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Water Quality Evaluation of the River Ganga: A Review of Physico-Chemical and Microbiological Parameters

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ABSTRACT

Water quality assessment is important for safeguarding community health, sustaining aquatic ecosystems, and supporting long-term water security. The Ganga River, the world's third-largest river by discharge and a source of livelihood, drinking water, and cultural significance for over five Indian states, faces continuous pressure from domestic sewage, industrial effluent, agricultural runoff, and large-scale religious bathing events. This review synthesizes published data (2009–2025) on the physico-chemical parameters (temperature, pH, electrical conductivity, total dissolved solids, turbidity, total hardness, total alkalinity, dissolved oxygen, biochemical and chemical oxygen demand, and major ions) and microbiological indicators (Most Probable Number, Standard Plate Count, faecal and total coliform, and emerging metagenomic data on antibiotic resistance genes) reported for the Ganga across multiple stretches, seasons, and mass-gathering events including the Kumbh and Kanwar Melas. Most parameters remain within permissible limits under routine conditions, but recurrent deviations in dissolved oxygen, biochemical oxygen demand, and coliform counts are consistently reported during mass-bathing events and at sites downstream of untreated sewage discharge. Seasonal patterns show elevated turbidity and microbial load during the monsoon and comparatively better water quality in the dry season. The review highlights the need for continuous, standardized monitoring, stronger enforcement of pollution-control measures, and sustained investment in sewage treatment infrastructure to support ongoing rejuvenation efforts such as Namami Gange.

Introduction

Water covers approximately 71% of the Earth's surface, of which nearly 97% is saline seawater; only about 3% is freshwater, and less than 1% is readily accessible for human use (Grey *et al.,* 2013). As the resource underpinning nearly all biological processes, water is fundamental to life on Earth (Gupta and Orbán, 2018; Frappart, 2013). Globally, an estimated 768 million people lack adequate access to safe water, with over 80% of this population residing in rural areas (WHO and UNICEF, 2013), and roughly 1.1 billion people face shortages of drinking water (WHO, 2015). Global water consumption has grown at roughly twice the rate of population growth over the past century, placing increasing strain on freshwater systems, including those supporting peri-urban livelihoods (Gomes *et al.,* 2018).

Rivers remain the primary source of freshwater for drinking, agriculture, industry, and recreation. Expanding anthropogenic activity has placed river systems under sustained pollution pressure, making regular, spatio-temporally resolved water-quality monitoring essential for effective management.

The Ganga is India's most significant river, both hydrologically and culturally. It originates as the Bhagirathi at Gaumukh (3,900 m) in the Gangotri glacier, and is joined by the Alaknanda at Devprayag to form the Ganga proper. From there it descends through the northern plains across five states — Uttarakhand (110 km), Uttar Pradesh (1,450 km), Bihar (445 km), and West Bengal (520 km) — for a total length of approximately 2,525 km before draining into the Bay of Bengal through the Sundarbans delta (CPCB, 2019). Major cities along its course include Rishikesh, Haridwar, Kanpur, Prayagraj, and Varanasi (Uttar Pradesh); Patna and Bhagalpur (Bihar); and Kolkata (West Bengal). The Ganga basin covers approximately 862,769 km², around 26% of India's land area (CWC, 2014), and the river ranks as the 20th largest in Asia and 41st longest globally. Its major tributaries include the Yamuna, Ramganga, Gomti, Ghaghara, Gandak, Damodar, and Kosi (CPCB, 2019).

Contamination and scarcity of water remain pressing global concerns (Zubaidi *et al.,* 2018; Hasan *et al.,* 2019). Water pollution is driven predominantly by anthropogenic activity: agricultural runoff (pesticides, insecticides, fertilisers), industrial discharge (heavy metals, dyes, and other toxic effluents), and improper disposal of household waste, all of which degrade both surface and groundwater quality (Boelee *et al.,* 2019; Anand *et al.,* 2021; Li *et al.,* 2021; Sasakova *et al.,* 2018). Pathogenic microorganisms and their genetic material constitute an additional and increasingly monitored dimension of water pollution (Anand *et al.,* 2021), and untreated municipal and industrial wastewater discharge remains a principal driver of riverine contamination (Chau *et al.,* 2015). Continuous monitoring of physico-chemical and microbiological parameters, paired with advanced treatment technologies, is essential to reducing pollution loads and protecting downstream human and ecological health (Bisi-Johnson *et al.,* 2017; Chatanga *et al.,* 2019; Oliveira *et al.,* 2021; Weng, 2020; Mishra *et al.,* 2021). Pollution in the Ganga threatens not only human health but also aquatic biodiversity, including an estimated 140 fish species, 90 amphibian species, and the endangered Gangetic river dolphin (Jain, 2020); the river is also a major contributor to marine plastic pollution (Chowdhury *et al.,* 2020; Nelms *et al.,* 2021).

The Ganga holds deep religious significance for Hindus, who bathe in its waters, perform rituals, and carry "Ganga Jal" home for ceremonial use. Mass bathing festivals such as Kumbh Mela, Ardh Kumbh, and Kanwar Yatra draw millions of pilgrims to sites including Haridwar, Prayagraj (Triveni Sangam), and Varanasi. These events place acute, short-term pressure on water quality, frequently pushing physico-chemical and microbiological parameters beyond permissible limits during the bathing period (Khullar and Khullar, 2004; Sati and Paliwal, 2008; Seth *et al.,* 2016), which is why targeted monitoring of Catchment Area Drainage water bodies during these events is essential.

Beyond religious activity, expanding urban and semi-urban settlement along the Ganga's banks contributes substantially to its pollution load. The Central Pollution Control Board estimated in 2014 that human settlements along the river generate roughly 8,250 million litres per day (MLD) of wastewater, of which around 2,550 MLD is discharged directly into the river without treatment. Case studies from Kanpur have linked inadequate sewage infrastructure and industrial effluent discharge to measurable water-quality decline, particularly during the monsoon when drainage systems overflow (Vidyarthi *et al.,* 2020). Mass bathing events are also associated with sharp, short-term increases in faecal and total coliform counts, an important indicator given that the WHO standard specifies no detectable coliform bacteria per 100 ml of water.

Materials and Methods

This review synthesises peer-reviewed research articles, government monitoring reports (Central Water Commission, Central Pollution Control Board, National Mission for Clean Ganga), and grey literature reporting physico-chemical and microbiological water-quality data for the Ganga River and, where directly comparable, other Indian rivers, published between 2009 and 2025. Sources were identified through literature searches and were selected for reporting quantitative measurements of at least one standard physico-chemical parameter (temperature, pH, conductivity, TDS, turbidity, hardness, alkalinity, dissolved oxygen, BOD, COD, or major ions) or microbiological indicator (MPN, SPC, coliform counts, or metagenomic community data) at named sampling sites along the river. Data are organised by parameter to allow comparison across studies, sites, and seasons, followed by a synthesis of microbiological findings and an overall assessment of water-quality trends and management implications.

Physico-Chemical Parameters

pH

pH governs the solubility and biological availability of chemical constituents in water and is a core indicator of river health. During the Maha Kumbh Mela 2025, pH across six sampling sites (Haridwar, Garhmukteshwar, Naini, Shastri Bridge, Chhatnag, Varanasi) remained consistently alkaline, ranging from 7.09 to 8.32, with the highest value recorded at Naini and the lowest at Haridwar (CWC, 2025). At Varanasi's ghats, Poul and Myrthong (2023) recorded a comparable range, with the highest pH (8.57) at Dasaswamedh Ghat in March and the lowest (7.53) at Harish Chandra Ghat in February, attributing the fluctuation to sewage discharge from drains.

Seasonal variation is a consistent theme across studies. At Bhagalpur, Mishra *et al.,* (2022) reported pH peaking during the monsoon (8.1) and falling to its lowest in summer (6.4), with strong positive and negative correlations to turbidity, conductivity, bicarbonate, total alkalinity, and dissolved oxygen. At Prayagraj, Tripathi *et al.,* (2014) recorded a similar seasonal pattern — high in summer (8.76 ± 0.15) and low in winter (7.33 ± 0.005), with an overall mean of 7.87 ± 0.05 — and found pH positively correlated with temperature, alkalinity, COD, salinity, chloride, sulphate, and conductivity, but negatively correlated with hardness. During the 2019 Kumbh at Prayagraj, Mishra *et al.,* (2021) recorded the highest pH (8.6) at Sangam in February and the lowest (7.4) at Arail Kachhar and Arail Uparhar. During the Kanwar Mela at Haridwar, Kumar *et al.,* (2018) recorded a narrower alkaline range (8.32–8.76), attributed to ritual bathing and laundering activity.

Taken together, these studies show the Ganga's pH consistently falling within the mildly alkaline range typical of Indian rivers, with the principal drivers of deviation being seasonal runoff and episodic anthropogenic loading during mass-bathing events, rather than sustained baseline degradation.

Water Temperature

Water temperature regulates the rate of metabolic and biological processes in aquatic ecosystems and strongly influences dissolved oxygen availability. At the Manas River, temperature ranged from a winter low of 8°C to a monsoon high of 27°C (Sarmah, 2023); at Bhagalpur, Mishra *et al.,* (2022) recorded a comparable seasonal range, from 13.3 ± 1.8°C in winter to 29.5 ± 0.6°C in summer, with statistically significant relationships to conductivity, pH, turbidity, BOD, and COD. At Prayagraj, Tripathi *et al.,* (2014) reported winter and summer means of 20.16 ± 0.5°C and 31.16 ± 0.46°C respectively, with temperature positively correlated with salinity, chloride, sulphate, conductivity, alkalinity, and pH. By contrast, during the Kanwar Mela at Haridwar, temperature remained comparatively stable (18.25–18.42°C), reflecting the short observation window rather than the absence of seasonal variation (Kumar *et al.,* 2018).

Turbidity

Turbidity — a measure of suspended particulate matter — consistently peaks during the monsoon across all reviewed studies, driven by watershed runoff carrying silt and organic debris. At Prayagraj, turbidity ranged from 28.66 ± 1.52 NTU in winter to 63.66 ± 10.4 NTU in the monsoon (mean 44.55 ± 7.72 NTU; Tripathi *et al.,* 2014), while at Bhagalpur the monsoon peak reached 85.6 ± 0.4 NTU against a summer low of 25.6 ± 0.6 NTU (Mishra *et al.,* 2022). At the Manas River, values ranged far more widely — from 0.1 NTU (Mothanguri and Narayanguri, winter) to 121 NTU (Kalgachia, monsoon) — reflecting greater site-to-site heterogeneity (Sarmah, 2023). During the 2025 Maha Kumbh, turbidity was highest at Garhmukteshwar (40.2 NTU) and lowest at Varanasi (3.7 NTU) (CWC, 2025). Across studies, turbidity is consistently reported as definitely connected with temperature and negatively connected with dissolved oxygen and transparency.

Free CO_2

Free carbon dioxide — dissolved CO_2 not bound in other compounds — lowers pH and increases water corrosivity as its concentration rises, making it an important secondary indicator of aquatic ecosystem stress. At the Manas River, free CO_2 ranged from a winter low of 0.8 ± 0.08 mg/L (Mothanguri) to a retreating-monsoon high of 4.4 ± 0.08 mg/L (Kalgachia) (Sarmah, 2023).

Transparency

Transparency followed an inverse seasonal pattern to turbidity, as expected: at Prayagraj, it was highest in the dry season (28 ± 0.2 cm) and lowest during the monsoon (18.6 ± 0.51 cm), with a positive correlation to dissolved oxygen, BOD, and COD, and a negative correlation to hardness and pH.

Salinity

Salinity reflects the concentration of dissolved ions (sodium, chloride, magnesium, sulphate) and is an important indicator of hydrochemical status. At Prayagraj, salinity was highest in summer (148.9 ± 6.41) and lowest in winter (79.5 ± 5.31), positively correlated with temperature, pH, sulphate, and conductivity.

At the Manas River, the range was far lower in absolute terms — 0.05 ± 0.01 ppt (Kalgachia, pre-monsoon) to 1.85 ± 0.03 ppt (Mothanguri, monsoon) — reflecting differences in units and site characteristics between studies (Sarmah, 2023).

Electrical Conductivity

Electrical conductivity (EC) reflects the concentration of dissolved ionic species and is widely used as a proxy for overall mineralisation. At Prayagraj, EC was higher in the dry season (490 ± 7.54 µmhos/cm) than in winter (454.3 ± 20.3 µmhos/cm), positively correlated with temperature, alkalinity, and turbidity. During the Kanwar Mela, EC ranged from 0.153–0.164 dS/m, attributed to large-scale ritual bathing (Kumar *et al.,* 2018). During the 2019 Kumbh, EC peaked at Gaughat in March (0.69 dS/m) and was lowest at Chhatnag in January (0.31 dS/m) (Mishra *et al.,* 2021). At Varanasi's ghats, EC ranged more widely — from 131 µS/cm (Asi Ghat, January) to 564 µS/cm (Tulsi Ghat, April) — attributed to mineral input from organic matter breakdown (Poul and Myrthong, 2023). During the 2025 Maha Kumbh, EC ranged from 170.6 µmhos/cm (Haridwar) to 856 µmhos/cm (Naini) (CWC, 2025).

Total Dissolved Solids (TDS)

TDS represents the cumulative concentration of dissolved inorganic salts and minor organic matter, and is a standard indicator of mineralisation and potability. During the Kanwar Mela, total solids, TDS, and total suspended solids peaked at Har ki Pauri, Haridwar (545, 320, and 225 mg/L respectively), attributed to mass ritual bathing (Kumar *et al.,* 2018). During the 2019 Kumbh at Prayagraj, TDS ranged from 275.6–407.2 ppm, driven by particulate matter generated by dense crowds (Srivastava *et al.,* 2020). At the Manas River, TDS ranged from 22.8 ± 0.08 ppm (Mothanguri, retreating monsoon) to 270 ± 0.08 ppm (Mothanguri, pre-monsoon) (Sarmah, 2023); at Varanasi's ghats, from 229 mg/L (Manikarnika Ghat, January) to 319.67 mg/L (Asi Ghat, February) (Poul and Myrthong, 2023). Singh *et al.,* (2025) reported markedly higher values at Babarpur — up to 1,843 mg/L in July — falling to 497 mg/L at Durwasha Ashram, Prayagraj, in January, and noted that TDS was, counterintuitively, higher outside mela periods, suggesting effective sewage-discharge control specifically during mela gatherings at that site.

Dissolved Oxygen (DO)

DO is among the most direct indicators of aquatic ecological health, with higher concentrations reflecting better water quality. During the 2025 Maha Kumbh, DO ranged from 7.6 mg/L (Naini) to 10.2 mg/L (Haridwar), with all sites remaining within acceptable regulatory thresholds despite site-to-site variation (CWC, 2025). At Varanasi's ghats, DO was highest at Manikarnika Ghat (8.20 mg/L, January) and lowest at Tulsi Ghat (5.91 mg/L, January), with declines attributed to biological and photosynthetic activity as well as pollution loading (Poul and Myrthong, 2023). At the Manas River, DO ranged from 6.5 ± 0.08 mg/L (Kalgachia, retreating monsoon) to 14.55 ± 0.008 mg/L (Mothanguri, winter) (Sarmah, 2023). At Bhagalpur, DO was highest during the monsoon (7.8 ± 0.8 mg/L) and lowest in summer (3.4 ± 0.2 mg/L) (Mishra *et al.,* 2022). During the 2019 Kumbh, the highest DO (8.3 mg/L) was recorded at Ganga Arti Ghat in December and the lowest (3.6 mg/L) at Daraganj and Chhatnag (Mishra *et al.,* 2021) further showed that DO dropped sharply during peak bathing days — from 15 to 8.94 mg/L at Mauni Amavasya and from 15.6 to 11.5 mg/L at Makar Sankranti — directly linking crowd density to acute oxygen depletion.

Biochemical Oxygen Demand (BOD)

BOD measures the oxygen required to oxidise organic matter and is a direct indicator of organic pollution load. During the 2025 Maha Kumbh, BOD ranged from 0.96 mg/L (Haridwar) to 4.63 mg/L (Chhatnag), with occasional exceedances linked to concentrated religious bathing (CWC, 2025). At Varanasi's ghats, the highest BOD (4.63 mg/L) occurred at Asi Ghat in March and the lowest (2.70 mg/L) at Harish Chandra Ghat in January, however all values continued within permissible limits (Poul and Myrthong, 2023). At Bhagalpur, BOD peaked during the monsoon (3.1 ± 0.5 mg/L) and fell in summer (2.4 ± 0.2 mg/L), showing a strong positive relationship with DO (Mishra *et al.,* 2022). During the 2019 Kumbh, the highest BOD (5.9 mg/L) occurred at Sangam in March (Mishra *et al.,* 2021) recorded a comparable range (3.8–5.6 ppm) peaking on Mauni Amavasya. During the Kanwar Mela, BOD was highest at Har ki Pauri (4.76 ± 0.12 mg/L) relative to the Bhimgoda Barrage control site (Kumar *et al.,* 2018).

Chemical Oxygen Demand (COD)

COD, which is consistently reported as higher than BOD across the reviewed studies, reflects the total oxidisable organic and inorganic load. During the 2025 Maha Kumbh, COD ranged from 4.83 mg/L (Haridwar) to 18.6 mg/L (Chhatnag), with several sites exceeding permissible limits due to crowding (CWC, 2025). At Bhagalpur, COD was uppermost in summer (9.7 ± 0.5 mg/L) and lowermost in winter (2.02 ± 0.4 mg/L), positively correlated with DO (Mishra *et al.,* 2022). Srivastava *et al.,* (2020) recorded a much higher range (37–96.3 ppm), peaking on Mauni Amavasya; during the Kanwar Mela, COD was highest at Har ki Pauri (6.89 ± 0.88 mg/L) relative to the control site (Kumar *et al.,* 2018). At Prayagraj, seasonal COD ranged from 29.53 ± 1.44 mg/L (summer) to 36.4 ± 2.7 mg/L (dry season), positively correlated with DO and negatively with hardness and total solids.

Total Hardness (TH)

Total hardness reflects the collective concentration of calcium and magnesium salts and provides a degree of ecological buffering against low-pH stress in fish (Ehiagbonare and Ogunrinde, 2010). At Varanasi's ghats, the highest TH (138.33 mg/L) occurred at Tulsi Ghat in the month February and the lowest (78.33 mg/L) at Asi Ghat in month January (Poul and Myrthong, 2023). During the 2019 Kumbh, the highest TH (420 mg/L) occurred at Gaughat in April and the lowest (145 mg/L) at Chhatnag in February, with higher hardness generally associated with domestic settlement density along the banks (Mishra *et al.,* 2021). During the Kanwar Mela, hardness at Har ki Pauri (232.54 ± 1.64 mg/L) and Pul Jatwara (221 ± 1.26 mg/L) both exceeded the control site (Kumar *et al.,* 2018). At Prayagraj, TH peaked in the monsoon (231.3 ± 3.05 mg/L) and fell in summer (202.6 ± 11.84 mg/L), correlating positively with total solids, nitrate, and phosphate, and negatively with pH, DO, BOD, COD, and transparency.

Total Alkalinity (TA)

Total alkalinity measures the water's buffering capacity against acidification, arising primarily from carbonates, bicarbonates, phosphates, and silicates. During the Kanwar Mela, TA was higher at Har ki Pauri (158.36 ± 1.20 mg/L) than at Pul Jatwara (146.37 ± 2.52 mg/L), both above the control site (Kumar *et al.,* 2018). During the 2019 Kumbh, the highest TA (89 mg/L) occurred at Sangam in December and the lowest (56 mg/L) at Daraganj (Mishra *et al.,* 2021). At Bhagalpur, TA peaked in summer (57.5 ± 1.0 mg/L) and fell during the monsoon (46.3 ± 2.10 mg/L), correlating with DO and COD (Mishra *et al.,* 2022). At Varanasi's ghats, TA ranged from 78.67 mg/L (Harish Chandra Ghat, January) to 114.33 mg/L (Tulsi Ghat, April) (Poul and Myrthong, 2023); at the Manas River, from 75 ± 0.18 mg/L (Kalgachia, winter) to 170 ± 0.83 mg/L (Jogighopa, pre-monsoon) (Sarmah, 2023). Singh *et al.,* (2025) reported TA exceeding acceptable thresholds in May (243 ppm at Bankar Tari, Baripur), flagging a pollution risk.

Chloride

Elevated chloride is a well-established marker of anthropogenic pollution from sewage, or industrial discharge, and accelerates both ecological stress and infrastructure corrosion. During the Kanwar Mela, chloride was highest at Har ki Pauri (124.50 ± 0.55 mg/L) relative to the control site (Kumar *et al.,* 2018). During the 2019 Kumbh, chloride ranged from 22 mg/L (Daraganj, December) to 200.5 mg/L (Gaughat, May) (Mishra *et al.,* 2021). At Bhagalpur, chloride peaked during the monsoon (34.6 ± 0.7 mg/L) and fell in winter (21.7 ± 1.0 mg/L), correlating with phosphate (Mishra *et al.,* 2022). Singh *et al.,* (2025) recorded a much wider seasonal range at Babarpur (197–391 mg/L), peaking in August.

Sulphate

Sulphate concentration reflects both natural mineral input and anthropogenic loading, particularly agricultural runoff. Singh *et al.,* (2025) recorded a peak of 398.0 ppm at Sitamarhi, Bhadohi in August and a low of 9.6 ppm at Saidabad in May. During the Kanwar Mela, sulphate ranged from 219.40–228.34 mg/L, highest at Har ki Pauri (Kumar *et al.,* 2018). At Prayagraj, sulphate was higher in summer (25 ± 5 mg/L) than winter (18.33 ± 1.52 mg/L), positively correlated with temperature, alkalinity, and conductivity.

Magnesium

Magnesium concentration in the Ganga is generally attributed to anthropogenic input rather than natural background levels. Mishra *et al.,* (2021) reported the highest magnesium hardness (260 mg/L) at Sangam in March; Singh *et al.,* (2025) recorded a seasonal peak of 232.0 ppm at Gangoli Shivala, Jhunsi in August, falling to 112.0 ppm at Saidabad in September.

Nitrate

Nitrate is the most soluble and mobile form of soil and water nitrogen, and elevated concentrations typically indicate agricultural runoff or sewage input. At Prayagraj, nitrate was higher during the monsoon (0.81 ± 0.01 mg/L) than the dry season (0.35 ± 0.0 mg/L), positively correlated with hardness and negatively with pH, DO, BOD, COD, and transparency. During the Kanwar Mela, nitrate was substantially higher — 73.0–76.88 mg/L — likely reflecting a different analytical unit or method (Kumar *et al.,* 2018). At the Manas River, nitrogen concentration (expressed as kg/ha) ranged from 5 kg/ha (winter) to 67 kg/ha (monsoon) at Bekipar (Sarmah, 2023).

Phosphorus

Phosphorus availability governs plant energy metabolism and root development and is frequently limiting in freshwater systems. At Prayagraj, phosphate peaked during the monsoon (0.750 ± 0.026 mg/L) and fell in summer (0.27 ± 0.025 mg/L), positively correlated with turbidity. At Bhagalpur, the seasonal pattern was similar but at much lower absolute concentrations (0.071–0.098 mg/L) (Mishra *et al.,* 2022). At the Manas River, phosphorus ranged from 1 kg/ha (winter) to 6.7 kg/ha (monsoon) at Bekipar (Sarmah, 2023).

Biological and Microbiological Parameters

Most Probable Number (MPN) is the standard method for detecting coliform bacteria in water, having higher values indicating larger faecal contamination. Singh *et al.,* (2025) reported that MPN values consistently rise during the monsoon, when increased organic matter supports bacterial growth, and fall during the dry season — a pattern the authors used to recommend the dry season as the safer period for bathing.

Community-level microbial and zooplankton surveys add further resolution. Singh and Katiyar (2020) identified 49 microorganism species across Prayagraj and Varanasi, with amphipod richness highest at Prayagraj and rotifer richness highest at Varanasi; protozoans consistently showed the lowest richness, diversity, and evenness at both sites. At Varanasi, dominant taxa (*Volvox*, *Branchiopus*, *Colpoda*) alongside elevated BOD and organic carbon indicated stronger organic pollution, whereas Prayagraj's dominant taxa (*Daphnia*, *Amoeba*, *Copepoda*, *Hartmanella*) were more closely associated with turbidity, dissolved oxygen, and hardness.

In a metagenomic study of the Saryu River — a Ganga tributary — Maurya *et al.,* (2025) identified multiple antibiotic resistance genes (including rpoB2, tetB, and acrB) and found Cyanobacteria dominant at the phylum level, underscoring the value of metagenomic surveillance for tracking antimicrobial resistance in riverine systems.

Coliform data collected during mass-bathing events show a consistent pattern: sharp spikes during the bathing period followed by measurable recovery afterward. During the 2025 Maha Kumbh, faecal coliform ranged from 4,900–34,000 MPN/100 ml during the bathing (snan) days, falling to 1,700–3,100 MPN/100 ml afterward — the lowest levels recorded at Naini and the highest at Chhatnag in both phases (CWC, 2025). During the Kanwar Mela, Standard Plate Count (SPC) and faecal coliform (FC) both peaked at Har ki Pauri (6.8×10^6 SPC/ml; 4.6×10^8 MPN/ml) relative to Pul Jatwara, attributed to concentrated ritual bathing (Kumar *et al.,* 2018).

Table.1 Summary of Reported Ranges

Parameter	Reported Range (Approx.)	Typical Seasonal / Event Pattern	Key Source(s)
pH	5.73 – 8.76	Higher in summer/dry season; lower in winter/monsoon; alkaline shift during mass bathing	CWC 2025; Poul & Myrthong 2023; Mishra *et al.,* 2022; Tripathi *et al.,* 2014; Kumar *et al.,* 2018
Water Temperature	8 – 31.2 °C	Winter minimum, summer/monsoon maximum	Sarmah 2023; Mishra *et al.,* 2022; Tripathi *et al.,* 2014
Turbidity	0.1 – 121 NTU	Monsoon peak (runoff-driven); dry-season minimum	Sarmah 2023; Tripathi *et al.,* 2014; Mishra *et al.,* 2022; CWC 2025
Electrical Conductivity	131 – 856 µmhos/cm	Higher in dry/summer season; site-dependent	Poul & Myrthong 2023; CWC 2025; Mishra *et al.,* 2021; Tripathi *et al.,* 2014
Total Dissolved Solids	22.8 – 1,843 mg/L	Elevated at industrial/urban sites; mixed mela-period trend	Sarmah 2023; Singh *et al.,* 2025; Srivastava *et al.,* 2020; Poul & Myrthong 2023
Dissolved Oxygen	3.4 – 14.6 mg/L	Depressed during mass bathing and summer; higher in winter/monsoon	CWC 2025; Sarmah 2023; Mishra *et al.,* 2022; Srivastava *et al.,* 2020
Biochemical Oxygen Demand	0.96 – 5.9 mg/L	Monsoon/bathing-event peaks; generally within permissible limits	CWC 2025; Poul & Myrthong 2023; Mishra *et al.,* 2021; Kumar *et al.,* 2018
Chemical Oxygen Demand	2.02 – 96.3 ppm/mg/L	Summer/bathing-event peaks; consistently exceeds BOD	CWC 2025; Mishra *et al.,* 2022; Srivastava *et al.,* 2020; Kumar *et al.,* 2018
Total Hardness	78.3 – 420 mg/L	Higher near dense riverside settlement; monsoon peak at some sites	Poul & Myrthong 2023; Mishra *et al.,* 2021; Kumar *et al.,* 2018; Tripathi *et al.,* 2014
Total Alkalinity	46.3 – 243 mg/L	Summer peak; May exceedance linked to pollution risk	Kumar *et al.,* 2018; Mishra *et al.,* 2021; Mishra *et al.,* 2022; Singh *et al.,* 2025
Chloride	9.5 – 391 mg/L	Monsoon/August peak; anthropogenic marker	Kumar *et al.,* 2018; Mishra *et al.,* 2021; Mishra *et al.,* 2022; Singh *et al.,* 2025
Faecal Coliform / MPN	1,700 – 34,000 MPN/100 ml	Sharp spike during bathing days; recovers post-event; monsoon > dry season	CWC 2025; Kumar *et al.,* 2018; Singh *et al.,* 2025

During the 2019 Kumbh, Srivastava *et al.,* (2020) documented immediate post-bathing increases in COD, TDS, conductivity, and chloride alongside sharp DO decline, together with a shift from Bacillariophyceae to Chlorophyceae dominance in the plankton community; the Palmer Algal Genus Index fluctuated between 12 and 19, indicating moderate pollution. At the national scale, Kapse *et al.,* (2024) linked faecal contamination of drinking water to diarrhoeal disease incidence across India for 2017–2019, noting that although piped water access rose sharply — from 17% of households in August 2019 to 57% by January 2023 — much of the population still relies on raw surface or groundwater, and that most water-related health risks in India remain bacteriological rather than chemical in origin. Bacterial species commonly detected in Indian drinking water sources include *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella* sp., *Staphylococcus aureus*, and *Enterobacter aerogenes* (Suthar *et al.,* 2009), with contamination linked primarily to inadequate sanitation infrastructure (Raman and Muralidharan, 2019; Bindra *et al.,* 2021).

Earlier baseline data from Varanasi (Mishra, 1995 study cited in reviewed literature) found faecal coliform, faecal streptococci, total coliform, *E. coli*, and *Clostridium perfringens* consistently exceeding permissible limits, concluding that direct consumption or bathing in untreated Ganga water carries measurable health risk. Redox potential and the related Oxidation-Reduction Index (rH2) — governed by ambient temperature and hydrogen ion concentration — have been proposed as complementary pollution indicators, with negative Eh values and low rH2 corresponding to reducing, more polluted conditions.

Summary of Reported Ranges

Table 1 summarises the reported ranges for the most frequently monitored parameters across the studies reviewed, to allow direct comparison across sites and seasons.

In conclusion, the evidence reviewed here indicates that the Ganga River's water quality is under sustained pressure from multiple, overlapping anthropogenic sources: untreated sewage discharge, industrial effluent, agricultural runoff, inadequate solid-waste management, and — episodically but acutely — mass religious bathing events. Under routine conditions, most physico-chemical parameters remain within permissible regulatory limits, and the river demonstrates a natural capacity for seasonal recovery. However, this resilience is measurably eroded during mass-gathering events: Kumbh and Kanwar Mela data consistently show elevated BOD, COD, and total dissolved solids, alongside reduced dissolved oxygen and sharp spikes in faecal coliform, with the most severe deviations concentrated at high-density bathing sites such as Har ki Pauri and around the Sangam.

Correlation analyses across the reviewed studies reinforce the interdependence of these parameters — for example, the consistent inverse relationship between turbidity and dissolved oxygen, or between temperature and dissolved oxygen — which has direct management relevance: interventions targeting one parameter (for instance, reducing organic loading to improve BOD) are likely to yield measurable co-benefits across several others.

Seasonal monitoring data further show that the monsoon consistently produces the highest turbidity and microbial loading, while the dry season offers comparatively better water quality, a pattern with direct implications for the timing of both public bathing advisories and infrastructure interventions.

These findings underscore the continued need for standardized, high-frequency water-quality monitoring across the Ganga's length, particularly around mass-gathering events; stronger enforcement of effluent discharge standards; and sustained investment in sewage treatment infrastructure to support ongoing rejuvenation initiatives such as Namami Gange and Ganga Samagra.

Forthcoming work would advantage from harmonized sampling protocols and units across studies — several of the inconsistencies identified in this review stem directly from studies reporting comparable parameters in different units or over different observation windows — to enable more robust cross-site and cross-year comparison.

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Author Contributions

Anamika Negi: Investigation, formal analysis, writing—original draft. Shailendra Kumar Singh: Validation, methodology, writing—reviewing. Md. Akhlaqur Rahman:—Formal analysis, writing—review and editing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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