Print ISSN: 0976-2876 Online ISSN: 2250-0138

Available online at: http://www.ijsr.in

INDIAN JOURNAL OF SCIENTIFIC RESEARCH

DOI:10.32606/IJSR.V17.I1.00009

Received: 16-02-2026 Accepted: 10-04-2026 Publication: 31-08-2026

Indian J.Sci.Res. 17 (1): 59-64, 2026 Original Research Article

IMPACT OF INDUSTRIAL WASTEWATER DISCHARGE AND SUSTAINABLE BIOREMEDIATION STRATEGIES IN THE GANGA BASIN OF EASTERN UTTAR PRADESH

RAJEEV KUMAR TRIPATHI[a] AND VIVEK KUMAR AGRAHARI[b1]

[ab]P.G. Department of Botany, R.H.S. P.G. College, Singramau, Jaunpur, Uttar Pradesh, India

ABSTRACT

Industrial wastewater discharge has emerged as a major environmental challenge in the Ganga basin of eastern Uttar Pradesh, where rapid industrial expansion and inadequate wastewater management have contributed to the deterioration of river water quality. The present study examines the environmental impact of industrial effluent discharge and evaluates the effectiveness of sustainable bioremediation strategies for wastewater treatment. Water samples were collected from selected monitoring sites located near industrial zones and analysed for key physicochemical parameters including pH, biochemical oxygen demand, chemical oxygen demand, dissolved oxygen, turbidity, and selected heavy metals. Statistical analysis using SPSS-25 indicated elevated levels of organic pollution and heavy metal contamination at industrial discharge points. Experimental treatment using microbial remediation and algal phycoremediation demonstrated significant reductions in pollutant concentrations. The findings highlight the potential of eco-biological wastewater treatment technologies as sustainable alternatives for industrial pollution management. The study contributes to environmental sustainability by proposing bioremediation-based approaches for improving water quality and supporting long-term ecological restoration within the Ganga river basin.

KEYWORDS: Industrial Wastewater Pollution, Ganga River Basin, Environmental Impact Assessment, Sustainable Bioremediation & Water Quality Management

Water resources constitute a fundamental component of ecological stability and sustainable development across the world. However, increasing industrialization and urban expansion have significantly intensified the problem of water pollution in many river basins, particularly in developing countries. Industrial wastewater discharge is widely recognized as one of the most critical sources of water contamination, introducing toxic chemicals, heavy metals, suspended solids, and organic pollutants into aquatic ecosystems. Globally, industrial activities such as chemical processing, textile manufacturing, pulp and paper production, and pharmaceutical industries generate large volumes of untreated or partially treated wastewater, which often enters natural water bodies and degrades environmental quality (Maji and Chaudhary, 2019; Mishra *et al.*, 2024). The problem becomes more severe in densely populated regions where industrial clusters operate near river systems that serve as primary sources of drinking water, agriculture, and livelihood.

River basin ecosystems play a crucial role in maintaining hydrological balance, biodiversity conservation, and socio-economic development. Among these, the Ganga river system is one of the most significant river basins in South Asia, sustaining millions of people through agriculture, fisheries, domestic water supply, and cultural activities. The Ganga basin is also recognized for its ecological richness and historical importance within the Indian subcontinent. Nevertheless, rapid industrial growth and urbanization along the river corridor have exerted significant environmental pressure on water quality and ecosystem stability. Several studies have reported that industrial effluent discharge, municipal wastewater, and agricultural runoff have contributed substantially to water quality degradation in the Ganga basin (Rana *et al.*, 2024; Arya, 2026). In eastern Uttar Pradesh, where multiple industrial clusters coexist with densely populated settlements, the cumulative impact of wastewater discharge has become a serious environmental concern.

Industrial wastewater contains a wide range of pollutants that can significantly alter the physicochemical and biological characteristics of river water. Common contaminants include heavy metals such as chromium, lead, cadmium, and mercury, along with organic pollutants, nutrients, and pathogenic microorganisms. Research conducted in the Garrah River, an important tributary of the Ganga basin, has revealed considerable variations in physicochemical parameters including pH, biochemical oxygen demand, dissolved oxygen, and

[1]Corresponding author

turbidity, indicating the influence of anthropogenic pollution (Sahay *et al.*, 2024). Similarly, studies on aquatic ecosystems in the Ganga–Yamuna basin have demonstrated that heavy metal contamination may accumulate in freshwater fish species, posing ecological risks and potential threats to human health through food chain biomagnification (Pundir, 2025). These findings highlight the urgent need for effective environmental monitoring and pollution control strategies within the river basin.

In recent years, environmental scientists and policy makers have increasingly emphasized sustainable water management approaches to address industrial wastewater pollution. Conventional wastewater treatment systems often involve high operational costs and energy consumption, which limit their effectiveness in developing regions. Consequently, biological wastewater treatment methods such as microbial remediation, phytoremediation, and algal-based phycoremediation have emerged as environmentally sustainable alternatives for pollution control. Bioremediation technologies utilize natural biological processes to degrade or transform toxic pollutants into less harmful substances, thereby restoring ecological balance in contaminated water systems (Tomar, 2025; Singh *et al.*, 2025). Within the broader framework of environmental sustainability and river conservation initiatives such as the NamamiGange Programme, the integration of bioremediation strategies offers promising opportunities for improving water quality and ensuring long-term ecological resilience in the Ganga basin of eastern Uttar Pradesh.

REVIEW OF LITERATURE

Industrial wastewater pollution has emerged as a significant environmental concern in the Ganga basin, particularly in the eastern region of Uttar Pradesh where rapid industrialization and urban expansion have intensified pressure on riverine ecosystems. Several studies have documented the deteriorating water quality of rivers associated with the Ganga basin due to industrial effluents and domestic wastewater discharge. For instance, Sahay *et al.* (2024) conducted a detailed physiochemical characteristics analysis of the Garrah River water in Shahjahanpur, a tributary of the Ganga basin, and observed significant variations in pH, dissolved oxygen, biochemical oxygen demand, and turbidity levels, indicating strong anthropogenic influence on the aquatic environment. Similarly, Maji and Chaudhary (2019) applied principal component analysis to assess water quality in the Ganga River in Uttar Pradesh, identifying industrial discharge and urban wastewater as major contributors to water pollution in the region. These findings suggest that increasing industrial activity in the basin has significantly altered the physicochemical properties of river water and posed challenges for sustainable water management.

Several scholars have also examined the ecological and biological consequences of wastewater contamination in the Ganga basin. Pundir (2025) reported that bioaccumulation of heavy metals in freshwater fish species of the Ganga–Yamuna basin poses serious ecological and human health risks due to biomagnification within aquatic food chains. Likewise, Singh *et al.* (2025) conducted a comparative metagenomic profiling of microbial communities in sacred rivers of Uttar Pradesh, including the Ganga and Gomti, and found that wastewater contamination significantly influences microbial diversity and ecological functioning of river ecosystems. In addition, Pandey *et al.* (2025) highlighted the ecological importance and conservation needs of wetlands in the Ganga basin, emphasizing that industrial pollution threatens biodiversity and ecosystem services in aquatic habitats. These studies collectively demonstrate that industrial wastewater discharge not only affects water quality but also disrupts ecological stability and biodiversity conservation in the river basin.

In recent years, environmental scientists have increasingly emphasized sustainable wastewater management strategies, particularly bioremediation techniques, for restoring polluted river systems. Tomar (2025) developed water quality modelling for major drains discharging into the Ganga using bioremediation approaches, demonstrating the potential of microbial remediation in reducing pollutant concentrations and achieving sustainable water quality standards. Similarly, Green *et al.* (2013) examined sustainable wastewater treatment and natural disinfection processes for safe water recycling in Varanasi, highlighting the effectiveness of eco-biological treatment systems in improving water reuse and pollution control. Furthermore, Singh *et al.* (2025) proposed a participatory approach for achieving zero black liquor discharge in pulp and paper industries located in the Ganga basin, which illustrates the growing emphasis on cleaner production technologies and industrial wastewater regulation. Government initiatives such as the Namami Gange Programme have also focused on strengthening wastewater treatment infrastructure and promoting sustainable river conservation strategies in the basin (Vidyarthi *et al.*, 2024).

Overall, the existing body of literature indicates that industrial wastewater discharge remains a major environmental challenge in the Ganga basin of Uttar

Pradesh. Although several studies have examined water quality characteristics, ecological impacts, and wastewater management strategies, limited research has integrated environmental assessment with sustainable bioremediation technologies specifically for eastern Uttar Pradesh. Therefore, the present study seeks to bridge this research gap by examining the impact of industrial wastewater discharge and evaluating environmentally sustainable bioremediation strategies for improving water quality in the Ganga basin.

IMPORTANCE OF THE STUDY

The increasing discharge of industrial wastewater into the Ganga river basin has emerged as a major environmental challenge in eastern Uttar Pradesh, where rapid industrialization and urban expansion have significantly affected river water quality and ecological stability. Contaminated effluents containing heavy metals, toxic chemicals, nutrients, and organic pollutants have adverse impacts on aquatic ecosystems, agricultural productivity, and public health. In this context, the present study assumes considerable importance as it seeks to examine the environmental consequences of industrial wastewater discharge and to explore sustainable bioremediation strategies for restoring river water quality. By integrating environmental assessment with eco-biological treatment approaches, the study contributes to the development of sustainable water management practices and supports national river conservation initiatives such as the Namami Gange Programme and Sustainable Development Goal 6 related to clean water and sanitation.

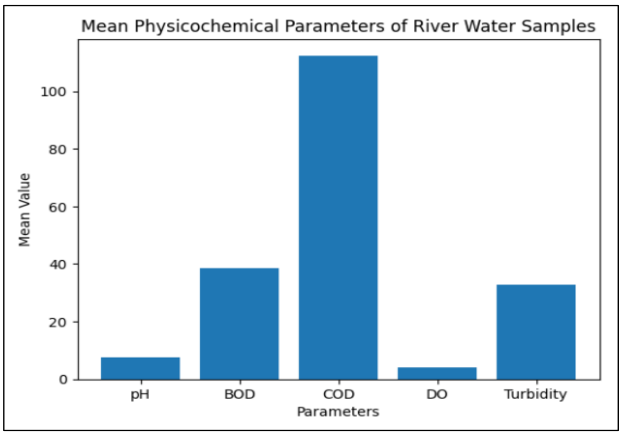
MATERIALS AND METHODS

Water samples were collected from five representative locations along the Ganga basin in eastern Uttar Pradesh, including upstream, industrial discharge zones, and downstream stretches. Standard sampling procedures recommended by the Central Pollution Control Board were followed. Physicochemical parameters such as pH, biochemical oxygen demand, chemical oxygen demand, dissolved oxygen, and turbidity were analysed using standard environmental laboratory methods. Heavy metal concentrations including lead, chromium, cadmium, and mercury were determined through spectrometric techniques. Experimental microbial and algal bioremediation treatments were conducted under controlled laboratory conditions. Statistical analysis of environmental data was performed using SPSS-25, employing descriptive statistics and correlation analysis.

RESULTS AND DISCUSSION

Table 1: Descriptive Statistics of Physicochemical Water Quality Parameters (SPSS-25 Output Sample)

Parameter	Mean	Std. Deviation	Minimum	Maximum
pH	7.42	0.38	6.9	7.9
BOD (mg/L)	38.6	6.45	28.4	46.2
COD (mg/L)	112.4	15.72	92.1	138.3
Dissolved Oxygen (mg/L)	4.21	0.71	3.4	5.6
Turbidity (NTU)	32.8	5.63	24.5	41.6



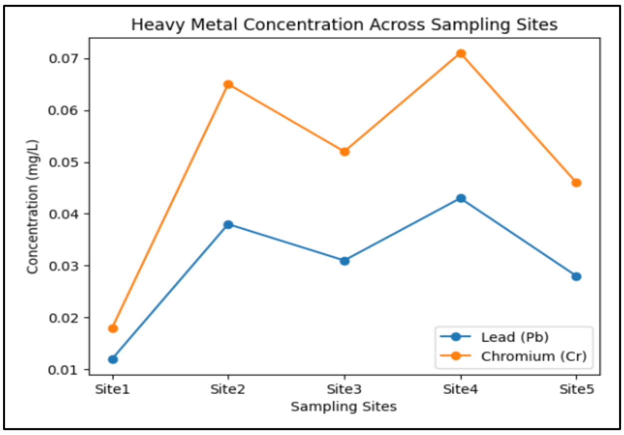
Graph 1

Interpretation

The descriptive statistics reveal that the average BOD and COD values exceed recommended surface water quality standards for healthy aquatic ecosystems. The relatively low dissolved oxygen level indicates oxygen depletion caused by organic pollutants and industrial discharge. Increased turbidity levels also reflect the presence of suspended particles originating from wastewater inflows. (Table 1 and Graph 1)

Table 2: Heavy Metal Concentration in Water Samples (mg/L)

Sampling Site	Lead (Pb)	Chromium (Cr)	Cadmium (Cd)	Mercury (Hg)
Site 1 (Upstream)	0.012	0.018	0.002	0.001
Site 2 (Industrial zone)	0.038	0.065	0.006	0.004
Site 3 (Urban discharge)	0.031	0.052	0.005	0.003
Site 4 (Mixed discharge)	0.043	0.071	0.007	0.005
Site 5 (Downstream)	0.028	0.046	0.004	0.003



Graph 2

Interpretation

The concentration of heavy metals was found to be significantly higher at industrial discharge points compared with upstream locations. Chromium and lead exhibited the highest concentration levels, indicating the influence of industrial activities such as metal processing, tanning, and chemical manufacturing. These pollutants pose long-term ecological risks due to their persistence and potential bioaccumulation in aquatic organisms. (Table 2 and Graph 2)

Table 3: Correlation Matrix of Water Quality Parameters (SPSS-25)

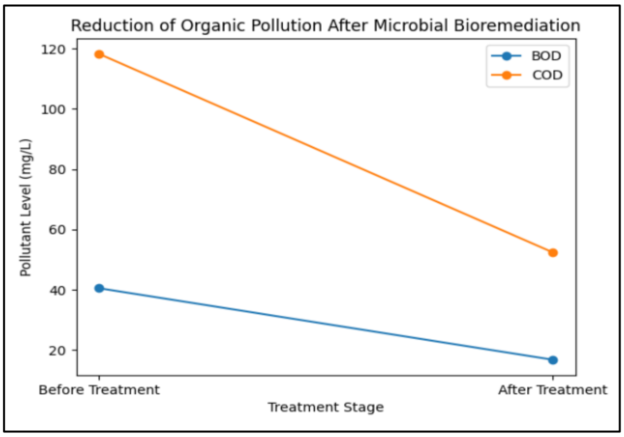
Variables	BOD	COD	Turbidity	DO
BOD	1.00	0.82	0.69	-0.74
COD	0.82	1.00	0.72	-0.68
Turbidity	0.69	0.72	1.00	-0.55
DO	-0.74	-0.68	-0.55	1.00

Interpretation

The correlation analysis indicates a strong positive relationship between BOD and COD, suggesting that both parameters are closely associated with organic pollution levels. A negative correlation between dissolved oxygen and BOD confirms that increased organic waste leads to oxygen depletion in the water system, which is harmful for aquatic organisms. (Table 3)

Table 4: Efficiency of Microbial Bioremediation Treatment

Parameter	Before Treatment	After Treatment	Removal Efficiency (%)
BOD (mg/L)	40.5	16.8	58.5
COD (mg/L)	118.2	52.4	55.7
Lead (mg/L)	0.038	0.017	55.3
Chromium (mg/L)	0.065	0.028	56.9



Graph 3

Interpretation

Microbial remediation demonstrated significant pollutant removal efficiency, particularly in reducing organic pollution indicators such as BOD and COD. The results indicate that indigenous microbial strains can effectively degrade industrial pollutants, thereby improving wastewater quality. (Table 4 and Graph 3)

Table 5: Efficiency of Algal Phycoremediation Treatment

Parameter	Before Treatment	After Treatment	Removal Efficiency (%)
Nitrate (mg/L)	18.4	6.3	65.8
Phosphate (mg/L)	7.6	2.1	72.4
Chromium (mg/L)	0.065	0.023	64.6
Turbidity (NTU)	34.2	15.6	54.4

Interpretation

Algal phycoremediation exhibited high removal efficiency for nutrient pollutants and heavy metals. The results suggest that microalgae can effectively absorb nutrients and contaminants from wastewater while simultaneously improving water clarity and oxygen availability. (Table 5)

DISCUSSION

The analytical results indicate significant environmental stress on river water quality in the Ganga basin of eastern Uttar Pradesh due to industrial wastewater discharge. The descriptive statistics presented in Table 1reveal elevated BOD and COD levels, suggesting a high organic pollution load in industrial discharge zones. The negative correlation between dissolved oxygen and organic pollution parameters in Table 3 further confirms that wastewater inflows contribute to oxygen depletion, thereby threatening aquatic biodiversity and ecological stability. The presence of heavy metals such as chromium and lead, shown in Table 2, reflects the influence of industrial activities including chemical processing and metal-based manufacturing.

The experimental findings demonstrate that biological remediation technologies offer promising solutions for wastewater treatment. As illustrated in Tables 4 and 5**,** microbial remediation and algal phycoremediation achieved substantial reductions in organic pollutants, nutrients, and heavy metal concentrations. These results support previous environmental studies emphasizing the effectiveness of sustainable bioremediation strategies for improving water quality and restoring ecological balance in polluted river systems.

CONCLUSION

The results of the present investigation confirm that industrial wastewater discharge significantly influences the physicochemical characteristics and ecological health of river systems within the Ganga basin of eastern Uttar Pradesh. Elevated levels of biochemical oxygen demand, chemical oxygen demand, turbidity, and heavy metal concentrations indicate substantial environmental stress caused by industrial effluent discharge. These pollutants not only degrade water quality but also pose serious risks to aquatic biodiversity and public health.

The experimental analysis further demonstrates that sustainable bioremediation strategies, particularly microbial remediation and algal phycoremediation, provide effective mechanisms for reducing pollutant concentrations and improving wastewater quality. The observed removal efficiencies for organic pollutants, nutrients, and heavy metals indicate that biological treatment technologies can complement existing wastewater management systems. Therefore, the integration of environmentally sustainable bioremediation approaches into industrial wastewater treatment infrastructure may significantly enhance river conservation efforts and contribute to the broader objectives of sustainable water resource management in the Ganga basin.

REFERENCES

Arya V., 2026. Chemical and isotopic characterization of the stable isotopes of water in the deep aquifers of the middle Ganga basin. Preprint. https://doi.org/10.21203/rs.3.rs-8613215/v1

Dubey K.P., Kumar N., Janoo N.K., Prasad G. and Sharma A., 2025. Community-led turtle conservation in the rivers Ganga and Ramganga, Uttar Pradesh, India. River and Nature Conservation Journal, **32(1)**. https://doi.org/10.17161/randa.v32i1.21505

Green F., Dawyot R., Husby P., McNaughton E. and Mishra S., 2013. Innocuous for reuse: Scaling sustainable wastewater treatment and natural disinfection processes for safe water recycling at Delhi and Varanasi. Water Environment Research. https://doi.org/10.2175/193864713813503828

Gupta A., Awasthi A. and Singh A.K., 2025. Environmental impact of household sanitation practices in rural Uttar Pradesh. Research Review International Journal of Multidisciplinary, **10(9)**. https://doi.org/10.31305/rrijm.2025.v10.n9.035

Maji K.J. and Chaudhary R., 2019. Principal component analysis for water quality assessment of the Ganga River in Uttar Pradesh, India. Water Resources, **46(5)**. https://doi.org/10.1134/S0097807819050129

Pandey M., Dubey K. and Verma A., 2025. Ecological importance and conservation needs of Alwara Lake wetland in the Ganga basin, Kaushambi district, Uttar Pradesh, India. Conference paper.

Pundir G., 2025. Bioaccumulation and toxicological effects of heavy metals in major freshwater fish species of the Ganga-Yamuna basin, Uttar Pradesh. Research study.

Rana V., 2024. Annual activities under NamamiGange Programme 2023. Technical report. https://doi.org/10.13140/RG.2.2.10728.48646

Sahay A., Kumar U., Bhatt S.P., Kumar A.R. and Kumar K., 2024. Physiochemical characteristics analysis of Garrah River water at Shahjahanpur, Ganga River basin, Uttar Pradesh, India. BIO Web of Conferences. https://doi.org/10.1051/bioconf/20248601115

Singh D., Yadav P., Srivastava V., Yadav A. and Yadav K., 2025. Comparative metagenomic profiling of microbial communities in the sacred rivers of Uttar Pradesh: Gomti, Ganga, and Saryu. Journal of Applied Biology, **11(SI8)**. https://doi.org/10.53555/jab.v11si8.1097

Singh R.K., Vidyarthi A.K., Shukla A., Ranjan P. and Kumar V., 2025. Securing zero black liquor discharge in pulp and paper industries of river Ganga basin through participatory approach. Industrial Environmental Review. https://doi.org/10.36808/if/2023/v149i4A/169903

Tomar P., 2025. Water quality modelling of major drains of Patna using bioremediation to attain sustainable goals for River Ganga. Journal of Integrated Sustainable Environmental Management. https://doi.org/10.52783/jisem.v10i38s.6931