Heavy Metals Analysis and Sediment Quality Values in Urban Lakes

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Abstract: Problem statement: The objective of this research was to evaluate the degree of heavy metal contamination in lakes and the extent to which the sediment quality of the lakes of Bangalore city has deteriorated. **Approach:** In this study, heavy metals such as Cd, Co, Cu, Cr, Mn, Pb, Ni and Zn in lake bed sediments were analyzed using comparative sediment quality guidelines from various derived criteria. The selection of sampling points was based upon inflow and outflow regions of the lakes; geographical proximity of industrial units in relation to their effluent discharges; proximity of residential sites located on the banks of the wetland systems; drainage patterns and accessibility towards the lakes. Digestion and analysis of the samples were done by microwave-assisted digestion and atomic absorption spectrophotometry respectively. **Results:** The extent of sediment quality deterioration was more pronounced in Cu (203.50 ppm) and Ni (97.64 ppm) followed by Pb (206.0 ppm) and Cd (8.38 ppm). Cr (96.70 ppm) failed a single sediment quality guideline while Zn (220.0 ppm), Mn (176.0 ppm) and Co (47.7 ppm) remained within the safety levels of sediment quality guidelines prescribed for the study. The Sediment Geo-accumulation Index showed that Co, Cu and Pb showed moderate levels of pollution while the Pollution Load Index (PLI) between heavy metals in the lakes produced the following outputs: Ni > Pb > Cd > Cu > Cr > Co > Zn > Mn. **Conclusion:** This study proves that the level of sustained metal contamination of the fragile urban wetlands has not receded even after the recent urban wetlands rejuvenation works were completed. This prolonged presence in excessive levels of the studied heavy metals in the bed sediments casts doubt on the choice and effectiveness of the any mitigation measures in the long run.

Key words: Sediment quality guidelines, microwave digestion, atomic absorption spectrophotometry

INTRODUCTION

The problems associated with heavy metals in waste and storm water drainage entering the natural urban aquatic ecosystems have been well documented and studied. Heavy metals are widespread pollutants of great environmental concern as they are non-degradable, toxic and persistent with serious ecological ramifications on aquatic ecology[1-3]. Humans have always depended on aquatic resources for food, medicines and materials as well as recreational and commercial purposes such as fishing and tourism[4]. In addition, aquatic ecosystems have significant impact on migratory bird species that use the water bodies as sanctuary and stop-over for food, breeding and nesting. 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[5]. All these released pollutants have a great ecological impact on the water quality and its surrounding food web[6,7],

Sediments are integral and inseparable parts of the aquatic environments because they help to determine the overall assessment of heavy metals in water vis-avis aquatic life and survivability[8]. Since sediments play a very important role in physicochemical and ecological dynamics, any change in toxic concentrations of heavy metal residues on the sediments will affect the natural aquatic life support systems. Locally, not enough studies have been documented in details on the fate of lake bed sediments in the study area. However, Lokeshwari and Chandrappa[9,10] have characterized in details the fate of soil and sediment contamination in other lakes of the study area. Assuming background values of a rejuvenated lake as bench mark for uncontaminated sediments, these studies were able to also derive the sediment geo-accumulation index in these lakes in order to determine the scale of

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contamination of a chemical species involved using case studies on selected lakes.

The overall objective of this research work was to evaluate the degree and extent to which the heavy metal contamination has affected the lakes inside the urban perimeters of Bangalore. In this study, heavy metals such as Cadmium (Cd), Cobalt (Co), Copper (Cu), Chromium (Cr), Manganese (Mn), Lead (Pb), Nickel (Ni) and Zinc (Zn) in lake bed sediments were analyzed using comparative sediment quality guidelines from various derived criteria. The results were also subjected to the Geo-accumulation and Pollution Load Indices. The purpose of this entire experiment was to establish an overall deterioration trend in these fragile wetlands and help mobilize appropriate ways in the current conservation efforts to save the vanishing urban aquatic ecosystems.

MATERIALS AND METHODS

About the Study Area: Bangalore (Fig. 1 and 2) is located at a Lat. of 12°59'N and Long 77°55'E at an altitude of 920 m above mean sea level and city's area is about 741 km^2[11]. The population of Bangalore City is estimated at 5,868,448 under a greater Bangalore area of 741 km^2. Given this scenario, it is not hard to imagine the sheer quantity of unaccounted sewage that ends up in the fragile wetlands of the city causing chemical pollution as well as public discomfort.

The department of economics and statistics, Government of Karnataka indicates that 95,232 ha of the land in Bangalore Urban District has been converted to non-agricultural use while 4,885 ha remain as barren land. This accounts to 100,117 ha of the total geographical area of 217,410 ha or 46% of the total geographical area of the district. In addition, approximately 1,600 acres of land in Bangalore City between Bangalore Municipal Authority (BBMP) and Bangalore Development Authority (BDA) zones are under industrial sites. These sites sometimes are closely located to lakes under this study such as Bellandur, Kengeri, Arekere, Agara, Hebbal, Byramangala, Karihobanhalli, Hebbal and their cascading drainage channels and which may be directly or indirectly responsible for the release or seepage of their hazardous effluents into these exhausted basins.

Selection of sampling areas and sampling stations: In carrying out the present study, a total of 17 lake systems located in three major watershed zones of Bangalore-Vrishabavarthy, Koramangla-Challagatta and Hebbal Valley systems with 5 of its total 6 lake series within these valley systems were selected for sampling (Table 1, Fig. 1 and 2).

Fig. 1: A Google Earth imagery of Bangalore showing selected lakes in the study area
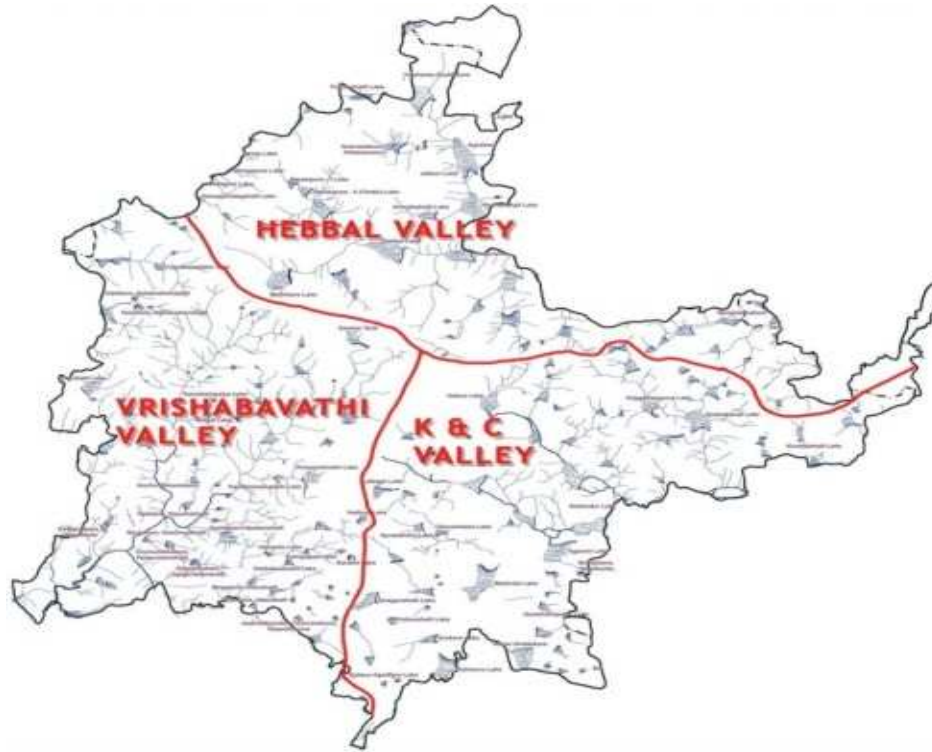
Fig. 2: A map showing the main watershed regions of Bangalore

Table 1: Sampling locations, position and sampling Points

Sr. No.	Sampling location (Name of the lake)	Position Lat	Long	Area (ha)	Lake series	Basin
LI	Byramangala	12°46'02.5"N	77°25'36.0"E	246.64	Byramangala	Vrishabavathi
L2	Hosakere	12°55'41.45"N	77°28'56.58"E	17.20	Byramangala	Vrishabavathi
L3	Shivapura	13°01'23.82"N	77°30'24.04"E	11.39	Madavara	Vrishabavathi
L4	Karihobanahalli	13°01'14.93"N	77°29'50.77"E	22.32	Madavara	Vrishabavathi
L5	Hebbal	13°02'49.17"N	77°35'12.48"E	58.23	Yellamallappa	Hebbal
L6	Kengeri	13°54'56.60"N	77°29'14.17"E	10.73	Byramangala	Vrishabavathi
L7	Venganaiahkere	13°01'00.97"N	77°41'56.28"E	18.87	Yellamallappa	Hebbal
L8	Yellamallappa	13°01'39.39"N	77°43'67.63"E	37.56	Yellamallappa	Hebbal
L9	Vartur	12°56'49.50"N	77°44'10.54"E	165.75	Vartur	Koramangala Challaghatta
L10	Arekere	12°52'58.50"N	77°35'55.86"E	12.43	Hulimavu	Koramangala Challaghatta
L11	Hulimavu	12°52'14.06"N	77°36'20.48"E	23.00	Hulimavu	Koramangala Challaghatta
L12	Madiwala	12°54'22.07"N	77°37'06.82"E	91.87	Puttenahalli	Koramangala Challaghatta
L13	Agara	12°55'10.84"N	77°38'27.33"E	41.08	Puttenahalli	Koramangala Challaghatta
L14	Ibblur	12°55'19.50"N	77°40'00.45"E	8.24	Vartur	Koramangala Challaghatta
L15	Bellandur	12°56'17.62"N	77°40'00.78"E	335.09	Vartur	Koramangala Challaghatta
L16	Ullal	12°57'40.70"N	77°28'53.24"E	11.03	Byramangala	Vrishabavathi
L17	Malathalli	12°57'54.78"N	77°29'42.29"E	50.38	Byramangala	Vrishabavathi

The selected lakes are located around the Peri-urban rim of Bangalore-an area between the City's Corporation Limits (known as BBMP Area) and the Bangalore Development Authority (BDA) boundary and out towards the rural districts which are now being merged into a Greater Bangalore area. About 64 sampling points were selected in this study. The criterion of selection of sampling points was based upon inflow and outflow regions of the lakes; geographical proximity of industrial units in relation to their effluent discharges; proximity of residential sites located on the banks of the wetland systems; drainage patterns and accessibility towards the lakes.

Sampling of sediments for heavy metals analysis: Samples 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[12]. Sampling tools were washed and dried with water before the next sample was collected. 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. The samples were then stored in a polythene container ready for digestion and analysis[13-16].

Microwave digestion of sediments for heavy metals analysis: 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[17]. The use of closed vessel microwave-assisted digestion systems under high temperature and pressure for acid digestion has now become routine[18,19] 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[20,21]. Moreover, they are safer and simpler and provide more controlled and reproducible conditions than hot plate or block digesters[20,21].

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 <2 mm 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 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 software) for 6 min of microwave digestion at 300 W power and then another 5 min of microwave digestion at 500 W power-then left for automatic ventilation after the digestion process for 10 min. Afterwards, the digested solution was cooled and filtered using Whatman filter paper No. 40. The filtered sample was then made up to 100 mL with metal-free distilled water and stored in a special container ready for analysis.

Sample analysis for heavy metals: A Shimadzu type Atomic Absorption Spectrophotometer (AAS) 6300 model with Air-C_2H_2 flame type of an average fuel flow rate of between 0.8-4.0 L min^{-1} and the support gas flow rate between 13.5-17.5 L min^{-1} was used for sample analysis and operated as per the equipment

manual. The single element hollow cathode lamps for respective metals were of Hamamatsu Photonics 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, 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, 2 and 3 ppm-for these metals were prepared from the purchased stock solution. The standards were prepared by pipetting 0.1, 0.2 and 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. Percentage recoveries (%) rates between metals ranged 94.8-102.3%. The samples were finally injected into the Flame AAS and the reading was directly measured by a computer in ppm.

Interpretation of data: The results were compared with a series of universal guidelines on sediment toxicity limits by different international environmental authorities[17,22]. The sediment guidelines authorities that have been referred to herewith and of vital interest in this study are: The Screening Levels Guidelines (SLG) of Ontario Ministry of Environment (Canada) showing low and severe toxic levels for benthic and aquatic biota; the Sediment Quality Guidelines of the National Oceanographic and Atmospheric Administration (NOAA) of the United States which show the Effect Range-Low (ERL) and Effect Range - Median (ERM) representing the percentile ranges of toxicity tolerance in bioassay tests for aquatic and benthic biota; the Threshold Effect Level (TEL) and the Probable Effect Level (PEL) of the Florida State Department of Environmental Protection (PDEP) in the United States; the Interim Canadian Sediment Quality Guidelines of the Canadian Council of Ministries of Environment (CCME) showing the interim sediment quality goals (IG) and the Probable Effect Level (PEL) and the Sediment Quality Objectives of the Government of Netherlands with Target Values (TV) and the Maximum Permissible Concentration (MPC)[22]. The Critical Soil Concentration range in soil is also presented on the table of results for comparison[23].

Application of SPSS 12.0 software package for analytical evaluation of the results followed standard statistical methods[24]. This included determination of the correlation coefficient measuring the strength of linear relationship between the heavy metals in sediments in the two main seasons. Also, a One-Way

ANOVA technique in assessing the sample means between and within specified groups. In the case of this study, the priority was on the significant relationship in group means between the spatial and temporal assessment of various parameters[5]. The results are displayed in line with accepting or rejecting the Null Hypothesis and with degrees of Freedom (dF), F-Value and the corresponding p-value respectively. In this case, a test of significance was focused upon the effects of variation between sampling locations (spatial variation) and sampling period (temporal variation) for each analyzed variable.

RESULTS

The results of the sediment quality analysis of heavy metals and their comparative assessment with different international sediment quality guidelines are tabulated in Table 2. The results for Sediment Geo-Acumulation Index (GeoI) are presented on Table 3. On the part of sediment's metal contamination factor and the resulting metal Pollution Load Index (PLI) in sediment deposits in different sampling stations, the results are presented on Table 4. The results for Pearson's Correlation Coefficient are displayed on Table 5.

Cd ranged 4.68-14.25 ppm. The mean was 8.38 ppm. Comparative analysis showed that the Cd mean in the study area failed FDEP and CCME sediment quality goals. Moreover, Cd showed moderately high positive correlation with Cu and Pb. In fact there was a statistical significance (moderately high positive correlation) with Co (0.05 level). No correlation was found with Cr, Mn, Ni and Zn. One way ANOVA analysis on Cd between and within groups showed that there was no significant difference between and within sampling stations, $F(16,44) = 1.579$, $p<0.001$.

During the Dry Season 2007-Cobalt (Co) ranged 19.61-82.30 ppm. The mean value was 47.7 ppm. The generally acceptable range of 4-20 ppm is reported for sediments[27]. But there is little literature on sediment quality guideline for Co but the critical range has been suggested to be between 25-50 ppm for soil[23]. There

was generally no positive correlation with many other metal species. ANOVA analysis on Co between and within groups during both dry and wet seasons showed that there was no significant difference between and within sampling stations, $F(16,44) = 0.720$, $p>0.001$ and at $F(16,44) = 0.842$, $p>0.001$ respectively.

The results showed that Cr in lake sediments ranged 10.6-320 ppm. The mean was 96.7 ppm. On comparison it was found that the Cr mean level in lake sediments failed only the CCME (Canada) sediment quality guidelines[22]. There was an excellent and very high positive relationship with Mn, Ni and Zn at 0.01 Level. Seasonally, during the Dry Season, a statistically significant correlation with Fe and Zn was noted at 0.01 Level while another statistically significant relationship with Fe, Mn, Ni and Zn was noted during the Wet Season. ANOVA analysis on Cr in sediments between and within groups during both seasons showed that there was marked significant difference between and within sampling stations, $F(16,44) = 4.433$, $p<0.001$ and $F(16,44) = 6.687$, $p<0.001$ respectively.

Concentration in Cu ranged 74.9-882.2 ppm. The mean value was 203.5 ppm. This average was above all the compared sediment quality guideline authority except for the NOAA. The average was also above the soil critical concentrations. There was also an excellent and very high positive relationship with Pb at <0.01 Level while low positive correlation with Pb and Zn was noted. A moderately high positive correlation with Mn was identified. Seasonally, during the dry season, a statistically significant correlation with Pb and Zn was noted at <0.01 Level while another statistically significant relationship with Ni at <0.05 was identified during the Monsoon Season. There was no clear significant difference between and within sampling stations in the dry season, $F(16,44) = 0.977$, $p>0.001$. But this was opposite during the wet season when there was clear significant difference between and within sampling stations, $F(16,44) = 11.720$, $p<0.001$.

Table 2: Concentrations of heavy metals (ppm) in the bed sediments of Bangalore Urban lakes

Metal	Mean (ppm)	Range (ppm)	Screening level guidelines of Ontario ministry of environment[22]		NOAA sediment quality guidelines[22]		FDEP sediment quality guidelines[22]		The (CCME) interim sediment quality		Sediment quality objectives in guidelines Netherlands [17,22,29]		Critical soil concentration ranges[23] (ppm)
			Low	Severe	ERL	ERM	TEL	PEL	IGM	PEL	TV	MPC	
Cd	8.38	4.68-14.25	0.6	10	1.2	9.6	0.68	4.21	0.6	3.5	0.8	12	3-8
Co	47.70	19.61-82.30	-	-	-	-	-	-	-	-	-	-	25-50
Cr	96.70	10.68-320.0	26.0	110	81.0	370.0	52.30	160.00	37.3	90.0	-	-	75-100
Cu	203.50	74.90-882.2	16.0	110	34.0	270.0	18.70	108.00	35.7	197.0	36.0	73	60-125
Mn	176.00	60.00-534.5	460.0	1110	-	-	-	-	-	-	-	-	1500-3000
Ni	97.64	28.31-495.6	16.0	75	20.9	51.6	15.90	42.80	-	-	-	-	100
Pb	206.00	36.58-2266.3	31.0	250	46.7	218.0	30.20	112.00	35.0	91.3	85.0	530	100-400
Zn	220.90	19.60-1118.25	120.0	820	150.0	410.0	124.00	271.00	123.0	315.0	140.0	620	70-400

Table 3: Sediment Geo-Accumulation Indices (Igeo) of metals in lakes of Bangalore

Lakes	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn
Byramangala	0.00	1.76	0.27	0.95	0.00	0.85	1.03	1.66
Hosakere	0.14	2.00	0.00	1.80	0.00	0.84	0.89	1.43
Shivapura	0.23	1.72	0.86	1.72	0.00	2.66	1.98	2.68
Karihobanhalli	0.58	1.73	0.38	3.08	0.00	1.23	5.02	1.83
Hebbal	0.84	1.65	0.00	1.24	0.00	0.71	1.83	2.05
Kengeri	0.46	2.22	0.00	1.43	0.00	0.73	0.90	1.40
Venganaiahkere	0.62	1.72	0.00	2.04	0.00	1.78	1.40	0.00
Yellamallappa	0.64	2.46	0.00	1.22	0.00	0.15	1.47	0.00
Vartur	0.50	1.75	0.00	1.18	0.00	0.20	1.13	0.47
Arekere	0.00	0.00	0.00	0.61	0.00	0.61	1.37	0.00
Hulimavu	0.06	1.90	0.00	1.18	0.00	0.30	1.29	0.00
Madiwala	0.36	1.84	0.00	1.30	0.00	0.06	1.94	0.00
Agara	0.23	2.07	0.00	1.55	0.00	0.38	1.68	0.00
Ibblur	0.67	1.83	0.00	1.18	0.00	0.00	1.79	0.00
Bellandur	0.14	1.02	0.00	1.16	0.00	0.00	2.25	0.00
Ullal	0.39	2.17	0.02	1.34	0.00	0.87	2.24	0.00
Malathalli	0.99	2.03	0.00	1.30	0.00	1.24	1.61	0.00

Note: Igeo scale[9]: 0-1 (Least polluted) 1-2 (moderately polluted) 2-3 (moderate to strongly polluted) 3-4 (strongly to very strong pollution) 4-5 (strong to very strong pollution) more than 5 (extreme pollution)

Table 4: Metal contamination factor (cf) and sediment Pollution Load Index (PLI)[33]

Lakes	CF_{Cd}	CF_{Co}	CF_{Cr}	CF_{Cu}	CF_{Mn}	CF_{Ni}	CF_{Pb}	CF_{Zn}	PLI
Byramangala	1.34	0.82	1.97	0.53	0.16	2.25	0.46	1.28	0.840
Hosakere	1.74	1.05	0.92	1.24	0.10	2.23	0.40	1.01	0.811
Shivapura	1.89	0.79	3.56	1.15	0.48	13.81	1.19	3.55	1.900
Karihobanhalli	2.68	0.79	2.20	4.48	0.28	3.28	24.82	1.51	2.270
Hebbal	3.51	0.73	0.84	0.71	0.15	1.95	1.02	1.89	0.983
Kengeri	2.39	1.30	1.03	0.86	0.24	2.00	0.40	0.98	0.920
Venganaiahkere	2.79	0.79	0.24	1.58	0.08	5.71	0.67	0.19	0.682
Yellamallappa	2.85	1.65	0.46	0.70	0.08	1.12	0.71	0.06	0.530
Vartur	2.47	0.81	0.12	0.67	0.13	1.17	0.51	0.39	0.512
Arekere	0.00	0.00	0.34	0.38	0.10	1.77	0.65	0.08	0.260
Hulimavu	1.60	0.94	0.00	0.67	0.08	1.30	0.59	0.07	0.461
Madiwala	2.15	0.89	0.73	0.75	0.10	1.02	1.14	0.19	0.625
Agara	1.89	1.11	0.98	0.97	0.12	1.41	0.89	0.19	0.703
Ibblur	2.95	0.88	0.74	0.67	0.05	0.85	0.98	0.08	0.508
Bellandur	1.74	0.39	0.81	0.65	0.08	0.79	1.56	0.11	0.501
Ullal	2.23	1.24	1.52	0.79	0.25	2.28	1.55	0.18	0.926
Malathalli	4.07	1.08	0.72	0.76	0.21	3.31	0.82	0.14	0.809

Table 5: Overall Pearson's correlation coefficient of Heavy Metals in Lake Bed Sediments

	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn
Cd	1.000							
Co	0.507(*)	1.000						
Cr	-0.063	0.015	1.000					
Cu	0.188	0.005	0.381	1.000				
Mn	0.076	0.089	0.869(**)	0.329	1.000			
Ni	0.014	-0.079	0.720(**)	0.205	0.791(**)	1.000		
Pb	0.127	-0.082	0.363	0.949(**)	0.297	0.056	1.000	
Zn	0.023	-0.079	0.825(**)	0.289	0.797(**)	0.766(**)	0.225	1

: Correlation is significant at the 0.01 level (2-tailed); *:** Correlation is significant at the 0.05 level (2-tailed)

The mean value for Mn in the lake bed sediments were 176.0 ppm. The range was 60.0-534.5 ppm. Little literature is there on the Mn sediment toxicity limit for aquatic life but Mn in the study area can be considered to be under safe limit as prescribed by the Screening Level Guidelines (SLG). A strong correlation with Ni and Zn was noted at <0.01 Level. Meanwhile, a low positive correlation with Pb was also noted. Seasonally, an excellent relationship was found with Ni and Zn at <0.01 Level during the wet season but there was a clear significant difference between and within sampling stations during the dry season, $F_{(16,44)} = 7.156$, $p < 0.001$. But during the wet season, no significant difference between and within sampling stations was noted, $F_{(16,44)} = 0.853$, $p > 0.001$.

The results show that Ni in lake bed sediment samples ranged 28.31-495.6 ppm. The mean was 97.64 ppm. The results indicate that Ni average in the study area was above the SLG and NOAA sediment quality guidelines and the probable effect level of 35.9 ppm[22]. A strong correlation with Zn was noted at <0.01 Level. Seasonally, an excellent relationship was found with Zn at <0.01 Level during the wet season. There was significant difference between and within sampling stations during the dry season, $F_{(16,44)} = 11.874$, $p < 0.001$; but not during the wet season, $F_{(16,44)} = 1.528$, $p > 0.001$.

The results show that the Pb concentrations deposited in the lake bed sediments ranged 36.58-2266.3 ppm. The mean was 206.0 ppm. The mean was above the FDEP and CCME sediment quality guidelines[22]. Pb was within critical concentration range for soils[23]. There was no significant difference during the dry and wet seasons between and within sampling stations, $F_{(16,44)} = 1.186$, $p > 0.001$ and $F_{(16,44)} = 2.238$, $p > 0.001$, respectively.

Zn in the study ranged 19.6-1118.25 ppm. The mean value was 220.9 ppm. With this mean value, the average Zn in the lake sediments were within all stipulated guideline limits. This is also supported by the PEL limit of 315.0 ppm[22,29,30]. There was no significant difference between and within sampling stations during the dry season, $F_{(16,44)} = 2.455$, $p > 0.001$. But during the wet season the difference between and within sampling stations was $F_{(16,44)} = 4.803$, $p < 0.001$.

Sediment geo-accumulation index: Sediment Geo Accumulation Index (GeoI) is the quantitative check of metal pollution in aquatic sediments. It can be determined as:

$$GeoI = ln [Can/1.5*Bn)$$

Where:
C = The concentration of the metal in the sediments
Bn = The background value (reference) in an uncontaminated sediment environment in water bodies[9]

In the study area, the background or reference values for sediments in fresh water aquatic environment have been employed from previous studies[9]. These

background values are Cu (27.0 ppm), Ni (23.0 ppm), Pb (10.0 ppm) and Zn (51 ppm). Background value for Co in India has been reported to be 20.0 ppm[27]. Cd background value is quoted from the universally accepted PEL threshold limit of 3.5 ppm[17,22]. The GeoI values show that the heavy metal species contamination in the lake bed sediments of the study area following the trend:

$$Co > Pb > Ni > Cu > Zn > Cd > Cr > Mn$$
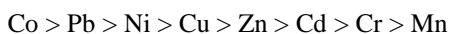
Pollution load index for metals in sediments: This index is used to determine the mutual contamination effect of the studied metal species and has been derived as the Pollution Load Index (PLI) as the *n*th root of the Contamination Factor (CF) of studied metals in an aquatic ecosystem. In the equation, $PLI = (CF_{metal})^{1/nth}$ where nth denotes the number of metal ions being investigated[33]. The value for Contamination Factor of the metal is obtained by the dividing the concentration of the individual metal species to its respective background value.

DISCUSSION

The average abundance of Cd in the Earth's crust is 0.16 ppm; in soils it is 0.1- 0.5 ppm. Cadmium metal is used mainly as an anticorrosive, electroplated on to steel. Cadmium sulfide and selenide are commonly used as pigments in plastics. Also used in electric batteries and in various electronic components. Along with inorganic fertilizers produced from phosphate ores which constitute a major source of diffuse cadmium pollution, these are the main sources of Cd effluent discharge[25-27,31]. Moreover, when ingested by humans, cadmium accumulates in the intestine, liver and kidney[28]. The kidney cortex is regarded as the most sensitive organ. The health effects of chronic exposure of Cd include proximal tubular disease and osteomalacia.

The average Cobalt abundance in earth's crust is 29 ppm; in soils it is 1.0-14 ppm; Cobalt is widely used as alloy for various steels, in electroplating, in fertilizers, porcelain and glass making. Cobalt is considered essential for algae and bacteria but not essential to higher plants. In animals it is only requires in trace basis[25,27,28].

Chromium is found chiefly in Chrome-Iron Ore (FeO-Cr_2O_3).Chromium is considered non-essential for plants, but an essential element for animals. The average abundance of Cr in the earth's crust is 122 ppm; in soils Cr ranges from 11-22 ppm. It is used in alloys, in electroplating and in pigments. Chromium

and its salts are used in the leather tanning industry, the manufacture of catalysts, pigments and paints, fungicides, the ceramic and glass industry and in photography and for chrome alloy and chromium metal production, chrome plating and corrosion control[25,27,28]. Hexavalent compounds are carcinogenic by inhalation and are corrosive to tissue.

The average abundance of Copper is 68 ppm; in soils it is between 9 and 33 ppm. Copper is widely used in electrical wiring, roofing, various alloys, pigments, cooking utensils, piping and in the chemical industry. Copper is present in munitions, alloys (brass, bronze) and coatings. Copper compounds are used as or in fungicides, algicides, insecticides and wood preservatives and in electroplating, azo dye manufacture, engraving, lithography, petroleum refining and pyrotechnics. Copper compounds can be added to fertilizers and animal feeds as a nutrient to support plant and animal growth Copper compounds are also used as food additives[25,27,28]. In addition, copper salts are used in water supply systems to control biological growths in reservoirs and distribution pipes and it forms a number of complexes in natural waters with inorganic and organic ligands[28]. The aqueous species of Copper include Cu^{2+}, $Cu(OH)_2$ and $CuHCO^{3+}$.

Mn in Earth's crust is 1060 ppm; in soils it is 61-1060 ppm. The common aqueous species found in water is predominantly Mn^{2+} and Mn^{4+}. Manganese is essential for plants and animals. Manganese dioxide and other manganese compounds are used in products such as batteries, glass and fireworks. Potassium permanganate is used as an oxidant for cleaning, bleaching and disinfection purposes. Manganese greensands are used in some locations for potable water treatment. An organic manganese compound, Methylcyclopentadienyl Manganese Tricarbonyl (MMT), is used as an octane-enhancing agent in unleaded petrol in Canada, the USA, Europe, Asia and South America. Other manganese compounds are used in fertilizers, varnish and fungicides and as livestock feeding supplements. Manganese can be adsorbed onto soil, the extent of adsorption depending on the organic content and cation exchange capacity of the soil. It can bioaccumulate in lower organisms (e.g., phytoplankton, algae, molluscs and some fish) but not in higher organisms; bio-magnification in food chains is not expected to be very significant[25,27,28].

The background value for Ni in Earth's crust is 1.2 ppm; in soils it is 2.5 ppm. The common aqueous species found in water is predominantly Ni^{2+}. It is suspected to be essential trace elements for plants and animals. Nickel may be present in some ground waters

as a consequence of dissolution from nickel ore-bearing rocks. Nickel is used principally in its metallic form combined with other metals and nonmetals as alloys. Nickel alloys are characterized by their hardness, strength and resistance to corrosion and heat. Nickel is also used mainly in the production of stainless steels, non-ferrous alloys and super alloys. Other uses of nickel and nickel salts are in electroplating, as catalysts, in nickel-cadmium batteries, in coins, in welding products and in certain pigments and electronic products. It is estimated that 8% of nickel is used for household appliances. Nickel is also incorporated in some food supplements, which can contain several micrograms of nickel per tablet[25,27,28].

The average abundance is Earth's crust is 13 ppm; in natural soils background level ranges from 2.6-25 ppm; The common aqueous species are hydroxides and carbonates of Pb^{2+}. Lead in water comes from industrial, mines and smelter discharges before being deposited in the sediment sinks. Lead is non essential for plants and animals and is toxic by ingestion-being a cumulative poison. Lead is also used in the production of lead acid batteries, solder, alloys, cable sheathing, pigments, rust inhibitors, ammunition, glazes and plastic stabilizers. Tetraethyl and tetramethyl lead are important because of their extensive use as antiknock compounds in petrol[25,27,28,32]. Lead toxicity leads to anaemia both by impairment of haemo-biosynthesis and acceleration of red blood cell destruction. Both are dose related. Lead also depresses sperm count[31]. In addition, Pb can also produce a damaging effect on the kidney, liver, male and nervous system, blood vessels and other tissues[31,32].

The average abundance of Zn in Earth's crust is 76 ppm; in soils it is 25-68 ppm, Zinc is used in a number of alloys including brass and bronze, batteries, fungicides and pigments. Zinc is an essential growth element for plants and animals but at elevated levels it is toxic to some species of aquatic life[25]. In addition, Zn is involved in a variety of enzyme systems which contribute to energy metabolism, transcription and translation. Zinc is also potentially hazardous and excessive concentrations in soil lead to phytotoxicity as it is a weed killer[27,28,31]. Zinc is used in galvanizing steel and iron products. Zinc oxide, used in rubber as a white pigment, for example, is the most widely used zinc compound. Peroral zinc is occasionally used to treat zinc deficiency in humans. Zinc carbamates are used as pesticides[31].

CONCLUSION

From the above observations, it is clear that Cu and Ni showed more pronounced levels of pollution followed by Pb and Cd. Chromium failed a single sediment quality guideline while Zn, Mn and Co remained within the safety levels of all sediment quality guidelines prescribed for the study. The Sediment Geo-accumulation Index showed that Co, Cu and Pb levels showed moderate pollution while the Pollution Load Index (PLI) between heavy metals in the lakes produced the following outputs:

$$Ni > Pb > Cd > Cu > Cr > Co > Zn > Mn$$

PLI shows the magnitude and extent of the heavy metals deposition in the lake bed sediment of the study area over a long period of time. In this case, the results suggest that the lake bed sediments in Madhavara and Byramangala Series are deposited with more heavy metal accumulation than those in the Yellamallappa, Vartur, or Hulimavu series, respectively. This study therefore indicates the increasing levels of various heavy metals species in the sediment deposits of the lake beds of the urban wetlands. If this trend is allowed to continue unabated, it is mostly likely that the local food web complexes in these fragile wetlands might be at highest risk of induced heavy metals contamination.

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