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Comprehensive Assessment of Heavy Metal Pollution and Ecological Risk in Lakes of Bangalore, Karnataka, India

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ABSTRACT

The contamination of water and sediment by heavy metals poses significant challenges to freshwater ecosystems, agriculture, and aquaculture. This study focused on assessing heavy metal pollution in Ulsoor and Agara Lakes, prominent freshwater reservoirs in Bengaluru utilized for aquaculture. The presence of heavy metals such as Cd, Cu, Zn, Cr and Pb levels were analyzed in water and sediment samples of both lakes over a period of one year (from August 2021 to July 2022), using an Atomic Absorption Spectrometer. Pollution indices (CF, Igeo, PLI, ERI) were computed for sediment, revealing higher metal concentrations compared to water. Correlation analysis identified strong associations between Zn and Cu, Pb and Zn in water, and Cu and Cd in sediment, suggesting common pollution sources. While sediment showed relative safety based on PLI, Igeo, and ERI, CF indicated an unpolluted to moderately polluted status. In conclusion, this study revealed that most metals in the water exceeded permissible limits, highlighting the need for effective remediation measures.

Keywords Environmental pollution indices, Ecological risk index, Pollution load index, Metrocity, Lakes.

INTRODUCTION

Evaluating the presence of heavy metals in urban lakes is crucial for understanding environmental conditions and potential risks to aquatic ecosystems. Heavy metals, such as lead (Pb), mercury (Hg), cadmium (Cd), arsenic (Ar), chromium (Cr), copper (Cu) and zinc (Zn), pose significant threats and can stem from various sources like industrial discharges, urban runoff, agriculture, and atmospheric deposition (Müller *et al.* 2020). Exposure to these metals is known to cause severe health issues, including cancer, organ damage, autoimmunity and in extreme cases, death.

The rapid growth of Bengaluru has brought an influx of people and small-scale industries, contributing to toxic metal pollution in water bodies of Bengaluru, particularly Ulsoor and Agara Lakes. The persistence of heavy metals calls for action by the Bruhath Bengaluru Mahanagara Palike (BBMP) to

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curb pollution and mitigate consequences. Previous studies in Bengaluru's lakes, like like Bellanduru, Hebbala, Varthur, Madiwala, Lalbagh and Sankey Lake, have traced pollution to sewage discharge, rainwater influx, and fossil fuel emissions (Gorain *et al.* 2018, Ramachandra *et al.* 2018, Sudarshan *et al.* 2020, Wilson *et al.* 2016). Also, the aquatic organisms exposed to elevated metal levels experience accumulation in organs, leading to impaired functions, oxidative stress, and DNA damage (Garai *et al.* 2021, Gorain *et al.* 2018).

Hence, consistent monitoring of water and sediment quality is essential due to their role as pollutant reservoirs. Thus, the present aims to assess the impact of human activities on the concentrations of toxic heavy metals (Cd, Cu, Zn, Cr and Pb) in the water and sediments of Ulsoor and Agara Lakes in Bengaluru in a season-dependent manner and to investigate seasonal variations and associated risks to human health.

MATERIALS AND METHODS

Study area and sample collection

Water and sediment samples were collected from Ulsoor Lake (12°58′53.3″N, 77°37′9.17″E) and Agara Lake (12°92'07.07"N, 77°64'1.442"E) of Bengaluru, one of the major metropolitan cities in India. In Bengaluru, the majority of lakes are severely polluted, limiting their use to irrigation and industrial cooling. Only about 13% of the lakes are suitable for supporting wildlife, and 2% can be utilized as potable water after undergoing proper disinfection. Among them, the selected lakes stand out as prominent examples and have been utilized for fish farming for many years. Furthermore, no pollution index was evaluated for these lakes.

Randomly selected, five sampling stations were established in both Ulsoor and Agara Lakes, covering the entire lake region (Fig. 1). Over a year, from August 2021 to July 2022, water and sediment samples were collected bi-monthly. The year was divided into three seasons: Pre-monsoon (March to June), Monsoon (July to November), and Post-monsoon (December to February). Collected samples were promptly transported within 3 hrs to the laboratory at the Department of Life Sciences, CHRIST (Deemed to be University), Bengaluru, in a dark cooler box (4°C). Water quality parameters were assessed following APHA standard protocols (Baird *et al.* 2012).

Surface water samples, collected in 1L polyethylene bottles, were cleaned with 10% HNO_3 and double distilled water in the lab and rinsed with lake water. Filtered through 0.45 m pore Teflon filters, the samples were acidified with HNO_3 to a pH 2 or below, stored at 4°C until analysis (Gemeda *et al.* 2021, Villa-Achupallas *et al.* 2018). Sediment samples (approximately 100 g) were hand-collected at each sampling position using protective gloves and marked with a Global Positioning System (GPS) tracer. The chosen locations considered factors like human activity and industrial discharge topography. The collected sediment samples were thawed, dried at 60°C, disaggregated with an agate mortar, and sieved (<63 μm fraction). Metal concentrations in sediments were reported as dry-weight sediment. All sediment samples were analyzed within three days, following protocols and standards (Baird *et al.* 2012).

Sample preparation and analysis

The analysis of heavy metal levels in both lake (Ulsoor and Agara Lakes) water and sediment samples adhered to established APHA protocols with minor adjustments (Baird *et al*. 2012). In summary, 100 ml water samples underwent digestion with a mixed acid solution (3:1 ratio of HNO_3 and HCl) on a hotplate within a fume hood at 80°C until the solution became colorless. The digested samples were diluted with distilled water (50 ml), filtered through Whatman filter paper (0.45 mm), and stored in cold storage. Sediment samples were dried at 80°C for 24 hrs, finely ground, homogenized, and sieved (100 mesh, 150 μm). A 1 g portion of the ground sample was digested with a mixed acid solution (3:1 ratio of HNO_3 and HCl), left aside for 12 hrs and then digested on a hotplate at 40°C. The digested samples underwent analysis to determine selected heavy metals using an Atomic Absorption Spectrometer (Shimadzu AA 6880 Japan). For each metal, the instrument is adjusted to a specific cathode lamp at a specific wavelength with a standard graph.

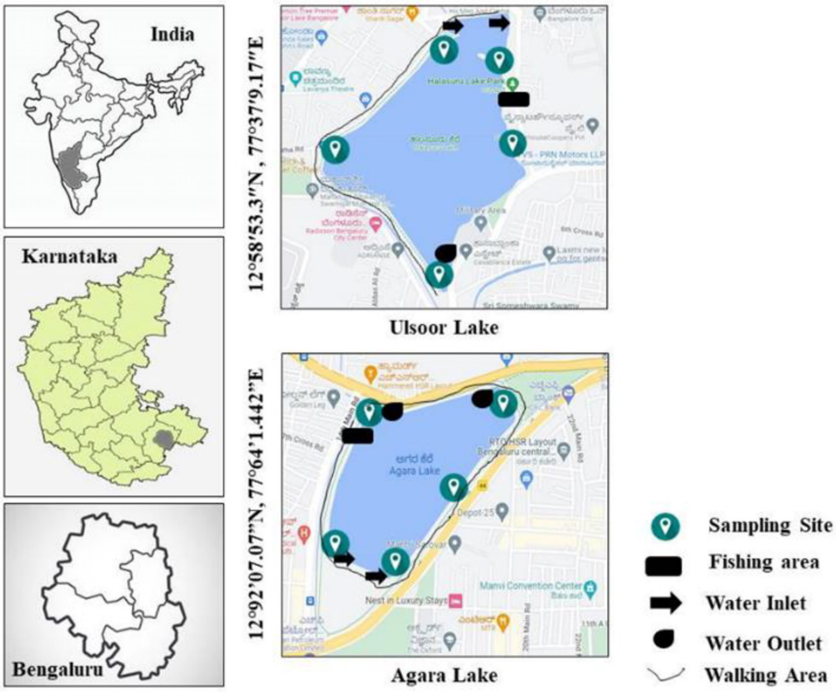

Fig. 1. Map of sampling sites along both lakes.

Assessment of contamination level of heavy metals

Contamination factor (CF): To calculate the extent of contamination caused by various metals, the CF is utilized, as described by Salomons and Förstner (1984). The contamination factor is expressed using the following formula :

$$CF = \frac{\text{Concentration of metals in sediment}}{\text{World average shale values for sediment}}$$

Due to the lack of regional reference metal values, the crust material values were adopted (Turekian and Wedepohl 1961). The values, expressed in milligrams per kilogram (mg kg^{-1}), are as follows: 0.3 for Cd, 45 for Cu, 90 for Cr, 20 for *Pb*, and 95 for Zn.

Pollution load index (PLI): PLI is calculated as the mean of the CF values of multiple metals values, as proposed by Tomlinson *et al.* (1980). This index is derived from the CF of each metal found in the sediment at a contaminated site.

$$PLI = (CF1 \times CF2 \times CF3 \ldots \times CFn)1/n$$

PLI offers a straightforward and comparative analytical method for evaluating the extent of toxic metal pollution. It is calculated depending on the CF of each metal, with 'n' representing the number of metals considered. The PLI is used to classify the pollution level, into the following categories: Extremely heavy pollution: PLI > 3, Heavy pollution: 2 < PLI < 3, Moderate pollution: 1 < PLI < 2 and No pollution: PLI < 1.

***Geoaccumulation index* (I*geo*):** I*geo* aids in assessing the levels of metals in sediments by comparing the present heavy metal with levels from pre-industrial periods. The state of contamination in the study area was determined by calculating the *Igeo* based on the heavy metal concentrations of metals in the soil. This calculation followed the approach outlined by Muller (1979).

$$Igeo = log^{2}\left[\frac{Cn}{(1.5 \times Bn)}\right]$$

Where, *Cn* represents the levels of metal 'n' in the soil, *Bn* denotes the geochemical background value for metal 'n' in sediments (average shale), and a factor of 1.5 is applied to accommodate potential variations in background data resulting from lithology effects.

The ecological risk index (ERI): ERI were calculated using the methodology developed by Hakanson (1980). This method incorporates the toxicity factor of respected metal to determine the potential ecological risk. By considering the toxicity factor, it becomes possible to predict the present contamination level status of that particular metal in the particular ecosystem.

$$E_r^i = T_r^i \times C_f^i$$

$$ERI = \sum E_r^i$$

Where E_r^i ecological risk index of each metal, C_f^i contamination factor (a ratio of the concentration of the metal in samples and previous reference value for the metal C_f^i = Ci/Cn), and T_r^i = Toxic factor of each metal. T_r^i values are assigned as follows: 10 for As, 30 for Cd, 2 for Cr, 1 for Mn, 5 for Pb and 1 for Zn (Hakanson 1980). The standard factors were adjusted based on the work of Liu *et al.* (2009). The toxic metal pollution stated, as determined by the ecological risk index (ERI), is classified as follows: Low contamination (RI≤110), moderate contamination (110< RI≤ 220), high contamination (220<RI ≤440), and extreme contamination (RI>440).

Statistical analysis

The statistical package IMB SPSS software version 27.0 was used to carry out an analysis of variance (ANOVA) with Tukey's post hoc test to check significant differences between temporal and spatial averages of heavy metals. Also, a Pearson correlation test was performed in MS Excel (2019) to look for heavy metals with similar behavior, mean and standard deviation.

RESULTS AND DISCUSSION

Physico-chemical parameters of Ulsoor and Agara Lakes water

Table 1 summarizes the results of physico-chemical parameters in this study. During the pre-monsoon season, the highest temperature (28ºC) was observed, attributed to elevated atmospheric temperatures (36.8ºC) in the environment. Water pH levels ranged between 6.6 and 7.3 in both Lakes, remaining consistent across all seasons. pH fluctuations are often linked to rainfall and untreated sewage water inflow. Electrical Conductivity (EC) revealed higher values in Agara Lake compared to Ulsoor Lake, indicating increased dissolved salts (Bhagde *et al.* 2020). Notably, Agara Lake surpassed the Bureau of Indian Standards (BIS) limit of 300 µs/cm, particularly during pre-monsoon seasons, similar to trends observed in Hebbal Lake during heavy rainfall (Sudarshan *et al.* 2019).

Turbidity levels remained consistent throughout the year, with Ulsoor Lake exceeding BIS limits in all seasons due to solid particle influx affecting algae and phytoplankton growth (Kumar *et al.* 2022). Hebbal Lake exhibited higher turbidity than Agara Lake but less than Ulsoor Lake (Sudarshan *et al.* 2019). Total Dissolved Solids (TDS) were below BIS limits, with higher levels in pre-monsoon for Ulsoor Lake and post-monsoon for Agara Lake, attributed to rainwater runoff. Alkalinity levels were higher in post-monsoon for Ulsoor Lake but consistent in Agara Lake throughout all seasons. Elevated alkalinity can impact water hardness, yet values in both lakes were within acceptable limits. Pre-monsoon in Ulsoor and post-monsoon in Agara Lakes recorded higher hardness levels. The total alkalinity is influenced by carbonate and bicarbonate levels (Egleston *et al.* 2010).

Correlation analysis of physico-chemical parameters

Utilizing correlation analysis as a valuable tool to explore associations between toxicants, this study elucidates the co-fluctuation of physico-chemical parameters within Ulsoor and Agara Lakes, as presented in Table 2. In Ulsoor Lake, positive correlations were observed between TDS and EC, as well as between Hardness and EC. Furthermore, a notably strong relationship emerged between alkalinity and pH (r-value = 0.8865), indicating a potential common source of pollutants impacting these parameters (Table 2). Conversely, in Agara Lake, no substantial connections

Table 1. Physico-chemical parameters of Ulsoor and Agara Lakes.

Month	Temperature (°C)		Turbidity (NTU)		EC (µs/cm)		pH	
	Ulsoor	Agara	Ulsoor	Agara	Ulsoor	Agara	Ulsoor	Agara
Aug-21	26±0.57	26±0.35	10.1±1.12	0.78±0.18	158±10.36	242±30.32	7.0±0.89	6.9±0.15
Sep-21	26±0.39	27±0.49	10.6±0.98	0.76±0.12	148±13.37	255±16.75	6.8±0.36	7±0.36
Oct-21	25±0.53	25.5±0.50	10.2±0.78	0.75±0.02	133±20.12	246±39.19	7.2±0.52	7.1±0.32
Nov-21	25±0.63	25±0.38	10.5±1.43	0.73±0.03	162±15.94	255±45.37	7.3±0.43	7.2±0.21
Dec-21	24±0.12	24.5±0.16	10.3±1.11	0.79±0.21	125±17.63	224±28.53	6.9±0.39	7.1±0.39
Jan-22	26±0.28	26±0.23	10.9±1.32	0.86±0.15	163±19.45	268±23.76	7.2±0.64	7.2±0.14
Feb-22	27±0.38	27±1.21	11±1.36	0.75±0.08	168±12.75	275±41.36	7.3±0.38	7.3±0.49
Mar-22	28±0.51	28±0.54	10.1±0.98	0.83±0.07	180±25.81	288±48.24	7.1±0.46	7.1±0.25
Apr-22	28±0.58	28±0.38	9.5±0.98	0.7±0.03	188±20.74	291±31.16	6.9±0.28	6.9±0.17
May-22	26±0.38	25±0.57	11±1.12	0.9±0.09	198±30.27	301±39.48	7.1±0.39	7.0±0.23
Jun-22	25±0.51	25±0.59	11.1±1.68	0.87±0.10	215±28.36	309±43.89	6.9±0.16	6.8±0.62
Jul-22	24±0.60	24±0.34	11.55±1.88	0.9±0.12	228±38.49	317±40.32	6.6±0.36	6.6±0.61
Average	25.83	25.91	10.57	0.80	172.16	272.58	7.04	7.01
SD	1.33	1.32	0.56	0.06	31.15	29.12	0.18	0.19
Range	24-28	24-28	9.5-11.5	0.7-0.9	125-228	224-317	6.6-7.3	6.6-7.3
BIS	-		1		300		6.5-8.5	

Table 1. Continued.

Month	TDS (mg/L)		Hardness (mg/L)		Alkalinity (mg/L)	
	Ulsoor	Agara	Ulsoor	Agara	Ulsoor	Agara
Aug-21	175±21.36	387±51.79	100±10.30	98±12.36	180±31.25	120±18.50
Sep-21	151±25.31	388±53.21	120±12.36	92±15.36	160±12.36	130±22.54
Oct-21	248±32.56	385±52.36	95±21.36	100±8.45	170±25.76	138±10.32
Nov-21	246±31.47	375±43.98	92±14.87	125±15.37	200±40.84	149±13.72
Dec-21	155±32.14	414±31.79	103±16.82	140±15.36	168±21.65	145±11.17
Jan-22	175±14.31	401±45.19	150±15.98	135±14.36	190±14.35	140±140.25
Feb-22	135±17.79	413±44.48	135±21.71	120±18.98	200±16.39	155±40.98
Mar-22	180±28.99	387±57.88	110±19.91	130±17.89	190±19.65	150±20.87
Apr-22	246±64.21	373±45.87	155±15.63	115±21.46	160±12.33	140±17.95
May-22	284±55.53	400±55.43	140±12.21	103±17.16	176±4.36	156±25.74
June-22	302±51.36	380±33.17	150±16.54	100±20.09	156±9.36	148±33.65
July-22	335±69.97	374±21.46	156±20.12	93.9±17.02	145±15.48	147±19.54
Average	219.33	389.75	125.5	112.65	174.58	143.16
SD	66.08	14.27	24.82	16.96	17.86	10.37
Range	135-335	373-414	92-156	92-140	145-200	120-156
BIS	500		300		200	

were identified among the parameters, distinctly pointing towards distinct sources of pollutants affecting the two lakes. It is essential to acknowledge that the presence and strength of correlations among physico-chemical parameters can exhibit variability based on the specific system or substances being studied (Ahmed *et al.* 2022).

Heavy metal analysis in water and sediment

The measured concentration of Cd, Cu, Zn, Cr and Pb analyzed in water and sediment samples collected from Ulsoor and Agara Lakes were depicted in Tables 3–4.

Cadmium (Cd)

In the present study, Cd concentrations in water samples ranged from 0.0005 to 0.0171 mg/L in Ulsoor Lake and 0.0013 to 0.0345 mg/L in Agara Lake (Table 3). Notably, during the post-monsoon period, Cd levels in Ulsoor Lake increased due to the influx of pollutants from the catchment region throughout the monsoon season. Conversely, Agara Lake exhibited

Table 2. Correlation coefficient (r) matrix for physico-chemical parameters in water sample of Ulsoor and Agara Lakes.

Lake	Parameters	Temperature	Turbidity	EC	pH	TDS	Hardness	Alkalinity
Ulsoor Lake	Temperature	1						
	Turbidity	-0.4996	1					
	EC	0.0705	0.4999	1				
	pH	0.2164	-0.0222	-0.2879	1			
	TDS	-0.3604	0.3591	0.7267	-0.2392	1		
	Hardness	0.1670	0.4433	0.7401	-0.3327	0.3981	1	
	Alkalinity	0.3698	-0.1362	-0.3693	0.8865	-0.5362	-0.4117	1
Agara Lake	Temperature	1						
	Turbidity	-0.4889	1					
	EC	0.0060	0.5672	1				
	pH	0.3222	-0.4260	-0.5375	1			
	TDS	-0.0275	0.0955	-0.3907	0.5938	1		
	Hardness	0.1567	-0.1453	-0.3201	0.6499	0.4775	1	
	Alkalinity	-0.1671	0.3291	0.5075	0.2056	0.2255	0.3457	1

elevated Cd levels during the pre-monsoon phase, a consequence of treated sewage water discharge from the Sewage Treatment Plant (STP) into the lake. In sediment samples, Cd concentrations ranged from 0.0019 to 0.1218 mg/kg in Ulsoor Lake and 0.0111 to 0.0566 mg/kg in Agara Lake (Table 4). Remarkably, Ulsoor Lake demonstrated higher Cd concentrations during the monsoon season, linked to rainwater entry through sewage canals carrying pollutants such as plastics, oil, combustion by products, and e-waste from the catchment region. In contrast, Agara Lake maintained relatively consistent Cd concentrations across all seasons, attributed to its lack of direct sewage connection.

The concentrations of Cd in both water and sediment displayed significant variations throughout the year ($p<0.05$). Notably, the measured Cd values in water for both lakes exceeded the permissible limits set by WHO (2008), EPA (2002), USEPA (2006), ECR (1997), and BIS (2009) (Table 4). However, sediment Cd values adhered to permissible limits established by various organizations. Prior studies by Ramachandra *et al.* (2018) and Sudarshan *et al.*

Table 3. Results of heavy metals in water samples (mg/l) of Ulsoor and Agara Lakes of Bengaluru during the period of August 2021 to July 2022. BDL - Below the detectable limit, NA - not available. According to Duncan's Multiple Range Test (DMRT), the means of words (a-g) in the same column differ significantly ($p<0.05$).

Heavy metals	Cd		Cu		Zn	
Sites	Ulsoor	Agara	Ulsoor	Agara	Ulsoor	Agara
Aug-21	0.0005±0.0002^{e}	0.001±0.0008^{c}	0.18±0.30^{c}	0.01±0.03^{c}	0.07±0.04^{de}	0.04±0.02^{de}
Sep-21	0.002±0.0007^{de}	0.004±0.001^{c}	0.01±0.0001^{c}	BDL	0.15±0.13^{d}	0.07±0.07^{d}
Oct-21	0.003±0.001^{de}	0.005±0.001^{c}	0.78±0.13^{a}	0.83±0.11^{a}	0.40±0.11^{b}	0.485±0.04^{b}
Nov-21	0.002±0.0003^{de}	0.004±0.0007^{c}	0.83±0.21^{a}	0.77±0.16^{a}	0.80±0.04^{a}	0.77±0.02^{a}
Dec-21	0.003±0.001^{de}	0.005±0.0008^{c}	0.38±0.39^{b}	0.2±0.36^{b}	0.22±0.12^{c}	0.16±0.09^{c}
Jan-22	0.01±0.006^{a}	0.01±0.0006^{b}	BDL	BDL	0.01±0.02^{e}	0.0005±0.02^{e}
Feb-22	0.002±0.0008^{de}	0.006±0.008^{c}	BDL	BDL	0.03±0.02^{de}	0.03±0.007^{de}
Mar-22	0.001±0.0006^{e}	0.006±0.01^{c}	BDL	BDL	0.03±0.03^{de}	0.03±0.008^{de}
Apr-22	0.01±0.004^{b}	0.02±0.008^{b}	0.01±0.0002^{c}	0.002±0.0001^{c}	0.10±0.03^{de}	0.08±0.02^{d}
May-22	0.009±0.004^{bc}	0.02±0.009^{b}	0.008±0.01^{c}	0.004±0.004^{c}	0.08±0.05^{de}	0.07±0.02^{d}
June-22	0.002±0.001^{de}	0.005±0.001^{c}	BDL	BDL	0.05±0.03^{e}	0.002±0.0003^{e}
July-22	0.006±0.001^{cd}	0.03±0.01^{a}	BDL	BDL	0.03±0.01^{de}	0.04±0.01d^{e}
Mean	**0.005**	**0.01**	**0.31**	**0.30**	**0.16**	**0.15**
Range	**0.0005-0.01**	**0.001-0.03**	**0.008-0.83**	**0.002-0.83**	**0.01-0.80**	**0.0005-0.77**
p value	**<0.000**	**<0.000**	**0.098**	**0.097**	**0.051**	**0.056**

Table 3. Continued.

Heavy metals	Cr		Pb	
Sites	Ulsoor	Agara	Ulsoor	Agara
Aug-21	BDL	BDL	0.003±0.0001[c]	0.01±0.004[e]
Sep-21	0.02±0.005[f]	0.003±0.0003[f]	0.01±0.02[c]	BDL
Oct-21	0.12±0.02[b]	0.10±0.01[c]	0.22±0.16[c]	0.59±0.21[b]
Nov-21	0.07±0.008[d]	0.07±0.01[d]	3.98±0.11[a]	4.09±0.10[a]
Dec-21	0.06±0.007[de]	0.09±0.05[cd]	0.44±0.03[b]	0.44±0.06[c]
Jan-22	BDL	BDL	0.01±0.004[c]	0.17±0.11[d]
Feb-22	0.01±0.01[fg]	0.009±0.005[f]	0.02±0.02[c]	0.04±0.01[e]
Mar-22	0.03±0.01[f]	0.02±0.01[ef]	BDL	0.008±0.005[e]
Apr-22	0.05±0.01[r]	0.04±0.01[e]	BDL	0.03±0.01[e]
May-22	0.09±0.01[c]	0.06±0.01[b]	BDL	BDL
June-22	0.24±0.02[a]	0.16±0.02[a]	BDL	BDL
July-22	0.25±0.01[a]	0.21±0.03[a]	BDL	BDL
Mean	**0.09**	**0.08**	**0.67**	**0.67**
Range	**0.01-0.25**	**0.003-0.21**	**0.003-3.98**	**0.008-4.09**
p value	**0.007**	**0.004**	**1.295**	**1.353**

(2020) similarly identified high Cd concentrations in the sediments of Varthur and Bellandur Lakes in Bengaluru. This heightened Cd level was linked to rainwater carrying road dust, sewage mixed with lubricants, pesticides, and insecticides, leading to increased Cd concentrations in both water and sediment (Karak and Bhattacharyya 2010). In comparison, the Cd levels in this study's water samples exhibited lower concentrations compared to those found in Hussain Sagar Lake (Ayyanar and Thatikonda 2020), Kashmir Lake (Showqi *et al.* 2018), Dhanbad Lake (Pal and Maiti 2018), East Kolkata Wetland (Avijit and Kamalakannan 2023), and Ox-Box Lake Assam (Das and Choudhury 2016). Additionally, the observed Cd levels in sediment align with findings from Revalsar Lake (Meena *et al.* 2017). Exposure to low Cd levels resulted in DNA damage and the formation of micro-nucleated and bi-nucleated cells in the gills, liver, and blood of fishes during subchronic cadmium chloride exposure (Omer *et al.* 2012).

Copper (Cu)

The concentration of Cu in Ulsoor Lake water ranged

Table 4. Results of heavy metals in sediment samples (mg/kg) of Ulsoor and Agara Lakes of Bengaluru during the period of August 2021 to July 2022. NA - not available; According to Duncan's Multiple Range Test (DMRT), the means of words (a-g) in the same column differ significantly ($p<0.05$).

Heavy metals	Cd		Cu		Zn	
Sites	Ulsoor	Agara	Ulsoor	Agara	Ulsoor	Agara
Aug-21	0.002±0.0007[b]	0.01±0.007[b]	1.35±0.66[ab]	0.52±0.31[c]	1.46±0.34[a]	1.17±0.30[ab]
Sep-21	0.002±0.002[b]	0.02±0.01[b]	0.81±0.71[ab]	0.64±0.29[bc]	1.17±0.50[a]	1.15±0.19[ab]
Oct-21	0.002±0.001[b]	0.02±0.01[ab]	0.83±0.61[ab]	1.15±0.76[bc]	1.32±0.53[a]	1.29±0.24[ab]
Nov-21	0.002±0.0002[b]	0.02±0.02[b]	0.63±0.20[ab]	1.35±1.17[bc]	1.05±0.25[a]	1.21±0.50[ab]
Dec-21	0.001±0.0002[b]	0.03±0.03[ab]	2.15±0.67[a]	2.14±1.07[ab]	1.06±0.31[a]	1.36±0.20[ab]
Jan-22	0.01±0.0003[b]	0.01±0.001[b]	0.18±0.16[b]	0.47±0.16[b]	1.05±0.55[a]	0.65±0.32[c]
Feb-22	0.007±0.0005[b]	0.02±0.01[b]	1.53±1.59[ab]	0.75±0.20[bc]	1.03±0.55[a]	1.11±0.37[ab]
Mar-22	0.01±0.002[b]	0.03±0.01[ab]	1.99±2.003[a]	1.19±0.39[bc]	1.31±0.51[a]	1.46±0.39[ab]
Apr-22	0.01±0.005[b]	0.02±0.01[b]	1.26±0.99[ab]	0.99±0.31[bc]	1.30±0.65[a]	1.42±0.17[ab]
May-22	0.009±0.002[b]	0.02±0.01[b]	1.42±1.22[ab]	1.26±0.37[bc]	1.37±0.64[a]	1.60±0.15[a]
June-22	0.12±0.22[a]	0.05±0.04[a]	1.51±1.06[ab]	2.84±3.13[a]	1.40±0.41[a]	1.37±0.48[ab]
July-22	0.07±0.13[ab]	0.03±0.01[ab]	1.47±1.08[ab]	1.11±0.28[bc]	1.59±0.32[a]	1.39±0.21[ab]
Mean	**0.02**	**0.02**	**1.26**	**1.27**	**1.26**	**1.26**
Range	**0.001-0.12**	**0.01-0.05**	**0.18-2.15**	**0.52-2.84**	**1.03-1.59**	**0.65-1.60**
p value	**0.001**	**0.000**	**0.317**	**0.549**	**0.035**	**0.057**

Table 4. Continued.

Heavy metals	Cr		Pb	
Sites	Ulsoor	Agara	Ulsoor	Agara
Aug-21	0.54 ± 0.05^{d}	0.33 ± 0.10^{b}	0.88 ± 0.39^{ab}	0.51 ± 0.16^{abc}
Sep-21	0.54 ± 0.20^{d}	0.31 ± 0.08^{b}	0.59 ± 0.25^{ab}	0.40 ± 0.08^{bc}
Oct-21	0.93 ± 0.64^{cd}	0.43 ± 0.09^{b}	1.22 ± 1.34^{ab}	0.62 ± 0.001^{abc}
Nov-21	0.74 ± 0.17^{d}	0.48 ± 0.35^{b}	1.56 ± 0.18^{a}	1.36 ± 0.50^{a}
Dec-21	0.79 ± 0.33^{d}	0.39 ± 0.12^{b}	0.76 ± 0.20^{ab}	0.91 ± 0.68^{abc}
Jan-22	0.78 ± 0.33^{d}	0.47 ± 0.13^{b}	0.99 ± 0.80^{ab}	1.13 ± 1.92^{ab}
Feb-22	0.93 ± 0.23^{cd}	0.76 ± 0.72^{b}	0.72 ± 0.71^{ab}	0.24 ± 0.07^{bc}
Mar-22	1.00 ± 0.29^{cd}	0.79 ± 0.73^{b}	1.322 ± 1.07^{ab}	0.71 ± 0.18^{abc}
Apr-22	1.86 ± 0.49^{b}	0.73 ± 0.14^{b}	0.97 ± 0.71^{ab}	0.60 ± 0.10^{abc}
May-22	2.62 ± 0.55^{a}	1.06 ± 0.20^{b}	0.83 ± 0.52^{ab}	0.51 ± 0.20^{abc}
June-22	1.55 ± 1.31^{bc}	3.65 ± 3.27^{a}	1.07 ± 0.55^{ab}	0.87 ± 0.27^{abc}
July-22	1.73 ± 0.39^{b}	1.19 ± 0.23^{b}	1.27 ± 0.75^{ab}	0.55 ± 0.18^{abc}
Mean	**1.17**	**0.88**	**1.01**	**0.70**
Range	**0.54-2.62**	**0.31-3.65**	**0.59-1.56**	**0.24-1.36**
p value	**0.406**	**0.838**	**0.080**	**0.100**

from 0.0088 to 0.8311 mg/L, while Agara Lake exhibited levels between 0.0020 and 0.8394 mg/L (Table 3). Elevated Cu concentrations were observed during the post-monsoon periods in both lakes, followed by the monsoon and pre-monsoon phases, suggesting a shared pollution source impacting both bodies of water. A strong correlation was identified between Cu and Zn in water, with an r-value of 0.9099 in Ulsoor Lake and 0.9468 in Agara Lake (Table 5). Although ANOVA analysis indicated no significant variation ($p>0.05$), the recorded values exceeded the upper limits set by USEPA (2006) and BIS (2009) (Table 4).

In sediments, copper concentrations ranged from 0.1804 to 2.1521 mg/kg in Ulsoor Lake and 0.5263 to 2.8415 mg/kg in Agara Lake (Table 4). The yearly fluctuation of copper in water was not deemed significant ($p>0.05$). For Ulsoor Lake, sediment exhibited the highest Cu concentration during the post-monsoon phase, followed by the monsoon and pre-monsoon seasons. Conversely, Agara Lake's sediment displayed its peak Cu concentration during the monsoon, followed by post-monsoon and pre-monsoon periods. However, both sediment values exceeded the permissible limit (0.2 mg/kg) set by FAO (1985) (Table 4). Recorded Cu levels in water in this study were slightly higher compared to Avalahalli Lake (Goswami *et al.* 2020), Lalbagh Lake (Kumar *et al.* 2016), and Hebbala Lake (Wilson *et al.* 2016) in Bengaluru but significantly lower than those found in Agara Lake of Bengaluru (Kumar *et al.* 2016), Kolleru Lake (Das Sharma 2019), and Hussain Sagar Lake (Ayyanar and Thatikonda 2020). Varthur and Bellandur Lakes in Bengaluru, contaminated by urban sewage, reported higher Cu concentrations in sediment samples, indicating a more concerning environmental impact (Ramachandra *et al.* 2018, Sudarshan *et al.* 2020). Prolonged exposure to copper can adversely affect survival, growth, reproduction, as well as impact brain function, blood chemistry, enzyme activity and metabolism in organisms (Garai *et al.* 2021).

Table 5. Permissible limit for Water and Sediment by various organizations.

		Water			
WHO 2004	NA	2	NA	0.05	0.01
WHO 2008	0.003	NA	3	0.05	0.001
USEPA 2006	0.0025	0.013	0.12	0.1	0.0025
EPA 2002	0.01	1.3	NA	NA	0.05
ECR 1997	0.005	1	5	0.05	0.05
BIS 2009	0.003	0.05	5	0.05	0.05
		Sediment			
WHO 2004	6	NA	123	25	NA
WHO 2008	NA	NA	5	0.05	NA
FAO 1985	NA	0.2	2	0.1	5
USEPA 1999	0.6	NA	110	25	40

Zinc (Zn)

In this investigation, the concentration of Zn ranged

Table 6. Correlation of heavy metal in water and sediment of Ulsoor and Agara Lakes, Bengaluru.

	Ulsoor Lake water						Agara Lake water				
	Cd	Cu	Zn	Cr	Pb		Cd	Cu	Zn	Cr	Pb
Cd	1					Cd	1				
Cu	-0.306	1				Cu	-0.3363	1			
Zn	-0.2597	0.9099	1			Zn	-0.3071	0.9468	1		
Cr	-0.1114	0.0231	-0.001	1		Cr	0.4347	0.1671	0.1116	1	
Pb	-0.1929	0.7105	0.9103	-0.0364	1	Pb	-0.2554	0.7386	0.9008	0.0504	1
	Ulsoor Lake sediment						Agara Lake sediment				
	Cd	Cu	Zn	Cr	Pb		Cd	Cu	Zn	Cr	Pb
Cd	1					Cd	1				
Cu	0.1723	1				Cu	0.942	1			
Zn	0.4876	0.2743	1			Zn	0.561	0.5908	1		
Cr	0.3554	0.2439	0.4874	1		Cr	0.8262	0.7071	0.2809	1	
Pb	0.2111	-0.1488	0.2022	0.0329	1	Pb	0.1365	0.2241	-0.2865	0.0687	1

from 0.0184 to 0.8019 mg/L in Ulsoor Lake and from 0.0005 to 0.7778 mg/L in Agara Lake (Table 3). Similar to Cu, Zn exhibited a comparable pattern, with higher concentrations during the post-monsoon period, followed by the monsoon and pre-monsoon seasons. Additionally, a robust correlation was observed between Zn levels and those of Cu and Pb in the water samples of both lakes (Table 6). Zn concentrations in the water did not exceed the permissible limits set by most organizations, except for USEPA (2006) (Table 5).

Concerning sediment, Zn concentration varied between 1.0327 to 1.5971 mg/kg in Ulsoor Lake and 0.6553 to 1.6024 mg/kg in Agara Lake (Table 4). In Ulsoor Lake, Zn levels were highest during the monsoon season, followed by the pre-monsoon and post-monsoon periods. Conversely, in Agara Lake, Zn concentrations peaked during the pre-monsoon season, followed by the monsoon and post-monsoon phases. However, the measured Zn concentrations in both lakes' sediment remained significantly below the permissible limits established by various organizations (Table 5). The concentration of Zn in sediment samples from Ulsoor Lake demonstrated notable variation ($p<0.05$) throughout the study period, while sediment samples from Agara Lake and water samples from both lakes exhibited insignificant variation ($p>0.05$) (Table 4). Zinc levels in water align well with previous research by Goswami *et al.*

Table 7. Contamination factor (CF) and pollution load index (PLI) of metals in Ulsoor and Agara Lakes of Bengaluru.

	Ulsoor Lake sediment						Agara Lake sediment					
	Cd	Cu	Zn	Cr	Pb	PLI	Cd	Cu	Zn	Cr	Pb	PLI
Aug-21	0.009	0.030	0.015	0.006	0.044	1.12E-09	0.038	0.011	0.012	0.003	0.025	5.36E-10
Sep-21	0.009	0.018	0.012	0.006	0.029	3.85E-10	0.069	0.014	0.012	0.003	0.020	8.71E-10
Oct-21	0.008	0.018	0.013	0.010	0.061	1.43E-09	0.095	0.025	0.013	0.004	0.031	4.99E-09
Nov-21	0.009	0.014	0.011	0.008	0.078	9.34E-10	0.086	0.030	0.012	0.005	0.068	1.21E-08
Dec-21	0.006	0.047	0.011	0.008	0.038	1.16E-09	0.114	0.047	0.014	0.004	0.045	1.57E-08
Jan-22	0.053	0.004	0.011	0.008	0.049	1.02E-09	0.037	0.010	0.006	0.005	0.056	8.13E-10
Feb-22	0.026	0.034	0.010	0.010	0.036	3.6E-09	0.073	0.016	0.011	0.008	0.012	1.51E-09
Mar-22	0.045	0.044	0.013	0.011	0.066	2.06E-08	0.106	0.026	0.015	0.008	0.035	1.37E-08
Apr-22	0.034	0.028	0.013	0.020	0.048	1.36E-08	0.082	0.022	0.015	0.008	0.030	6.79E-09
May-22	0.031	0.031	0.014	0.029	0.041	1.77E-08	0.090	0.028	0.016	0.011	0.025	1.3E-08
Jun-22	0.406	0.033	0.014	0.017	0.053	1.88E-07	0.188	0.063	0.014	0.040	0.043	3.04E-07
Jul-22	0.235	0.032	0.016	0.019	0.063	1.6E-07	0.100	0.024	0.014	0.013	0.027	1.34E-08

(2020), Gorain *et al.* (2018), and Showqi *et al.* (2018). However, Ayyanar and Thatikonda (2020) and Pal and Maiti (2018) reported higher Zn concentrations in Hussain Sagar and Dhanbad Lakes, respectively. The sediment concentration of Zn in this study was considerably lower than other reports from various locations in India. For instance, Pandiyan *et al.* (2021) found significantly lower zinc concentration in the sediment of PCW Lake, Tamil Nadu. Although zinc is essential, elevated concentrations can lead to problems like reduced swimming activity, equilibrium loss, delayed egg-hatching, and bone malfunctions due to inefficient calcification (Wang *et al.* 2010).

Chromium (Cr)

In the current study, the concentration of chromium (Cr) in water exhibited a mean range of 0.0188 to 0.2543 mg/L in Ulsoor Lake and 0.0033 to 0.2199 mg/L in Agara Lake. Notably, these values exceeded the permissible limit established by USEPA (2006) (Table 3). Conversely, in sediment samples, Cr concentrations were recorded between 0.5431 to 2.6292 mg/kg in Ulsoor Lake and 0.3194 to 3.6535 mg/kg in Agara Lake (Table 4). The Cr levels within sediment samples from both lakes surpassed the allowable limits defined by FAO (1985) and WHO in (2008) (Table 4). The concentration of chromium (Cr) both water and sediment samples of Ulsoor Lake demonstrated an increase during the pre-monsoon season, followed by the monsoon and post-monsoon periods. Similarly, in Agara Lake, the highest Cr concentration was recorded during the monsoon season, followed by the pre-monsoon and post-monsoon phases. Comparatively, the concentration of Cr in this study was lower compared to levels found in Kashmir Lake (Showqi *et al.* 2018), yet higher in Avalahalli Lake, Bangalore (Goswami *et al.* 2020). A similar Cr level was observed in the Point Calimere Wildlife Sanctuary (PCWL) in Tamil Nadu (Pandiyan *et al.* 2021). In terms of sediment, elevated Cr concentrations were reported in Varthur and Bellandur Lakes in Bengaluru (Ramachandra *et al.* 2018, Sudarshan *et al.* 2020). Chromium accumulation in fish organs leads to a decrease in biochemical contents and can alter blood coagulation. Chronic exposure to chromium can result in decreased glycogen content in the liver, accumulation in the kidney, and potential kidney problems (Garai 2021, Islam *et al.* 2020).

Lead (Pb)

The concentrations of lead (Pb) in water displayed a range of 0.0030 to 3.9827 mg/L in Ulsoor Lake and 0.0086 to 4.0910 mg/L in Agara Lake (Table 3). Notably, Pb concentrations were undetectable in Ulsoor Lake during the pre-monsoon season, followed by increases in the post-monsoon and subsequent monsoon periods. Similarly, Agara Lake exhibited its highest Pb concentration during the post-monsoon season, followed by the monsoon and pre-monsoon seasons. It's noteworthy that the Pb levels in water exceeded the permissible limits recommended by WHO (2004) and (2008), USEPA (2008), EPA (2002), ECR (1997), and BIS (2009) (Table 5). Regarding sediment, Pb concentrations ranged from 0.5907 to 1.5612 mg/kg in Ulsoor Lake and 0.2422 to 1.3638 mg/kg in Agara Lake (Table 4). Sediment samples from both lakes indicated that Pb exhibited its highest concentration during the post-monsoon season, likely due to the settling of pollutants introduced into the lakes during the monsoon period. In contrast to water, sediment samples demonstrated lower Pb concentrations, well below the acceptable limits established by FAO (1985) and USEPA (1999) (Table 5).

Comparatively, Avalahalli Lake, Kashmir Lake, and Ox-Box Lake registered lower amounts of Pb compared to the present study (Goswami *et al.* 2020, Showqi *et al.* 2018, Das and Choudhury 2016). Conversely, Varthur and Bellandur Lakes in Bengaluru reported elevated Pb levels compared to this research (Sudarshan *et al.* 2020, Ramachandra *et al.* 2018). Prolonged exposure to Pb in fish can result in histological damage, decreased hemoglobin and red blood cell counts, neuronal malfunctions, morphological changes, and alterations in the reproductive system (Müller *et al.* 2020).

Correlation coefficient analysis of heavy metals in Ulsoor and Agara Lakes

Pearson correlation analysis is employed to investigate the connections between metals, aiding in identifying potential sources and migration patterns of toxic heavy elements (Huang *et al.* 2020). The exploration of relationships among selected heavy metals in the water and sediment samples of Ulsoor

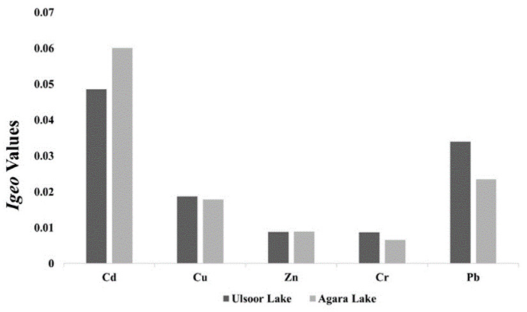

Fig. 2. Igeo value of the metals in Ulsoor and Agara Lakes of Bengaluru.

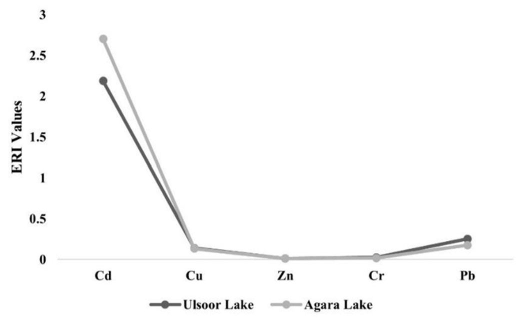

Fig. 3. ERI values of heavy metals in Ulsoor and Agara Lakes of Bengaluru.

and Agara Lakes is detailed in Table 6. The results revealed several positive correlations among the metals in the water, indicating potential common sources of pollutants for heavy metals with high r-values. Notably, strong correlations were observed between Zn and Cu, as well as Zn and Pb in the water samples of both lakes. Additionally, in Ulsoor Lake, a positive relationship between Pb and Cu was observed, and in Agara Lake, a similar correlation between Pb and Cu was evident (Table 6). However, in the sediment of Ulsoor Lake, none of the heavy metals exhibited a significant correlation with each other. In contrast, in Agara Lake sediment, a relatively robust correlation was found between Cu and Cd, and positive correlations were noted between Cr and Cd, as well as Cr and Cu (Table 6).

Evaluation of metal toxicity and contamination in sediment

The Contamination Factor (CF) assesses the concentration of a specific pollutant in comparison to a reference or background value, providing insights into the contamination extent. The computed CF values, detailed in Table 7, are all below one. The Pollution Load Index (PLI) is commonly used to evaluate overall pollution levels in a specific area or environmental sample, like sediment. PLI values in this study, all below one, categorize pollution levels as minimal to none, indicating a safe environment (Table 7) (Tomlinson *et al.* 1980). The Geoaccumulation Index (Igeo) qualitatively measures contamination levels, with scores ranging from 0 (no contamination) to 6 or higher (significant contamination). Figure 2 illustrates the assessed Igeo values of the sediment based on background values, falling within the range of 0 to 1, indicating unpolluted to moderately polluted sediment (Fig. 2). Conversely, Ecological Risk Index (ERI) values were low and within safe limits ($RI \leq 110$) (Fig. 3). Therefore, the collective results from *Igeo*, CF, ERI and PLI suggest that heavy metal pollution in Ulsoor and Agara Lakes of Bengaluru is at a safe and mildly polluted level.

CONCLUSION

The study observed elevated heavy metal concentrations in water and sediment samples from Ulsoor and Agara Lakes in Bengaluru, surpassing permissible limits and indicating increased contamination. The accumulation results from a mix of human activities and natural processes. However, computed values for contamination indices (CF, PLI, ERI and Igeo) collectively suggested a non-severe contamination level. Igeo values indicated a range from unpolluted to moderately polluted. Elevated pollution impacts aquatic life and leads to heavy metal buildup in fish, posing risks to human health. Monitoring metal contamination in water and sediment is crucial for evaluating overall environmental health and understanding potential impacts on ecosystems and human well-being. Implementing regulatory measures and effective management strategies is essential to mitigate heavy metal pollution and preserve the quality of freshwater habitats.

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