



Assessment of water quality and heavy metal contamination in the Yamuna River across different locations in Agra city

Shweta Verma, Ravi Prakash, Pancham Kumar

Department of Chemistry, B.S.A. College, Mathura, Uttar Pradesh, India

Abstract

The Yamuna River, regarded as a sacred river and a primary water source for several cities, is experiencing severe pollution due to the continuous discharge of untreated sewage and industrial effluents into its surface waters. Rapid urban expansion, industrial development, and increasing population pressure have significantly contributed to this degradation, particularly through the introduction of heavy metals. The present study aimed to conduct a comprehensive assessment of water quality and heavy metal contamination in the Yamuna River at different locations within Agra city during pre-monsoon and post-monsoon periods. The findings indicate that concentrations of zinc (Zn) and copper (Cu) remained within acceptable limits, whereas levels of iron (Fe), chromium (Cr), manganese (Mn), and zinc (Zn) showed an increase during the post-monsoon season. Elevated chromium levels are likely associated with effluents from leather processing industries in the region. Among all the sampling sites, the Taj Ganj area exhibited comparatively higher pollution levels, indicating a more critical water quality condition than other locations studied.

Keywords: Heavy metals, dissolved oxygen, biological oxygen demand, pH

Introduction

The Yamuna River, one of the most revered rivers and a major source of water for many cities, plays a crucial role in sustaining urban populations. However, its water quality has been steadily deteriorating due to the continuous discharge of untreated sewage into surface waters, driven by rapid urbanization and increasing population pressure^[1, 2, 3]. Water pollution can be described as the introduction of harmful substances into natural environmental components, leading to adverse effects on human health, living organisms, ecological balance, and the functional integrity of the environment^[4, 8].

The degradation of water quality is largely attributed to the accumulation of organic pollutants and heavy metals in both surface and groundwater systems. This contamination originates from urban and semi-urban development activities, disposal of domestic sewage, large-scale waste dumping, unregulated mining operations, and increased sedimentation within urban regions. These factors collectively contribute to the deterioration of aquatic ecosystems and pose significant risks to human health^[4, 6]. Statistical projections indicate that by the year 2025, nearly two-thirds of the global population may experience water scarcity, alongside a substantial rise in pollution levels^[9, 12]. The primary contributors to the rapid decline in river water quality include industrial discharges and organic waste inputs. Furthermore, studies conducted by TERI have highlighted that even moderate concentrations of toxic metals significantly contribute to the pollution of Yamuna River water^[13, 15].

Heavy metals refer to a group of elements, generally including transition metals, characterized by their metallic properties and potential toxicity. The presence of these metals, along with other hazardous substances, has significantly impacted both the quality and availability of groundwater and surface water. According to a WHO report (2006), approximately 80% of human diseases are linked to the consumption of contaminated groundwater, making such pollution a major contributor to toxicity in aquatic systems

^[5]. The concentration of heavy metals in water bodies has increased due to industrial effluents and the leaching of metal ions into rivers and lakes, often facilitated by acid rain^[9, 14, 15].

The persistence of these toxic metals in aquatic environments poses serious threats to both aquatic life and overall ecosystem stability, as they tend to accumulate over time in water bodies^[6, 12]. Certain metals such as cobalt (Co), copper (Cu), nickel (Ni), chromium (Cr), manganese (Mn), iron (Fe), magnesium (Mg), and molybdenum (Mo) are essential for various biochemical and physiological processes. However, these elements are beneficial only at trace concentrations and become toxic when their levels exceed permissible limits. In contrast, non-essential heavy metals, including gold (Au), lead (Pb), lithium (Li), mercury (Hg), platinum (Pt), silver (Ag), titanium (Ti), vanadium (V), and cadmium (Cd), are inherently toxic even at very low concentrations^[9, 15, 10].

Monitoring and controlling heavy metal contamination in river systems is critically important, as these metals tend to accumulate and magnify through food chains, posing severe risks to both living organisms and the environment due to biomagnification^[16, 17]. The overall level of heavy metal pollution in water bodies can be assessed using the Heavy Metal Pollution Index (HPI), which evaluates the combined impact of individual metal ions on overall water quality^[18, 20]. Although several studies have examined heavy metal contamination in the Yamuna River, limited research has addressed both urban and rural stretches comprehensively. Therefore, the present study aims to evaluate the concentration of metal ions in the Yamuna River in Agra, the city of the Taj Mahal, during pre-monsoon and post-monsoon seasons.

Materials and Methods

1. Sample Collection and Analysis

Agra is located in the western part of Uttar Pradesh, with geographical coordinates extending from 27.11° North latitude and 78.0° to 78.2° East longitude. The city lies at an

average elevation of approximately 169 meters above mean sea level. In this region, the water quality of the Yamuna River has been significantly affected by heavy metal contamination.

For the present study, water samples were collected from four selected locations within Agra city, namely Taj Ganj, Jiwani Mandi, Kailash Mandir, and Poiya Ghat, during both pre-monsoon and post-monsoon seasons. To prevent any contamination or alteration in sample composition, the samples were collected in acid-washed containers. After collection, the samples were preserved at a temperature of 4°C and subsequently transported to the laboratory for further analysis.

Throughout the study, analytical reagent (AR) grade chemicals and deionized water were used to ensure accuracy and reliability of results. The detection limits for the analyzed heavy metals were determined as follows: iron (Fe) 0.02 mg/L, copper (Cu) 0.01 mg/L, manganese (Mn) 0.01 mg/L, cadmium (Cd) 0.002 mg/L, nickel (Ni) 0.02 mg/L, zinc (Zn) 0.005 mg/L, lead (Pb) 0.05 mg/L, and chromium (Cr) 0.02 mg/L, respectively.

Results and Discussions

1. pH Analysis

pH analysis of water samples collected from different regions of Agra shows that the river water is alkaline in nature. The results of pH analysis clearly indicate that the water samples were in the range of 7.78 to 8.48 and within the permissible limit of 6.5-8.5 drinking water quality standards of BIS (as shown in Table 1)

Table 1: pH value at different locations of Agra

Area	pH
Taj Ganj	8.48
Jiwani Mandi	8.34
Kailash Mandir	7.69
Poiya Ghat	7.78

2. Dissolved oxygen (DO) and Biological Oxygen Demand (BOD) Analysis

The dissolved oxygen (DO) levels in the analyzed river water samples ranged from 4.32 mg/L to 4.90 mg/L during the pre-monsoon season, while higher values between 6.52 mg/L and 8.83 mg/L were recorded in the post-monsoon period. These observations indicate an improvement in dissolved oxygen concentration following the rainy season. The reduction in DO levels during the pre-monsoon period can be attributed to factors such as increased biological respiration, decomposition and transformation of organic matter, elevated temperature, and the presence of inorganic pollutants.

In a similar trend, the biological oxygen demand (BOD) values varied from 11.01 mg/L to 20.27 mg/L during the pre-monsoon season and from 12.25 mg/L to 24.46 mg/L during the post-monsoon season. The relatively high BOD values observed across different sampling locations suggest

significant organic pollution in the river, indicating a substantial load of biodegradable organic matter.

3. Heavy metal concentration analysis

The concentrations of heavy metals during the pre-monsoon and post-monsoon seasons are presented in Table 2. Based on the calculated mean values, the descending order of metal concentration during the pre-monsoon season was observed as: Zn > Fe > Cu > Ni ≥ Mn > Cr > Pb > Cd. In contrast, during the post-monsoon season, the order changed to: Zn > Fe > Mn > Cu > Ni > Cr > Pb > Cd. Among all sampling locations, the highest concentrations were recorded in the Taj Ganj area, which can be attributed to significant discharges from chemical and fertilizer-based industries.

The majority of the analyzed heavy metals exceeded the maximum permissible limits prescribed by BIS, except for Zn, Cu, and Mn during the pre-monsoon season, and Zn and Cu during the post-monsoon season. Iron (Fe) concentrations were found to be 1.7 to 2.4 times higher than the permissible limit in the pre-monsoon period. During the post-monsoon season, the mean Fe concentration increased further, reaching levels 1.2 to 3.6 times above the standard limit.

Similarly, lead (Pb) and cadmium (Cd) concentrations were significantly elevated. During the pre-monsoon season, Pb levels were 3 to 7 times higher and Cd levels were 1.3 to 2.7 times above permissible limits. In the post-monsoon season, Pb concentrations remained 3 to 4 times higher, while Cd was approximately 1.3 times above the acceptable limit. In contrast, zinc (Zn) and copper (Cu) concentrations remained within permissible limits, indicating comparatively lower pollution potential from these metals in the Yamuna River.

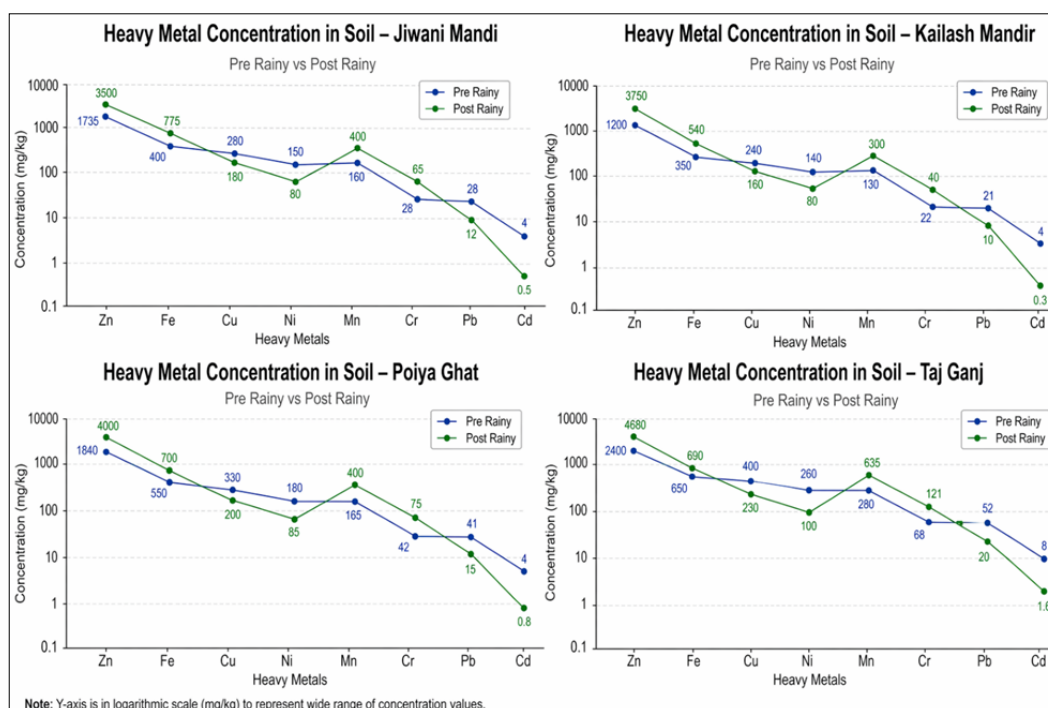
An increase of approximately 1.9 times in chromium (Cr) concentration was observed during the post-monsoon season, likely due to effluents from leather tanning industries. Nickel (Ni) concentrations were higher during the pre-monsoon period but showed a decline in the post-monsoon season, although industrial activities such as stainless steel processing and refining contribute to its presence in the river. Manganese (Mn) levels were within permissible limits during the pre-monsoon season but showed an increasing trend after the monsoon.

A general reduction in the concentrations of Pb, Cd, Cu, and Ni during the post-monsoon season can be attributed to dilution effects caused by increased water volume. Conversely, metals such as Zn, Fe, Mn, and Cr exhibited higher concentrations post-monsoon, possibly due to desorption processes from river sediments under changing environmental conditions. The relative increase in metal concentrations during the pre-monsoon period compared to the post-monsoon season followed the order: Mn > Cr > Zn > Fe. The spatial distribution of heavy metal concentrations across different locations in Agra is illustrated in Table 2 and Fig. 1.

Table 2: Heavy metal ion concentration at different locations of Agra

Heavy Metal	Pre-Rainy Season (Concentration in µg/L)				Mean (µg/L)	Post-Rainy Season (Concentration in µg/L)				Mean (µg/L)
	Taj Ganj	Jiwani Mandi	Kailash Mandir	Poiya Ghat		Taj Ganj	Jiwani Mandi	Kailash Mandir	Poiya Ghat	
Zn	2400	1735	1200	1840	1793.75	4680	3500	3750	4000	3982.5
Fe	650	400	350	530	482.5	690	775	540	700	676.25
Cu	400	280	240	330	312.5	230	180	160	200	192.5
Ni	260	150	140	180	182.5	100	80	80	85	86.25
Mn	280	160	130	165	184	635	400	300	400	433.75

Cr	68	28	22	42	40	121	65	40	75	72.25
Pb	52	28	21	41	35.5	20	12	10	15	14.25
Cd	8	4	4	4	5	1.6	0.5	0.3	0.8	0.8



Conclusion

The concentration of heavy metals in the Yamuna River at Agra was systematically collected and analyzed during both pre-monsoon and post-monsoon seasons. The results indicate that the water quality in the Taj Ganj region is severely contaminated with heavy metals, rendering it unsuitable for domestic use as well as irrigation purposes. In particular, the levels of chromium (Cr), lead (Pb), and cadmium (Cd) were found to exceed the permissible limits prescribed by BIS standards, posing significant risks to human health. Therefore, effective measures to control and reduce heavy metal contamination are essential before the river water can be safely utilized for domestic and industrial applications

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