

Evaluation of River Water Quality Using Physico-Chemical and Biological Indicators: A Study of the Ganga Basin

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Abstract

The Ganga River basin which extends through eleven Indian states and serves over 500 million residents encounters one of the world's most complicated and important freshwater pollution problems. The water quality across extensive sections of the river and its tributaries has suffered serious harm from continuous industrial wastewater dumping and the discharge of untreated sewage and agricultural runoff together with religiously related waste. The current environmental assessment of this destruction needs to proceed beyond chemical testing which needs to execute a complete system that uses both physico-chemical measurements and biological assessment tools. The article studies how dissolved oxygen and biochemical oxygen demand and pH and turbidity and heavy metals and nutrient concentrations interact with macroinvertebrate communities and phytoplankton diversity and coliform bacterial counts and biotic indices to create a complete understanding of Ganga basin water quality. The article uses published monitoring data together with research from essential parts of the river which includes the Himalayan headwaters and the polluted middle reaches and the deltaic lower basin to study the spatial and seasonal pollution patterns and determine the best indicator combinations for management and assess the success of restoration programs including the Namami Gange initiative. The gap between monitoring knowledge and management action remains troublingly large but integrated assessment approaches offer a credible pathway toward evidence-based river restoration.

Keywords: water quality assessment, biological indicators, river pollution, macroinvertebrates, Ganga river, physico-chemical parameters

I. Introduction

The Ganga is not just a river in the way that most rivers are rivers. For hundreds of millions of Hindus, it is sacred — a living deity whose waters purify, heal, and absolve. Every year, tens of millions of pilgrims bathe in its waters at Haridwar, Prayagraj, Varanasi, and dozens of smaller ghats along its 2,525-kilometer course from the Gangotri glacier to the Bay of Bengal. Farmers across the Indo-Gangetic Plain irrigate crops from it. Cities draw drinking water from it. Fishermen have built livelihoods along its banks for generations.

All of this depends on a river in reasonable ecological health. The trouble is that the Ganga is not, in most of its middle and lower reaches, in reasonable ecological health. It is one of the most polluted large rivers in the world by several measures — receiving approximately 12 billion liters of sewage per day, along with industrial effluents from tanneries, paper mills, chemical plants, and pharmaceutical manufacturers, as well as agricultural runoff carrying fertilizers, pesticides, and silt from some of the most intensively farmed land on earth.

The disconnect between the river's cultural centrality and its ecological reality is striking, and it has generated enormous research attention. Scientists, engineers, government agencies, and civil society organizations have been monitoring and studying Ganga water quality for decades. The data they have accumulated tells a complex story — one that varies dramatically by location, season, depth, and the specific indicators chosen for measurement.

This article focuses on how we actually evaluate river water quality — what physico-chemical and biological indicators tell us, individually and together, about the state of the Ganga basin. The goal is not just to recite pollution statistics but to explain what the measurement tools mean, what they reveal that other tools miss, and why choosing the right combination of indicators matters for both scientific understanding and practical water management.

II. The Ganga Basin: Geography, Hydrology, and Pollution Sources

2.1 Basin Characteristics and Human Pressure

The Ganga basin drains approximately 861,000 square kilometers — about 26% of India's total geographical area. The basin encompasses some of the most densely populated territory on the planet, including major cities

like Haridwar, Kanpur, Prayagraj, Varanasi, and Patna, as well as hundreds of smaller towns and thousands of villages directly dependent on river water for domestic and agricultural use.

The river's hydrology shapes everything about its pollution dynamics. Flows vary enormously between the monsoon season (July to September), when the river swells with Himalayan meltwater and rainfall runoff, and the dry season (December to April), when low discharge concentrates pollutants dramatically. A sewage outfall that dilutes to acceptable concentrations during peak monsoon can create dangerously high pollutant concentrations in the same location during dry-season low flow. Any meaningful water quality assessment must account for this seasonal variability, yet many monitoring programs historically collected data infrequently or without adequate seasonal coverage.

Major tributaries — the Yamuna, Ghaghara, Gandak, Kosi, Son, and Damodar — each bring their own pollution loads from their respective catchments, and their confluence points with the main Ganga often show sharp water quality changes detectable in monitoring data.

2.2 Key Pollution Sources

Domestic sewage is the largest volumetric contributor to Ganga pollution. Urban local bodies along the river generate far more sewage than existing sewage treatment plants can handle — many towns have no treatment capacity at all. Of the approximately 12 billion liters of sewage generated daily in Ganga basin cities, sewage treatment plants process less than half, and a portion of that treated effluent does not meet discharge standards anyway.

Industrial pollution receives more media attention than its volumetric contribution might warrant, partly because industrial effluents contain more concentrated and toxic compounds. Kanpur's leather tanning industry — historically one of the largest in the world — has discharged hexavalent chromium, sulfides, and organic waste into the Ganga and its tributary the Pandu for decades, creating one of the most severe heavy metal contamination hotspots on the river. Varanasi hosts textile dyeing units. Allahabad (now Prayagraj) receives pharmaceutical manufacturing waste. The cumulative industrial load across the basin is substantial and qualitatively distinct from domestic sewage in its toxicological character.

Agricultural runoff from intensive farm fields transports nitrates and phosphates and pesticide residues which create diffuse pollution that is more difficult to control than point-source emissions. The Indo-Gangetic Plain's heavy use of chemical fertilizers has resulted in increased nutrient levels which flow into Ganga tributaries and cause eutrophication in their slower-moving sections.

III. Physico-Chemical Indicators of Water Quality

3.1 Dissolved Oxygen and Biochemical Oxygen Demand

Dissolved oxygen (DO) serves as the primary measure which determines the ecological status of rivers. Aquatic organisms require oxygen which exists as a dissolved substance in water for their vital functions and survival. The process of organic waste entering a river system leads to microbial decomposition which consumes dissolved oxygen and results in declining DO levels. Most fish species experience stress when DO levels drop below 4 mg/L; only highly tolerant organisms can survive at 2 mg/L; when DO reaches zero the system enters anoxic conditions which produce hydrogen sulfide and methane through anaerobic processes.

Monitoring data from the Central Pollution Control Board (CPCB) consistently shows DO falling to critically low levels — sometimes below 2 mg/L — in the stretch of the Ganga between Kannauj and Varanasi, particularly during dry season when dilution capacity is minimal. Biochemical oxygen demand (BOD) — a measure of how much oxygen organic waste in the water will consume during decomposition — runs correspondingly high in these stretches, sometimes exceeding 30 mg/L against an Indian standard of 3 mg/L for Class B rivers.

These two parameters together tell you whether organic pollution is overwhelming the river's natural self-purification capacity. A river with adequate flow and relatively modest organic loading can recover its oxygen content through reaeration from the atmosphere and photosynthesis by aquatic plants. When the oxygen demand from organic waste exceeds the river's reaeration capacity, DO crashes and stays crashed across long distances.

3.2 pH, Turbidity, and Conductivity

The Ganga's pH in its upper reaches near Rishikesh and Haridwar typically falls in the mildly alkaline range of 7.5–8.5, which matches the pH levels of well-oxygenated water that remains relatively pure. Industrial effluents from tanneries and chemical plants can drive local pH to extreme values which create dangerous conditions for aquatic organisms because the water becomes either strongly acidic or alkaline. The monitoring activities in Kanpur stretches observed pH values that fell outside the 6.5–8.5 range which aquatic ecosystems require during industrial discharge events.

Turbidity — the cloudiness of water caused by suspended particles — increases dramatically during monsoon floods when the river carries enormous sediment loads from eroded Himalayan catchments. Post-monsoon turbidity can be so high that light penetration is severely reduced, limiting primary productivity. Elevated turbidity also interferes with the feeding behavior of visual predators like fish and clogs the filter-feeding apparatus of invertebrates.

Electrical conductivity measures the concentration of dissolved ions in water and provides a broad-spectrum indicator of contamination from industrial and agricultural sources. Rising conductivity in Ganga tributaries across the Indo-Gangetic Plain reflects the combined contribution of fertilizer-derived ions, industrial salts, and domestic waste.

3.3 Nutrients and Heavy Metals

Nitrate and phosphate concentrations in the Ganga and its tributaries have increased substantially over the decades as agricultural fertilizer use has intensified. Elevated nutrient concentrations fuel algal growth, and periodic algal blooms in slower-moving reaches create their own oxygen depletion problems as the algal biomass decomposes. Some Ganga tributaries in Bihar show eutrophication signatures — elevated chlorophyll, reduced transparency, and seasonal oxygen crashes — directly attributable to agricultural nutrient runoff.

Heavy metal contamination is spatially concentrated but locally severe. Chromium in Kanpur stretches, arsenic in parts of the Bengal delta (partly from geogenic sources), lead and cadmium from industrial zones in Uttar Pradesh and Jharkhand — these represent acute toxicological risks that neither DO nor BOD measurements would capture. Heavy metal analysis requires specialized analytical techniques and is routinely absent from basic monitoring programs, creating gaps in our understanding of the true toxicological burden on Ganga basin ecosystems and human populations drawing water from the river.

As illustrated in Figure 1, the spatial pattern of key physico-chemical parameters along the main Ganga stem reveals a consistent deterioration from the relatively clean upper reaches to severely polluted middle reaches, with partial recovery in some lower stretches where dilution from large tributaries provides temporary relief.

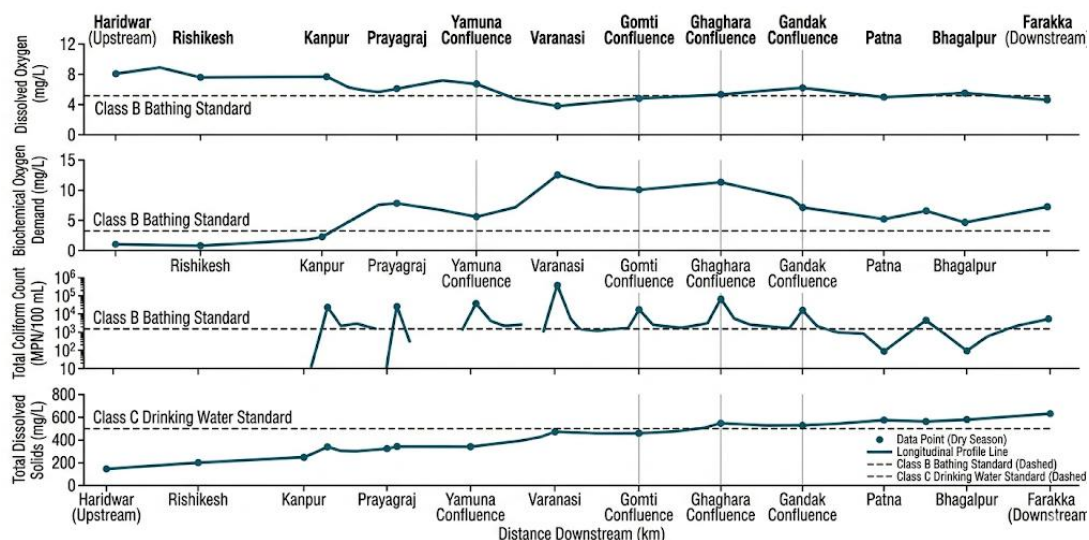


Figure 1: Spatial Variation in Key Physico-Chemical Water Quality Parameters Along the Main Ganga River Stem from Haridwar to Farakka

The multi-panel line graph displays the longitudinal variation in four physico-chemical parameters — dissolved oxygen (mg/L), biochemical oxygen demand (mg/L), total coliform count (MPN/100 mL), and total dissolved solids (mg/L) — measured at twelve monitoring stations along the main Ganga from Haridwar (upstream) to Farakka (downstream) during the dry season. The x-axis represents distance downstream, with major cities and tributary confluence points marked. The y-axis scales are adjusted independently for each parameter. Indian water quality standards for Class B (bathing water) and Class C (drinking water with treatment) designations are shown by horizontal dashed lines which indicate the standards. The graph shows a dramatic deterioration in DO and BOD between Kanpur and Varanasi, with coliform counts rising steeply below major urban centers before partial improvement downstream of the Ghaghara and Gandak confluences where tributary dilution provides measurable relief.

IV. Biological Indicators of River Health

4.1 Why Biological Indicators Matter

Physico-chemical measurements capture water quality at the moment of sampling. Take a water sample on a day when industrial discharge is minimal and flows are high, and the chemistry might look acceptable even in a chronically polluted stretch. Biological communities, by contrast, integrate conditions over time — they reflect not just what the water is like today but what it has been like over weeks, months, or years. An invertebrate community depleted of pollution-sensitive taxa tells you the river has been hostile to those organisms for long enough to eliminate them, regardless of what the instantaneous DO reading says.

This temporal integration is one of the most valuable properties of biological indicators, and it makes them essential complements to physico-chemical monitoring rather than optional extras. Experienced river ecologists often say that if you want to know what a river is really like, look at what is living in it.

4.2 Macroinvertebrate Communities

Aquatic macroinvertebrates — insects (particularly mayflies, stoneflies, and caddisflies, collectively known as EPT taxa), crustaceans, mollusks, worms, and leeches — are the most widely used biological indicators in river quality assessment globally. Different taxonomic groups show markedly different tolerances to pollution, and the composition of the community at a site provides a sensitive indicator of water quality conditions.

Stonefly nymphs and many mayfly species are highly sensitive to low dissolved oxygen and organic pollution — they disappear from degraded sites rapidly. Tubificid worms and chironomid midge larvae, at the other extreme, tolerate extremely low DO and high BOD, sometimes thriving in near-anoxic conditions where nothing else can survive. A sampling site dominated by tubificids and chironomids in the near-total absence of EPT taxa is biologically screaming that water quality is very poor.

Biotic indices — numerical scores derived from macroinvertebrate community data that weight species by their pollution tolerance — allow quantitative comparison across sites and time. The BMWP (Biological Monitoring Working Party) score and the Hilsenhoff Biotic Index have been adapted for Indian river conditions, though standardization and baseline development for the Ganga basin specifically remains incomplete. Research by Sharma and Rawat (2009) applied modified biotic indices to Ganga macroinvertebrate communities across a gradient from relatively clean to severely polluted sites and found strong alignment between biological index scores and concurrent physico-chemical measurements — validation that both approaches are measuring the same underlying reality from different angles.

4.3 Phytoplankton and Periphyton

Algal communities — both free-floating phytoplankton and the periphyton (attached algae) growing on submerged surfaces — respond sensitively to nutrient enrichment, light availability, temperature, and toxicant exposure. Diatom assemblages are particularly useful indicators because different species show well-characterized ecological preferences, diatom cells preserve well in sediment records allowing historical reconstruction of water quality, and large reference datasets exist for European rivers that can inform (with adaptation) Indian applications.

In nutrient-enriched Ganga stretches, phytoplankton communities tend to shift from diverse assemblages including diatoms and green algae toward cyanobacteria-dominated communities. Cyanobacterial blooms — blue-green algae — are concerning not just as symptoms of eutrophication but because many species produce cyanotoxins that pose direct health risks to people and animals using the water. Several tributaries of the Ganga in Bihar and West Bengal have reported cyanobacterial bloom events with associated livestock deaths and human illness, though systematic surveillance for cyanotoxins remains inadequate.

4.4 Microbial Indicators

Fecal coliform bacteria — particularly *Escherichia coli* — serve as indicator organisms for sewage contamination and the associated risk of fecal-oral pathogen transmission. Indian water quality standards for bathing water specify that total coliform counts should not exceed 500 MPN (Most Probable Number) per 100 mL. Fecal coliform standards for drinking water are even more stringent.

Ganga monitoring data from CPCB consistently shows total coliform counts of hundreds of thousands to millions of MPN per 100 mL at bathing ghats in Varanasi, Prayagraj, and Kanpur — three to four orders of magnitude above the bathing water standard. People bathing in these waters — which tens of millions do during festivals like Kumbh Mela — face genuine risk of waterborne disease from pathogens including cholera, typhoid, hepatitis A, and numerous diarrheal diseases that travel with fecal contamination. The paradox of the Ganga's religious significance creating massive human-water contact at some of its most polluted points is one of the most acute public health dimensions of the basin's water quality crisis.

V. Spatial and Seasonal Patterns of Water Quality

5.1 The Upstream-Downstream Gradient

The Ganga's water quality follows a broadly predictable spatial pattern that reflects the increasing accumulation of pollution inputs as the river moves downstream through progressively more urbanized and industrialized terrain. The upper reaches near Rishikesh and Haridwar are relatively clean — mountain water with adequate DO, low BOD, manageable coliform counts, and diverse aquatic communities. This is where Gangetic dolphins (*Platanista gangetica*) are still occasionally sighted, and where fish populations retain some semblance of diversity.

Below Haridwar, the river enters the plains and begins accumulating pollution from a long succession of cities and towns. The stretch between Kannauj and Varanasi is widely considered the most severely degraded section of the entire river. Multiple studies place DO at near-zero during dry season low flows in this stretch, BOD in the severely polluted range, coliform counts in the millions, and macroinvertebrate communities stripped of pollution-sensitive taxa and dominated by pollution-tolerant worms.

Below Varanasi, large tributaries including the Ghaghara and Gandak introduce cleaner water that dilutes Ganga pollution to some degree. DO recovers partially. Coliform counts drop. Fish diversity, which essentially collapses in the most polluted stretches, shows some recovery downstream. This natural dilution-recovery pattern was more pronounced before the tributaries themselves became more heavily polluted, and demonstrates why protecting tributary water quality is as important as managing the main stem.

5.2 Seasonal Dynamics

Monsoon hydrology dramatically alters water quality dynamics across the entire basin. Flood flows dilute point-source discharges, raise DO through turbulent reaeration, and physically flush accumulated sediments. Many water quality parameters improve during peak monsoon — which partly explains why historical monitoring programs that sampled infrequently sometimes produced optimistic assessments that did not reflect the chronic dry-season reality.

Post-monsoon drawdown is the most critical period. As flows decline sharply through October and November while cities continue generating the same volumes of sewage, dilution capacity shrinks and pollutant concentrations rise. December through May — when flows are lowest — represents the period of worst water quality in most monitored sections. Aquatic organisms adapted to clean water that survived monsoon conditions face maximum stress during this prolonged low-flow period.

Figure 2 illustrates the seasonal pattern of dissolved oxygen and total coliform counts at two contrasting monitoring stations — one in the relatively clean upper Ganga and one in the heavily polluted middle reach — demonstrating how dramatically water quality varies through the annual hydrological cycle.

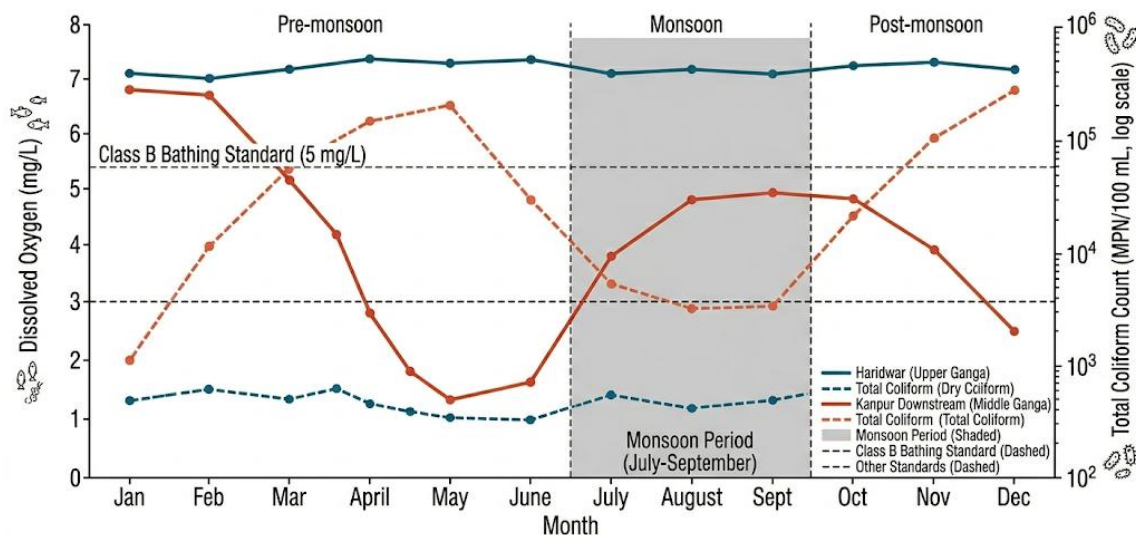


Figure 2: Seasonal Variation in Dissolved Oxygen and Total Coliform Count at Upper Ganga (Haridwar) and Middle Ganga (Kanpur) Monitoring Stations Across a Full Annual Hydrological Cycle

This dual-axis time series graph displays monthly measurements of dissolved oxygen (mg/L, left axis, shown as solid lines) and total coliform count (MPN/100 mL, right axis, shown as dashed lines, log scale) across twelve months for two monitoring stations: Haridwar (upper Ganga, represented in blue) and Kanpur downstream (middle Ganga, represented in red). The x-axis shows months from January through December, with the monsoon period (July–September) shaded in grey. The graph reveals that at Haridwar, DO remains

consistently above 7 mg/L year-round with modest seasonal variation and coliform counts stay relatively low. At Kanpur, DO plunges to below 3 mg/L during dry season months (January–June) while coliform counts climb to several hundred thousand MPN/100 mL, with both parameters showing partial improvement during monsoon due to dilution before deteriorating again in the post-monsoon drawdown period.

VI. Conclusion

The Ganga basin's water quality crisis is real, severe, and consequential for hundreds of millions of people who depend on the river for drinking water, irrigation, livelihoods, and cultural sustenance. Evaluating that crisis accurately requires the best available combination of physico-chemical and biological indicators — not as competing frameworks but as complementary lenses that together produce a far more complete and reliable picture than either provides alone.

The scientific tools are adequate. Dissolved oxygen, BOD, nutrient concentrations, heavy metal analysis, macroinvertebrate biotic indices, phytoplankton composition, and microbial indicators together constitute a robust and internationally validated assessment toolkit. What India needs is more consistent, more frequent, more spatially comprehensive deployment of these tools, along with genuine commitment to making the resulting data publicly available and using it to drive management decisions.

The Namami Gange programme represents a genuine national commitment to reversing decades of neglect, and it has produced real infrastructure and some measurable improvement at specific sites. Sustaining and accelerating that improvement requires honest assessment of where progress is real and where it is not — which is exactly what rigorous, integrated water quality monitoring can provide. The Ganga deserves nothing less, and neither do the people who have depended on it for millennia.

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