Impact assessment of heavy metals pollution of Vartur lake, Bangalore

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Abstract : The unscientific disposal of wastes and pollution in urban water bodies has caused immense problems not only to human beings but also to the aquatic biodiversity. Assessment of heavy metals in Vartur Lake, Bangalore, revealed that Cadmium (Cd), Cobalt (Co), Chromium (Cr), Nickel (Ni), and Lead (Pb) all exceeded drinking water standards. Nevertheless, Chromium (Cr) exceeded the CPCB's tolerance limits for water bodies subjected to effluent discharge. In *Eichornia crassip*es, Cd, Co, Cr, and Ni were critical.   In the sediments, Cadmium (Cd) and Nickel (Ni) exceeded the Probable Effect Level (PEL). Sediment Geo-accumulation Index of the lake showed moderate contamination with Mn, Cu, and Pb. Cr had the highest plant/sediments metal concentration factor even though its bioavailability in plants (71.5 ppm) was lower compared to Manganese (192.3 ppm). This calls for immediate action to be implemented to carry out necessary environmental mitigation measures for the lake.

Keywords: Microwave digestion, Probable effect level, Sediment geo-accumulation index, Pollution load index

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INTRODUCTION

Wetlands can be defined as land transition between terrestrial and aquatic ecosystems where the water table is usually at or near the surface or the land is covered by shallow water (Bergstrom and Stoll,1990; Satyasiba, 2007).They are life supporting systems providing fishes, forest products, agriculture, water, flood control, erosion buffering, plant gene pool, wildlife, recreation, etc and they have immense socio-economic and ecological importance (Satyasiba, 2007). However, many Indian cities are under tremendous pressure of urbanization as they are expanding more horizontally than vertically where urban sprawling is conquering the rural areas. With high population density, shortage of monsoon rainfalls, and increasing water depletion, many fresh water bodies in Indian cities are now polluted and disappearing (Karmakar, 2007). Also, Das and Acharya (2003) state that the surface water resources serve as the best sinks for the discharge of domestic as well as industrial wastes. This unscientific disposal of wastes has caused immense problems not only to human beings but also to the aquatic environment. Nowadays, The urban aquatic ecosystems are strongly influenced by long term discharge of untreated domestic and industrial wastewaters, storm water runoff, accidental spills and direct solid waste dumping (Phuong *et al.,* 1998). Aquatic plants play a key role in protecting water quality and providing habitat. They also provide shelter for fish, wildlife, and invertebrates that in turn provide food for other organisms. They help improve water quality, protect shorelines, and lake bottoms while playing significantly

in adding to aesthetic quality of the lake (Jafari,2007). They definitely play a key role in biogeochemical cycles and food webs in lake systems. They are primary producers and their metabolic activities accelerate the physico-chemical conditions of a water system. These aquatic macrophytes are also large, predominantly plants inhabiting various sections of aquatic ecosystems in different zones of life sphere (Gopal *et al.,*2002) within a water spread area and around the banks.

Macrophytes are known as good indicators of heavy metals contamination in aquatic ecosystems and they also act as good biofilters by accumulating heavy metals from the surrounding environment (Vardanyan *et al.,*2007). But aquatic macrophytes also have the tendency to bioaccumulate heavy metal residues present in water or the sediment stratum. All these released pollutants have a great ecological impact on the water quality and especially on environmental resistance of aquatic macrophytes.

In addition, Ikem *et al.* (2003) have characterized importance of sediments in heavy metals pollution. They state that sediments are important sinks for various pollutants like heavy metals and play a significant role in the remobilization of contaminants in aquatic systems under favorable conditions and in interactions between water and sediment. This direct transfer of chemicals from sediments to organisms is a major route of exposure for aquatic life. Heavy Metals distribute in sediments as exchangeable, carbonate bound, iron-manganese oxide bound, organic matter bound and residual bound species. The speciation of metals can be evaluated by carefully

choosing the extracting solutions and digestion conditions. This objective of the study was to investigate the level of heavy metal contamination of water, their bio-accumulation in aquatic and wetland macrophytes located within the water spread area and on the shoreline banks, and their deposition in the bottom sediments of the Vartur Lake.

MATERIALS AND METHODS

About the study area : Vartur lake (Fig. 1) is located inside Koramangala-Challagatta Valley in the eastern periphery of Bangalore city at 12°56'49.50N and 77°44'10.54E. Vartur lake original area was 216 ha. Recently, due to erratic rainfalls, siltation and encroachment, the area has been reduced to 165.75 ha. The lake's length is estimated to be 2.1 km while its Breadth is 1.0 km. The mean depth is 4 m. The entire length of the shore line is approximately 7.23 km. The lake lies at an elevation of 880 m above sea level. This lake is severely polluted due to inflow of water from a severely polluted Bellandur. The major economic activity around the lake at the present moment is still agriculture but encroachment caused by the expansion of the suburban layouts in the northern and southern banks of the catchment is exacerbating already perilous environmental conditions of this lake. In 2001 the water spread area was at 119.0 ha. The lake has been extensively covered with water hyacinth *(Eichornia crassipes)*, an invasive and exotic species responsible for suffocation of majority of lakes of Bangalore.

Sampling and analysis strategy: The entire work of sampling and analysis of heavy metals in water, aquatic macrophytes, and in sediments was done between May 2006 and December 2007. All chemicals used were of reagent grade and distilled/de-ionized water was used throughout the experimentation. Washing procedures, sampling for heavy metals determinations, sample holding times and preservation techniques conform to standard methods for water and wastewater analysis (APHA,1995). Procedural blanks, reagent blanks, preparation of standard solutions under clean laboratory environment, calibration of Shimadzu AAS-6300 atomic absorption spectrophotometer (AAS) using certified standards and the analyses of calibrated standards were employed as per the equipment manual.

Sampling of water: Standard methods for examination of water and waste water (APHA,1995) were employed. Surface water samples were collected seasonally in selected sampling zones 10cm below the surface of the lake water (Das and Acharya, 2003) using the fresh 2-L plastic containers that had been previously washed with 1:3 HNO_3. The samples were brought to laboratory for digestion and analysis.

Sampling of plants: Plant samples which were studied were water hyacinth (*Eichornia crassipes*). This species has been known to infest many lakes in Urban Bangalore including Vartur. Plant samples were collected from the selected sampling points corresponding to the inlet, middle, and outlet zones of the lake and kept in clean polythene bags and brought to the laboratory where they were thoroughly washed in distilled water to remove surface particles. In order to enhance the accuracy of the results, samples from within the littoral zone (McGee *et al.,*2007) and immediately within the tidal line of the lake were selected. Only aerial parts of the plants were chosen and cut using stainless steel scissors. In the laboratory the samples were washed with distilled water several times (Farago and Mehra,1989) and dried at 105°C for 48 hours (Burton and John,1977).

Sampling of sediments: Samples of sediments were taken from along the banks of the sampling station. All samples were taken from the top 10 cm layer to a depth of over 30 cm (Pilotte *et al.,*1978). Sampling tools were washed and dried with water before the next sample was collected (Singh *et al.,*2002). The collected samples were stored in polythene plastic containers. Samples were air dried in the laboratory at room temperature, ground in fine mixture using mortar and pestle before sieved under 2 mm mesh (Kronfeld and Navrot,1975; Bifano and Mogollon,1995; Jose *et al.,*1989 and Neto *et al.,* 2005). The samples were stored in a polythene container ready for analysis.

Microwave digestion: The accurate measurement of trace metal concentrations is an important goal in environmental monitoring and research, as many of these elements have been identified as potentially hazardous pollutants (Canadian Environmental Protection Act,1999 and Nouri *et al.,*2007). The use of closed vessel microwave- assisted digestion systems under high temperature and pressure for acid digestion has now become routine (Nouri *et al.,* 2007) as it allows shorter digestion times and good recoveries, even for volatile elements. In addition, it reduces the risk of external contamination and requires smaller quantities of acids, thus improving detection limits and the overall accuracy of the analytical method (Sandroni *et al.,*2003 and Nouri *et al.,* 2007). Moreover, they are safer and simpler and provide more controlled and reproducible conditions than hot plate or block digesters (Nadkarni,1984 and Nouri *et al.,* 2007). In this study, heavy metals digestion was done using EPA Method 3015 (Ikem *et al*., 2003) and involved a high performance microwave assisted digestion Milestone Labstation using a 6 Monobloc Microwave Ethos D Microwave Labstation (Baron *et al.,* 2004) - an automatic user interface system with a direct automatic temperature and pressure control of up to 300°C and 100 Bar respectively under the given power reference.
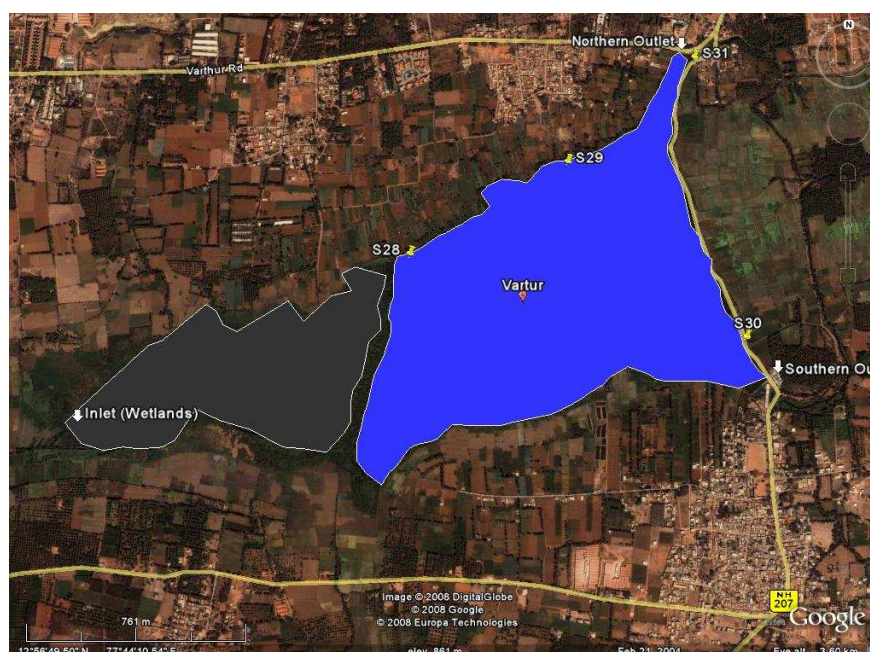
Fig. 1. Satellite imagery of Vartur lake with color imposition.

Digestion of water samples: For digestion of water samples, procedures according to the equipment manual were followed. In this case, 10ml of a sample was added with 1 ml of conc. HNO_3. The solution was put in a reference reaction vessel (a mono-bloc) which was then inserted into a carousel and fitted into a microwave unit ready for digestion. The system was then pre-programmed using the Ethos D control terminal (equipped with SoftWave software) for 5 minutes of microwave digestion at 250 W power (as per the equipment manual of operation) – left for automatic ventilation after the digestion process for 2 minutes – and then filtered using Whatmann filter paper No. 40. The filtered sample was then made up to 100ml with metal-free distilled water and stored in a special container ready for analysis.

Digestion of plant samples: For acid digestion of Plant samples, after the samples were first dried in a hot air oven at 105° C for 48 hours, they were then ground into fine powder and stored in a plastic bag. Afterwards 0.5 g of each sample was then added into the reference vessel respectively; subsequently, 4 ml of conc. HNO_3 and 0.2 ml of H_2O_2 were also added in the reference vessels. The vessels were inserted into their carousels and then into the microwave unit ready for digestion. The microwave digestor was then pre-programmed using the Ethos D control terminal (equipped with Softwave software) for 5 minutes of microwave digestion at 250 W power and then another 5 minutes of microwave digestion at 500 W power (as per the equipment manual) – then left for automatic ventilation after the digestion process for 10 minutes –

before finally filtered using Whatmann filter paper No. 40. The filtered sample was then made up to 100ml with metal-free distilled water and stored in a special container ready for analysis.

Digestion of sediment samples: For digestion of sediment samples, the samples were first dried in a room temperature. The dried samples were then ground into fine powder, sieved with < 2mm sieve and stored in a plastic bag. Afterwards, about 0.25 g of the sample was then added into the reference vessel. Then 2.5 ml of conc. HNO_3 and 2.5 ml of HF acid were added in the reference vessel. The solution was put in a reference reaction vessel which was then inserted into a carousel and into the microwave unit ready for digestion. The system was then pre-programmed using the Ethos D control terminal (equipped with SoftWave software) for 6 minutes of microwave digestion at 300 W power and then another 5 minutes of microwave digestion at 500 W power – then left for automatic ventilation after the digestion process for 10 minutes – and then filtered using Whatmann filter paper No. 40. The filtered sample was then made up to 100ml with metal-free distilled water and stored in a special container ready for analysis

Sample analysis: A Shimadzu type Atomic Absorption Spectrophotometer (AAS) 6300 model with Air-C_2H_2 flame type of an average fuel flow rate of between 0.8 to 4.0 L/min and the support gas flow rate between 13.5 to 17.5 L/min was used for sample analysis. The single element hollow cathode lamps used were of Hamamatsu Photonics

Table 1. Concentrations of heavy metals in the water of Vartur lake.

Metal	Mean	Range	Standard limits and guidelines for drinking water (in parts per million)							CPCB[6] Effluent's Discharge (Tolerance) Limits for Inland Surface Water (parts per million)
			BIS[1]		ICMR[2]	USEPA[3]	FAO[4]	WHO[5]	Sharma (2001)	
Cd	0.12	BDL – 0.35	0.01	-	0.001	0.01	-	0.005	-	2.0
Co	1.89	BDL- 4.87	-	-	-	-	0.01	-	1.0	-
Cr	2.13	0.57 – 4.07	0.05	-	-	0.05	0.01	0.05	-	2.0
Cu	0.32	0.04 – 0.59	0.05	1.5	0.05	1.0	-	2.0	-	3.0
Mn	0.02	BDL – 0.09	0.1	0.3	0.5	0.05	0.2	0.05	2.0	2.0
Ni	1.03	BDL – 2.66	-	-	-	0.1	0.2	0.1	0.1	3.0
Pb	2.72	0.27 – 4.78	0.05	0.1	0.05	0.015	-	0.01	-	0.1
Zn	0.25	0.03 – 0.54	5	15.0	-	5	2.0	5.0	-	5.0

1: Bureau of Indian Standards   2: Indian Council for Medical Research. 3: US Environment Protection Agency
4: Food and Agricultural Organization   5: World Health Organization.   6:   Central Pollution Control Board

Co. Ltd – L2433 series. The atomic absorption analysis standards for the given elements were purchased from Inorganic Ventures Inc. and Sisco Research Laboratories Ltd. Calibration curves for various elements obtained from these standards were of first order reaction. The sample for Cd, Co, Cu, Cr, Fe, Mn, Ni, Pb, and Zn analysis was aspirated with the help of an Automatic Sampler for Atomic Absorption Spectrophotometer measurement respectively. Series of reference standards - 1 ppm, 2ppm, 3 ppm - for these metals were prepared from the purchased stock solution manufactured from Sisco Research Laboratories, Mumbai PVT Ltd. The standards were prepared by pipetting 0.1, 0.2, 0.3, ml respectively of the metal reference standards and made up to 100 ml and mounted on the Automatic sampler for standard calibration curve measurement. Afterwards the samples were injected into the Flame AAS and the reading was directly measured by a computer in ppm. The results were then converted to mg/Kg.

RESULTS AND DISCUSSION

The results for concentrations of heavy metals in water, plants, and sediments are represented on Tables 1, 2, and 3 respectively. For sediment geo-accumulation index, the classification table is represented on Table 4. For Pollution Load Index (PLI), the results are presented on Table 5.

Cadmium: Cadmium is a non-essential element that causes kidney damage in humans and negatively affects plant growth and development. It is released into the environment by power stations, heating systems, metal working industries or urban traffic. It is also used in electroplating, pigment, plastic stabilizers, and Nickel-Cadmium batteries. The common source of contaminants is due to corrosion of galvanized pipes, erosion of natural deposits, discharge from metal refineries, run-off from waste batteries and paints. The mean Cd value in water was 0.12 ppm (BDL-0.35). This exceeded drinking water standards of BIS, USEPA, and WHO. However, the range was within the stipulated CPCB tolerance limit for water bodies subject to pollution discharge (2.0 ppm). In plants, Cd accumulates in several tissues and complexes with amino acids, organic acids, and other major parts of plant metabolism (Benavides *et al.,*2005). In the study, the overall mean for Cd in plants was 8.0 ppm. The range was 0.72 ppm – 21.53 ppm. The normal range for cadmium in plants is between 0.1 - 2.4 ppm (Maiti, 2003). Dalvi *et al.* (2007) put the range between 0.01 – 0.4 ppm. Also Maiti (2003) put critical concentrations in plants range between 5.0 ppm – 30 ppm while Dalvi *et al.* put the range at 0.4 – 2.3 ppm. The mean value Cd value in sediments was 8.66 ppm (BDL – 17.34). This was above the probable effect level of 3.5 ppm (Pascul-Barrera *et al.,*2004) and over the critical soil concentration range of 3 – 8 ppm (Maiti,2003)

Cobalt: Cobalt is widely used as alloy for various steels, in electroplating, construction processes including paints, in fertilizers, in porcelain and glass making. In water, Co ranged BDL – 4.87 ppm (Mean = 1.89 ppm). This was just above the 1.0 ppm limit reported by Sharma (2001). The overall mean for Co in plants was 28.80 ppm. The range was 8.40 ppm – 53.61 ppm. The normal range for Co in plants is 0.02 ppm – 1.0 ppm. The critical concentration range is 15 – 50 ppm (Maiti,2003). Results in sediments showed that the mean value was 40.82 ppm. The range was 11.68 – 69.37 ppm. This was above the uncontaminated Co range reported by Abbasi *et al.* (1998). It is interesting to note that the pollution aspects of Cobalt have received much less attention compared to other metals like Cd, Zn, Pb, and Cr.

Chromium : As the name Chromium denotes, the first applications were in the colour and pigment but now it is used in a variety of applications such as leather tanning, chromium plating, timber preservation, corrosion

Table 2. Concentrations of heavy metals in *Eichornia crassipes* of Vartur lake.

Metal	Mean (ppm)	Range (ppm)	Normal range in plants (ppm)			Critical range in plants (ppm)		
			Maiti (2003)	Dalvi *et al.* (2007)	Abbasi *et al.* (1998)	Maiti (2003)	Dalvi *et al.* (2007)	Nirmal Kumar *et al.* (2006)
Cd	8.0	0.72 – 21.53	0.1 – 2.4	0.01 – 0.4	-	5.0 – 30.0	0.4 – 2.3	-
Co	28.80	8.40 – 53.61	0.02 – 1.0	-	-	15.0 – 50.0	-	-
Cr	71.50	1.2 – 160.85	0.03 – 14.0	1 – 10	-	5.0 – 30.0	20 – 100.0	-
Cu	9.63	BDL – 20.95	1 – 50.0	4.0 – 15.0	4.0 – 15.0	5 – 30.0	20 - 100	25 – 90.0
Mn	192.43	100.5-306.8	20 – 100	-	-	300 – 500	-	-
Ni	47.91	26.0-65.32	0.02 – 5	0.02 – 5	-	10 – 100	10 – 100	10-50
Pb	63.42	22.0-98.5	0.2 – 20	0.1 – 10	-	30 – 300	30 – 300	-
Zn	42.93	27.4-58.30	1 – 400	3 - 100	-	100 – 400	100 - 400	-

protection, textiles, etc. Around 90% of leather is tanned using chromium salts. Toxicity of Chromium species is known to cause heritable genetic damage; harmful in contact with skin; and also toxic if swallowed and by inhalation. Cr causes irritation to respiratory system and skin and risk of serious damage to eyes. It is also very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment (Darrie, 2001). In water, Cr ranged 0.57 – 4.07 ppm (Mean: 2.13 ppm) exceeding the drinking water standards stipulated by BIS, EPA, and irrigation standards limit by FAO. Moreover, Cr exceeded tolerance limit for water bodies subject to pollution which is 2.0 ppm. In plants, the mean for Cr in macrophytes of Vartur Lake was 71.50 ppm. The range was 1.20 ppm – 160.85 ppm. According to Maiti (2003), the normal range of Cr in plants should be between 0.03 ppm – 14.0 ppm. The critical level range is between 5.00 ppm – 30.0 ppm. Dalvi *et al.* (2007) put the critical range between 20 – 100 ppm. Critical concentrations in Cr in plants are in the range of 5 – 30 ppm as reported by Maiti (2003). This shows that Cr in plants in Vartur Lake is in critical range. Cr in sediments ranged BDL – 21.37 ppm (Mean:10.68 ppm). This was below the probable effect level (PEL) of 90.0 ppm and under the background value of 32.0 ppm reported by Lokeshwari and Chandrappa (2006 a).

Copper: Copper reaches the aquatic environment through wet and dry depositions, mining activities, storm water run-offs, industrial, domestic, and agricultural waste disposal. Among industrial sources include copper plating, pulp and paper mills, e-waste, sewage and other forms of waste waters. The mean Cu in water was 0.32 ppm (Range: 0.04 – 0.59 ppm). Cu was within drinking water standards stipulated by ICMR and EPA, but exceeded BIS limit of 0.05 ppm. The overall mean for Cu in macrophytes of Vartur Lake was 9.63 ppm. The range was BDL – 20.95 ppm. The normal range of Copper in plants is 1 – 50 ppm although it is also reported that the normal range should be 4 – 15 ppm (Abbasi *et al.,*1998). Nirmal

et al. (2006) reports the critical range between 25 – 90 ppm. According to Maiti (2003), the normal range of Cu in plants should be between 5.0 ppm – 20.0 ppm. The critical level is between 5.00 ppm – 30.0 ppm. Dalvi *et al.* (2007) reported the normal range for Cu at 4 – 15 ppm while the critical range was between 20 – 100 ppm. Cu in plants was largely within the normal range. In sediments, the mean Cu value was 132.21 ppm (Range: 130.5 – 134.0 ppm). This was below the PEL value of 197.0 (Pascul-Barrera *et al.*,2004). However, the mean exceeded the background value of 27.0 ppm reported by Lokeshwari and Chandrappa (2006 b).

Manganese: Manganese (Mn) is an essential micronutrient throughout all stages of plant development. In humans, it has been implicated in with diseases such as diabetes, nervous instability, convulsions, bone disorders in babies and rheumatoid arthritis (Abbasi *et al.*,1998). It is important for vital plant functions and act as a cofactor in various enzymes as well as in the structure of chlorophyll. The mean Mn value in water was 0.02 ppm. The range was BDL – 0.09 ppm. This was within the stipulated drinking water standards. The overall mean for Mn in plants was 192.43 ppm. The range was 100.51 – 306.84 ppm. This range was within the critical plant concentration range of 300 – 500 ppm reported by Maiti (2003). In sediments, Mn ranged 112.0 – 167.0 ppm. The mean value was 139.36 ppm.

Nickel : Nickel is used extensively in Nickel plating and alloy manufacture. High nickel alloys are used in chemical, marine, electrical, oil refining, and other industrial processes. In water, Ni mean was 1.03 ppm. The range was BDL – 2.66 ppm. This was above drinking water standards stipulated for Nickel (Ni). But the mean was within the tolerance limit for water bodies subjected to pollution discharge. Similarly, Ni has been found in a variety of plants and ranges up to 340 ppm have been recorded non-edible wild plants. In benthic Algae of fresh water lakes, Ni concentrations have ranged between 52 –

Table 3. Concentrations of heavy metals (ppm) in the bed sediments of Vartur lake.

Metal	Mean (ppm)	Range (ppm)	CPCB[1] (2001)	PEL Barrera *et al.* (2004)	Background Values (Lokeshwari and Chandrappa ,2006)	Uncontaminated Sediments (Abbasi *et al*, 1998)	Critical Soil Concentration (Maiti, 2003)
Cd	8.66	BDL – 17.34	BDL	3.5	-	-	3 - 8
Co	40.52	11.68-69.37	-	-	-	4.7 – 20.0	25 – 50
Cr	10.68	BDL-21.37	389.3	90.0	32.0	12-44	75 – 100
Cu	132.21	130.52-134	113.0	197.0	27.0	-	60 – 125
Mn	139.36	112-167.0	225.2	-	-	-	1500-3000
Ni	42.04	16.2-68.0	54.5	35.9	23.0	1 – 20.0	100
Pb	46.5	4.43-88.5	64.9	91.0	10.0	2 -50.0	100 – 400
Zn	123.0	25.71-220.25	-	315.0	51.0	1 - 50	70 - 400

74 ppm (Abbasi *et al.*,1998*)*. Small amounts of Ni may be beneficial to plants and its plant toxicity varies in magnitudes according to plant species. Cases of Ni poisoning in plants include dwarfing or repression of growth (Sharma,2001).The overall mean for Ni in macrophytes of Vartur lake was 47.91 ppm. The range was 25.91 – 65.32 ppm. This is in critical category of Ni contents in plants as described by Nirmal *et al.* (2006) which is between 10 – 50 ppm. In sediments, the mean value for Ni was 42.04 ppm. The range was 16.2 – 68.0 ppm. This shows that Ni exceeded the probable effect level (PEL) reported by Pascul-Barrera *et al.* (2004).

Lead: Lead (Pb) can exist in several valences and are of critical environmental importance. In urban areas, the principal source of Pb in wetlands comes from gasoline additives, metal plating, e-waste and battery cells, electrical equipment, textile mills, dye and pigments, paper mills, chemical and fertilizer industries, and ghee manufacturing industries (Abbasi *et al.*,1998). Lead toxicity leads to anaemia both by impairment of haemoglobin biosynthesis and acceleration of red blood cell destruction in human beings. Lead also depresses sperm count (Anglin-Brown *et al.*,1995*).* The mean Pb value in water was 2.72 ppm. The range was 0.27 – 4.78 ppm. This range exceeded the drinking water standards and effluent discharge limits prescribed by CPCB. Nevertheless, Lead (Pb) has been known to accumulate in aquatic macrophytes in considerable levels based on the rooted and floating species. Lead's concentration ranging from 0.1 – 10.0 ppm has been known to inhibit growth of small macrophytes and algae. The critical range for Pb as described by Nirmal *et al.* (2006) and Maiti (2003) is 30 – 300 ppm. The overall mean for Pb in macrophytes of Vartur Lake was 63.42 ppm. The range was 21.98 – 98.44 ppm. In the sediments, results showed a mean value of 46.5 ppm (PEL = 91.0). However, the Pb concentration in Vartur Lake exceeded the background value for uncontaminated sediments reported by Lokeshwari and Chandrappa (2006 a).

Zinc : Zinc in urban lake water is caused by a variety of industrial effluents including phosphates fertilizers, Ghee Manufacturing, Metal Processing Units, Zinc Plating Industries, Silver plating industries, distillery units, landfill leachates, urban storm water, fly ashes of coal powered plants, poultry sewage, and compost (Abbasi *et al.*,1998). The Zn concentration in water ranged 0.03 – 0.59 ppm. The mean Zn value was 0.25 ppm. This was within the stipulated drinking water standards by BIS, ICMR, EPA, and irrigation limits by FAO. The overall mean for Zn in macrophytes of Vartur Lake was 42.93 ppm. The range was 27.44 – 58.27 ppm. This range did not exceed the critical concentration range in plants of 100 – 400 ppm reported by Maiti (2003). In sediments, the range for Zn was 25.71 – 220.28 ppm which was below the PEL limit of 315.0 reported by Pascul-Barrera *et al.* (2004). The mean Zn value was 123.0 ppm which was above the 51.0 reference background value reported by Lokeshwari and Chandrappa (2006 b).

Plant/Water bioaccumulation factor (BAF) : Studies of Bioaccumulation of heavy metal contaminants in aquatic macrophytes help us measure the degree and the extent to which various species of a wetland ecosystem are exposed to metal contaminants and how much of those contaminants are absorbed by these plant species. The plant BAF shows largely the chemical dynamics of inflow and outflow of the fresh water within that wetland ecosystem. It is to be noted here that in determining the metal accumulation in plants from its fresh water body, a number of factors have been included in making out such a trend. Firstly, the issue of the degree and extent of exposure of that wetland system by anthropogenic activities; the size of the wetland, the flushing effect of the basin depending upon the sufficient or erratic rainfalls, the life cycle of an exposed plant species and even the age of the sampled plant species from that sampling point. The results show that Manganese had the highest BAF value (9621.50) while Cobalt had the lowest (15.24). The metal bioaccumulation trend was as follows: Mn (9621.50)

Table 4. Classification of sediment geo-accumulation index.

Sediment geo-accumulation index	Class	Classification of contamination
< 0	0	Practically uncontaminated
> 0 - 1	1	Practically Uncontaminated to Moderate Contamination
> 1 - 2	2	Moderate Contamination
> 2 - 3	3	Moderate Contamination to Strong Contamination
> 3 - 4	4	Strong Contamination
> 4 - 5	5	Strong Contamination to Very Strong Contamination
> 5	6	Very Strong Contamination

Source: *Lokeshwari & Chandrappa* (2006)

Table 5. Classification of sediment geo-accumulation index.

Metal species	Sediment geoaccumulation index	Classification of contamination
Cd	0.5	Practically uncontaminated to moderate contamination
Co	0.3	Practically uncontaminated to moderate contamination
Cr	0	Practically uncontaminated
Cu	1.18	Moderate contamination
Mn	1.54	Moderate contamination
Ni	0.20	Practically uncontaminated to moderate contamination
Pb	1.12	Moderate contamination
Zn	0.47	Practically uncontaminated to moderate contamination

> Zn (171.72) > Cd (67) > Ni (46.51) > Cr (33.57) > Cu (30) > Pb (23.32) > Co (15.24). As reported by Lokeshwari and Chandrappa (2006 a), the accumulation of a particular metal is compared with the presence of that metal in the lake water. It is therefore significant to note that although Mn was least available metal in the lake water (0.02 ppm) its bioaccumulation factor was the highest. The same pattern can be inferred for Co which is more available in water (1.89 ppm) but has the lowest accumulation factor.

Plant/Sediment metal concentration ratio: The plant-sediment metal concentration ratio trend in Vartur lake was as follows: Cr (6.69) > Mn (1.38) > Pb (1.36) > Ni (1.14) > Cd (0.92) > Zn (0.35) > Co (0.71) > Cu (0.07). This indicates that Cr, Mn, Pb and Ni were more available in the plant system of the lake than in the surrounding sediments. It is interesting here to note that Cr had the highest plant/ sediments metal concentration factor even though its bioavailability in plants (71.5 ppm) was lower compared to Manganese (192.3 ppm).

Sediment geo accumulation index (GeoI): This is a quantitative check of metal pollution in aquatic sediments. It is calculated as follows: $GeoI = \ln [C_n/1.5*B_n]$ where "C" is the measured metal concentration and "B" is a compared background value (reference). Different countries employ their own respective values for "background levels" in relation to the existing environmental conditions that reflect their surroundings.

Lokeshwari and Chandrappa (2006 b) have attempted to use background levels of Vasanthapura Lake for five elements namely Fe (6571 ppm), Zn (51 ppm), Cu (27 ppm), Ni (23 ppm), and Pb (10 ppm). The reference levels used in this study attempts to include both the local reference values, the universally agreed Probable Effect Level (PEL) values above which contamination might occur for aquatic life (Cd = 3.5 ppm), background values for Co (20.0 ppm) reported by Abbasi *et al.* (1998) and the normal Mn range in soils reported by Maiti (2003).

The Sediment Geo-accumulation Index in Vartur lake reveals that Cr pollution in the sediments was practically uncontaminated (GeoI < 0) with Class 0, whereas Cd, Zn, Co and Ni ranged between uncontaminated to moderate contamination (> 0-1) at Class 1 with the Sediment Geo-accumulation Index ranging from 0.5, 0.47, 0.30, and 0.20 respectively. Manganese (Mn), Copper (Cu) and Lead (Pb) recorded moderate sediment contamination level (> 1-2) at Class 2 level ranging from 1.54, 1.18, and 1.12 respectively. These findings indicate that based on the Sediment Geo-accumulation Index, all metals with the exception of Chromium are at the level of moderate sediment contamination. This trend still poses the risk of enhanced bioaccumulation of these metals up the food web. (See Table 5).

Heavy metal pollution load index in Vartur lake: Pollution Load Index (PLI) is used in order to find out the mutual

effect of the different studied metals. According to El-Sammak (2001*),* PLI is calculated as follows:

$$PLI = (CF_{Cd} \times CF_{Co} \times CF_{Cr} \times CF_{Cu} \times CF_{Mn} \times CF_{Ni} \times CF_{Pb} \times CF_{Zn})^{1/8}$$

CF is the contamination factor whose value is obtained by dividing the concentration of metals in sediments divided by their respective background values. Here, the background values for Cr, Cu, Ni, Pb and Zn were obtained from Lokeshwari and Chandrappa (2006); Cd (Pascul Barrera *et al.,* 2004), Co (Abbasi *et al.,*1998), and Mn (Maiti,2003*).* The results show that the pollution load index of Vartur Lake was 2.41. This index can be used to compare the extent of contamination by similar metal species to other lakes.

Conclusion

Cadmium (Cd), Cobalt (Co), Chromium (Cr), Nickel (Ni), and Lead (Pb) all exceeded drinking water standards. Cobalt was compared to the tolerance limit reported by *Sharma* (2001). However only Chromium (Cr) exceeded the CPCB's tolerance limits for water bodies subjected to effluent discharge. In case of aquatic plants (*Eichornia crassipes*), Cadmium (Cd), Cobalt (Co), and Chromium (Cr) were above the maximum limit of the critical range (Maiti,2003*).* Nickel (Ni) was considered above critical concentration range reported by Nirmal *et al.* (2006). Zinc (Zn) and Copper (Cu) were within normal concentration ranges. In the sediments, Cadmium (Cd) and Nickel (Ni) exceeded the Probable Effect Level (PEL) reported by Pascul Barrera *et al.* (2004) respectively. Nevertheless, Cd concentration was above the critical range in soils reported by Maiti (2003). Apart from Manganese (Mn), the bioaccumulation between metals did not display much variation and the trend followed: Mn (9621.50) > Zn (171.72) > Cd (67) > Ni (46.51) > Cr (33.57) > Cu (30) > Pb (23.32) > Co (15.24). Mn was more bio-available while Co was the least. Sediment Geo-accumulation Index registered moderate sediment contamination with Mn, Cu, and Pb having more deposition compared to Cd, Zn, Co, and Ni. Cr had the highest plant/sediments metal concentration factor even though its bioavailability in plants (71.5 ppm) was lower compared to Manganese (192.3 ppm). Pollution Load Index for Vartur was 2.41.

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