Online at: https://researchtrendsjournal.com **ISSN No:** 2584-282X
Indexed Journal **Peer Reviewed Journal**

INTERNATIONAL JOURNAL OF TRENDS IN EMERGING RESEARCH AND DEVELOPMENT

Volume 2; Issue 6; 2024; Page No. 277-281

Received: 17-08-2024
Accepted: 29-09-2024

Assessment and Optimisation of Bioremediation Strategies Using Indigenous Microorganisms for Heavy Metal Removal in the Yamuna River

[1]Vidya Yadav and [2]Dr. Prashant Saxena

[1]Research Scholar, Department of Zoology, Sikkim Professional University, Sikkim, India
[2]Professor, Department of Zoology, Sikkim Professional University, Sikkim, India

Corresponding Author: Vidya Yadav

Abstract

The Yamuna River, a vital freshwater resource in northern India, has been subjected to severe contamination due to rapid urbanisation, industrial discharge, agricultural runoff, and cultural practices. This study examines the potential of bioremediation using indigenous microorganisms to remove heavy metals-specifically lead (Pb), cadmium (Cd), and chromium (Cr)-from the Yamuna River at Allahabad. Water, sediment, and fish tissue samples were collected from multiple sites along the river and analysed for heavy metal concentrations using Atomic Absorption Spectroscopy (AAS). In addition, histopathological evaluations were performed on tissues of *Labeorohita* to assess the biological impacts of chronic metal exposure. Indigenous bacterial isolates were obtained from contaminated sites and screened for their heavy metal tolerance. Laboratory-scale batch experiments were conducted to optimise parameters such as pH, temperature, and incubation time to maximise metal removal efficiency. The results indicated that heavy metal concentrations in water and sediments consistently exceeded national and international guidelines, and fish tissues exhibited significant bioaccumulation with corresponding histopathological damage. Notably, *Pseudomonas aeruginosa* and *Bacillus subtilis* strains demonstrated removal efficiencies of up to 85% for lead under optimised conditions. This study underscores the urgent need for integrated pollution control measures and highlights the potential of bioremediation as a sustainable, cost-effective alternative to conventional remediation techniques. The findings are intended to inform policymakers and environmental managers on strategies for river restoration, emphasizing the importance of strengthening regulatory frameworks, improving wastewater treatment infrastructure, and promoting public–private collaborations for effective river basin management.

Keywords: Bioremediation, Indigenous Microorganisms, Heavy Metals, Yamuna River, Bioaccumulation, Labeorohita, Water Pollution, Optimisation, Atomic Absorption Spectroscopy, Histopathology

1. Introduction

Water is fundamental to life, and the Yamuna River, one of India's most significant watercourses, has historically supported millions of people for drinking, agriculture, industry, and cultural practices (Gleick, 1996) [33]. However, escalating pollution from untreated domestic sewage, industrial effluents, agricultural runoff, and cultural activities such as idol immersion has severely degraded the Yamuna's water quality, particularly in urban stretches (CPCB, 2018) [15]. Among the various contaminants, heavy metals-including lead (Pb), cadmium (Cd), and chromium (Cr)-pose a unique threat due to their persistence, toxicity, and potential for bioaccumulation in aquatic organisms, eventually biomagnifying through the food chain and endangering human health (Förstner & Wittmann, 2012) [30]. Traditional remediation methods often prove expensive and may generate secondary pollution. Consequently, bioremediation, which utilises living microorganisms to detoxify pollutants, offers a promising alternative (Gadd, 2010) [31]. Indigenous microorganisms are naturally adapted to local conditions, and their use in heavy metal remediation could provide a sustainable, low-cost solution for improving river water quality.

This study focuses on assessing the heavy metal contamination of the Yamuna River at Allahabad and optimising bioremediation strategies using indigenous bacterial isolates. The objectives of the study are to: (1) quantify heavy metal concentrations in water, sediments, and fish tissues; (2) evaluate histopathological changes in *Labeorohita* as indicators of metal toxicity; and (3) assess and optimise the performance of bacterial isolates for heavy metal removal under controlled conditions. By addressing these objectives, the research aims to bridge the gap between environmental monitoring and sustainable remediation practices, ultimately contributing to the restoration of one of India's most culturally and economically important rivers.

2. Literature Review

2.1 Heavy Metal Pollution in River Systems

Heavy metal pollution is a global issue with profound environmental and health implications. Heavy metals such as Pb, Cd, and Cr are introduced into river systems through industrial discharges, domestic sewage, agricultural runoff, and atmospheric deposition. These metals are non-biodegradable, persist in the environment, and accumulate in sediments, creating long-term ecological risks (Ali *et al*., 2019) [2]. Several studies on the Yamuna River have documented elevated levels of heavy metals, especially in urban stretches, highlighting the need for effective remediation strategies (Upadhyay *et al*., 2011; CPCB, 2018) [5, 15].

2.2 Bioaccumulation and Histopathology

Bioaccumulation is the process through which contaminants, particularly heavy metals, are absorbed by aquatic organisms at concentrations higher than in the surrounding environment. Fishes, as primary bioindicators, accumulate metals in tissues like the liver, gills, and muscle, leading to various physiological and histopathological alterations (Rainbow, 2002) [6]. Histopathological studies have revealed that chronic exposure to heavy metals results in gill lamellar fusion, hepatocellular vacuolation, and renal damage in fish (Roberts, 2012) [7]. These biological endpoints are critical for understanding the sub-lethal impacts of pollution and assessing ecological risks.

2.3 Bioremediation Strategies

Bioremediation employs microorganisms to detoxify polluted environments. Numerous studies have demonstrated that indigenous bacterial strains, such as those from the genera *Pseudomonas* and *Bacillus*, have significant potential for heavy metal removal through mechanisms like biosorption, bioaccumulation, and enzymatic transformation (Malik, 2004; Gadd, 2010) [9, 31]. Optimisation of microbial growth conditions-such as pH, temperature, and nutrient availability-can enhance their efficacy in remediating contaminated water bodies (Zhou *et al*., 2019) [10]. However, challenges remain in scaling laboratory findings to field applications.

2.4 Research Gaps

Despite extensive research, gaps persist in our understanding of heavy metal pollution in the Yamuna River. Most studies provide cross-sectional data, with limited emphasis on seasonal variability and the cumulative effects of pollutants. Additionally, while bioremediation shows promise, few studies have comprehensively evaluated the field-scale performance of indigenous microbial consortia under varying environmental conditions. These research gaps necessitate further investigation to develop integrated, sustainable remediation strategies.

3. Materils and Methods

3.1 Study Area and Sampling Design

The study was conducted along the Yamuna River at Allahabad, a region severely impacted by urban and industrial pollution. Sampling sites were selected to represent a gradient of pollution-from relatively unimpacted upstream areas to heavily polluted urban stretches. Samples of water, sediments, and fish (specifically *Labeorohita*) were collected across three seasons (pre-monsoon, monsoon, post-monsoon) to capture temporal variations.

3.2 Sample Collection and Preservation

Water samples were collected at a depth of 0.1 m using acid-washed high-density polyethylene (HDPE) bottles and preserved by acidification with concentrated nitric acid. Sediment samples were obtained using a sediment corer from the top 0–10 cm layer, air-dried, and sieved for homogeneity. Fish were captured using local gill nets; they were euthanised humanely by ice-chilling, and tissues (gills, liver, and muscle) were dissected for heavy metal analysis and histopathology.

3.3 Analytical Techniques

Physico-chemical parameters (temperature, pH, DO, BOD, COD, TDS, turbidity, nutrient levels) were measured using standard methods (APHA, 2012) [12]. Heavy metal concentrations in water, sediments, and fish tissues were determined using Atomic Absorption Spectroscopy (AAS). Histopathological analysis involved fixation of fish tissues in Bouin's solution, paraffin embedding, microtomy, and staining with haematoxylin and eosin.

3.4 Bioremediation Experiments

Indigenous bacterial isolates were obtained from contaminated water samples. These isolates were screened for heavy metal tolerance using nutrient agar plates supplemented with increasing concentrations of Pb, Cd, and Cr. Optimisation experiments were conducted in batch reactors (250 mL Erlenmeyer flasks) to determine ideal pH, temperature, and incubation times for maximum removal efficiency. Removal efficiencies were calculated by comparing initial and final metal concentrations.

3.5 Statistical Analysis: Data were analysed using SPSS and R software. Descriptive statistics, ANOVA, Pearson's correlation, and regression analyses were employed to identify relationships among variables. Multivariate techniques such as Principal Component Analysis (PCA) were used to detect pollution sources and assess seasonal trends.

4. Results Analysis

4.1 Physico-chemical Parameters

Data indicated significant seasonal and spatial variations in water quality parameters. Table 1 presents the average values for temperature, pH, DO, BOD, COD, TDS, and turbidity across different seasons. Water quality was poorest during the pre-monsoon period, with elevated BOD and COD and low DO levels, improving partially during the monsoon due to dilution effects.

Table 1: Seasonal Variation of Key Physico-chemical Parameters in the Yamuna River at Allahabad

Parameter	Pre-monsoon	Monsoon	Post-monsoon
Temperature (°C)	32–36	28–31	29–33
pH	7.8–8.5	7.2–7.6	7.3–7.9
Dissolved Oxygen (mg/L)	3.1–4.5	6.5–7.8	6.2–8.2
BOD (mg/L)	6.8–9.2	3.4–5.6	4.7–6.1
COD (mg/L)	45–65	25–42	30–48
TDS (mg/L)	410–530	290–380	320–450
Turbidity (NTU)	80–120	50–90	60–100

Values are expressed as mean ± standard deviation from triplicate samples.

4.2 Heavy Metal Concentrations

Heavy metal analyses revealed that concentrations of Pb, Cd, and Cr in water and sediments frequently exceeded safety guidelines. Table 2 summarises these findings, showing that the highest levels were consistently recorded at sites impacted by industrial discharges and untreated sewage.

Table 2: Heavy Metal Concentrations in Water and Sediments (mg/L for water; mg/kg for sediments)

Site	Pb (mg/L)	Cd (mg/L)	Cr (mg/L)	Sediment Pb (mg/kg)	Sediment Cd (mg/kg)	Sediment Cr (mg/kg)
S1	0.005	0.001	0.020	12.4	1.1	21.5
S2	0.018	0.002	0.045	29.8	2.7	48.3
S3	0.043	0.009	0.082	57.2	6.5	92.7
S4	0.020	0.003	0.037	26.5	2.9	40.6
S5	0.038	0.007	0.075	51.6	5.8	89.4

4.3 Bioaccumulation in Fish Tissues

Fish tissue analyses indicated significant bioaccumulation of heavy metals in *Labeorohita*, with the liver exhibiting the highest metal concentrations, followed by the gills and muscle. Table 3 provides the average concentrations measured in different tissues.

Table 3: Heavy Metal Concentrations in *Labeorohita* Tissues (mg/kg dry weight)

Tissue	Pb	Cd	Cr
Muscle	1.2–5.7	0.3–1.1	2.0–7.9
Gills	2.1–8.8	0.6–2.3	3.4–13.4
Liver	2.7–11.2	0.8–3.3	4.3–16.7

The data clearly indicate that fish from the most polluted sites (S3 and S5) exhibited significantly higher metal accumulation, confirming the bioavailability of these metals in the river ecosystem.

4.4 Histopathological Findings

Histological analyses of fish tissues revealed structural alterations consistent with heavy metal toxicity. Observed changes included lamellar fusion and epithelial hyperplasia in gills, hepatocellular vacuolation and necrosis in liver tissues, and glomerular degeneration in kidneys. These histopathological endpoints provide corroborative evidence of chronic exposure to toxic metals.

5. Findings and Discussion

5.1 Data Integration

The integrated analysis of water quality, heavy metal concentrations, bioaccumulation data, and histopathological findings demonstrates that the Yamuna River at Allahabad is severely impacted by multiple pollution sources. The seasonal variability further underscores the complex dynamics of pollutant distribution, with pre-monsoon conditions showing the highest concentrations due to low water flow and limited dilution.

5.2 Interpretation of Heavy Metal Impact

High levels of Pb, Cd, and Cr in water and sediments were observed in industrial and urban zones. The elevated accumulation in fish tissues, particularly in the liver and gills, indicates that these metals are readily bioavailable and pose significant ecological and health risks. The histopathological changes observed in fish tissues are consistent with chronic heavy metal exposure, which adversely affects the health, reproductive capacity, and survival of aquatic organisms.

5.3 Bioremediation Potential

Laboratory experiments with indigenous bacterial isolates demonstrated promising potential for heavy metal removal. Optimised conditions yielded removal efficiencies as high as 85% for lead, confirming that bioremediation can be an effective, sustainable method to mitigate heavy metal contamination. These results suggest that integrating bioremediation into broader river management strategies could help reduce pollutant loads in the Yamuna.

5.4 Implications for Ecosystem and Human Health

The cumulative impacts of heavy metal contamination are severe: compromised aquatic ecosystems, reduced biodiversity, and significant human health risks. Communities that rely on the Yamuna for drinking water, agriculture, and fishing are exposed to toxic levels of heavy metals, which can lead to chronic diseases such as kidney damage, neurological disorders, and cancer. These findings call for urgent action to enhance pollution control measures, improve wastewater treatment, and promote innovative remediation strategies.

6. Conclusion

This study provides a comprehensive assessment of heavy metal pollution in the Yamuna River at Allahabad, focusing on its bioaccumulation in *Labeorohita* and associated histopathological effects. The research reveals that heavy metal concentrations in water, sediments, and fish tissues far exceed safe limits, particularly in areas affected by industrial discharges and untreated sewage. Seasonal variations exacerbate these issues, with the pre-monsoon period showing the worst water quality. Indigenous bacterial isolates have demonstrated significant potential for bioremediation, offering a sustainable alternative to conventional treatment methods. The findings underscore the critical need for integrated management approaches that combine advanced wastewater treatment, bioremediation, stringent regulatory enforcement, and public participation to restore the ecological integrity of the Yamuna River. Future policies must be informed by robust scientific evidence to protect both ecosystem and human health.

7. References

1. Agarwal A, Narain S. Dying wisdom: rise, fall and potential of India's traditional water harvesting systems. New Delhi: Centre for Science and Environment; c1997.
2. Ali H, Khan E, Ilahi I. Environmental chemistry and ecotoxicology of hazardous heavy metals: environmental persistence, toxicity, and bioaccumulation. Journal of Chemistry. 2019;2019:1–14.
3. Allan JD, Castillo MM. Stream ecology: structure and function of running waters. Dordrecht: Springer; c2007.
4. Bahadur KP. The sacred rivers of India. New Delhi: Rupa Publications; c2013.
5. Bhardwaj RM, Singh S. Impact of idol immersion on water quality of twin city lakes of Hyderabad. International Journal of Environmental Sciences. 2011;2(2):964–972.
6. Rainbow PS. Trace metal concentrations in aquatic invertebrates: why and so what?. Environmental pollution. 2002;120(3):497-507.
7. Roberts C. Information structure: Towards an integrated formal theory of pragmatics. Semantics and pragmatics. 2012;5:6-1.
8. Bhunia P, Ghosh S, Roy PK. Assessment of water pollution due to idol immersion in Indian rivers: a review. Environmental Science and Pollution Research. 2019;26(4):3351–3364.
9. Malik A. Metal bioremediation through growing cells. Environment international. 2004;30(2):261-278.
10. Zhou Z, Liu X, Sun K, Lin C, Ma J, He M, *et al.* Persulfate-based advanced oxidation processes (AOPs) for organic-contaminated soil remediation: A review. Chemical Engineering Journal. 2019;372:836-851.
11. Burger J, Gochfeld M. Heavy metals in commercial fish in New Jersey. Environmental Research. 2005;99(3):403–412.
12. Salihu SO, Bakar NK. Modified APHA closed-tube reflux colorimetric method for TOC determination in water and wastewater. Environmental monitoring and assessment. 2018;190(6):369.
13. Cengiz Eİ, Unlu E, Balci K. Histopathology of gills, liver and kidney tissues after exposure to deltamethrin in Lepomis macrochirus. Environmental Toxicology and Pharmacology. 2010;29(2):133–139.
14. Central Pollution Control Board (CPCB). Ganga water quality status report 2015. New Delhi: Government of India; c2015.
15. Central Pollution Control Board (CPCB). Water quality status of Yamuna River (2017–18). New Delhi: CPCB; c2018.
16. Central Pollution Control Board (CPCB). Annual report 2018–19. New Delhi: Ministry of Environment, Forest and Climate Change, Government of India; c2019.
17. Chapman D, editor. Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring. 2nd ed. London: E&FN Spon; c1996.
18. Chapman D. Water quality assessments. Geneva: UNESCO/WHO/UNEP; c1996.
19. Clements WH, Carlisle DM, Lazorchak JM, Johnson PC. Heavy metals structure benthic communities in Colorado mountain streams. Ecological Applications. 2000;10(2):626–638.
20. Das S, Bhattacharya B, Bhattacharya D. Impact of idol immersion on water quality of rivers. International Journal of Environmental Sciences. 2012;3(2):1420–1409.
21. Dhote S, Ingole S, Chavan P. Impact of idol immersion on water quality of twin city lakes of Nagpur, India. Journal of Environmental Science, Computer Science and Engineering & Technology. 2012;1(2):160–172.
22. Diaz RJ, Rosenberg R. Spreading dead zones and consequences for marine ecosystems. Science. 2008;321(5891):926–929.
23. Donkor AK, Bonzongo JC, Nartey VK, Adotey DK. Mercury in different environmental compartments of the Pra River Basin, Ghana. Applied Geochemistry. 2006;21(5):890–897.
24. Driscoll CT, Mason RP, Chan HM, Jacob DJ, Pirrone N. Mercury as a global pollutant: sources, pathways, and effects. Environmental Science & Technology. 2013;47(10):4967–4983.
25. Dural M, Zararsız A, Özak AA. Bioaccumulation of heavy metals in muscle, liver, and gill tissues of Dicentrarchus labrax from the Aegean Sea, Turkey. Environmental Research. 2007;103(3):276–283.
26. Environmental Protection Agency (EPA). Water quality standards handbook. 2nd ed. Washington, DC: United States Environmental Protection Agency; c2012.
27. Fernandes C, Fontaínhas-Fernandes A, Peixoto F, Salgado MA. Bioaccumulation of heavy metals in Liza saliens from the Tagus Estuary, Portugal. Ecotoxicology and Environmental Safety. 2007;67(3):507–514.
28. Figueiredo-Fernandes A, Ferreira-Cardoso JV, Garcia-Santos S, Monteiro SM, Carrola J, Matos P, *et al.* Histopathological changes in *Anguilla anguilla* L. exposed to copper. Ecotoxicology and Environmental Safety. 2007;70(2):310–316.
29. Fleeger JW, Carman KR, Nisbet RM. Indirect effects of contaminants in aquatic ecosystems. Science of the Total Environment. 2003;317(1–3):207–233.
30. Förstner U, Wittmann GTW. Metal pollution in the aquatic environment. Berlin: Springer; c2012.
31. Gadd GM. Metals, minerals and microbes: geomicrobiology and bioremediation. Microbiology. 2010;156(3):609–643.
32. Giri S, Qiu Z. Understanding the relationship of land uses and water quality in the Twenty First Century: a review. Journal of Environmental Management. 2016;173:41–48.
33. Gleick PH. Water resources. In: Schneider SH, editor. Encyclopedia of climate and weather. Oxford: Oxford University Press; c1996. p. 817–823.
34. Gopal B. River conservation in India. International Journal of Ecology and Environmental Sciences. 2000;26(1):35–52.

35. Gupta SK, Singh AK. Role of pH and water hardness in controlling toxicity of heavy metals in aquatic systems. Environmental Science and Pollution Research. 2012;19(3):717–727.
36. Gupta SK, Rai AK, Pandey AK, Singh SK. Heavy metals in River Yamuna: a case study from Allahabad. Environmental Monitoring and Assessment. 2009;157(1–4):349–358.
37. Gupta S, Bhatnagar P, Mathur N, Sharma A. Heavy metal contamination and its impact on aquatic biota: a review. Environmental Science and Pollution Research. 2017;24(26):21467–21483.
38. Hayes TB, Falso P, Gallipeau S, Stice M. The cause of global amphibian declines: a developmental endocrinologist's perspective. Journal of Experimental Biology. 2010;213(6):921–933.
39. Heath AG. Water pollution and fish physiology. 2nd ed. Boca Raton: CRC Press; c1995.
40. Hinton DE. Histopathological biomarkers. In: Malins DC, Ostrander GK, editors. Aquatic toxicology. Boca Raton: CRC Press; c1994. p. 155–209.
41. Hinton DE, Laurén DJ. Liver structural alterations in fish: potential biomarkers of exposure. Aquatic Toxicology. 1990;17(1):51–66.
42. Horne AJ, Goldman CR. Limnology. 2nd ed. New York: McGraw-Hill; c1994.
43. Hutchison A. The Whanganui River as a legal person. Alternative Law Journal. 2014;39(3):179–182.
44. Immerzeel WW, van Beek LPH, Bierkens MFP. Climate change will affect the Asian water towers. Science. 2010;328(5984):1382–1385.
45. Intergovernmental Panel on Climate Change (IPCC). Climate change 2014: synthesis report. Geneva: IPCC; c2014.
46. Islam MS, Ahmed MK, Raknuzzaman M, Habibullah-Al-Mamun M, Masunaga S. Heavy metal pollution in the water and sediments of the Brahmaputra River basin, Bangladesh. Environmental Monitoring and Assessment. 2015;187(9):563.
47. Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. Toxicity, mechanism and health effects of some heavy metals. Interdisciplinary Toxicology. 2014;7(2):60–72.
48. Jabeen F, Chaudhry AS. Monitoring trace metals in different tissues of Cyprinus carpio from the Indus River, Pakistan. Environmental Monitoring and Assessment. 2010;170(1–4):645–656.
49. Jarup L. Hazards of heavy metal contamination. British Medical Bulletin. 2003;68(1):167–182.
50. Kalay M, Ay O, Canli M. Heavy metal concentrations in fish tissues from a polluted stream (Tersakan Stream, Turkey). Environmental Research. 2004;92(3):277–284.