicating that maximum volume of water in site 3 was industrial discharge.

Heavy metal content in plant parts

The metal content in 15 aquatic plants collected from different drain sites of Rohtak and Bahadurgarh is listed in table 4. The maximum contents of metals were observed as Pb (212 mg kg^{-1}) and Zn (702 mg kg^{-1}) in *Eclipta alba* roots, Cr (110 mg kg^{-1}) and Ni (547 mg kg^{-1}) in *Eichhornia crassipes* roots, Cu (421 mg kg^{-1}) and Fe (4047 mg kg^{-1}) in *Ranunculus sceleratus* roots, while minimum contents of metals were observed as Pb (1.8 mg kg^{-1}) and Cr (29.01 mg kg^{-1}) in *Lepidium didymium* stem, Zn (56.03 mg kg^{-1}) in *Typha angustifolia* stem, Cu (92.9 mg kg^{-1}) in *Eichhornia crassipes* stem, Fe (180 mg kg^{-1}) in *Ranunculus dentatus* stem, Ni (2.3 mg kg^{-1}) in *Alternanthera sessilis* root. It was observed that mostly uptake of metals was maximum in roots followed by leaves and stem in almost all the plant samples. This pattern was also observed in analysis on bioaccumulation of metals in aquatic plants (Singh *et al.,* 2017). Allen

(1989) quoted the safe/threshold limit of various heavy metals in plants. According to Allen criterion safe limit of Pb, Zn, Cr, Ni, Cu and Fe in plants are 10, 100, 0.5, 5, 25 and 3000 mg kg^{-1}, respectively. The mean concentrations

Table 4: Heavy metal content in aquatic plants.

Site	Plant species	Plant parts	Pb (mg/kg)	Zn (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Ni (mg/kg)
1	*Ranunculus sceleratus*	Root	42.5±4.46	265±7.45	47.5±1.0	272±7.4	4047±90	79.2±6.5
		Stem	16.6±1.38	82±3.98	41.3±2.8	108±2.7	272±22	43±2
		Leaves	3.2±0.80	221±14	42.5±1.8	131±6.7	597±4.2	44.3±5.4
1	*Eclipta alba*	Root	6.01±0.80	2668±14	51.8±1.8	138±7.7	3746±150	57.1±3.5
		Stem	11.1±1.38	146±19	50±1.8	107±5.4	234±42	44.8±4.8
		Leaves	2.31±0.80	82±10	51.2±1.06	116±5.9	826±64	46.1±1.3
2	*Lepidium didymum*	Root	23.6±3.67	230±9	83.9±4.6	124±6	2872±107	65.8±2.3
		Stem	1.8±0.80	173±13	78.3±1.0	109±5.4	1184±132	55.1±3.6
		Leaves	6.9±1.38	185±15	82.7±4.6	124±7.2	2507±274	63.8±8.7
2	*Rumex dentatus*	Root	5.5±1.38	429±7.4	102±4.6	323±10.7	2989±90	92.3±7.4
		Stem	3.7±0.80	261±6.46	73.4±4.6	110±6	638±38	55.8±4.5
		Leaves	9.7±1.38	325±5.10	66.6±1.8	132±9.6	1451±28	58.9±4.9
2	*Ranunculus sceleratus*	Root	126±10	567±28.24	97.5±4.2	421±28.3	2892±151	182±9.8
		Stem	4.1±1.38	424±13	102±3.8	144±5.7	1255±50	85.1±1.6
		Leaves	88.±3.49	585±33	108±6.5	280±10	1527±114	152±20
3	*Eichhornia crassipes*	Root	36.1±2.77	680±32	110±5.6	189±3.3	3387±198	547±29
		Stem	6.9±1.38	228±20	45±1.0	97±3.4	562±30	123±3.3
		Leaves	3.2±0.80	184±54	47.5±3.8	98±3.9	1315±125	144±4.0
3	*Eclipta alba*	Root	47.6±1.60	702±1.9	78.3±4.6	204±10	1856±55	127±12
		Stem	2.3±0.80	6680±11	51.8±3.7	153±10	507±27	127±10
		Leaves	6.01±0.80	692±17	59.2±3.7	154±14	1538±25	100±7.7
4	*Eichhornia crassipes*	Root	59±0.80	629±2.4	100±5.5	147±3.3	3227±105	182±12
		Stem	26±2.40	161±13	70.9±1.0	92.9±1.5	536±55	85.8±8.2
		Leaves	1.8±0.80	158±39	69.1±2.8	93.4±2.2	790±23	725±3.8
4	*Eclipta alba*	Root	212±5.78	671±31	108±4.6	137±6.4	3277±50	177±6.2
		Stem	113±6.94	385±10	70.9±2.8	96.9±3.3	2280±85	68.7±6.4
		Leaves	36±4.24	377±11	91.9±2.8	105±6.9	2178±23	81±4.2
5	*Eclipta alba*	Root	74±0.80	176±14	69.7±2.8	133±2.7	1381±75	64.3±1.6
		Stem	9.2±0.80	157±3.9	66.6±1.8	128±8	465±37	56.6±2.3
		Leaves	25±1.60	186±10	70.9±2.8	132±18	848±65	63.5±1.1
6	*Typha angustifolia*	Root	19.9±0.80	114±14	81.4±1.8	173±6.9	551±35	92.5±6.5
		Stem	6.01±0.80	56±7.9	72.2±1.8	107±5.2	231±16	59.4±2.7
		Leaves	3.70±0.80	102±4.2	69.7±2.1	108±9.3	259±6.9	56.6±3.1
7	*Rumex dentatus*	Root	7.87±0.80	158±4.3	70.3±1.8	124±0.75	3744±56	60.5±1.7
		Stem	3.70±0.80	221±25	69.7±1.0	120±7.2	180±5.9	53.0±4.6
		Leaves	3.24±0.80	250±13	73.4±1.0	141±14	1228±54	60.5±6.4
7	*Ranunculus sceleratus*	Root	17.1±1.60	370±6.6	94.4±3.2	191±17	3780±106	81.0±8.0
		Stem	2.31±0.80	190±2.7	75.9±4.8	150±13	627±18	56.9±5.3
		Leaves	10.6±0.80	302±26	80.2±2.1	125±4.7	1693±58	77.9±4.3
7	*Lepidium didymum*	Root	9.7±1.38	190±19	79±2.8	98±1.3	1235±83	6.15±0.76
		Stem	3.2±0.80	202±5.9	29±3.8	100±3.3	1020±11	5.38±0.76
		Leaves	11.1±1.38	301±16	75.9±4.8	120±4.6	1946±126	4.87±0.44
7	*Alternanthera sessilis*	Root	10.1±1.60	182±2.5	33.3±4.8	114±0.7	932±59	2.30±0.11
		Stem	9.7±1.38	360±7.6	30.2±2.8	112±11	675±13	4.61±0.76
		Leaves	10.6±0.80	347±10	74±1.8	144±13	936±58	7.69±0.76
	Mean		25.2	490	71	174	1560	98.3
	Range		1.8-212	56-6680	29-110	92-1471	180-4047	2.3-725

of Pb, Zn, Cr, Ni, Cu and Fe in the study area were found 25.2, 490, 71, 174, 98 and 1560 mg kg^{-1}, respectively. The mean concentrations of Pb, Zn, Cr, Ni, Cu were exceeding the Allen criteria, suggesting that these heavy metals were toxic to the plant in the study area and growth of these plant might be retarded. Similar study has been conducted by Mishra *et al.,* (2008) in Govind Ballabh Sagar lake. They reported higher concentration of Cu, Cd, Mn, Pb and Hg in this lake. They collected various macrophytic plants viz., *Eichhornia crassipes, Azolla pinnata, Lemna minor, Spirodela polyrrhiza, Potamogeton pectinatus, Marsilea quadrifolia, Pistia stratiotes, Ipomea aquqtica, Potamogeton crispus, Hydrilla verticillata and Aponogeton natans* from the lake. The higher concentration of Cu, Cd, Mn, Pb and Hg in different parts of these plants has been observed due to bioaccumulation during the study. The concentration of heavy metals was higher in roots in comparison to leaves. They also emphasized that strong positive correlations were recorded among the water and plant heavy metals. Similar trends have been observed in the present study. The maximum concentration of heavy metals found in *Eichhornia crassipes* and *Eclipta alba* at site 3 along with higher concentration of heavy metals in water at this site.

Bioaccumulation factor (BAF)

BAF is an important tool to identify hyperaccumulator species. BAF for the metals investigated in different aquatic plants are listed in table 5. Plants with BAF>100 have potential to act as hyperaccumulator and indicator of pollution (Wilson and Pyatt, 2007).

Among all the aquatic plants, *Ranunculus sceleratus, Eclipta alba* and *Eichhornia crassipes* were found as good hyperaccumulators. For Cr, none of the plants were found as hyperaccumulator.

Table 5: Bioaccumulation factor for different plant species.

Site	Plants	BAF					
		Pb	Ni	Zn	Cr	Fe	Cu
1	*Ranunculus sceleratus*	92.12	1242	512	29.31	585	240
	Eclipta alba	12.47	857	523	31.98	548	121
2	*Lepidium didymum*	57.08	5507	201	53.27	531.	84.5
	Rumex dentatus	12.92	8100	374	65.02	548	219
	Ranunculus sceleratus	301	15214	74.5	61.89	543	291
3	*Eichhornia crassipes*	23.61	362	54.6	23.00	33.4	79.8
	Eclipta alba	30.32	83.4	56.1	16.32	18.35	85.9
4	*Eichhornia crassipes*	144	464	684	55.93	729	104
	Eclipta alba	514	452	747	60.76	730	97.3
5	*Eclipta alba*	190	3225	475	52.91	303	66.6
6	*Typha angustifolia*	90.77	3384	202	53.24	76.9	130
7	*Rumex dentatus*	15.74	4425	274	47.39	766	96.6
	Ranunculus sceleratus	34.25	5925	641	63.60	773	148
	Lepidium didymum	19.44	450	337	53.21	252	76.5
	Alternanthera sessilis	20.37	168	315	22.44	190	89.1

BAF of different metals in aquatic plants followed an order as mentioned below.

Pb: *Eclipta alba> Ranunculus sceleratus> Eichhornia crassipes*

Ni: *Ranunculus sceleratus>Rumex dentatus> Lepidium didymum>Typha angustifolia>Eclipta alba> Eichhornia crassipes> Alternanthera sessilis*

Zn: *Eclipta alba> Eichhornia crassipes> Ranunculus sceleratus> Rumex dentatus> Lepidium didymum> Alternanthera sessilis> Typha angustifolia*

Fe: *Ranunculus sceleratus> Rumex dentatus> Eclipta alba> Eichhornia crassipes> Lepidium didymum> Alternanthera sessilis*

Cu: *Ranunculus sceleratus> Rumex dentatus> Typha angustifolia>Eclipta alba> Eichhornia crassipes*

Conclusion

The current study measured the drains water quality and heavy metals contents (Pb, Zn, Cr, Cu, Ni and Fe) in aquatic plants with the purpose to find out the hyperaccumulating aquatic plants species for various heavy metals. The study revealed that considerable variations found in the physico-chemical parameters of water samples and heavy metals in plant samples. The water of various drains sites of Rohtak and Bahadurgarh showed that physico-chemical properties and heavy metals exceeded the permissible limits of Bureau of Indian Standards (BIS). The BOD and COD were found maximum at site 4, indicating the influence sewage treatment plant discharge. The heavy metals (Pb, Zn, Cr, Cu, Ni and Fe) in drains water was found maximum at site 3, indicating the influence of industrial effluent of Hisar bypass industrial area comprising of various metal plating industry. The increasing levels of metal content in aquatic plants signify their hyperaccumulation potential. Most appropriate macrophytic species for bioaccumulation of heavy metals from selected contaminated sites based on bioaccumulation factor (BAF) were in the order of *Ranunculus sceleratus> Eclipta alba> Eichhornia crassipes> Rumex dentatus> Typha angustifolia.* The maximum heavy metals accumulation occurred in roots of aquatic plants.

The present study conclude that the drains water of Rohtak and Bahadurgarh were highly polluted with organic and inorganic contaminants. Furthermore, *Ranunculus* *sceleratus, Eclipta alba* and *Eichhornia crassipes* were showed the good accumulation potential for heavy metals in study area. It is recommended that the industrial and sewage effluents should be discharge in drains after complete treatment.

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