ISSN: 0973-4929, Vol. 20, No. (**3**) 2025, Pg. 1360-1366

Current World Environment

www.cwejournal.org

Assessment and Management of Hebbal Lake, Bangalore: Water Quality, Pollution, and Restoration Strategies

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Abstract

Urban lakes are vital freshwater resources that support biodiversity, ecological balance, and human activities. Hebbal Lake, located in northern Bangalore, India, is a historically significant and ecologically important water body that faces challenges from urbanization, sewage inflow, and industrial discharge. This study assessed the water quality, microbial contamination, and heavy metal concentrations in lake sludge. Forty-nine water samples and four sludge samples were collected from different locations in the lake. Chemical parameters such as pH, nitrates, phosphates, fluoride, biochemical oxygen demand, and dissolved oxygen were analyzed along with microbiological parameters including total coliforms and *Escherichia coli*. Results indicated that most chemical parameters were within regulatory limits, while biochemical oxygen demand and coliform counts were high, reflecting eutrophication and fecal contamination. Sludge analysis revealed chromium slightly above permissible limits, whereas other heavy metals were within standard levels. An action plan is proposed involving boundary mapping, pollution source identification, eco-friendly rejuvenation techniques, and continuous monitoring. This study emphasizes the urgent need for scientific restoration and sustainable management of Hebbal Lake to maintain ecological integrity and water security.

Article History
Received: 01 December 2025
Accepted: 06 January 2026

Keywords
Heavy Metals;
Hebbal Lake;
Lake Rejuvenation;
Microbial Contamination;
Water Quality;
Urban Lakes.

Introduction

Water is a critical natural resource, essential for life, agriculture, industry, and urban development. Rapid population growth, urbanization, and industrialization have increased the pressure on freshwater resources in India.[1-4] Surface water bodies, including lakes, are particularly vulnerable to pollution, nutrient enrichment, and habitat degradation.[5-7]

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Doi: http://dx.doi.org/10.12944/CWE.20.3.31

Urban lakes play a multifunctional role: they provide freshwater, habitat for diverse flora and fauna, regulate hydrological cycles, improve microclimate, and offer recreational and aesthetic benefits.[8-10] Hebbal Lake, established in 1537 by Kempe Gowda in northern Bangalore, historically served as a major freshwater source. The lake is seasonal, filling during monsoon and often drying in summer, and supports rich biodiversity including over 70 species of water birds, 40 of which are migratory.[11]

Due to urban encroachment, untreated sewage inflow, and industrial discharge, Hebbal Lake's water quality has declined.[12-14] Previously used for drinking, the lake now serves secondary purposes such as cattle washing, pisciculture, irrigation, and recreational activities.[15-17] This study evaluates the current physicochemical, microbiological, and heavy metal status of Hebbal Lake, identifies sources of pollution, and proposes strategies for sustainable restoration.

Fig. 1: The Satellite Image of Hebbel Lake and its surrounding

Materials and Methods

Study Area

Hebbal Lake is located at 13˚ 5' N to 13˚ 1'15" N latitude and 77˚ 33'45" to 77˚ 36'15" longitude in northern Bangalore (Figure 1). The lake covers approximately 150 acres with a catchment area of 3,750 ha, including urban localities like Yeshwanthpur, Mathikere, Rajmahal Vilas Extension Bharat Electronics Limited and Hindustan Machine Tools Limited colonies. The lake's water level fluctuates seasonally, with an estimated annual inflow of 15.2 million cubic meters and a storage capacity of 2.38 million cubic meters, which can increase to 4.07 million cubic meters through desilting.

Climate of the Area

Bangalore experiences a tropical savanna climate, with southwest and northeast monsoons contributing to most rainfall. Seasonal variation in rainfall directly affects Hebbal Lake's water levels, with low water availability during dry months exacerbated by urban demand.

Vegetation and Ecology

Hebbal Lake is eutrophic due to nutrient-rich sewage inflow, supporting growth of aquatic plants like water hyacinth (*Eichhornia crassipes*) and Typha species. The surrounding wetlands and shallow zones provide habitat for aquatic birds, fish, and other fauna.

Sample Collection and Preparation

Water samples were collected from 49 locations across the lake, while four sludge samples were obtained from three sites (Figure 2). Chemical samples were collected in pre-cleaned 2 L polythene bottles, and microbiological samples in 500 mL sterilized biochemical oxygen demand bottles. Surface measurements of temperature, pH, and dissolved oxygen were recorded in situ.

The collected composite water samples were taken to the laboratory for chemical parameter analysis, including nitrates, sulphates, free ammonia, sodium adsorption ratio, phosphate, boron, lead, copper, zinc, cadmium, iron, fluoride, conductivity, and biochemical oxygen demand. Microbiological analyses included total coliforms and *Escherichia coli*, performed according to standard methods.

Water quality results were evaluated against Karnataka State Pollution Control Board standards, while sludge analyses were compared with Central Pollution Control Board guidelines.

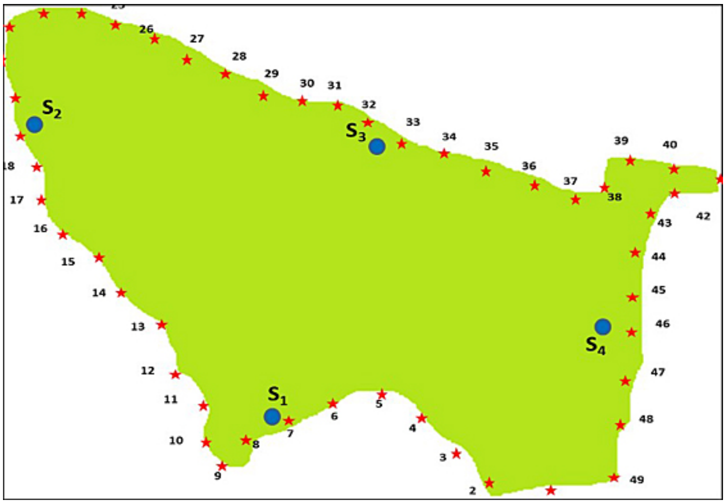

Fig. 2: Sampling sites of Lake Water and Sludge

1-49: Samples collected at different locations of the Lake: S1: Sludge sample collected at Southside, S2: Sludge sample collected at Westside, S3: Sludge sample collected at North side, S4: Sludge sample collected at East side.

Results

Physicochemical Analysis of Lake Water

Table 1 summarize the chemical and microbiological characteristics of water samples collected from various locations in Hebbal Lake. This table include results for pH, biochemical oxygen demand, nutrients (nitrates, phosphates, sulphates), heavy metals, fluoride, conductivity, dissolved oxygen, and microbial counts.

pH

The recorded pH of Hebbal Lake water ranged from 6.55 to 8.2, remaining within the Karnataka State Pollution Control Board recommended range for freshwater ecosystems (6.5–8.5). Lower pH values (6.55) were recorded near sewage inflow points, likely caused by biodegradation of organic material and release of organic acids, while higher pH values (8.2) were observed in open water zones, possibly influenced by photosynthetic activity of aquatic plants, which reduces carbon dioxide levels. Overall, the pH levels suggest that the water remains suitable for aquatic life, although localized acidification may stress sensitive species such as fish and invertebrates.

Dissolved Oxygen

Dissolved oxygen concentrations ranged between 4.1 to 6.2 mg/L. Lower dissolved oxygen levels were observed in areas with high organic load, such as residential and industrial inflows, reflecting oxygen consumption during microbial decomposition. Higher dissolved oxygen values (up to 6.2 mg/L) were recorded in open water and aerated zones, likely due to mixing and re-aeration from wind and turbulence. Areas with dissolved oxygen below 4.5 mg/L may require intervention to support aquatic life.

Conductivity

Specific conductivity ranged from 882 to 1468 µS/cm, indicating moderate to high levels of dissolved ions. Elevated conductivity near industrial and residential runoff sites reflects increased dissolved salts and trace metals. High ionic concentrations may impact osmotic balance in aquatic organisms and contribute to eutrophication, highlighting the need for runoff management and pollutant filtration strategies.

Nutrients: Nitrates and Phosphates

Phosphate concentrations ranged from 0.1 to 0.47 mg/L, with some open water sites showing non-detectable levels, while nitrate concentrations varied from 6.6 to 16 mg/L. Elevated nutrient levels near inflows indicate domestic sewage and fertilizer runoff, promoting the growth of invasive species such as water hyacinth (*Eichhornia crassipes*) and Typha spp., which reduce light penetration and oxygen levels, stressing aquatic life. Nutrient reduction strategies, including constructed wetlands and bioremediation, are recommended.

Biochemical Oxygen Demand

Biochemical oxygen demand values ranged from 1.9 to 5.2 mg/L, exceeding permissible limits in several locations. High biochemical oxygen demand correlates with low dissolved oxygen, confirming the inverse relationship between organic load and oxygen availability. Areas near sewage inflows exhibited the highest biochemical oxygen demand, highlighting the need for domestic wastewater management and removal of organic debris to maintain aquatic health.

Table 1: Chemical and Microbiological Characteristics of Hebbal Lake Water (n=49)

Parameter	Min	Max	Mean ± SD	Permissible Limits	Observations
pH	6.55	8.2	7.63 ± 0.36	6.5–8.5	Slightly acidic near inflows
Dissolved Oxygen (mg/L)	4.1	6.2	5.36 ± 0.53	≥4	Lower in high organic load zones
Conductivity (µS/cm)	882	1468	914 ± 145	≤1000	Elevated near industrial/ residential runoff
Biochemical Oxygen Demand (mg/L)	1.9	5.2	3.09 ± 0.93	3	High near sewage inflows
Nitrates (mg/L)	6.65	16.27	7.97 ± 2.11	50	Elevated near inflows; may cause eutrophication
Phosphates (mg/L)	<0.05	1.0	0.32 ± 0.26	–	High near sewage; supports invasive plants
Sulphates (mg/L)	2.3	11.23	10.68 ± 2.31	400	Within limits; slightly lower at inflows
Free Ammonia as N (mg/L)	0.02	0.29	0.17 ± 0.07	1.2	Low; localized organic pollution
S.A. Ratio	2.35	3.11	2.57 ± 0.19	26	Stable; slight increase near inflows
Fluoride (mg/L)	0.6	0.82	0.70 ± 0.06	1.0	Within limits
Boron (mg/L)	<0.1	<0.1	<0.1	2	Within permissible range
Lead (mg/L)	<0.05	<0.05	<0.05	0.1	Within limits
Copper (mg/L)	<0.05	<0.05	<0.05	1.5	Within limits
Zinc (mg/L)	<0.05	<0.05	<0.05	15	Within limits
Cadmium (mg/L)	<0.05	<0.05	<0.05	–	Within limits

Iron (mg/L)	<0.2	<0.2	<0.2	0.5	Within limits
Total Coliform (CFU/100 mL)	2,400	3,480, 000	478,542 ± 821,105	500	Highest near sewage inflows; public health concern
E. coli (CFU/100 mL)	Present	Present	–	Absent	Found in almost all locations; indicates fecal contamination

Fluoride

Fluoride concentrations ranged between 0.6 to 0.82 mg/L, within the permissible limit of 1.0 mg/L for drinking and ecological purposes. Consistent values across all sites indicate minimal industrial fluoride contamination.

Microbiological Analysis

All water samples showed high total coliform counts and presence of *Escherichia coli*, indicating significant fecal contamination from untreated sewage, stormwater runoff, and livestock activities. Such contamination poses public health risks, including typhoid, cholera, and gastrointestinal infections, and contributes indirectly to nutrient enrichment and eutrophication. Microbial loads were highest near inflows and shallow areas, emphasizing the need for sewage diversion, biofiltration, and constructed wetlands.

Heavy Metals in Lake Sludge

Sludge samples from Hebbal Lake showed the metal trend Mn > Zn > Cr > Cu > Ni > Fe (Table 2). Most metals were within Central Pollution Control Board permissible limits, except for chromium, which slightly exceeded permissible levels at one location, likely due to industrial effluent. While manganese and zinc contribute to natural nutrient cycling, chromium accumulation necessitates monitoring and selective sediment removal. Heavy metals in sediments pose long-term ecological risks due to potential resuspension and bioaccumulation in the food chain.

Table 2: Chemical results of Sludge samples collected at various locations of Hebbal Lake

Location	Sludge-1	Sludge-2	Sludge-3	Sludge-4	Limits (CPCB)
Parameters	Results	Results	Results	Results	-
pH Value	7.64	8.18	7.78	7.34	-
Conductivity, µs/cm	1813	1595	1798	1854	-
Copper as Cu, mg/L	28.2	34.6	28.1	35.2	5000
Iron as Fe, %	1.93	1.67	1.54	1.74	50000
Cadmium as Cd, mg/L	1.28	1.51	1.35	1.78	50
Lead as Pb, mg/L	37.7	35.4	36.5	34.8	5000
Zinc as Zn, mg/L	54.8	61.6	55.1	62.8	20000
Vanadium as V, mg/L	<0.01	<0.01	<0.01	<0.01	5000
Chromium as Cr, mg/L	51.6	57.2	50.4	64.5	50
Manganese as Mn, mg/L	345	361	328	345	5000
Nickel as Ni, mg/L	29.1	26.5	22.6	31.1	5000
Mercury as Hg, mg/L	<0.01	<0.01	<0.01	<0.01	50
Arsenic as As, mg/L	<0.01	<0.01	<0.01	<0.01	50
Selenium as Se, mg/L	<0.01	<0.01	<0.01	<0.01	50

Ecological Implications

The combined physicochemical, microbiological, and sediment data indicate moderate to high pollution levels in Hebbal Lake. Elevated nutrients and organic load contribute to eutrophication, while microbial contamination reflects untreated sewage inflows. Observed reductions in bird sightings and degradation of fish habitats suggest ecological stress, although quantitative ecological surveys would be required for stronger inference.

Discussion

Hebbal Lake is under significant anthropogenic pressure due to nutrient enrichment, organic pollution, microbial contamination, and localized heavy metal accumulation. The observed trends in water quality, microbial load, and sediment contamination collectively indicate that the lake is experiencing moderate to severe ecological stress (Tables 1; Table 2).

Elevated nutrient and organic loads, along with high microbial contamination, are driving eutrophication and supporting the proliferation of invasive aquatic vegetation, which reduces oxygen availability and alters habitat conditions. Localized accumulation of heavy metals, particularly chromium in sediments, poses long-term ecological risks due to potential bioaccumulation in benthic and higher trophic organisms.

These combined stressors have ecological consequences, including degradation of fish habitats and declines in populations of migratory birds. The lake's overall ecological balance and biodiversity are therefore at risk.

Sustainable management strategies are necessary to restore and maintain the lake's ecological health. Key measures include reducing nutrient loads through constructed wetlands and biofilters, controlling microbial pollution via sewage diversion and aerobic microbial consortia, managing sediments with targeted removal of chromium-rich sludge, and controlling invasive vegetation to improve water flow and oxygenation. Long-term monitoring and community engagement are critical to ensure effective restoration and protection of the lake as an essential freshwater resource.

Recommendations

To restore and maintain the ecological health of Hebbal Lake, nutrient management through constructed wetlands, biofilters, and phytoremediation is recommended to reduce nitrate and phosphate loads. Microbial pollution should be addressed by diverting untreated sewage, installing septic systems, and introducing aerobic microbial consortia. Sediment management, including removal of chromium-rich sludge and regular monitoring of metal accumulation, is essential. Periodic mechanical removal of invasive vegetation will improve water flow and oxygen levels. Finally, community engagement through awareness campaigns and citizen participation is crucial to reduce waste discharge and support sustainable lake management.

Conclusion

Hebbal Lake, a historically and ecologically significant urban water body in Bangalore, is currently under considerable environmental stress due to nutrient enrichment, organic pollution, microbial contamination, and localized heavy metal accumulation. While most chemical parameters remain within regulatory limits, elevated biochemical oxygen demand, high levels of nitrates and phosphates, and widespread fecal contamination indicate ongoing eutrophication and potential public health risks. Chromium accumulation in lake sludge, likely from industrial effluents, highlights the need for targeted sediment management. This study emphasizes the urgency of implementing a structured action plan, eco-friendly restoration techniques, and long-term monitoring is crucial to restore the lake's ecological balance, maintain biodiversity, and secure freshwater resources for Bangalore.

Acknowledgement

The authors wish to express sincere gratitude to the DSIR-Approved Research and Development Centre, Robust Materials Technologies Pvt. Ltd. Bangalore for their support and research facilities.

Funding Sources

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Conflict of Interest

The authors do not have any conflict of interest.

Data Availability Statement

This statement does not apply to this article.

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement

This study did not involve human participants, and therefore, informed consent was not required.

Permission to Reproduce Material from other Sources

Not Applicable

Author Contributions

- **Spoorthi:** Conceptualization, Methodology, Data Collection, Analysis, Writing, Review & Editing – Original Draft.
- **K.R. Ravi Kumar:** Funding Acquisition, Resources, Visualization, Supervision, Project Administration.

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