

Assessment of Heavy Metal Contamination Using Fish Scales and Aquatic Macrophytes as Dual Bioindicators in Motia Lake, Bhopal

Mukesh Dixit¹, Deepti Sankat², Vartika³, Vijay Shankar Maurya⁴, Piyush Soni⁵

¹Professor and Head, Department of Zoology, Sarojini Naidu Govt. Girls PG (Auto.) College, Bhopal

²Professor, Department of Botany, Sarojini Naidu Govt. Girls PG (Auto.) College, Bhopal

^{3,4,5}Research Scholar, Department of Zoology and Applied Aquaculture, Barkatullah University, Bhopal

Abstract—The study assesses heavy metal contamination in Motia Lake, Bhopal, using fish scales of *Labeo rohita* and aquatic macrophytes as dual bioindicators. Water, fish and plant samples were collected during summer and monsoon seasons and analyzed for cadmium (Cd), mercury (Hg) and zinc (Zn) using standard analytical techniques. Physicochemical parameters indicated moderate water quality with seasonal variation. Fish scales showed higher zinc (27.32 ppm) and mercury (0.0804 ppm) accumulation in summer, while macrophytes displayed elevated zinc levels (up to 96.07 ppm in *Polygonum glabrum*) in monsoon. The overall trend of metal accumulation followed Zn > Hg > Cd, suggesting low to moderate pollution. The findings highlight the efficacy of fish scales and macrophytes as non-invasive bioindicators for monitoring urban freshwater ecosystems.

Index Terms—Motia Lake, *Labeo rohita*, Water quality, Heavy metals, Scale deformities, Macrophytes, Bioindicators.

I. INTRODUCTION

Water is the foundation of life and a critical component for sustaining ecological balance, biodiversity and human well-being. In recent decades, the degradation of freshwater ecosystems due to industrial effluents, domestic waste discharge and urban runoff has emerged as a significant environmental concern in India. Heavy metal contamination of aquatic bodies has attracted special attention because of its persistence, non-biodegradability and potential to bioaccumulate

through food chains, adversely impacting aquatic flora and fauna (Sahu et al., 2023).

Fish and aquatic macrophytes are among the most reliable biological indicators used for evaluating the health of aquatic ecosystems. Fish species such as *Labeo rohita* (Rohu) are highly sensitive to environmental changes and have been extensively used as bioindicators for monitoring water pollution levels. The analysis of fish scales in particular provides a non-lethal and sensitive method to assess the accumulation of toxic metals such as lead (Pb), cadmium (Cd), chromium (Cr), zinc (Zn) and copper (Cu) (Parvez et al., 2025). Macrophytes, including *Eichhornia crassipes* (water hyacinth), *Hydrilla verticillata* and *Typha latifolia* are similarly known for their remarkable capacity to absorb, translocate and sequester heavy metals, acting both as bioindicators and phytoremediators (Yadav & Dwivedi, 2025). India's urban lakes such as Motia Lake in Bhopal, Madhya Pradesh have witnessed increasing anthropogenic pressures due to urban expansion and untreated waste discharge. This has resulted in elevated levels of heavy metals and the subsequent deterioration of aquatic biodiversity (Kumar et al., 2022). Employing a dual bioindicator approach integrating fish scales and macrophytes offers a comprehensive and cost-effective method to assess contamination levels, ecological risk and biological responses to pollution in freshwater environments (Arshad et al., 2023). This integrated method enhances accuracy by correlating the biotic uptake of metals across different trophic levels, thus providing an effective ecological assessment model for semi-urban aquatic systems.

The present study aims to quantify and compare heavy metal accumulation in fish scales and aquatic macrophytes from Motia Lake, Bhopal, to evaluate their potential as dual bioindicators. This integrative approach bridges aquatic toxicology and biomonitoring, providing a reliable framework for urban lake management and ecological restoration.

II. METHODOLOGY

Study Area

The study will be conducted at Motia Lake (Figure 1) located in the central part of Bhopal, Madhya Pradesh, India (Latitude: 23.25°N, Longitude: 77.41°E). The lake is an important freshwater body surrounded by residential and commercial settlements, receiving inflow from domestic sewage and urban runoff. Its eutrophic nature and anthropogenic influence make it suitable for studying bioaccumulation patterns of heavy metals.



Figure 1. Motia lake with four sampling sites as Outlet (Site 1), Fish Hut (Site 2), Inlet (Site 3) and Center (Site 4).

Sampling Design

To evaluate the spatial and temporal variations in heavy metal contamination, systematic sampling will be conducted at four strategically selected sites within Motia Lake, Bhopal. These include inlet (site-3) the primary entry point of domestic wastewater and urban runoff, representing the most contaminated section of the lake, center (site-4) characterized by water mixing and moderate anthropogenic influence, outlet (site-1) where accumulation of pollutants due to sedimentation and outflow occurs and fish hut (site-2) where fisherman works (Fig. 1). Sampling will be carried out seasonally during the pre-monsoon (April–June), monsoon (July–September) and post-monsoon (October–December) periods.

Water Sample Collection and Analysis

Water samples were collected from selected sites during the summer and monsoon seasons and stored in clean transparent plastic bottles. Each bottle was clearly labeled with the date, sample code and sampling location. The samples were then transported to the laboratory for analysis of various physico-chemical parameters, including water temperature, pH, dissolved oxygen (DO), biological oxygen demand (BOD), nitrate, phosphate, total alkalinity, total hardness and total dissolved solids (TDS). In addition, heavy metals such as cadmium (Cd), mercury (Hg) and zinc (Zn) were examined to determine their concentration levels in the water.

Fish Scales Collection and Analysis

The indigenous and commercially valuable fish species *Labeo rohita* (Rohu) will be selected for analysis due to its ecological importance and sensitivity to environmental contaminants. Fish will be collected from each of the four sampling stations using traditional cast nets with the help of local fishermen. Immediately after collection, the fish will be washed thoroughly with lake water to remove adhered sediments and debris. The scales will be

carefully removed from the dorsal region of each specimen to ensure consistency, as this area is least affected by external abrasions and provides stable bioaccumulation records. The collected scales will then be rinsed with double-distilled water, air-dried and stored in pre-cleaned polyethylene bags to prevent contamination. In the laboratory, samples will be oven-dried at 60°C for 24 hours to remove moisture content before being subjected to acid digestion for heavy metal analysis.

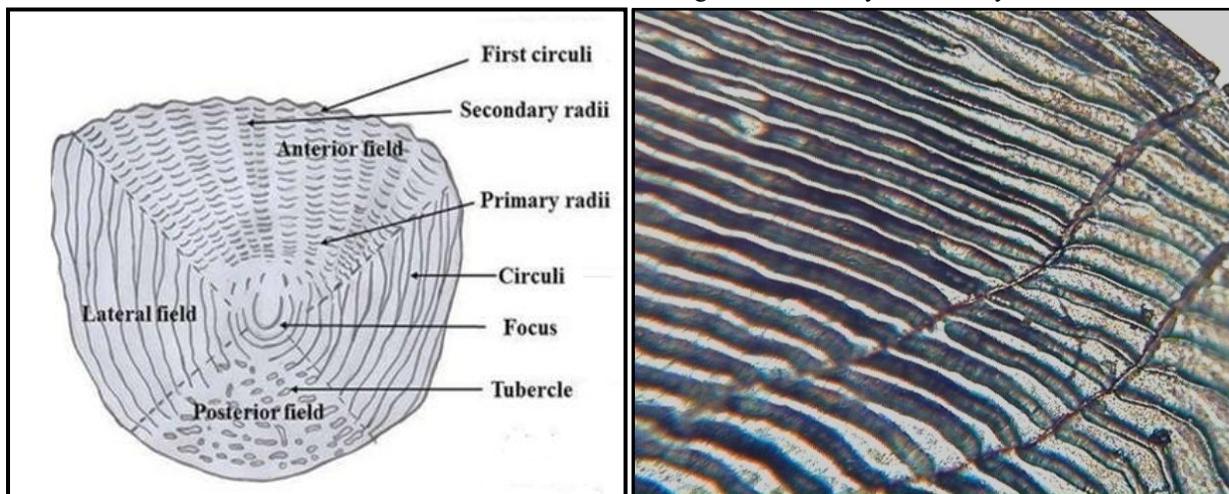


Figure 2. Structure of Fish Scale.

Macrophyte Samples Collection and Analysis

Macrophyte samples were collected from various designated sites within the study area for habitat assessment and heavy metal analysis. All sampling activities were conducted in accordance with ethical guidelines to minimize disturbance to the aquatic environment. Visual surveys were performed at each site to estimate and document macrophyte abundance, with particular focus on rooted species. Photographic documentation with GPS coordinates, along with the date, time and location, was recorded for each collected specimen. The samples were placed in labeled poly bags indicating the sample number, species name, sampling station and date. In the laboratory, the specimens were thoroughly washed to remove debris and sediments, sorted by species and identified to the lowest possible taxonomic level using standard floras and relevant taxonomic references. In the laboratory, the plants will be segregated into roots, stems and leaves to study metal distribution within different plant parts. Each portion will be oven-dried at 70°C until constant weight is achieved, ensuring the removal of

all moisture content. The dried material will then be ground into fine powder using a stainless-steel mill and stored in airtight containers for subsequent digestion and analysis. For heavy metal analysis, the samples were air-dried and subsequently dried in a hot air oven to determine fresh and dry weights and the corresponding records were maintained.

Data Analysis

Data were statistically analyzed using standard version of MS excel. Mean, standard deviation were calculated to compare spatial and seasonal differences of water parameter.

III. RESULTS

Table 1. Water parameters (Mean ± SD) of Motia Lake during study period.

Parameter	Summer	Monsoon
Water Temp (°C)	32 ± 1.5	26 ± 1.2
pH	6.57 ± 0.08	6.63 ± 0.09

DO (mg L ⁻¹)	5.6 ± 0.3	5.2 ± 0.2
BOD (mg L ⁻¹)	3.2 ± 0.2	2.8 ± 0.3
Total Dissolved Solids (mg L ⁻¹)	282 ± 15	386 ± 18
Total Alkalinity (mg L ⁻¹)	146.9 ± 7.5	187.35 ± 8.2
Total Hardness (mg L ⁻¹)	178.6 ± 8.9	218.3 ± 10.1
Phosphate (mg L ⁻¹)	0.27 ± 0.02	0.21 ± 0.01
Nitrate (mg L ⁻¹)	3.05 ± 0.25	1.61 ± 0.15
Chloride (mg L ⁻¹)	23 ± 2.0	20 ± 1.8

The physicochemical analysis of Motia Lake during the summer and monsoon seasons indicates moderate water quality (Table 1) with noticeable seasonal fluctuations driven by temperature, runoff and dilution effects. Water temperature ranged from 32 ± 1.5 °C in summer to 26 ± 1.2 °C in monsoon, reflecting the influence of seasonal climate. The elevated summer temperature enhances metabolic activity and decomposition rates, thereby reducing dissolved oxygen (DO) and increasing the biological oxygen demand (BOD). Lower temperatures during monsoon improve oxygen solubility and overall water quality. The pH values (6.57 ± 0.08 in summer; 6.63 ± 0.09 in monsoon) are slightly acidic to near neutral, remaining within the permissible range (6.5–8.5) for aquatic life. The marginal rise in pH during monsoon can be attributed to dilution by rainwater and increased photosynthetic activity of macrophytes, which consume CO₂. DO levels (5.6 ± 0.3 mg/L in summer; 5.2 ± 0.2 mg/L in monsoon) and BOD values (3.2 ± 0.2 mg/L and 2.8 ± 0.3 mg/L, respectively) suggest moderately clean but organically influenced water. The slightly lower DO and higher BOD in summer indicate elevated organic decomposition and microbial activity, typical of eutrophic tendencies during high temperature and stagnation periods. In monsoon, improved mixing and dilution reduce BOD. TDS increased notably from 282 ± 15 mg/L in summer to 386 ± 18 mg/L in monsoon, possibly due to surface runoff carrying suspended solids and dissolved ions into the lake. Similarly, total alkalinity and hardness rose from 146.9 ± 7.5 mg/L to 187.35 ± 8.2 mg/L and 178.58 ± 8.9 mg/L to 218.26 ± 10.1 mg/L, respectively. These

increases suggest the influx of bicarbonates, calcium and magnesium ions from urban drainage and soil erosion during rains. While these levels are still within acceptable limits for freshwater ecosystems, the trend indicates nutrient enrichment and potential for long-term salinization if unchecked. Phosphate (0.27 ± 0.02 mg/L in summer; 0.21 ± 0.01 mg/L in monsoon) and nitrate (3.05 ± 0.25 mg/L in summer; 1.61 ± 0.15 mg/L in monsoon) levels confirm the lake’s moderate nutrient load. The higher summer concentrations reflect evaporation-induced concentration and domestic sewage inflow, promoting algal and macrophytic growth. The monsoon dilution reduces nutrient levels but may still support eutrophic conditions. Chloride concentrations decreased slightly from 23 ± 2.0 mg/L to 20 ± 1.8 mg/L, indicating that the ionic load is mainly natural and not from significant industrial contamination.

Table 2. Heavy Metals Analysis of Water

Parameter	Summer	Monsoon
Cadmium (ppm)	0.0002	0.0004
Mercury (ppm)	0.0001	0.0001
Zinc (ppm)	0.000	0.0963
Chromium (ppm)	0.0005	0.0007
Copper (ppm)	0.0079	0.0027

Trace concentrations of cadmium (0.0002–0.0004 ppm), mercury (0.0001 ppm), chromium (0.0005–0.0007 ppm) and copper (0.0027–0.0079 ppm) were detected, while lead remained below detection limits (Table 2). Zinc appeared only in monsoon (0.0963 ppm), likely introduced by surface runoff or vehicular pollution. Although these levels are within national and WHO permissible limits, the detectable presence of cadmium and mercury indicates minor but chronic contamination, potentially leading to bioaccumulation in aquatic biota over time.

Table 3: Heavy Metals Analysis of *Labeo rohita* scales.

Test parameters	Summer	Monsoon
Cadmium (ppm)	0.001	0.001
Mercury (ppm)	0.0701	0.0706
Zinc (ppm)	20.32	23.52

Motia Lake showed detectable levels of mercury (Hg) and zinc (Zn) while cadmium (Cd) remained below detection limits in both seasons (Table 3) suggesting minimal Cd contamination. Mercury levels were slightly higher in summer (0.0701 ppm) than in monsoon (0.0706 ppm), indicating mild bioaccumulation influenced by temperature and evaporation. Zinc showed the highest accumulation with 20.32 ppm in summer and 23.52 ppm in monsoon, reflecting moderate contamination likely from urban runoff and domestic sources. Metal

accumulation followed the trend Zn > Hg > Cd indicating low to moderate pollution. The results confirm that fish scales serve as effective non-invasive bioindicators of chronic metal exposure in Motia Lake’s aquatic ecosystem.

Macrophytes Analysis

A total of four macrophyte species were recorded during the summer season in Motia Lake, namely *Nymphaea odorata*, *Polygonum glabrum*, *Ludwigia glabrum* and *Vallisneria natans* (Table 4).

Table 4: Heavy Metals Analysis of Macrophytes in Summer.

Parameters	<i>N. odorata</i>	<i>P. glabrum</i>	<i>L. glabrum</i>	<i>V. natans</i>
Cadmium (ppm)	0.0560	0.0832	0.0739	0.0943
Mercury (ppm)	0.1190	0.0814	0.0906	0.0841
Zinc (ppm)	44.42	91.02	62.22	82.39

Table 5: Heavy Metals Analysis of Macrophytes in Monsoon.

Parameters	<i>N. odorata</i>	<i>P. glabrum</i>	<i>L. glabrum</i>	<i>L. alata</i>
Cadmium (ppm)	0.0632	0.0845	0.0866	0.1042
Mercury (ppm)	0.1216	0.0901	0.1092	0.0951
Zinc (ppm)	46.77	96.07	68.80	89.88

During the monsoon season *Vallisneria natans* was replaced by *Ludwigia alata* (Table 5). These macrophyte species were examined to determine the presence and concentration of heavy metals such as cadmium (Cd), zinc (Zn) and mercury (Hg). Cadmium concentrations ranged from 0.0560 to 0.0943 ppm in summer and 0.0632 to 0.1042 ppm in monsoon. The highest Cd accumulation was recorded in *Vallisneria natans* (0.0943 ppm) during summer and *Ludwigia alata* (0.1042 ppm) during monsoon. These values suggest that submerged and emergent species with extensive root systems tend to accumulate higher Cd levels from sediments. The slightly higher Cd levels during the monsoon season indicate enhanced metal mobility due to surface runoff and sediment resuspension. Although the concentrations remain within non-toxic limits, their persistence highlights ongoing low-level contamination from anthropogenic inputs such as domestic wastewater and agricultural discharge. Mercury concentrations were relatively consistent

across seasons, ranging from 0.0814 to 0.1190 ppm in summer and 0.0901 to 0.1216 ppm in monsoon. The maximum mercury content was observed in *Nymphaea odorata* during both seasons (0.1190–0.1216 ppm), suggesting its strong capacity for metal bioaccumulation in floating-leaved tissues. The relatively stable mercury concentrations across species indicate chronic background contamination in Motia Lake, potentially from atmospheric deposition and vehicular emissions. Despite being below hazardous limits, the detectable Hg levels in all macrophytes raise concerns about long-term bioaccumulation and biomagnification risks within the lake’s food web. Zinc was found in markedly higher concentrations compared to Cd and Hg, with 44.42–91.02 ppm in summer and 46.77–96.07 ppm in monsoon. *Polygonum glabrum* exhibited the highest Zn accumulation in both seasons (91.02–96.07 ppm), followed by *Ludwigia alata* and *Vallisneria natans* (Table 4). The high Zn levels suggest that Motia Lake receives consistent zinc input, likely from domestic

sewage, urban runoff and corrosion of galvanized materials. The slight increase during monsoon may be attributed to runoff-induced input of zinc-bearing particulates. Although zinc is an essential micronutrient for plant growth, such elevated concentrations can cause oxidative stress in aquatic macrophytes affecting their physiological and enzymatic functions.

IV. DISCUSSION

The present study demonstrates moderate levels of heavy metal contamination in Motia Lake, Bhopal as reflected by the bioaccumulation patterns observed in both fish scales and aquatic macrophytes. The overall metal concentration trend $Zn > Hg > Cd$ aligns with observations from earlier limnological studies on Bhopal's urban lakes, such as the Upper and Lower Lakes, where zinc was also reported as the dominant metal contaminant due to urban runoff and domestic sewage inputs (Gupta et al., 2012).

The concentrations of cadmium (0.056–0.104 ppm) and mercury (0.081–0.121 ppm) recorded in macrophytes were comparatively lower than those reported by Vishwakarma and Sharma (2023), who identified higher Cd and Hg levels in sediments of the City of Lakes, Bhopal, particularly near densely populated catchments. This variation may be attributed to Motia Lake's smaller hydrological size and relatively limited industrial inflow compared to the larger Bhopal lake systems. Detectable concentrations of these metals indicate persistent anthropogenic pressure from domestic wastewater and vehicular emissions (Vishwakarma et al., 2023). Macrophytes such as *Polygonum glabrum* and *Ludwigia alata* exhibited strong metal accumulation potential, particularly for zinc (91.02–96.07 ppm). These findings corroborate those of Pathak (2015), who reported elevated Zn uptake in macrophytes from Upper Lake, Bhopal, due to runoff from zinc-coated infrastructure and stormwater drains. The high accumulation observed in *P. glabrum* suggests its suitability as a biomonitor and potential phytoremediator for zinc contamination. Fish scale analysis of *Labeo rohita* showed bioaccumulation consistent with environmental exposure, Indian major carps effectively reflect ambient metal concentrations due to their trophic position and long-term habitat exposure. The higher zinc and mercury content in

summer scales compared to monsoon indicates that evaporation and low dilution rates enhance bioavailability during warmer months, a pattern also observed by Jan et al. (2024) in Lower Lake, Bhopal. When compared to earlier biological studies on Motia Lake, such as those by Kumar et al. (2018), which focused on plankton and fish diversity rather than heavy metals, the present findings fill a critical data gap by linking physicochemical conditions to bioindicator-based metal accumulation. The recorded metal values in this study are lower than industrially influenced systems but remain a concern for trophic transfer and long-term ecological health. The consistency of results across both bioindicator groups fish and macrophytes strengthens the argument for dual-bioindicator monitoring approaches. Similar integrative assessments have been recommended for eutrophic urban lakes in central India to enhance early detection of metal stress (Mukherjee et al., 2022). The moderate contamination levels observed in Motia Lake emphasize the need for continuous biomonitoring and the implementation of green buffer zones and sediment management to mitigate urban pollutant inflows.

V. CONCLUSION

The present investigation provides an integrated assessment of heavy metal contamination in Motia Lake, Bhopal, using *Labeo rohita* fish scales and selected aquatic macrophytes as dual bioindicators. The results revealed detectable but moderate levels of zinc (Zn), mercury (Hg) and cadmium (Cd) across all environmental matrices water, fish and plants. Among the metals analyzed, zinc consistently exhibited the highest concentration, followed by mercury and cadmium ($Zn > Hg > Cd$), indicating a predominant influx of zinc-rich urban runoff and vehicular emissions. Fish scale analysis confirmed that *Labeo rohita* effectively reflects bioavailable metal fractions in the aquatic environment, while macrophytes such as *Polygonum glabrum*, *Ludwigia alata* and *Nymphaea odorata* demonstrated strong accumulation potential, particularly for zinc and mercury. This dual bioindicator approach enhances the reliability of ecological monitoring by correlating trophic-level responses and sediment-water interactions. When compared to earlier studies on Bhopal's lakes (Pathak, 2015; Vishwakarma et al.,

2023; Jan et al., 2024), the findings suggest that Motia Lake is presently under low to moderate contamination pressure, primarily from domestic sewage, surface runoff and atmospheric deposition rather than direct industrial effluents. However, the persistence of cadmium and mercury, even at trace levels, indicates chronic exposure risks that warrant ongoing surveillance.

The study underscores the value of employing non-invasive and cost-effective bioindicator systems for urban freshwater monitoring. Regular assessment of fish scales and macrophytes can serve as an early warning mechanism to detect metal-induced ecological stress and support the formulation of sustainable lake management policies. The inclusion of phytoremediation strategies using high-uptake macrophytes such as *P. glabrum* and *L. alata* is recommended to enhance natural purification processes and restore the ecological integrity of Motia Lake.

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