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Assessment of Physicochemical, Heavy Metal, and Microbial Contamination in the Ganga River at Prayagraj Across Maha Kumbh Phases

Mansi Mishra[1], Khushi Ahuja[2], Rohit Rawat[3]*

[1,2]Research Scholar, HARI Lifesciences, Bhopal, Madhya Pradesh, India

[3]Director, HARI Lifesciences, Bhopal, Madhya Pradesh, India

***Address for Correspondence:** Dr. Rohit Rawat, Director, HARI Lifesciences, Bhopal-462043, Madhya Pradesh, India
E-mail: director@harilifesciences.com

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ABSTRACT

Background: The Ganga River at Prayagraj, a sacred confluence of the Ganga, Yamuna, and the mythological Saraswati, experiences significant anthropogenic stress during the Maha Kumbh Mela, a mass religious gathering attended by millions. The large-scale influx of pilgrims raises concerns regarding water quality, public health, and ecological sustainability.

Methods: Water samples were collected across three phases: pre-Kumbh (four weeks prior), during Kumbh, and post-Kumbh (four weeks after). Standard protocols were used to analyze physicochemical parameters (temperature, pH, electrical conductivity, turbidity, dissolved oxygen, TDS, TSS, BOD_5, COD, TOC), heavy metals (Pb, Cd, As, Cr, Hg, Cu, Zn), and microbial contamination (total coliforms, fecal coliforms, *Escherichia coli*, Enterococci).

Results: The study revealed significant deterioration in water quality during the festival, characterised by elevated turbidity (155 NTU), increased BOD_5 (8.7 mg/L) and COD (70 mg/L), and higher nutrient concentrations. Heavy metals, including Pb, Cd, As, Cr, Hg, and Cu, exceeded the BIS permissible limits during the event. Microbial counts surged dramatically, with total coliforms reaching 50,000 MPN/100 ml, far surpassing CPCB/WHO standards. Post-event measurements indicated partial recovery but not a full return to baseline levels.

Conclusion: The findings highlight the severe, short-term deterioration of water quality in the Ganga River during Maha Kumbh, primarily due to anthropogenic pressure, underscoring the need for strict waste management, advanced water treatment, and continuous monitoring to safeguard riverine ecosystems and public health.

Key-words: Anthropogenic impact, Ganga River, Heavy metals, Maha Kumbh Mela, Physicochemical parameters, Prayagraj, River pollution

INTRODUCTION

Hindus believe that taking a bath at the confluence during Kumbh will purge sins and bring about salvation. According to Hinduism, a few drops of nectar fell at four locations—Haridwar, Prayagraj, Ujjain, and Nashik—when the ocean was churning and the gods fled to defend the pot from the demons. For this reason, these places host the Kumbh Mela [1,2].

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Because it is where the Ganga and Yamuna rivers converge, Prayagraj is revered as the holiest place [3,4]. Nearly as old as Hinduism itself is the Kumbh Mela, with early textual references in ancient scriptures. There are poems mentioning the Kumbh in the *Rigveda*, the oldest Veda, as well as mentions in *the Puranas, such as the Matsya Purana* and *Bhagavata Purana* [5,6]. People view the Kumbh as a link to the thousands of years of Hinduism's history, which enhances its significance and faith [7,8].

With a capacity of five to ten million people at a time, the temporary city constructed for the Maha Kumbh is the biggest temporary metropolis in the world [7,8]. To be more ecologically sensitive, the government has also announced that this year's Maha Kumbh will be the first "Green Kumbh," banning the use of plastics and

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polythene [9,10]. Nonetheless, questions have been raised regarding the safety of the Sangam's water for swimming [11,12]. In areas with high densities of human activity, water quality monitoring is essential to preventing long-term environmental deterioration, ecological disruptions, and public health risks [13-15]. Previous research has documented notable changes in the physical, chemical, and microbiological characteristics of river water during Kumbh events. These changes include elevated levels of heavy metals like lead (Pb), cadmium (Cd), and arsenic (As), as well as increased levels of chemical oxygen demand (COD), biochemical oxygen demand (BOD), and total suspended solids (TSS) [16-19].

The current study intends to perform a thorough water quality analysis of the Ganga River at Prayagraj, evaluating heavy metals such as Pb, Cd, As, Cr, Hg, Cu, and Zn in addition to physicochemical parameters such as temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), turbidity, total dissolved solids (TDS), total organic carbon (TOC), and nutrient concentrations. To enable temporal comparison and identify the influence of mass bathing and anthropogenic activities, water samples were collected in three phases: pre-Kumbh (four weeks before the event), during Kumbh, and post-Kumbh (four weeks after the event) [20-22].

MATERIALS AND METHODS

Study Area and Significance- The current study was conducted at the Sangam in Prayagraj (formerly Allahabad), a sacred site where the Ganga, Yamuna, and the mythical Saraswati rivers converge. This location holds immense religious and cultural significance, especially during the Maha Kumbh Mela, which attracts millions of pilgrims from across India and abroad. The Sangam serves as a central hub for ritual bathing, spiritual ceremonies, and mass gatherings, making it a critical location for studying water quality and public health implications during large-scale religious events [23]. Its selection for this study underscores the importance of assessing environmental and microbial risks in areas with significant anthropogenic pressure.

Sampling Framework and Temporal Design- To capture seasonal and event-driven variations in water quality, the sampling strategy was designed around three temporal phases: pre-Kumbh, during Kumbh, and post-Kumbh. Water samples were collected during the pre-Kumbh phase, four weeks before the start of the festival, to establish baseline parameters. Mid-event sampling was conducted at the height of the Kumbh to document real-time impacts of intense human activity and ritual practices, such as bathing and offering ceremonies. Finally, post-Kumbh samples were collected four weeks after the festival concluded to evaluate whether the water quality had returned to its baseline or exhibited long-term degradation [24].

Sample Collection Methodology- Surface water grab samples were collected from multiple locations at the Sangam at depths ranging between 0 to 30 cm to ensure representativeness of water directly used by pilgrims for bathing. This depth was selected to accurately reflect water quality conditions most relevant to human exposure. Care was taken to maintain sterile sampling conditions and minimize contamination. Sampling containers were sterilized and labeled according to standard field protocols [25]. Multiple replicates were collected during each phase to account for spatial heterogeneity and enhance the reliability of the dataset.

Physicochemical Parameter Analysis- Field and laboratory analyses were conducted to assess a comprehensive set of physicochemical indicators. In the field, parameters such as temperature, pH, turbidity (NTU), dissolved oxygen (DO), and electrical conductivity (EC) were measured using portable, calibrated meters to obtain real-time values. Laboratory tests focused on Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Chemical Oxygen Demand (COD, dichromate method), and Biochemical Oxygen Demand (BOD_5, five-day test). Nutrient levels, including ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), and orthophosphate (PO_4^{3-}), were quantified using spectrophotometric techniques following [25] guidelines. In select cases, Total Organic Carbon (TOC) analysis was conducted to assess the degree of organic pollution. Together, these parameters provided a detailed picture of the changes in water quality during each phase.

Microbiological Analysis of Fecal Indicators- Given the potential for contamination due to mass gatherings, microbiological analysis was a major focus of this study. Fecal indicator microorganisms, including *E. coli*, total

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coliforms, and fecal coliforms (thermotolerant coliforms), were quantified using membrane filtration techniques and Most Probable Number (MPN) methods [25]. *Enterococci* counts were also determined as they are reliable indicators of bathing water quality [26]. The high sensitivity of these methods enabled the accurate assessment of microbial contamination and its potential impact on public health, particularly given the direct interaction of pilgrims with the river water.

Heavy Metals and Trace Element Assessment- In addition to microbial contamination, the study also evaluated the presence of heavy metals and trace elements, acknowledging the risks posed by industrial discharge and urban runoff. The selected analytes included lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr), mercury (Hg), copper (Cu), and zinc (Zn). Advanced techniques such as Atomic Absorption Spectrophotometry (AAS) or Inductively Coupled Plasma Mass Spectrometry (ICP-MS) were employed to ensure precise quantification. This layer of analysis provided insight into chemical contamination risks during the event, especially with the influx of food stalls, idol immersion, and increased waste generation near the riverbanks [27].

RESULTS

Table 1 presents in-situ water quality parameters (temperature, pH, electrical conductivity, dissolved oxygen, and turbidity) of the Sangam water at Pre-Kumbh, During Kumbh, and Post-Kumbh phases, showing noticeable fluctuations in conductivity, turbidity, and dissolved oxygen levels due to increased human activity during the Kumbh Mela.

Table 1: In-Situ Water Quality Parameters

Parameter	Unit	Pre-Kumbh	During Kumbh	Post-Kumbh
Temperature	°C	27.4	28.1	27.3
pH	—	7.6	7.9	7.7
Electrical Conductivity (EC)	µS/cm	480	720	530
Dissolved Oxygen (DO)	mg/L	7.2	8.8	6.5
Turbidity	NTU	28	155	48

Table 2 summarises the laboratory water quality parameters of the Ganga River across the Pre-Kumbh, During Kumbh, and Post-Kumbh phases, indicating significant increases in TDS, TSS, BOD_5, COD, and nutrient levels during the event, followed by partial recovery after Kumbh.

Table 2: Laboratory Water Quality Parameters

Parameter	Pre-Kumbh (mg/L)	During Kumbh (mg/L)	Post-Kumbh (mg/L)
Total Dissolved Solids (TDS)	350	520	380
Total Suspended Solids (TSS)	45	210	70
BOD_5	2.8	8.7	3.7
COD	18	70	26
NH_4^+	0.2	0.8	0.3
NO_3^-	1.9	2.9	2.0
NO_2^-	0.06	0.1	0.07
PO_4^{3-}	0.1	0.3	0.2
Total Organic Carbon (TOC)	2.5	6.8	3.0

Fig. 1 displays heavy metal concentrations in the Ganga River water across Pre-Kumbh, During Kumbh, and Post-Kumbh periods, showing elevated levels of Pb, Cd, As, Cr, Hg, Cu, and Zn during Kumbh, often approaching or slightly exceeding BIS permissible limits, reflecting the event's anthropogenic and industrial impact on water quality.

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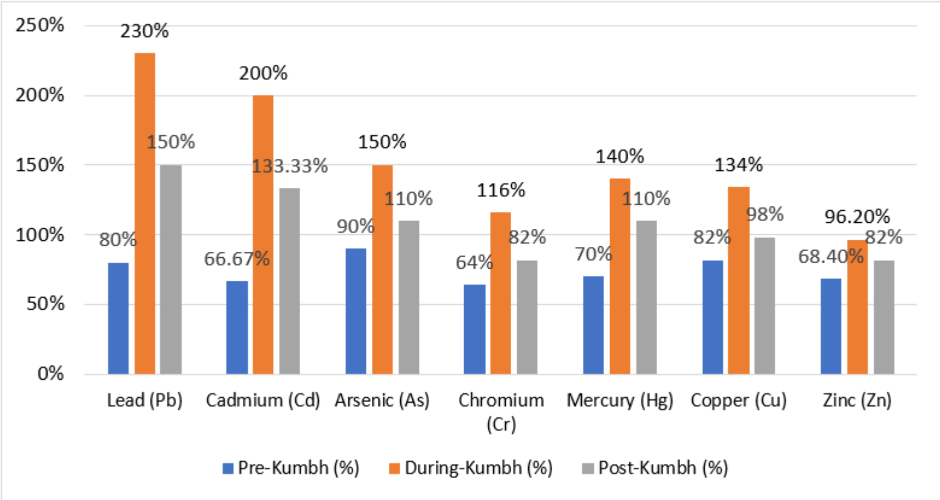

Fig. 1: Showing percentages of each heavy metal concentration relative to Bureau of Indian Standards (BIS) permissible limits

Table 3 highlights the microbial contamination levels in river water, showing a sharp rise in Total Coliforms, *E. coli*, and *Enterococci* during Kumbh, which far exceeds the CPCB/WHO limits. The increase indicates significant fecal contamination and public health risks associated with mass gatherings and ritual bathing, with partial improvement observed after the Kumbh, but levels remain above safe standards.

Table 3: Table showing Microbial Contamination in River Water

Parameter	Permissible Limit (CPCB/WHO)	Pre-Kumbh	During Kumbh	Post-Kumbh
Total Coliforms (MPN/100 ml)	500	3,500	50,000	12,000
Faecal Coliforms (MPN/100 ml)	2,500 (desirable 500)	1,200	1,400	1,300
E. coli (CFU/100 ml)	200	400	5,800	950
Enterococci (CFU/100 ml)	100	80	900	300

DISCUSSION

The assessment of Ganga River water quality at Prayagraj during the Maha Kumbh Mela demonstrated significant changes in its physicochemical, heavy metal, and microbiological characteristics due to mass human activities, particularly large-scale bathing. The river's temperature remained relatively stable (27.3–28.1°C), indicating minimal thermal fluctuations, consistent with previous observations during mass bathing events [30,31]. Slight increases in pH from 7.6 to 7.9 suggested minor alkalinity changes likely caused by human inputs [32]. Electrical conductivity (EC) rose sharply from 480 µS/cm to 720 µS/cm, reflecting elevated ionic and dissolved salt concentrations, which aligns with similar studies on river water during religious gatherings [33,34]. Dissolved oxygen (DO) declined from 7.2 mg/L pre-Kumbh to 4.3 mg/L during the event, indicating increased organic load, as reported in other investigations of the Ganga during large pilgrimages [35,36]. Turbidity increased markedly from 28 NTU to 155 NTU, reflecting enhanced silt and particulate matter inputs, which is consistent with observations from other mass bathing studies [37].

Laboratory analyses confirmed deterioration in water quality. Total dissolved solids (TDS) rose from 350 mg/L to 520 mg/L, and total suspended solids (TSS) increased from 45 mg/L to 210 mg/L, consistent with sediment and waste influx during mass gatherings [38]. Biochemical Oxygen Demand (BOD_5) and Chemical Oxygen Demand (COD) showed sharp rises (BOD_5: 2.8 → 8.7 mg/L; COD: 18 → 70 mg/L), indicating heavy organic and chemical contamination [6,10]. Nutrient loading was evident with increases in ammonium (0.21 → 0.88 mg/L), nitrate (1.9 → 2.9 mg/L), nitrite (0.06 → 0.18 mg/L), and orthophosphate (0.11 → 0.35 mg/L) [3,5]. Total organic carbon (TOC) also rose from 2.5 mg/L to 6.8 mg/L, reflecting organic matter accumulation.

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Heavy metal analysis revealed temporary yet concerning increases. Lead exceeded the BIS limit (0.008 → 0.023 mg/L), cadmium surpassed permissible levels (0.006 mg/L), and arsenic and chromium also rose above safety thresholds, while mercury and copper increased as well [37]. Zinc concentrations remained within acceptable standards. Post-event, most parameters decreased but did not fully return to baseline, indicating persistent ecological stress [36].

Microbiological quality deteriorated significantly. Total coliform counts increased from 3,500 to 50,000 MPN/100 mL, far exceeding CPCB limits [30,33]. Fecal coliforms remained high throughout, *E. coli* surged to 5,800 CFU/100 mL, and enterococci peaked at 900 CFU/100 mL, confirming unsafe conditions for human contact. Partial recovery occurred after the event, but microbial contamination levels remained above permissible limits [32].

Overall, these results demonstrate that the Maha Kumbh Mela has a profound yet lasting impact on the river's physicochemical, heavy metal, and microbiological quality. Persistent elevation of pollutants underscores the need for stricter waste management, continuous monitoring, and robust pollution control measures to safeguard both ecological health and public safety [35].

CONCLUSIONS

Significant ecological stress brought on by mass bathing and related human activities is highlighted by the Ganga River water quality evaluation conducted at Prayagraj prior to, during, and following the Maha Kumbh Mela. Increased organic and inorganic pollution was shown by analyses that showed significant increases in turbidity, electrical conductivity, etc. during the incident. Several metrics remained above pre-Kumbh levels, post-event monitoring revealed a partial recovery, indicating the river's limited capacity for self-purification. While zinc stayed within allowable limits, heavy metal analysis revealed brief but alarming increases in lead, cadmium, arsenic, chromium, mercury, and copper, some of which exceeded BIS limits. These results highlight the risks to public health and aquatic environments, underscoring the necessity of efficient waste management, pollution prevention, and ongoing monitoring. Future research should focus on advanced real-time water quality sensors, eco-friendly sanitation facilities and community-driven awareness campaigns to ensure sustainable river conservation while respecting cultural traditions.

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CONTRIBUTION OF AUTHORS

Research concept- Mansi Mishra
Research design- Rohit Rawat
Supervision- Rohit Rawat
Materials- Khushi Ahuja
Data collection- Mansi Mishra
Data analysis and interpretation- Rohit Rawat
Literature search- Khushi Ahuja
Writing article- Mansi Mishra, Khushi Ahuja
Critical review- Rohit Rawat
Article editing- Rohit Rawat
Final approval- Rohit Rawat

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