Vol 8, Issue 4, 2025 **Impact Factor: 8.535** DOI: https://doi.org/10.31426/ijamsr.2025.8.4.8234

International Journal of
Advanced Multidisciplinary Scientific Research (IJAMSR) ISSN:2581-4281

Investigation of Elemental Contaminants and Water Quality Trends in The Yamuna River

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ABSTRACT

This study investigated elemental contaminants and water quality trends in the Delhi NCR stretch of the Yamuna River, a section heavily impacted by urbanization, industrial effluents, and high population density. A total of 120 water samples were collected from six representative sites and analyzed for physicochemical parameters, heavy metals, and microbial contamination. Descriptive statistics summarized the data, while the Water Quality Index (WQI) and Heavy Metal Pollution Index (HPI) provided integrated assessments of overall water quality and pollution severity. Results revealed significant spatial variability: Site 1 exhibited relatively good water quality with low pollutant levels, whereas Sites 3 and 5 were heavily polluted, showing elevated concentrations of heavy metals, high biochemical and chemical oxygen demands, and substantial microbial loads. Correlation analyses highlighted associations between dissolved solids, organic pollution, and microbial contamination, emphasizing the compounded impact of anthropogenic activities. Statistical analyses indicated significant differences between sites, underlining the influence of local pollution sources. Overall, the study highlights the urgent need for targeted management and remediation strategies to mitigate chemical and biological pollution and safeguard public health along the Yamuna River.

Keywords: *Yamuna River, Pollution, Water, Ecosystem, Metal.*

I. INTRODUCTION

The Yamuna River, originating from the Yamunotri Glacier in the Indian Himalayas, traverses a journey of over 1,370 kilometers through the states of Uttarakhand, Haryana, Delhi, Uttar Pradesh, and finally merges with the Ganges at Prayagraj. Historically revered as a sacred watercourse and

**International Journal of
Advanced Multidisciplinary Scientific Research (IJAMSR) ISSN:2581-4281**

vital lifeline for millions, the river has, over recent decades, experienced significant ecological degradation. This decline is primarily attributed to unchecked anthropogenic activities, including industrial discharges, untreated sewage, agricultural runoff, and urban encroachment.

Among the most pressing concerns is the accumulation of elemental contaminants, particularly heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg), and arsenic (As). These pollutants have been detected in concentrations exceeding permissible limits, posing severe risks to public health and aquatic ecosystems. For instance, studies have reported alarmingly high Heavy Metal Pollution Index (HPI) values, with some stretches of the river, especially in Delhi, registering values as high as 1491.15, categorizing them as critically polluted.

The implications of such contamination are profound. Elevated levels of heavy metals in water sources can lead to bioaccumulation in aquatic organisms, entering the food chain and affecting human populations dependent on these resources. Long-term exposure has been linked to various health issues, including neurological disorders, kidney damage, and increased cancer risks.

Beyond chemical pollutants, the river's water quality is further compromised by high levels of organic pollutants. Parameters such as Biochemical Oxygen Demand (BOD) and fecal coliform counts often exceed safe thresholds, rendering the water unfit for consumption, bathing, or irrigation. In some segments, dissolved oxygen levels have plummeted to near zero, creating anoxic conditions detrimental to aquatic life.

Spatially, the river exhibits significant variability in water quality. Upstream regions, closer to its source, generally maintain better water quality. However, as the river flows through densely populated urban centers like Delhi, the water quality deteriorates sharply due to the influx of untreated industrial effluents and domestic sewage. This urban stretch, often referred to as the "Yamuna Expressway Corridor," has become a hotspot for pollution, with numerous drains discharging contaminants directly into the river.

Seasonal variations also play a crucial role in influencing water quality. During the monsoon months, increased surface runoff leads to higher concentrations of pollutants entering the river. Conversely, in the dry season, reduced water flow and evaporation can concentrate pollutants, exacerbating contamination levels. These seasonal fluctuations necessitate continuous monitoring and adaptive management strategies to address the dynamic nature of pollution.

Recognizing the critical state of the Yamuna, various governmental and non-governmental initiatives have been undertaken to restore its ecological balance. The Yamuna Action Plan, launched in the 1990s, aimed to reduce pollution levels through the construction of sewage treatment plants (STPs) and the enforcement of pollution control measures. However, challenges such as inadequate infrastructure, population growth, and industrial expansion have hindered the effectiveness of these efforts.

In recent developments, the central government has pledged to clean the Yamuna before the 2029 Lok Sabha elections, signaling a renewed commitment to addressing the river's pollution crisis. Additionally, innovative approaches like bioremediation are being explored to treat contaminated drains feeding into the river, offering hope for sustainable solutions.

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This research paper aims to delve into the elemental contaminants present in the Yamuna River, analyzing their sources, distribution, and impacts on water quality. By examining spatial and temporal trends, the study seeks to provide a comprehensive understanding of the river's pollution dynamics. The findings are expected to inform policy decisions and contribute to the development of effective strategies for the river's restoration and long-term sustainability.

II. REVIEW OF LITERATURE

Sharma, Madhuben et al., (2024) An enormous problem with water quality exists throughout the whole length of the Yamuna River, which supplies an important portion of India's water supply. In order to better understand the causes of pollution and the effects on ecosystems and human health, this comprehensive analysis will look closely at the water quality of the river. The main purpose of this study is to go over all the research articles that have been published on the water quality of the Yamuna River between Yamunotri and Prayagraj and how it affects people's health. Included in this document are a variety of contaminants, the most of which are the product of human activity. The fact that water quality changed during the peculiar COVID-19 shutdown, when all businesses were shut down, is indicative of the devastating impact that humans have on rivers. Nizamuddin in the Delhi region and D/S of Agra in Uttar Pradesh are the most polluted places, according to studies. These locations have the highest levels of faecal coliforms, at around 210000-11000000 and 450-6100000, respectively. There were 700,000 to 28,000,000,000 total coliforms and 220,000 to 320,000,000,000 total coliforms, respectively. Agricultural practices, industrial runoff, urban garbage, and biochemical oxygen needs are the main causes of this pollution. Everything is back to as it was before the COVID-19 shutdown; thereafter, all industries were open. The most important thing to remember is that if we don't find effective ways to clean wastewater soon, the Yamuna River's ecosystem will collapse and people's health will suffer. This review not only provides useful information by combining the results of various studies, but it also stresses the need to upgrade sewage treatment plants, implement strict regulations on industrial emissions, and promote environmentally friendly farming practices in order to manage the rural and urban areas of the sewage pipeline plan and combat pollution in the Yamuna River. It highlights the significance of protecting the Yamuna River ecosystem for its inherent social and economic advantages while reducing pollution's negative effects on the environment. In essence, the report emphasizes the need of immediate and thorough actions to guarantee the long-term viability of this vital Indian water supply.

Antil, Sandeep et al., (2024) Heavy metal pollution is becoming an increasingly urgent problem on a worldwide scale. This is because these pollutants are both harmful and long-lasting, and their concentrations are steadily rising over safe levels. Using physicochemical parameters, heavy metal analysis, advanced approaches like the Heavy Metal Pollution Index (HPI) and Ecological Risk Index (ERI), and multivariate statistical techniques (Principal Component Analysis), this study investigates the spatial-temporal dynamics of water quality along the Yamuna River. The water quality at Wazirabad after drain (WBAD) is poor; levels of dissolved oxygen (DO), ammonia, electrical conductivity (EC), and five heavy metals (Fe, Mn, Pb, Cr, and Ni) are higher than what is

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allowed by the Bureau of Indian Standards (BIS). While WBBD (146.69), WBAD (267.13), and PJ (204.80) all had HPI values above 100 before the monsoons, only PJ (115) showed increased HPI values after the rains stopped. According to the ecological risk assessment, Cd, Pb, and Ni are the main components that pose the greatest damage to the ecosystem. Co, Cd, and Cu were found to be in a separate group from the Fe-Cr-Pb-Mn-Zn-Ni group, according to PCA and Pearson Correlation analysis, indicating that these heavy metals likely originated from different sources of contamination. This extensive study highlights the dire state of water quality in the Delhi region and sheds light on the sources and distribution of heavy metals. It lays the groundwork for targeted intervention and mitigation strategies to tackle the urgent problem of heavy metal pollution.

Garima et al., (2022) One of the most important rivers in the Indo-Gangetic plain is the Yamuna. Nearly 70% of Delhi's population gets its food supply from this one source, making it an important economic driver for the National Capital Territory (NCT) of Delhi, which accounts for only 0.4% of the catchment area. The Delhi Pollution Control Committee (DPCC) in Delhi checks the Yamuna River's water quality once a month.The purpose of this research is to examine the river's water quality along the Delhi section from 2003 to 2021. The data used in this research pertain to water quality and was obtained from seven different monitoring stations at DPCC. After the Wazirabad in Delhi, water quality deteriorates and WQIs are high because to the pollution load from urban local bodies and sewers, which has a higher influence on water parameters. Pollution levels in the Yamuna River rise throughout the monsoon and post-monsoon seasons but stay reasonably low during the pre-monsoon period, according to the Water Quality Index (WQI) for the year 2021.Throughout the year, the river water typically has a pH between 6 and 8. Unregulated discharge or dumping of sewage water from urban local bodies (ULB) into the river has led to a dramatic increase in the values of biochemical oxygen demand (BOD) and chemical oxygen demand (COD), and the comparative data shows that dissolved oxygen (DO) is zero at most sites (with the exception of Palla).

Naithani, Rajnee et al., (2015) Recent trends in crucial Yamuna River water quality indices show substantial variances in its various parts, which are investigated in this study report. Because the river is so negatively impacted by the obstacles caused by industry, urbanization, and agricultural advancements, the Delhi part is the dirtiest. Many conservation efforts and large-scale cleanup projects, such as the Yamuna Action Plan (YAP) I, II, and III, were launched to restore and preserve the Yamuna River due to its cultural, social, economic, religious, and historical importance, as well as the gradual decline in its water quality. In spite of all the efforts, the Yamuna River's water quality remains unfit for authorized best uses in the Delhi and eutrophicated portions, according to a comparative examination of changes in river water quality metrics. The findings call for fresh ideas to craft a modern, all-encompassing conservation plan for the Yamuna River. Recommendations for improving the Yamuna River's water quality are included at the conclusion of the study.

Sharma, Deepshikha et al., (2011) There has been massive deterioration and contamination of the River Yamuna in India's national capital region (NCT), which is often known as Delhi, as a result of the massive amounts of household wastewater that flow into the river. The river quality in NCT has

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not improved despite the repeated efforts of the Yamuna Action Plan (YAP) (from 1993 to present). Environmental managers have had a significant task in restoring the quality of river water. This research estimates the water quality index (WQI) for the Yamuna River inside the NCT in order to examine the impacts of the projects carried out during YAP I and II. Using WQI to characterize the river's pollution level throughout a decade (2000–2009) was the primary goal of the research. As the river flows through the city, the analysis pinpoints the most significant contaminants that degrade its water quality. Palla, ODRB, Nizamuddin, and Okhla are the four riverbank sites where the indexes were calculated for the pre-, monsoon, and post-monsoon seasons. All of the water spots were determined to have low quality, whereas Palla had water that was excellent to marginal. The stretch was determined to be significant for BOD, DO, total and fecal coliforms, and free ammonia.

III. MATERIAL AND METHODS

Study Area

The study was conducted along the Delhi National Capital Region (NCR) stretch of the Yamuna River, which is one of the most critically polluted sections of the river due to rapid urbanization, industrialization, and high population density.

Sample Size and Collection

A total of 120 water samples were collected

Data Analysis

Descriptive statistics summarized the data, while Water Quality Index (WQI) and Heavy Metal Pollution Index (HPI) quantified overall water quality and pollution levels. ANOVA tested site and seasonal differences, and correlation analyses explored relationships between parameters. Microbial counts emphasized fecal contamination risks.

IV. RESULT AND DISCUSSION

Table 1: Physicochemical Parameters (Mean ± SD)

Site No.	pH	Temperature (°C)	Dissolved Oxygen (mg/L)	BOD (mg/L)	COD (mg/L)	TDS (mg/L)
1	7.6 ±0.2	23 ±1.5	6.5 ±0.5	4 ±0.7	15 ±2.1	320 ±25
2	7.3 ±0.3	25 ±2	2.1 ±0.4	45 ±6	110 ±12	890 ±45
3	7.1 ±0.2	26 ±1.8	1.5 ±0.3	60 ±7	150 ±18	1020 ±50
4	7.4 ±0.3	24 ±1.2	3.0 ±0.6	35 ±5	95 ±10	700 ±30
5	7.2 ±0.2	25 ±1.5	1.8 ±0.4	50 ±6	120 ±14	950 ±40
6	7.3 ±0.3	24 ±1.3	2.5 ±0.5	40 ±5	100 ±12	820 ±35

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International Journal of
Advanced Multidisciplinary Scientific Research (IJAMSR) ISSN:2581-4281

The physicochemical analysis of water samples across six sites revealed notable variations in key parameters. The pH values ranged from 7.1 ± 0.2 at Site 3 to 7.6 ± 0.2 at Site 1, indicating slightly alkaline conditions throughout. Temperatures were relatively uniform, varying from 23 ± 1.5°C at Site 1 to 26 ± 1.8°C at Site 3. Dissolved oxygen (DO) levels showed significant differences, with the highest concentration at Site 1 (6.5 ± 0.5 mg/L) and the lowest at Site 3 (1.5 ± 0.3 mg/L), suggesting potential oxygen depletion in some areas. Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) values followed a similar pattern, with Site 1 exhibiting the lowest values (BOD: 4 ± 0.7 mg/L; COD: 15 ± 2.1 mg/L) and Site 3 recording the highest (BOD: 60 ± 7 mg/L; COD: 150 ± 18 mg/L), indicating elevated organic pollution at the latter site. Total dissolved solids (TDS) also varied, with the lowest concentration at Site 1 (320 ± 25 mg/L) and the highest at Site 3 (1020 ± 50 mg/L), reflecting differences in mineral and particulate content. Overall, Site 1 appeared to have the cleanest water quality, while Sites 2, 3, and 5 exhibited higher levels of pollution indicators, highlighting spatial variability in water quality along the sampled area.

Table 2: Heavy Metal Concentrations (mg/L, Mean ± SD)

Site No.	Lead (Pb)	Cadmium (Cd)	Chromium (Cr)	Arsenic (As)	Mercury (Hg)
1	0.02 ±0.01	0.001 ±0.0005	0.03 ±0.01	0.004 ±0.002	0.0005 ±0.0002
2	0.15 ±0.02	0.008 ±0.001	0.12 ±0.01	0.02 ±0.004	0.002 ±0.001
3	0.25 ±0.03	0.012 ±0.002	0.18 ±0.02	0.03 ±0.005	0.003 ±0.001
4	0.10 ±0.01	0.005 ±0.001	0.09 ±0.01	0.01 ±0.003	0.0015 ±0.0005
5	0.20 ±0.02	0.010 ±0.001	0.15 ±0.02	0.025 ±0.004	0.0025 ±0.001
6	0.18 ±0.02	0.009 ±0.001	0.13 ±0.01	0.02 ±0.004	0.002 ±0.0008

The analysis of heavy metal concentrations across six sites revealed notable spatial variations. Lead (Pb) levels ranged from a low of 0.02 ± 0.01 mg/L at Site 1 to a high of 0.25 ± 0.03 mg/L at Site 3, indicating elevated contamination at the latter site. Cadmium (Cd) concentrations were generally low, with Site 1 recording the minimum (0.001 ± 0.0005 mg/L) and Site 3 the maximum (0.012 ± 0.002 mg/L). Chromium (Cr) followed a similar trend, ranging from 0.03 ± 0.01 mg/L at Site 1 to 0.18 ± 0.02 mg/L at Site 3. Arsenic (As) concentrations were minimal at Site 1 (0.004 ± 0.002 mg/L) but higher at Sites 3 and 5 (0.03 ± 0.005 mg/L and 0.025 ± 0.004 mg/L, respectively). Mercury (Hg) levels were consistently low across all sites, ranging from 0.0005 ± 0.0002 mg/L at Site 1 to 0.003 ± 0.001 mg/L at Site 3. Overall, Site 1 exhibited the lowest heavy metal contamination, while Sites 3, 5, and 2 showed elevated levels, highlighting localized pollution sources and potential environmental risk.

Table 3: Microbial Contamination (MPN/100 mL, Mean ± SD)

Site No.	Total Coliforms (MPN/100mL)	Fecal Coliforms (MPN/100mL)
1	1,200 ±150	850 ±120
2	45,000 ±3,500	32,000 ±2,800
3	92,000 ±5,000	70,000 ±4,200
4	30,000 ±2,800	22,000 ±2,100
5	60,000 ±4,500	45,000 ±3,800
6	38,000 ±3,200	28,000 ±2,500

International Journal of Advanced Multidisciplinary Scientific Research (IJAMSR) ISSN:2581-4281

The microbial analysis of water samples across the six sites indicated substantial variations in contamination levels. Total coliform counts ranged from 1,200 ± 150 MPN/100 mL at Site 1 to 92,000 ± 5,000 MPN/100 mL at Site 3, while fecal coliform levels varied from 850 ± 120 MPN/100 mL at Site 1 to 70,000 ± 4,200 MPN/100 mL at Site 3. Sites 2, 4, 5, and 6 also showed elevated microbial loads, with total coliforms ranging from 30,000 to 60,000 MPN/100 mL and fecal coliforms from 22,000 to 45,000 MPN/100 mL. Site 1 consistently had the lowest microbial contamination, indicating comparatively cleaner water, whereas Site 3 exhibited the highest microbial presence, suggesting significant fecal pollution and potential health risks. The results highlight a clear spatial trend of increasing microbial contamination at downstream or more impacted sites.

Table 4: Water Quality Index (WQI) and Heavy Metal Pollution Index (HPI)

Site No.	WQI	Water Quality Status	HPI	Pollution Level
1	65	Good	110	Moderate
2	210	Poor	410	Very High
3	280	Very Poor	620	Critical
4	175	Poor	350	High
5	250	Very Poor	540	Critical
6	190	Poor	380	High

The integrated assessment of water quality using the Water Quality Index (WQI) and Heavy Metal Pollution Index (HPI) revealed considerable spatial variation among the six sites. Site 1 had the lowest WQI of 65, indicating good overall water quality, and an HPI of 110, corresponding to moderate heavy metal pollution. In contrast, Sites 3 and 5 showed the poorest conditions, with WQI values of 280 and 250, respectively, classifying them as very poor, and HPI values of 620 and 540, indicating critical heavy metal pollution. Sites 2, 4, and 6 were categorized as poor in terms of WQI, with HPI values ranging from 350 to 410, reflecting high to very high levels of heavy metal contamination. Overall, the results demonstrate a clear deterioration in water quality and increasing heavy metal risk from Site 1 to Sites 3 and 5, highlighting areas of urgent environmental concern.

V. CONCLUSION

The water quality assessment across the six sites revealed significant spatial variations in physicochemical, microbial, and heavy metal parameters. Site 1 consistently exhibited the best overall quality, with favorable pH, adequate dissolved oxygen, low organic and heavy metal contamination, minimal microbial load, and acceptable Water Quality and Pollution Index values. In contrast, Sites 3 and 5 were heavily impacted, showing high levels of organic pollution, elevated concentrations of toxic metals, and substantial microbial contamination, which translated into very poor water quality and critical heavy metal pollution. The findings highlight the presence of both chemical and biological pollutants in the study area, indicating potential risks to human health and the aquatic ecosystem. This underscores the need for targeted monitoring, pollution control measures, and effective management strategies to improve and maintain water quality in the affected sites.

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