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Ecotoxicological Assessment of Heavy Metals in Lower Lake of Bhopal, Madhya Pradesh, India

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Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by authors AJ, SB, RC and SP. The first draft of the manuscript was written by AJ and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript."

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ABSTRACT

The evaluation of contamination by heavy metals in the Lower Lake of Bhopal, Madhya Pradesh India, is the primary topic of the current investigation. A two-year assessment of the lake's water quality was conducted for this study. The area under study receives domestic raw sewage from

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surrounding populations; and also the activities such as cattle washing, cloth washing, bathing, and religious activities (like idol immersion etc.) paves the way for high concentration of harmful chemicals in the lake water. The investigation was focused on heavy elements including Lead (Pb), Mercury (Hg), Cadmium (Cd), and were determined by using AAS according to the Standard Methods (APHA, 2010). The water quality of the Lower Lake Bhopal reveals that although the situation is not too bad, however in future if the inflow of untreated domestic sewage and dumping of solid wastes continues, the quality of the lake's water may further deteriorate to an alarming level. The conclusions of this study emphasize that appropriate conservation and management plans and strategies should be formulated and implemented, at the governmental and public levels, for the restoration, conservation, and management of this body of water.

Keywords: Contamination; Heavy metals; Atomic absorption spectroscopy; Lower Lake of Bhopal.

1. INTRODUCTION

Our ecosystem has been degrading rapidly and continuously, which is causing pollution in both its biotic and abiotic constituents. Water contamination is indeed a pressing concern in today's world. India's water contamination is at an alarming level, as it is in other emerging nations. In India, lakes and rivers are already dead and dying, and there is no strategy for their rehabilitation or resuscitation. Although the administration hasn't been sat idle, all of its resources seem to be wasted in technical solutions that fail.

Heavy metal contamination in the ecosystem and agriculture has recently sparked widespread worries throughout worldwide [1]. These metals came from manmade and natural processes. When heavy metals are collected in many places in substantial quantities, environmental elements become harmful to people, animals, and plants. Some elements, such as Lead (Pb), Mercury (Hg), Copper (Cu), Cadmium (Cd), Arsenic (As), and Chromium (Cr), are extremely poisonous and interfere with living things metabolic processes [2]. Aquatic ecosystems are badly impacted by toxic metals, which are contaminants that are permanent and never degrade. By moving across water, sediments, and aquatic species, it could not only poison aquatic creatures but also pose a risk to people due to bioavailability along the food supply [3-5].

According to research, deposition is a vital part of the water habitats [6,7] and is crucial to the movement of toxic substances, which endangers aquatic life and waterways [8]. As a result, it is important to evaluate the particulate integrity in the water habitats. Many human impacts that emit various types of pollutants may be the source of heavy metals in groundwater [9]. The World Health Organization's recommended threshold for Hg, Pb, As, and Se levels that were exceeded in groundwater resources in south-west Punjab, raising concerns about the possible health consequences of heavy metal poisoning [10]. Both natural as well as man-made processes have the potential to contaminate freshwater supplies. Maharashtra and two other states are responsible for 80% of the toxic chemicals produced in India, especially heavy metal contamination, in accordance with the Central Pollution Control Board [11].

In addition to having several waterways nearby, Bhopal is located in the center of India. However, the majority of water sources are severely polluted as a result of their sluggish environment and the various anthropogenic factors that surround them. Utter garbage disposal in Bhopal, which has a population of about 18 lakhs, is 417.94 MLD each day, while overall wastewater is 334.5 MLD each day. Around the city, sewerage from about 27 nallahs is discharged into water bodies, causing the water purity to deteriorate. Since a long time ago, efforts have been made to maintain the Lake.

The state administration established several programmes for the conservation and maintenance of water bodies in and outside of the city, such as the "Samovars Hamari Dharohar" programme (a general populace acknowledgement plan for manual weed expulsion) as well as the Bhoj wetland project (a project sponsored by the Japanese Bank for International Cooperation, JBIC, Japan, to restrict the flow of waste directly into Lakes). Although the situation is not too bad, but it is alarming, because Bhopal and the surrounding areas are experiencing water shortages and a reduction in watercourses, so this situation requires careful consideration. Pollution has caused a decline in the amount and purity of usable lake water, which eventually leads to water shortage [12]. In order to improve the living conditions of surrounding reservoirs and rescue them from the worst effects of nutrient enrichment, it is necessary to continuously evaluate the water quality and contamination levels. To develop plans for the administration and safeguarding of diverse water resources, several researchers conducted similar types of studies on numerous reservoirs in and around Bhopal.

The current study is concerned with evaluating and comparing water quality. Considering their various locations and varied functions, Lower Lake waterways were chosen. The Lake is mostly used for leisure and ancillary uses. Due to Industrial processes, population growth, residential sewage disposal, road dust, agricultural runoff, and the combustion of fossil fuels all contribute hazardous heavy metals to waterways. The toxic metal residues such as Lead (Pb), Mercury (Hg) and Cadmium (Cd), have been found to be harmful to aquatic and human health as well.

2. MATERIALS AND METHODS

2.1 Description of the Sampling Site

The Lower Lake, also known as Chhota Talaab, is a Lake situated in Bhopal, the capital of the Indian province of Madhya Pradesh (coordinates: 23016'0"N 77025'0"E). The Lake has a 1.29 km2 (0.50 sq mi) contact area, a maximal depth of 10.7 meters, and normal depths of about 6.2 meters (20ft.) (35 ft.). In addition, the Lake's coverage area is 9.6 km2 (3.7 sq mi). It makes up the wetlands of Bhoj along with Bhojtal, or Lake Superior. The Upper Lake basement supplies the Lake with penetration water. A tiny offshoot of the Betwa River, the Halali River, is formed after it passes through the Patra River. The Chhota Talaab is plagued by contamination brought on by emptying nalllahs laden with sewage, a shortage of freshwater sources, and industrial laundry. The whole Lake is nutrient-rich, so the water is unfit for human consumption. The landscape of the sampling site is described in Fig. 1. Among all of this, tourists can find a great place to sit and enjoy the beauty of the city's surroundings at the Lake.

The Lower Lake Bhopal(or Chhota Talaab) as research site has been selected on the basis of the matrices, including the size of the aquatic ecosystem, fish fauna, productivity, anthropogenic activities; pollution load etc. The sample sites have been selected at various locations along the Lower Lake Bhopal. The current study was conducted in January, 2020 to December, 2021 to assess the water quality of Lower Lake from four different stations namely Ginnori, Bhoipura, Khatlapura and Center. Water samples have been gathered from surface and bottom waters in different months as well as seasons (quarterly) viz. January to March, April to June, July to September, October to December. For toxicological studies water samples were collected during different seasons (quarterly) viz. January to March, April to June, July to September, October to December. The descriptions of the sampling stations are described in Table 1.

Fig. 1. Lower Lake Bhopal
(Source: Google earth)

2.2 Detailed Description of the Stations are Given Below

2.2.1 Ginnori (L-1)

This station is close to Kamla Park at the Lake's northernmost end (Killole Park). The area of the Lake is among the most contaminated regions, has consistently shown exceptionally high levels of PO_4, NO_3, Ca, Mg, and other minerals. The water has an extremely high concentration of inorganic components since this area is a hub for washermen's work. As a result, *Microcystis aeruginosa* outbreaks at high densities and were consistently seen over the seasons in all water columns. The epilimnion region is also confined to a few millimeters, which restricts the development of subsurface macrophytes and speeds up breakdown processes. Elevated BOD and COD levels were also detected in the vicinity, which is consistent with washermen's activity.

2.2.2 Bhoipura (L-2)

This station lies close to Bhoipura. The wastewater that enters this site through the nearby inlets, which carries household pollutants from the numerous residential areas, has an effect on the water. This location is a highly impacted site for idol immersion practices as well as being vulnerable to human activities (swimming, bathing etc.).

2.2.3 Khatlapura (L-3)

This station is among the main locations for idol immersion events and is close to Khatlapura Mandir. In addition to all this, local devotees who visit the temples for devotion also toss the puja items (flowers, incense sticks, coconuts, etc.) into the lake. These are extremely degradable materials that are to blame for the water's rising biological oxygen requirement.

2.2.4 Center (L-4)

The sample station is located between MLB Hostel and MLB Campus. Sampling site L-4, which is located in the Lower Lake's bottom zones, is among the lake's highest contaminated regions. The purity of the water in this location, though, began to improve.

2.2.5 Sampling techniques

Following the recommended procedures, sterile glassware and jerry cans were used to gather water samples at every station [13]. To prevent any unforeseen variations in the physico-chemical properties, the bottles have been promptly sealed once the samples were collected and taken to the lab. Appropriate preserving procedures were used in accordance with the accepted practices. Temperature, visibility, conductance, dissolved oxygen, free carbon dioxide, and TDS were among the characteristics that were measured in the environment; the remaining parameters were measured in the lab using the techniques outlined in [14, 15, and 16]. Atomic absorption spectrophotometers are used to identify particular toxic metals such as Pb, Hg and Cd, etc. (Parkin Elmer Analyst 100).

2.3 Sources of Heavy Metals

Heavy metals are prevalent in the atmosphere from both natural and human-made processes. Oceans occasionally include natural origins like earthquakes or the degradation of rocks. Commercial discharges, fuel burning, the smelting processes, excavation, brick kilns, and the use of fertilizers, and insecticides in farming are all examples of anthropogenic activities [17]. Industries significantly contribute to environmental pollution and the disruption of our biogeochemical equilibrium. Industries that produce toxic metals in large amounts [18]. Toxic metals are released into the atmosphere in both organic and inorganic forms. They are produced by humans in large businesses including extraction, textile production, and smelting [19]. Cadmium is discharged into the ecosystem as a residue of the zinc purification process, along with lead from the production of paints and lead emitted into the environment through automotive emissions. The main source of heavy metal contamination is due to idol immersion in water quality of twin Lakes of Bhopal [20].

2.4 Determination of Heavy Metals

Toxic metals in water samples were extracted with conc. HCl and then preserved in a refrigerator till analysis for determination of Pb, Hg, and Cd (Parker, 1972). By using a UV-visible spectrophotometer (HACH DREL 4000), toxic metals have been examined in accordance with the Hach Manual's instructions (2010).

3. RESULTS AND DISCUSSION

3.1 Lead

3.1.1 Surface water

Variation in **Lead** in surface water during various months of 2020-2021 at different stations of Lower Lake is depicted in Table 2 and Fig. 2.

During the period of investigation, **Lead** at surface was detected between the levels of nil to 0.301µg/liter. The lowest value of Lead was recorded at many stations and the highest values of Lead were recorded at the station-4. During this period highest value of **Lead** were observed throughout the month of August, 2021, followed by October. Higher values of lead were recorded at L-1 and L-3 compared to other stations.

3.1.2 Bottom water

Variation in **Lead** in surface water during various months of 2020-2021 at different stations of Lower Lake is depicted in Table 3 and Fig. 3.

During the period of investigation, **Lead** at Bottom was observed within the range of nil to 0.241µg/liter. The lowest value of **Lead** was detected at station- 3 and the maximum value of **Lead** was recorded at the station-2. During this period maximum value of **Lead** was observed in the month of May 2021, followed by March, 2020. Higher values of lead were recorded at L-2 and L-1 compared to other stations.

3.2 Mercury

3.2.1 Surface water

Variation in **Mercury** in surface water during various months of 2020-2021 at various stations of Lower Lake was illustrated in Table 4 and Fig. 4.

During the period of investigation, **Mercury** at surface was found between the ranges of nil to 0.021µg/liter. The lowest value of **Mercury** was recorded at station- 4 and the highest value of **Mercury** was detected at the station-1. During this period highest value of **Mercury** was found in the month of September 2021. Larger values of mercury were recorded mostly at L-1 compared to other stations.

3.2.2 Bottom water

Variation in **Mercury** in surface water during various months of 2020-2021 at different stations of Lower Lake is depicted in Table 5 and Fig. 5.

During the period of investigation, **Mercury** at bottom was found within the range of 0.001 to 0.015µg/liter. The lowest value of **Mercury** was detected at many stations and the largest value of **Mercury** was detected at the station-2. During this period highest value of **Mercury** was found in the month of April & December 2021. Higher values of Mercury were recorded at L-1 compared to other stations.

3.3 Cadmium

3.3.1 Surface water

Variation in **Cadmium** in surface water during various months of 2020-2021 at different stations of Lower Lake is depicted in Table 6 and Fig. 6.

During the period of investigation, **Cadmium** at surface was noticed between the limit of nil to 0.016µg/liter. The lowest value of **Cadmium** was detected at many stations and the greatest value of **Cadmium** was detected at the station-3. During this period highest value of **Cadmium** was observed in the month of August 2021. Higher values of **Cadmium** were recorded at L-3 compared to other stations.

3.3.2 Bottom water

Variation in **Cadmium** in bottom water during various months of 2020-2021 at different stations of Lower Lake is depicted in Table 7 and Fig. 7.

During the period of investigation, **Cadmium** at bottom was observed within the range of 0.002 to 0.421µg/liter. The minimum value of **Cadmium** was detected at station- 2 and the maximum value of **Cadmium** was also noticed at the station-2. During this period highest value of **Cadmium** was observed in the month of June 2021. Higher values of **cadmium** were recorded at L-1 compared to other stations.

The data analyzed for various parameters during the period of investigation reveals considerable variations in physicochemical parameters and also in selective heavy metals from months to months. During the course of this investigation, it was found that the Lake water's ionic strength was at its peak during the rainy and post-monsoon phases.

During metal adsorption, Station 2 took the top spot, followed by Station 3. This had been ascribed to wastewater spills from nearby settlements whereby a well-developed and functional Wastewater Treatment Process has not yet been completely created. Pb, Hg, and Cd

Table 1. Sampling stations along with global positioning system

Sampling station	Latitude	Longitude	MASL
Ginnori (L-1)	23°01'09.81''N	77°23'37''E	437m
Bhoipura (L-2)	23º 07' 09.99" N	77º 35' 40.23" E	411 m
Khatlapura (L-3)	23º 11' 55.82" N	77º 39' 01.63" E	405 m
Center (L-4)	23º 17' 01.74" N	77º 41' 31.56" E	399 m

Table 2. Heavy metals in surface water of Lower Lake: Lead (µg/liter)

	2020												2021											
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Ginnori (L-1)	0.01	0.101	0	0.025	0	0.001	0.01	0.002	0	0	0.005	0	0.004	0.201	0.021	0	0.003	0.025	0.01	0	0.1	0.254	0.06	0.04
Bhoipura (L-2)	0.03	0.03	0.22	0.026	0.12	0.002	0.201	0.01	0.002	0.202	0.011	0.015	0.054	0.065	0.202	0.046	0.14	0.009	0.21	0.019	0.007	0.201	0.026	0.03
Khatlapura (L-3)	0	0	0.023	0.009	0.015	0.11	0.001	0	0.001	0	0.03	0.012	0	0.045	0.021	0.012	0.025	0.021	0.009	0.301	0	0	0.05	0.022
Center (L-4)	0	0.023	0.01	0	0.05	0	0.001	0.012	0.003	0.1	0	0.006	0.054	0.065	0.102	0.046	0.14	0.009	0.021	0.019	0.007	0.011	0.026	0.03
Min	0	0	0	0	0	0	0.001	0	0	0	0	0	0	0.045	0.021	0	0.003	0.009	0.009	0	0	0	0.026	0.022
Max	0.03	0.101	0.22	0.026	0.12	0.11	0.201	0.012	0.003	0.202	0.03	0.015	0.054	0.201	0.202	0.046	0.14	0.025	0.21	0.301	0.1	0.254	0.06	0.04
Mean	0.01167	0.0425	0.078833	0.01433	0.05083	0.03717	0.06917	0.006	0.0015	0.084	0.012667	0.008	0.02767	0.10367	0.09483	0.025	0.07517	0.01633	0.07817	0.10667	0.03567	0.12	0.04133	0.03067

Table 3. Heavy metals in bottom water of Lower Lake: Lead (µg/liter)

	2020												2021											
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Ginnori (L-1)	0.012	0.104	0.018	0.029	0.026	0.001	0.001	0.012	0.001	0.001	0.006	0.003	0.006	0.101	0.0214	0.011	0.0103	0.015	0.001	0.001	0.11	0.144	0.016	0.014
Bhoipura (L-2)	0.031	0.031	0.221	0.027	0.123	0.004	0.001	0.013	0.012	0.102	0.014	0.012	0.051	0.045	0.212	0.056	0.241	0.019	0.11	0.014	0.004	0.101	0.016	0.031
Khatlapura (L-3)	0.001	0.001	0.002	0.002	0.003	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.003	0.001	0.004	0..3	0.004	0.004	0.007	0.001	0.001	0.00.	0.004
Center (L-4)	0.003	0.004	0.001	0.001	0.004	0.001	0.001	0.202	0.003	0.1	0.001	0.002	0.002	0.004	0.002	0.003	0.001	0.001	0.001	0.002	0.003	0.001	0.002	0.001
Min	0.001	0.001	0.001	0.001	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.001	0.003	0.001	0.001	0.001	0.001	0	0.001	0.002	0.001
Max	0.031	0.104	0.221	0.029	0.123	0.004	0.001	0.202	0.012	0.102	0.014	0.012	0.051	0.101	0.212	0.056	0.241	0.019	0.11	0.014	0.11	0.144	0.016	0.031
Mean	0.0096	0.0282	0.0486	0.012	0.0318	0.0016	0.001	0.0458	0.0036	0.041	0.0048	0.0038	0.0122	0.0312	0.0475	0.0154	0.0633	0.008	0.0234	0.005	0.02	0.0496	0.009	0.0102

Table 4. Heavy metals in surface water of Lower Lake: MERCURY (µg/liter)

	2020												2021											
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Ginnori (L-1)	0.001	0	0	0.001	0.002	0.001	0.001	0.001	0.01	0	0.001	0	0.004	0.012	0.002	0.005	0.02	0.003	0	0.001	0.021	0.012	0.003	0.005
Bhoipura (L-2)	BDL	BDL	BDL	BDL	0.001	0.002	BDL	BDL	0.02	0.001	BDL	0.001	0.012	0.003	0.002	BDL	0.012	0.02	0.002	BDL	0.01	0.002	BDL	0.01
Khatlapura (L-3)	0.001	0.004	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.004	0.006	0.005	0.001	0.002	BDL	0.001	0.002	0.003	BDL	0.004	0.002
Center (L-4)	BDL	BDL	BDL	0.001	0.001	BDL	BDL	0.001	BDL	BDL	BDL	BDL	0.012	0.003	0.002	BDL	0.012	0.02	0.002	BDL	0.01	0.002	BDL	0.01
Min	0.001	0	0	0.001	0.001	0.001	0.001	0.001	0.01	0	0.001	0	0.004	0.003	0.002	0.001	0.002	0.003	0	0.001	0.003	0.002	0.003	0.002
Max	0.001	0.004	0	0.001	0.002	0.002	0.001	0.001	0.02	0.001	0.001	0.001	0.012	0.012	0.005	0.005	0.02	0.02	0.002	0.002	0.021	0.012	0.004	0.01
Mean	0.001	0.004	0	0.001	0.002	0.002	0.001	0.001	0.02	0.001	0.001	0.001	0.012	0.012	0.005	0.005	0.02	0.02	0.002	0.002	0.021	0.012	0.004	0.01

Table 5. Heavy Metals in Bottom Water of Lower Lake: MERCURY (µg/liter)

	2020												2021											
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Ginnori (L-1)	0.001	0.001	0.002	0.012	0.003	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.004	0.011	0.012	0.015	0.012	0.013	0.011	0.011	0.001	0.012	0.013	0.015
Bhoipura (L-2)	0.011	0.001	0.001	0.011	0.001	0.002	0.011	0.001	0.002	0.011	0.011	0.011	0.012	0.013	0.012	0.012	0.012	0.012	0.012	0.011	0.011	0.012	0.013	0.012
Khatlapura (L-3)	0.001	0.003	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.002	0.001	0.011	0.002	0.001	0.001	0.002	0.001	0.001	0.002	0.002
Center (L-4)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.012	0.003	0.002	0.002	0.002	0.002	0.002	0.001	0.01	0.002	0.001	0.01
Min	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.002	0.001	0.002	0.002	0.001	0.001	0.001	0	0.001	0.001	0.002
Max	0.011	0.003	0.002	0.012	0.003	0.002	0.011	0.002	0.002	0.011	0.011	0.011	0.012	0.013	0.012	0.015	0.012	0.013	0.012	0.011	0.01	0.012	0.013	0.015
Mean	0.003	0.0014	0.0012	0.0052	0.0014	0.0012	0.003	0.0012	0.0016	0.003	0.003	0.003	0.0068	0.0062	0.0056	0.0084	0.006	0.0058	0.0054	0.0052	0	0.0056	0.006	0.0082

Table 6. Heavy metals in surface water of Lower Lake: CADMIUM (µg/liter)

	2020												2021											
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Ginnori (L-1)	0.001	0.003	0.002	0	0.002	0	0.002	0.004	0.003	0.003	0	0	0.012	0.001	0.005	0.012	0.011	0.012	0.003	0.005	0.0124	0.004	0.005	0.002
Bhoipura (L-2)	0.004	0.005	BDL	BDL	0.003	0.002	0.001	0.003	0.001	0.001	BDL	BDL	0.002	0.003	0.002	0.012	0.005	0.001	0.003	0.005	0.001	0.004	BDL	0.012
Khatlapura (L-3)	0.003	0.004	BDL	BDL	BDL	0.002	BDL	BDL	BDL	BDL	0.001	0.003	0.002	0.001	BDL	0.005	0.002	0.004	0.011	0.016	BDL	0.015	0.004	0.001
Center (L-4)	0.005	0.002	0.005	0.001	BDL	0.003	0.002	BDL	BDL	0.003	0.004	0.001	0.002	0.003	0.002	0.012	0.005	0.001	0.003	0.005	0.001	0.004	BDL	0.012
Min	0.001	0.002	0.002	0	0.002	0	0.001	0.003	0.001	0.001	0	0	0.002	0.001	0.002	0.005	0.002	0.001	0.003	0.005	0.001	0.004	0.004	0.001
Max	0.005	0.005	0.005	0.001	0.003	0.003	0.002	0.004	0.003	0.003	0.004	0.003	0.012	0.003	0.005	0.012	0.011	0.012	0.011	0.016	0.0124	0.015	0.005	0.012
Mean	0.0033	0.0035	0.0035	0.0005	0.0025	0.0018	0.0017	0.0035	0.002	0.0023	0.00167	0.0013	0.0045	0.002	0.003	0.0103	0.0058	0.0045	0.005	0.0078	0.0048	0.0068	0.0045	0.0068

Table 7. Heavy metals in bottom water of Lower Lake: CADMIUM (µg/liter)

	2020												2021											
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Ginnori (L-1)	0.107	0.105	0.104	0.174	0.122	0.174	0.162	0.194	0.153	0.123	0.174	0.139	0.126	0.211	0.275	0.124	0.314	0.421	0.133	0.165	0.224	0.134	0.155	0.122
Bhoipura (L-2)	0.103	0.106	0.102	0.102	0.101	0.002	0.108	0.201	0.32	0.142	0.102	0.204	0.214	0.204	0.101	0.203	0.321	0.235	0.304	0.408	0.141	0.102	0.121	0.103
Khat-lapura (L-3)	0.104	0.105	0.231	0.217	0.123	0.122	0.141	0.123	0.211	0.301	0.217	0.127	0.102	0.103	0.102	0.112	0.105	0.201	0.103	0.105	0.101	0.104	0.175	0.112
Center (L-4)	0.203	0.204	0.217	0.234	0.217	0.302	0.218	0.264	0.267	0.213	0.2001	0.203	0.202	0.201	0.234	0.305	0.302	0.104	0.1021	0.056	0.178	0.125	0.204	0.101
Min	0.103	0.105	0.102	0.102	0.101	0.002	0.108	0.123	0.153	0.123	0.102	0.127	0.102	0.103	0.101	0.112	0.105	0.104	0.1021	0.056	0.1	0.102	0.121	0.101
Max	0.203	0.204	0.231	0.234	0.217	0.302	0.218	0.264	0.32	0.301	0.217	0.204	0.214	0.211	0.275	0.305	0.321	0.421	0.304	0.408	0.22	0.134	0.204	0.122
Mean	0.1372	0.1382	0.1645	0.1772	0.1468	0.1507	0.1592	0.1948	0.2373	0.2005	0.16868	0.1673	0.16	0.1722	0.1813	0.1935	0.2447	0.2477	0.1747	0.1997	0.16	0.1168	0.1633	0.1102

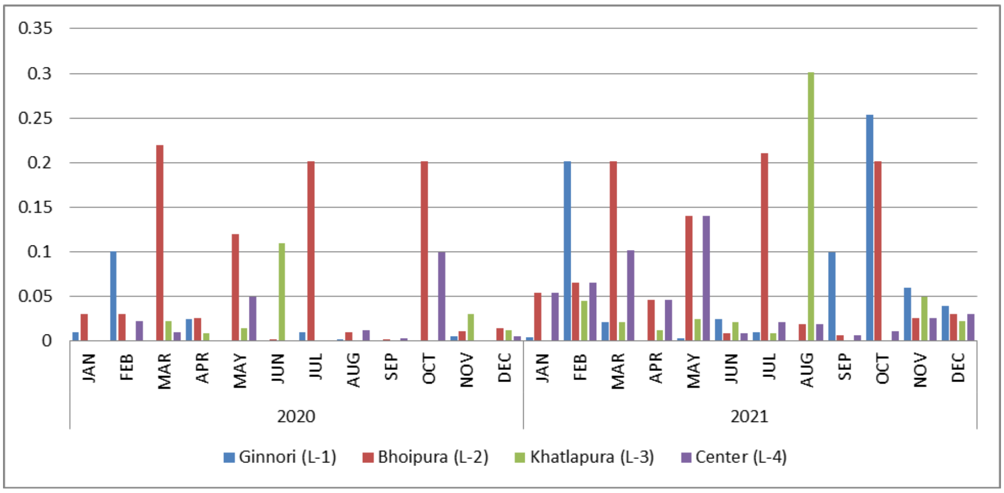

Fig. 2. Heavy metals in surface water of Lower lake: Lead (µg/liter) during 2020-2021

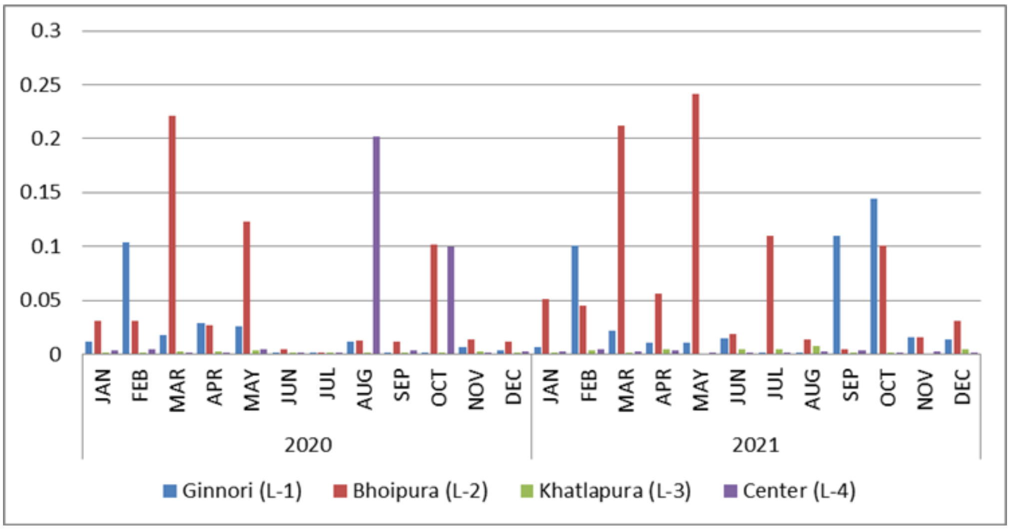

Fig. 3. Heavy Metals in Bottom Water of Lower Lake: Lead (µg/liter) during 2020-2021

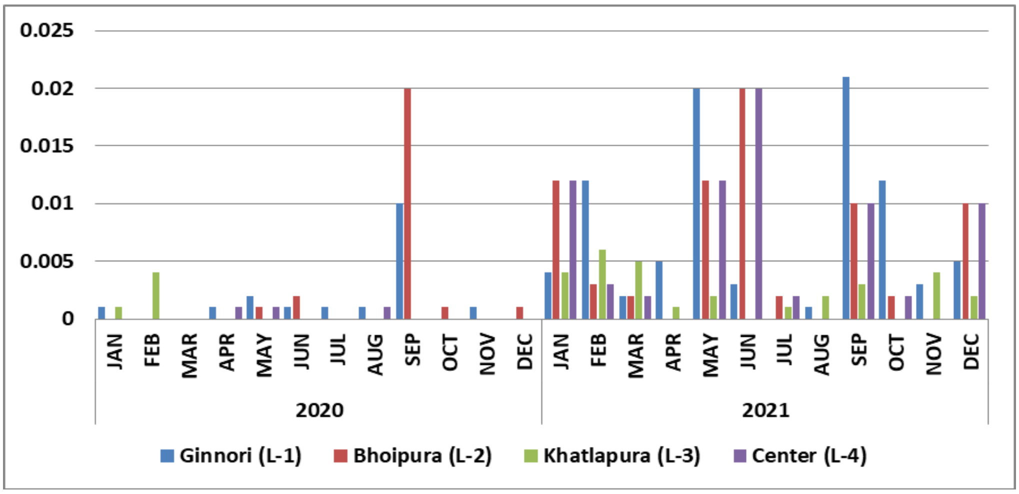

Fig. 4. Heavy Metals in Surface Water of Lower Lake: MURCURY (µg/liter) during 2020-2021

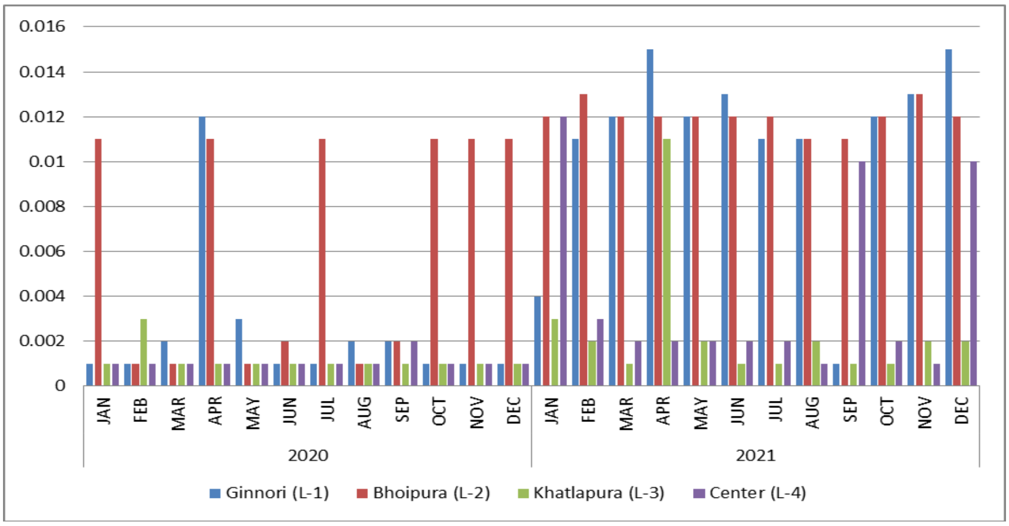

Fig. 5. Heavy metals in bottom water of Lower Lake: MERCURY (µg/liter) during 2020-2021

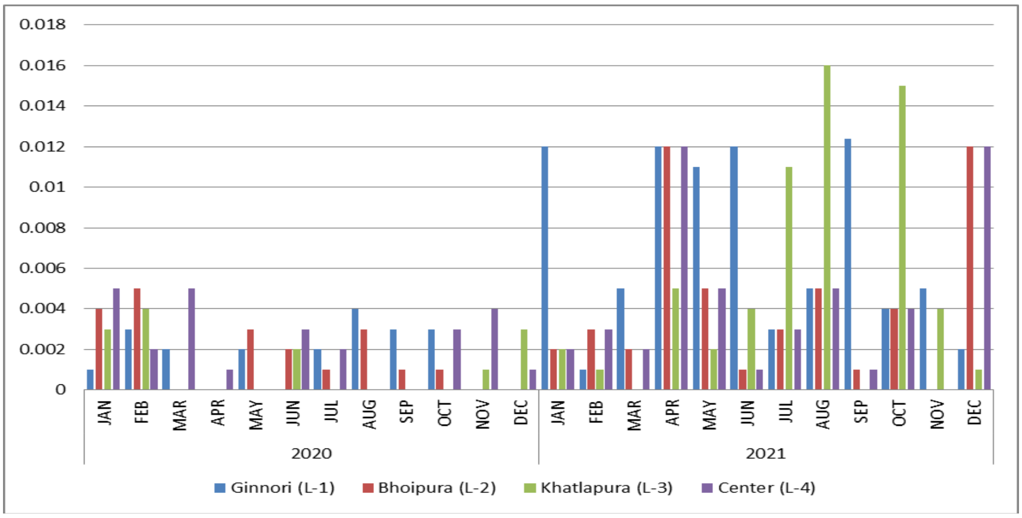

Fig. 6. Heavy Metals in Surface Water of Lower Lake: CADMIUM (µg/liter) during 2020-2021

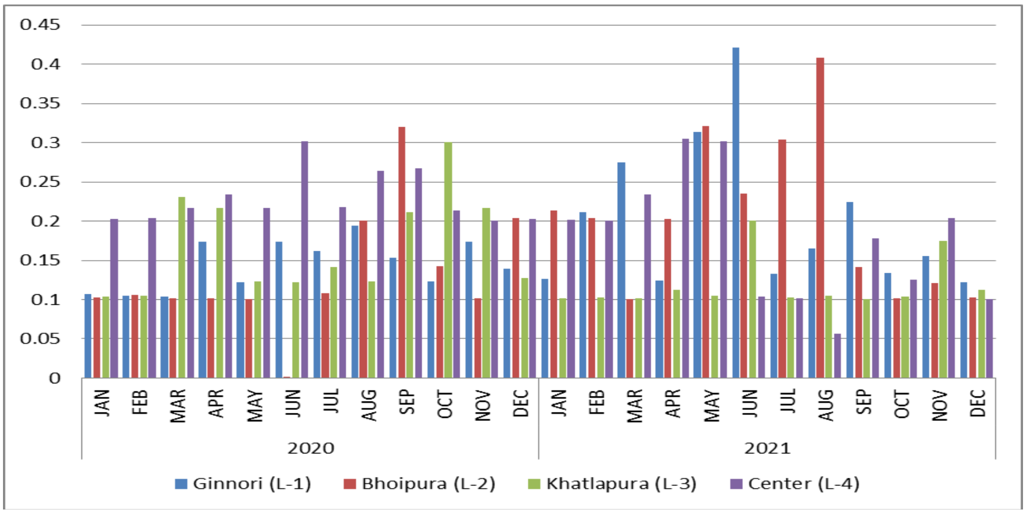

Fig. 7. Heavy Metals in Bottom Water of Lower Lake: CADMIUM (µg/liter) during 2020-2021

had been assessed for their greatest mean levels at stations 1, 2, and 3, accordingly. Station 1 detected the highest mean value for Hg, while station 2 found highest mean values for Cd. It has been linked to the massive volumes of untreated garbage and industrial effluents (automotive service centers, etc.) that have been dumped in the Lake through the nearby catchment regions. Domestic wastewater runoff, idols immersion and anthropogenic activities are responsible for the higher amounts of Mercury, Cadmium and Lead inside the Lake's water.

4. CONCLUSIONS

In general, most of the parameters during the period of investigation were found to be well below the Central Pollution Control Board's Class C permitted limits, while groundwater was being used for consumption and agriculture, which is the recommended optimal usage of water following standard treatments.

Although presently there is no alarming level of Heavy metal pollution in this water-body, and fish which are being consumed are safe as per the present analysis however, in future if the inflow of untreated domestic sewage and dumping of solid wastes continues, the quality of Lake water may further deteriorate to an alarming level.

The state of water bodies that are utilized for the main reasons must be preserved, while those utilized for secondary uses must be enhanced. For the rehabilitation, protection, and maintenance of this water body, appropriate preservation and administrative plans and tactics must be developed and implemented at the Governmental and private levels, because this Lake is backbone for the city of Bhopal.

DATA AVAILABILITY STATEMENT

The data sets generated during and/ or analyzed during the current study are available from the corresponding author on reasonable request.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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