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Original Article

Analysing the Changes in the Water Quality of River Yamuna, During 2012-2023

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Abstract - *The River Yamuna, one of the most significant rivers in northern India, plays a vital role in supporting agriculture, industry, and human settlements, but it continues to face severe pollution stress. This study examines the changes in the Yamuna's water quality between 2012 and 2023. Secondary data for key physico-chemical and microbiological parameters were collected from the Central Pollution Control Board (CPCB) website, and annual mean values were analyzed to identify long-term trends. The parameters studied include pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), conductivity, nitrates/nitrites, fecal coliform, and total coliform. The findings reveal that while pH remained relatively stable (7.5–7.8), DO levels fluctuated widely, with a minimum of 5.34 mg/L in 2014 and a peak of 12.57 mg/L in 2015. BOD consistently exceeded permissible limits, with the highest value of 16.05 mg/L recorded in 2022, indicating persistent organic pollution. Conductivity levels rose significantly over the decade, reaching over 1100 µmhos/cm in 2016, suggesting increasing dissolved solids from effluents. Microbiological contamination was a major concern, as fecal and total coliform counts remained alarmingly high throughout the study period, with 2012 showing extreme levels and only partial declines by 2023. Overall, the results highlight persistent anthropogenic pressures, primarily from untreated sewage and industrial discharges, that continue to degrade the Yamuna's water quality. Addressing these challenges requires integrated approaches, including seasonal and site-specific monitoring, expansion of tested parameters, and adoption of advanced analytical tools to support sustainable river management and policy interventions.*

Keywords - *Yamuna, Central Pollution Control Board, Physico-chemical, Permissible limits.*

1. Introduction

Water is the elixir of life and a basic necessity for human survival. It exists in three primary forms: surface water, groundwater, and glaciers [1]. Globally, glaciers and ice caps hold 68.7% of freshwater, groundwater 30.1%, and surface water only 1.2% [2]. Rivers, in particular, provide vital freshwater, regulate climate, support agriculture, generate hydropower, sustain ecosystems, and enable recreation [3]. However, deteriorating water quality threatens human health, ecosystems, and economies [4]. Polluted water spreads diseases like cholera, hepatitis, and typhoid [5], while industrial toxins, pesticides, and heavy metals such as arsenic and lead cause long-term effects, including cancer and organ damage [6]. Aquatic life is also impacted, as sewage and fertilizers trigger eutrophication, leading to algal blooms, oxygen depletion, fish kills, and biodiversity loss. Major contamination sources include industrial, agricultural, domestic, and urban waste [7][3].

The Yamuna, the largest tributary of the Ganga, originates from the Yamunotri Glacier at 6,387 m in Uttarakhand and flows through Himachal Pradesh, Uttar Pradesh, Haryana, and Delhi [1] [6]. It sustains aquatic biodiversity, enhances soil fertility in the Indo-Gangetic plains, irrigates millions of hectares, and provides water for drinking and industry, particularly in Delhi [1] [3]. Yet rapid urbanization in Delhi NCR, Agra, and Mathura has led to rising sewage, solid waste, and industrial effluents, especially from textiles, chemicals, tanneries, and power plants [7] [1]. These activities have increased heavy metal loads, altered pH and oxygen levels, and rendered the Yamuna increasingly unfit for both human and ecological use [7] [6]. Previous studies have examined various factors affecting the water quality of the Yamuna River. For instance, Isaac (2024) assessed seasonal variations at nine locations along the river, highlighting fluctuations in parameters such as dissolved oxygen and biochemical oxygen demand, and emphasizing the need for targeted seasonal interventions [8]. Additionally, Tiwari et al. (2024) investigated the impact of the COVID-19 lockdown, observing temporary improvements in water quality in the upper Ganga and Yamuna due to reduced anthropogenic activities. These studies underscore the influence of both natural and human-induced factors on river health and highlight the need for long-term, comprehensive monitoring to guide effective management strategies[9].

Although numerous studies have assessed Yamuna's pollution, most are restricted to short periods or specific stretches of the river. Long-term multi-parameter analyses covering more than a decade remain scarce, and limited attention has been given to seasonal variability, emerging contaminants, and the compounded effects of urbanization and industrialization. This study addresses the research gap by analyzing water quality changes in the Yamuna from 2012 to 2023, examining key parameters including pH, dissolved oxygen, BOD, COD, and heavy metals. Compared to previous short-term studies, it identifies persistent pollution hotspots and temporal trends and evaluates the effectiveness of mitigation measures.

The novelty lies in its long-term, comparative approach, providing a continuous, holistic assessment of water quality that highlights critical areas for intervention and informs sustainable river management strategies.

The current study aimed to evaluate long-term trends (2012–2023) in the Yamuna River's key physico-chemical and microbiological parameters using CPCB data.

2. Methodology

This study's long-term records of Yamuna River water quality from 2012 to 2023 were sourced from the Central Pollution Control Board (CPCB), Ministry of Environment, Forest, and Climate Change, Government of India. The analysis focused on key physico-chemical and microbiological indicators: temperature, pH, Dissolved Oxygen (DO), conductivity, Biochemical Oxygen Demand (BOD), nitrate–nitrite, fecal coliform, and total coliform. After organizing the raw dataset, annual averages were computed to capture decadal trends. These values were visualized through graphical plots generated in Microsoft Excel, enabling comparison with established CPCB and World Health Organization (WHO) guidelines to assess the river's quality for domestic, agricultural, and related applications.

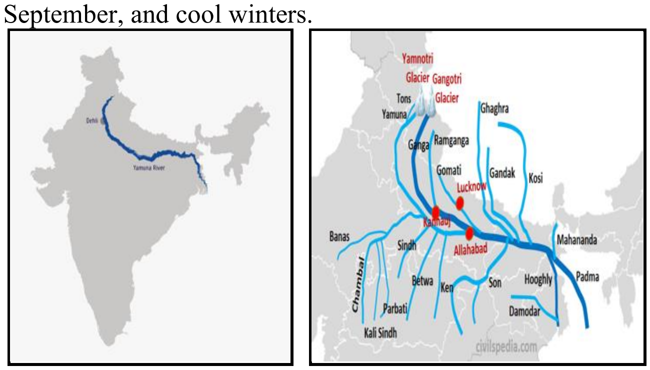
2.1. Parameters Under Study

1. Temperature: Affects the metabolic rates of aquatic organisms and oxygen solubility. Yamuna's seasonal and anthropogenic variations in temperature could indicate thermal pollution or climate-related shifts.
2. Dissolved Oxygen (DO): Acts as a critical indicator of river health, supporting aquatic life, and indicates the balance between the ratio and oxygen-demanding waste. Yamuna's low DO levels are tied directly to sewage and industrial effluent discharge. According to the CPCB standards, the permissible range for DO of river water should be >4 mg/l.
3. pH: Corresponds to the level of acidity or alkalinity of the river, affecting the solubility of nutrients and metals. Yamuna's variation in pH values can signal changes in the level of chemical pollution from industrial and domestic sources. According to the CPCB standards, the permissible pH range for river water should be 6.5-8.5
4. Conductivity (µmhos/cm): Correlates with the concentration of dissolved ions, reflecting pollution and salinity levels. Elevated levels in the Yamuna could be linked to waste, water, fertilisers, and industrial discharge.
5. Biochemical Oxygen Demand (BOD) (mg/L): Measures the amount of oxygen needed to decompose organic matter, directly reflecting organic pollution. High levels of this in the Yamuna have indicated sewage overload and untreated effluents. According to the CPCB standards, the permissible range for BOD of river water should be <3 mg/l.
6. Nitrate-N + Nitrite-N (mg/L): These nitrogen-containing polyatomic ions are indicators of nutrients, often linked to agricultural run-off and sewage. In the Yamuna, excessive levels of these ions contribute to eutrophication and algal blooms.
7. Fecal Coliform (MPN/100ml): Marker of human and animal waste contamination. Their presence in the Yamuna water highlights health risks and inadequate sewage treatment. According to the CPCB standards, the permissible range for Fecal Coliform of river water should be <2500 MPN/100ml.
8. Total Coliform (MPN/100ml): Gives a broad measure of microbial contamination, including pathogens. Monitoring them in the Yamuna helps assess the impact of untreated domestic discharge. According to the CPCB standards, the permissible range for Total Coliform of river water should be <5000 MPN/100ml.

The water quality of the Yamuna River is shaped by both natural and anthropogenic factors. Environmental events, including rainfall, flooding, and temperature fluctuations, influence dissolved oxygen, turbidity, and pollutant dispersion. Human activities are the primary contributors, with untreated sewage and livestock run-off increasing Biochemical Oxygen Demand (BOD) and microbial contamination, while industrial and agricultural effluents release heavy metals, fertilizers, and pesticides, elevating Chemical Oxygen Demand (COD) and nutrient levels. Solid waste from urban settlements, religious practices, and riverbank activities further increases turbidity, and microbiological contaminants such as fecal coliforms pose public health risks. Together, these pollutants degrade key water quality parameters and threaten aquatic ecosystems. Identifying their sources is crucial for targeted interventions, effective wastewater treatment, regulatory enforcement, and sustainable river management to restore the ecological health of the Yamuna.

2.2. Site Selection

The Yamuna River is a major river in northern India, and the second-largest tributary of the Ganga River. Originating from the Yamunotri Glacier on the southwestern slopes of the Banderpooch peaks in the Lower Himalayas, it starts at an altitude of approximately 6,387 meters in the Uttarkashi district of Uttarakhand. The river flows through multiple Indian states, including Uttarakhand, Himachal Pradesh, Haryana, Delhi, and Uttar Pradesh, covering a total length of about 1,376 kilometers. Its extensive basin spans approximately 366,223 km², accounting for around 40% of the Ganga Basin. Key towns and cities that the river flows through include Yamunotri, Paonta Sahib, Dehradun (via tributaries), Delhi, Mathura, Agra, Etawah, and finally Prayagraj, where it merges with the Ganga at Triveni Sangam. The Yamuna is fed by several tributaries, including the Chambal, Tons, Sindh, Betwa, and Ken rivers. It plays a vital role in agriculture, supporting extensive irrigation in the Indo-Gangetic plains, and is also a significant water source for drinking, industrial use, and religious practices in urban centers. The river is particularly important in Delhi, where it provides over 70% of the city's water supply. However, it also absorbs more than 60% of the city's untreated sewage and industrial effluents. The river's average width ranges from 200 to 2,500 meters, depending on the stretch and season, and the flow volume fluctuates significantly between pre-monsoon and monsoon periods. The Yamuna ecosystem is influenced by glacial melt, monsoonal rainfall, and anthropogenic discharges. It passes through a range of geomorphological zones from the Himalayan foothills to the alluvial plains of Uttar Pradesh. Its flow dynamics are affected by barrages at Hathnikund (upstream) and Okhla, Wazirabad, and ITO (in Delhi), which regulate water levels and impact sediment transport. Although the river holds religious and cultural significance, especially at sites like Mathura and Vrindavan, it is one of the most polluted rivers in India. High nutrient loads from nitrogen and phosphorus, heavy metals, and coliform bacteria are prevalent, particularly in the Delhi stretch. The river's depth and width vary with rainfall and barrages, and the total discharge at its mouth can differ greatly, especially during the peak monsoon. The Yamuna Basin's climate is subtropical, dominated by hot summers, a monsoon season from June to September, and cool winters.



(a) **(b)**

Fig. 1(a) Location of River Yamuna on the Map of India [10] (b) Route Map of India [11]

3. Results and Discussion

Table 1. Annual mean data for various water quality criteria throughout the length of the River Yamuna collected from the CPCB for a period of 10 years, from 2012 to 2023

	Mean of the Physico-chemical Parameters/year							
Year	**Temperature (ºC)**	**DO. (mg/l)**	**pH**	**Conductivity (µmhos/cm)**	**BOD (mg/l)**	**Nitrate-N+ Nitrite-N (mg/l)**	**Fecal Coliform (MPN/100ml)**	**Total Coliform (MPN/100ml)**
2012	19.35	7.23	7.7	308.07	9.42	0.84	1381980203	2534747501
2013	19.195	7.039	7.783	179.9	7.507	2.7829	14205.22	1433169.42
2014	22.2	5.341	7.704	457.083	10.275	1.18	42978.07	9932498.61
2015	24.93	12.577	7.85	742.11	9.466	--	13172.42	778756.75
2016	22.58	6.752	7.672	1130.52	10.08	0.3	2526353.167	4345599.82
2017	16.7	6.342	7.657	953.3	11.6375	1.4	3110590.962	4017029.077
2018	21.796	7.486	7.694	862.93	11.52	1.2	2075326.26	4856293.365
2019	22.44	7.006	7.56	973.8	9.314	1.51	1259407.241	1661876.414
2020	21.51	7.134	7.684	827.91	11.1	1.95	539556.35	1910207.1
2021	23.84	6.209	7.611	872.34	13.15	1.064	649876.42	913613.766
2022	21.885	7.1206	7.516	446.76	16.055	0.544	79740.58	30413.21
2023	20.824	6.544	7.717	711.292	11.668	0.72	218572.92	485836.46

Table 2. Permissible range for drinking water by parameter measured (World Health Organization standards 2024 [12] and CPCB water quality standards [13]

Parameter	Permissible range for drinking water
Temperature (◦C)	10 - 22
Dissolved O2 (mg/l)	> 6.5 - 8
pH	6.5 - 8.5
Nitrate + Nitrite (mg/l)	< 1
Conductivity (µmhos/cm)	< 800
BOD (mg/l)	< 2
Fecal Coliform (MPN/100ml)	< 1
Total Coliform (MPN/100ml)	< 50

3.1. Temperature

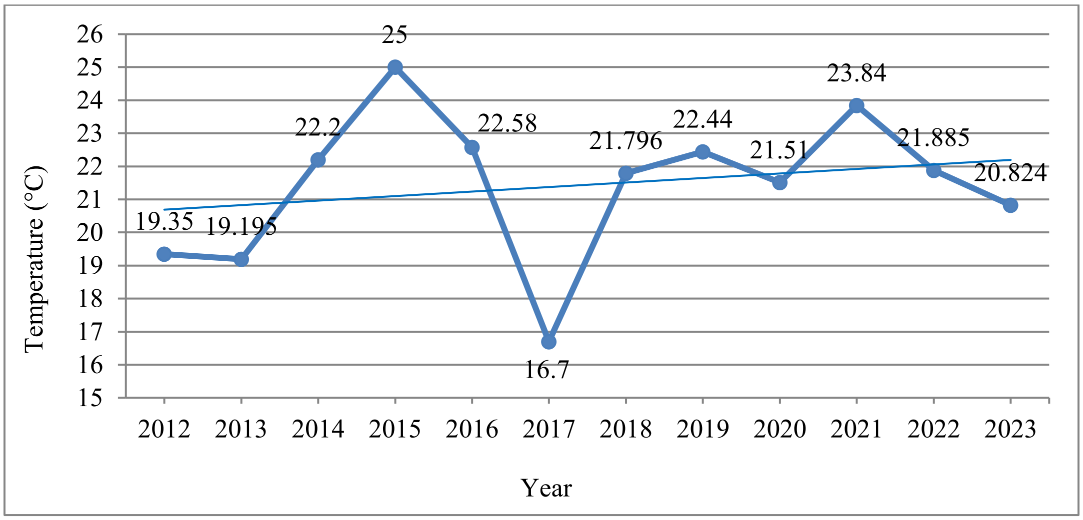


Fig. 2 Variation in annual temperature of the River Yamuna from 2012 to 2023

Temperature is a key factor that influences a river's biological activity and chemical processes. It impacts the solubility of oxygen, the metabolic rates of aquatic life, the breakdown of matter (organic and inorganic), and reproductive cycles. The ideal temperature range for a river like the Yamuna ranges between 20°C and 30°C, which helps support aquatic biodiversity. Beyond this range, species can experience physiological stress or ecosystem disruption. From 2012 to 2023, water temperature in the Yamuna (Figure 2) has ranged between 23.0°C (2013) and 30.0°C (2018). A gradual warming trend is evident, particularly between 2015 and 2018, where the temperature rose from 26.4°C to 30°C. This warming corresponds with urban heat island effects, reduced base flow during dry seasons, and reduced vegetation cover along riverbanks that normally provide shading. Industrial effluent discharge in areas like Delhi and Faridabad may also contribute to localized heating of river stretches [3], [**1**].

The ecological impact of this increasing temperature trend is significant. The acceleration of microbial decomposition rates leading to increased BOD levels is contributing to algal bloom formations in stagnant areas. In addition, high temperatures can also lead to altered breeding seasons and altered migration patterns of fish, alongside increasing ammonia toxicity.

To mitigate rising river temperatures, actions should include restoring riparian vegetation, increasing environmental flow (e-flow) releases from upstream reservoirs, and restricting thermal pollution through industrial regulation. Periodic de-siltation and flow augmentation may also help improve the river's thermal buffering capacity.

3.2. Dissolved Oxygen (DO)

Dissolved Oxygen (DO) refers to the level of free, non-compound oxygen present in water. It is vital for the survival of aquatic life and serves as a fundamental indicator of water body health. High DO signifies good water quality, while low DO levels suggest pollution and the presence of excessive biodegradable organic matter.

According to CPCB standards, the minimum DO level for Class A water is ≥6 mg/l and ≥5 mg/l for Class B usage. WHO recommends DO levels not falling below 5 mg/l for safe aquatic ecosystems.

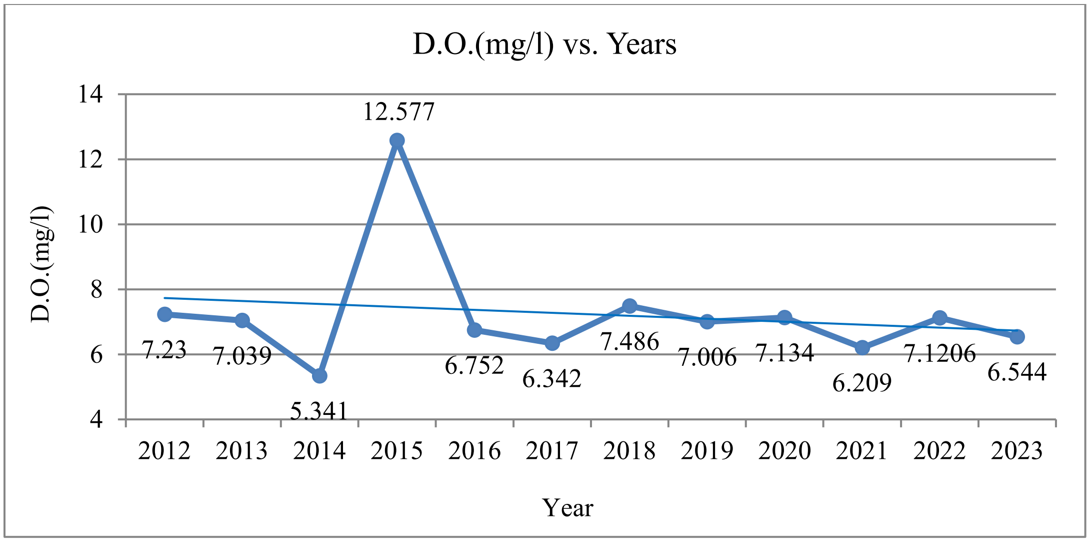


Fig. 3 Variation in annual DO of River Yamuna from 2012 to 2023

In the Yamuna dataset (2012–2023), DO levels ranged from a low of 5.341 mg/l in 2014 to an anomalously high peak of 12.577 mg/l in 2015. The data shows erratic fluctuations throughout the decade, with values largely oscillating between 6 mg/l and 7.4 mg/l, hovering near or just above the Class B threshold, but indicating poor oxygen availability in several years, like 2014 (5.341mg/l), 2016 (6.752 mg/l), and 2021 (6.209 mg/l).

The graph illustrates a dip in 2014 and 2017, with a sudden spike in 2015. This spike is unusual and might result from localized mitigation efforts or a sudden influx of freshwater. The broader trend, however, remains below optimal, likely due to high Biological Oxygen Demand (BOD), increased organic matter, decaying vegetation, and untreated sewage discharge, especially from urban settlements like Delhi [3][**1**]

Low DO levels in the Yamuna have direct ecological consequences, leading to hypoxic conditions that can kill fish and invertebrates, disrupt breeding cycles, and reduce overall biodiversity. Prolonged low oxygen levels also limit the self-purification ability of the river, further intensifying pollution[7].

Several actions are necessary to restore DO levels in the Yamuna. These include stringent control over sewage discharge, especially untreated domestic effluents, improvement of STP infrastructure, and preservation of riverine vegetation that supports oxygen cycling. Environmental flow (e-flow) maintenance must be enforced to support natural aeration processes and ecosystem stability [**1**]

3.3. pH

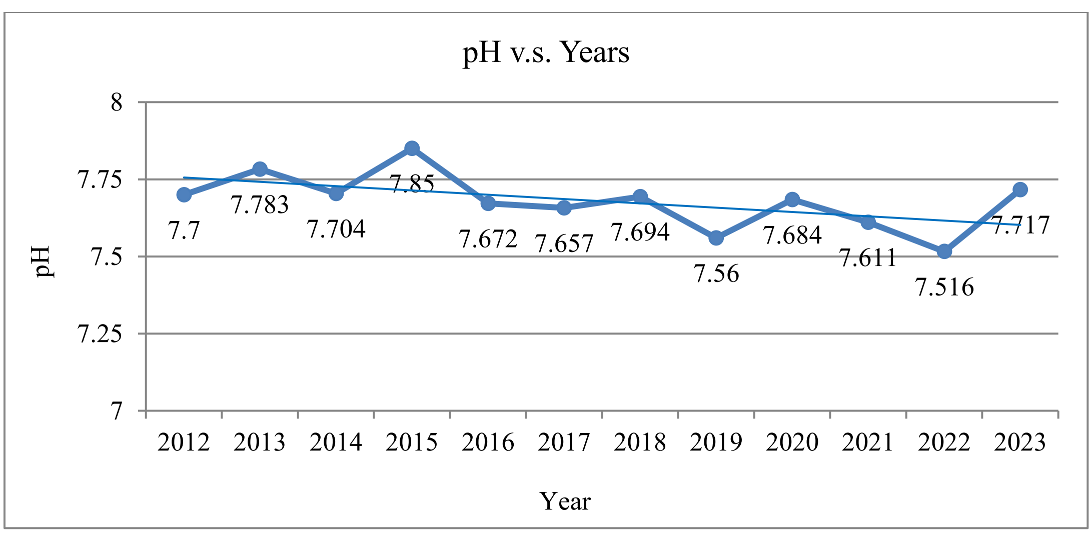


Fig. 4 Variation in annual pH of River Yamuna from 2012 to 2023

pH is a measure of the hydrogen ion concentration in water, which indicates acidity or alkalinity levels. It affects the solubility of nutrients and toxic substances, and looks at many biological and chemical processes in aquatic systems. A pH of 7 is ideal; however, deviations can stress or kill aquatic organisms. According to CPCB standards, the acceptable pH range for surface water is between 6.5 and 8.5. For River Yamuna, the pH values between 2012 and 2023 ranged between 7.45 (2017) and 7.93 (2022), which lie within the permissible ranges. The slight alkaline shift from 2017 to 2022, though, suggests increased alkaline industrial discharges, domestic effluents, or photosynthetic activity from algal blooms in eutrophication conditions [6][1]

None of the values exceed the permissible range, but the upward trend is still worth noting. Alkalinity can alter metal solubility, leading to bioaccumulation of heavy metals in aquatic organisms. This also influences ammonia toxicity, especially under high-temperature conditions. This makes the water less suitable for aquatic organisms to thrive, increasing physiological stress [14]

In cities like Delhi and Agra, there are numerous sewage outfalls, and the river flow is low. This leads to low pH buffering capacity, meaning minor changes in inflow composition could significantly alter the pH [3].

Effluent pre-treatment at industrial sites, limiting phosphate and alkali-rich household detergents, and restoration of natural wetlands are some of the ways to stabilize pH levels. Regular real-time pH monitoring using sensors is also essential at strategic barrages and outfalls for early detection of pollution.

3.4. Conductivity

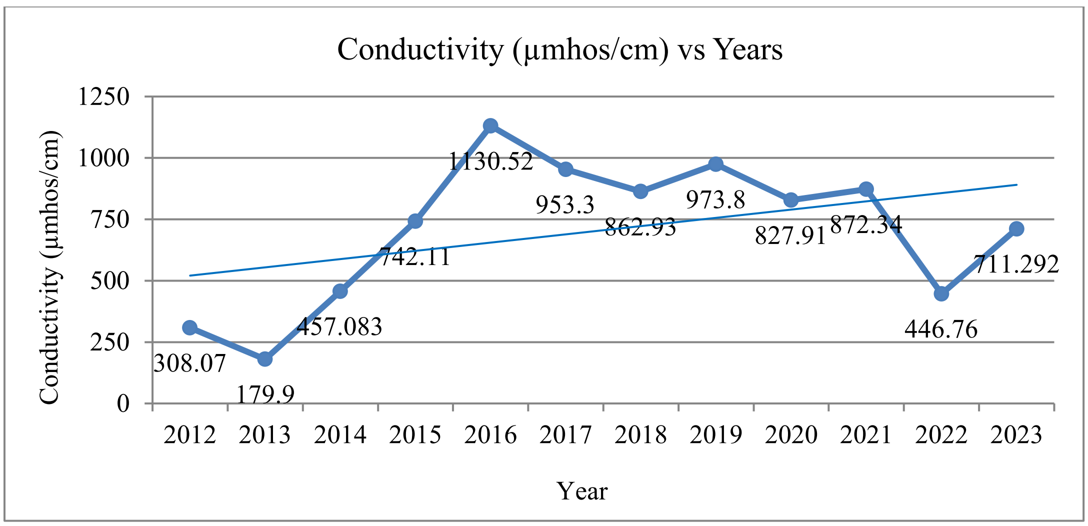


Fig. 5 Variation in annual Conductivity of River Yamuna from 2012-2023

Conductivity refers to water's ability to conduct electrical current. This depends on the concentration of dissolved ions such as chlorides, nitrates, phosphates, and heavy metals. It is widely used as an indirect measure of pollution and salinity. High conductivity often indicates contamination from industrial discharge, sewage inflow, or agricultural run-off.

While no strict WHO standard exists for drinking water conductivity, surface water used for irrigation or aquatic life should ideally remain below 2,250 µS/cm, according to CPCB guidelines.

In Yamuna from 2012 to 2023, conductivity ranged from 852.91 µS/cm (2013) to a peak of 1641.68 µS/cm (2015). The average remained between 1100–1400 µS/cm, suggesting moderate to high ionic load. The data shows a noticeable spike in 2015 and a general upward drift through 2021, possibly caused by increasing urban run-off, discharge from power plants and industrial units, and reduced freshwater inflow [1][3].

These elevated values suggest heavy pollution inputs, specifically domestic and industrial effluents rich in dissolved salts and metals. The rivers that stretch downstream of Delhi and Agra are especially vulnerable due to their limited flow and heavy usage. High conductivity also decreases agricultural productivity if used in irrigation and corrodes pipelines when used for industrial processing [14].

Actions must focus on regulating effluent discharge and establishing buffer strips in agricultural zones to mitigate high conductivity levels. The monitoring should also account for ion-specific loads to refine pollution control strategies.

3.5. BOD

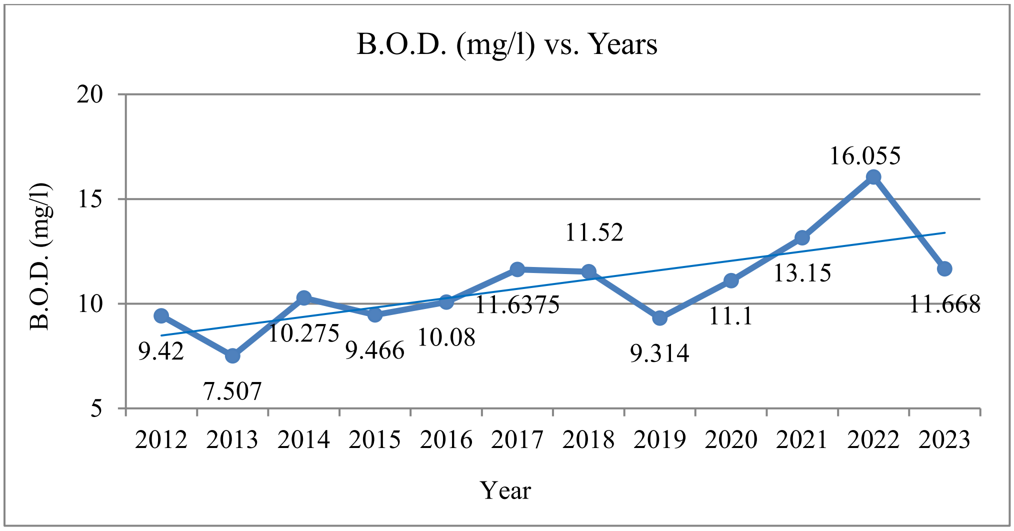


Fig. 6 Variation in annual BOD of River Yamuna from 2012 to 2023

Biochemical Oxygen Demand (BOD) refers to the amount of dissolved oxygen required by aerobic microorganisms to break down organic matter in water. It is an indicator of organic pollution, which reflects the degree of organic waste present and decomposing in water bodies. According to the Central Pollution Control Board (CPCB), the permissible BOD level for class B is ≤3 mg/l and for class A is ≤2 mg/l [**1**]

In the data about the Yamuna river spanning from 2012 to 2023, BOD values range from 7.507 mg/l in 2013 to a peak of 16.055 mg/l in 2022. In all the years studied, the measured BOD values exceed the CPCB limits, which indicates a consistent and severe organic pollution. On average, BOD levels stay above 10 mg/l, underlying persistent organic loading.

The observed trend showcases that the BOD levels fluctuate but consistently stay high with sharp increases in 2017-2018 and 2021-2022. These spikes could perhaps correlate with urban expansion, increased sewage inflow, and low dilution capacity due to reduced river flow [**1**]. Studies show that more than 85% of the pollution load in the Yamuna originates from domestic waste, especially from Delhi NCR. This region discharges large amounts of untreated and partially treated sewage directly into the river [3], [12].

Other contributors include industrial effluents, dumping of organic waste, and decaying aquatic biomass, especially in stagnant downstream stretches. The impacts of such elevated levels of BOD on ecological diversity and mankind are also concerning. High BOD levels reduce dissolved oxygen (DO) levels, creating hypoxic conditions that are unsuitable for aquatic life. Additionally, such waters are unsuitable for drinking, bathing, and even irrigation in sensitive zones [5]; [**1**]

To address the BOD concerns in the Yamuna, urgent measures need to be taken into consideration. These include the establishment of upgraded and expansive sewage treatment plants (STPs), enforcement of affluent norms for industries, and prohibition of solid and organic waste dumping near the river banks. Establishing buffer zones, decentralized wastewater treatment, and ensuring environmental flow (e-flow) to maintain natural dilution are critical [1] [3]

3.6. Nitrate+Nitrite

Nitrate and Nitrite are essential nitrogen-based nutrients that are commonly used as indicators of nutrient pollution in freshwater systems. These compounds enter rivers primarily through agricultural run-off, sewage discharge, urban stormwater, and decaying organic waste. While low concentration is needed for plants to thrive, excessive levels can lead to extreme cases of eutrophication, algal blooms, and aquatic oxygen depletion.

The WHO permissible range includes a maximum of 50 mg/L for nitrate and 3 mg/L for nitrite in drinking water. However, the CPCB does not set an exact limit for surface water, but uses nitrate as an ecological health indicator, especially in eutrophic and semi-stagnant river stretches.

From 2012 to 2023, Yamuna's data shows nitrate and nitrate values ranging from 1.07 mg/L in 2013 to 3.29 mg/L in 2021. The trend is relatively low but gradually increasing nutrient levels, especially between 2016 and 2021. This peaked during years of reduced base flow and high organic load. These figures are below the WHO permissible range, but high enough to signal nutrient enrichment of the river [1].

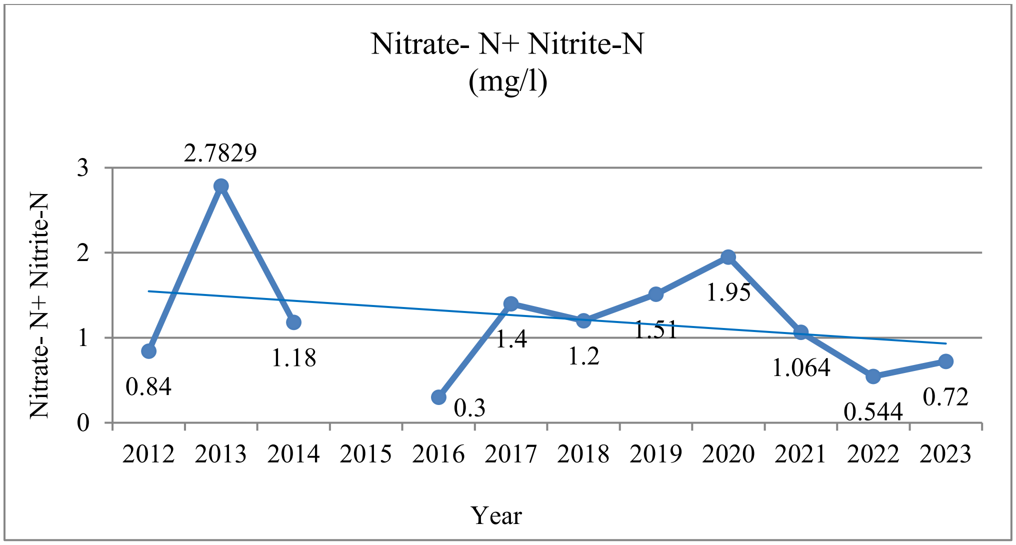


Fig. 7 Variation in annual Nitrate + Nitrite of River Yamuna from 2012-2023

As per Gupta et al. (2013), areas like Agra and Mathura receive untreated or poorly treated sewage containing nitrogenous compounds, which combine with run-off from agricultural fields to raise nutrient levels. Nabi et al. (2018) also found that during monsoon months, nitrate and nitrite levels rose due to extensive fertilizer leaching and decaying biomass entering the river. Additionally, leachate from unlined solid waste dumps near the Yamuna banks, especially in urban fringes, contributes significantly to nitrate accumulation [3].

The ecological impact of these trends is concerning. Increased nitrogen levels can trigger eutrophication, especially in slower-flowing downstream stretches. Excess algal growth consumes oxygen when decaying, causing hypoxic conditions and fish mortality. Furthermore, high nitrate in drinking water sources has been associated with blue baby syndrome (methemoglobinemia) in infants, underscoring the health risk of water abstraction from polluted zones[1]

To mitigate these risks, key actions include:

- Promoting organic and precision farming to reduce excess fertilizer run-off,
- Constructing vegetative buffer zones and riparian wetlands to intercept nutrients before reaching the river,
- Enforcing nitrogen effluent standards for industrial and municipal STPs,
- And monitoring nitrate/nitrite levels seasonally, particularly during pre- and post-monsoon periods [6] [1]

3.7. Fecal Coliform

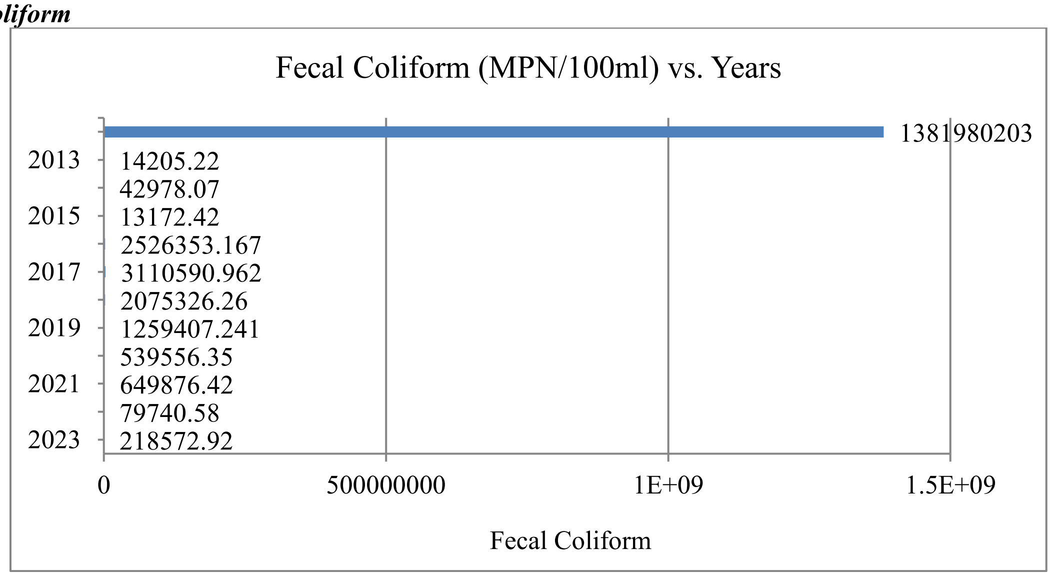


Fig. 8 Variation in annual Fecal of the River Yamuna from 2012 to 2023

Fecal coliform bacteria are a subgroup of total coliforms and serve as a key indicator of recent fecal contamination from human or animal sources. Their presence signals the likelihood of pathogenic organisms such as E. coli, Salmonella, Giardia, and viruses, which pose severe public health risks. Fecal coliforms are especially monitored in surface waters used for drinking, bathing, and agriculture.

According to CPCB standards, fecal coliform counts must not exceed 500 MPN/100ml for water designated for Class B (outdoor bathing) use, and should be absent in drinking water sources (Class A). WHO also stipulates zero tolerance for fecal coliforms in 100 ml of treated drinking water.

In the Yamuna dataset (2012-2023), fecal coliform values were alarmingly high, ranging from 1553.8 MPN/100ml (2013) to a staggering 22,865.3 MPN/100ml (2021). The overall trend shows increasing microbial contamination, especially between 2017 and 2022. These values exceed the safe threshold by 40 to 45 times, indicating severe and persistent sewage pollution in the river system.[1], highlight the Delhi stretch as the most polluted, where over 23 major drains discharge untreated or partially treated domestic sewage into the Yamuna. Similarly, [3] reports that only about 35% of the generated sewage in Delhi is effectively treated, with the remainder entering the river directly. [5] confirmed similar findings, documenting average FC counts between 10^4 to 10^6 MPN/100ml in the Delhi stretch, especially during dry months when dilution is minimal. Monsoon overflows and inadequate sanitation infrastructure further aggravate this issue.

The implications are severe. High fecal coliform levels indicate a high probability of waterborne disease outbreaks such as cholera, dysentery, typhoid, and hepatitis A/E, particularly among communities living near or using river water for washing or agriculture. Such contamination also degrades aquatic health, disrupts ecosystem services, and makes the river unsuitable for recreational, religious, or irrigation purposes.

To reduce microbial contamination, urgent interventions are needed:

- Expand and upgrade Sewage Treatment Plants (STPs) with a focus on biological treatment.
- Prevent illegal or untreated domestic discharges by ensuring 100% sewer connectivity.
- Establish decentralized wastewater treatment systems in peri-urban areas.
- Promote community toilet infrastructure, especially in riverfront settlements.
- And adopt real-time microbial monitoring at critical points like Wazirabad, Okhla, and Nizamuddin outfalls [**1**] [5]

3.8. Total Coliform

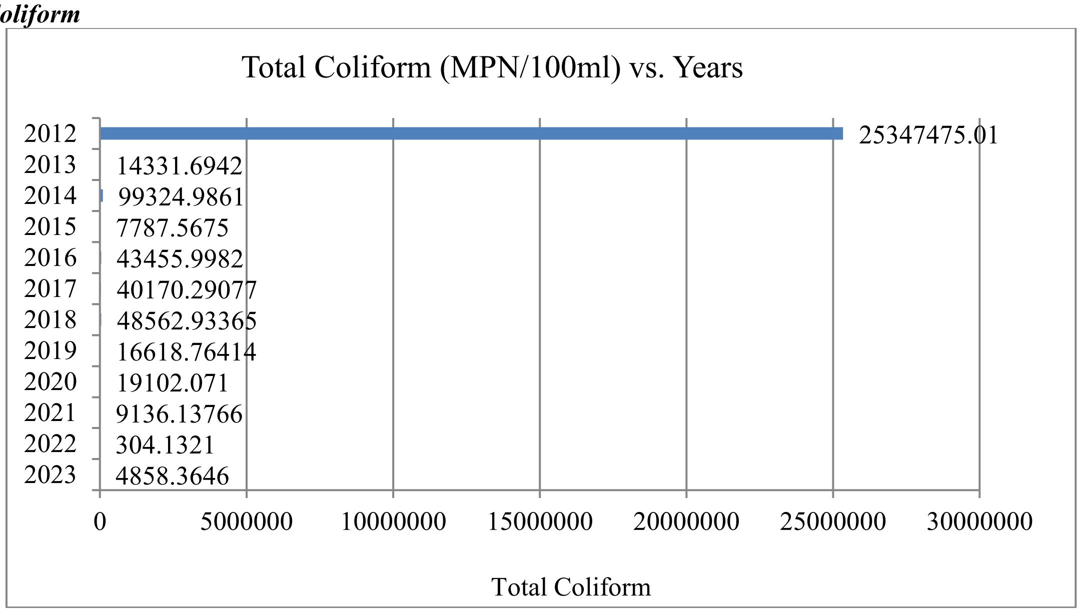


Fig. 9 Variation in annual Total Coliform of River Yamuna from 2012 to 2023

Total coliform bacteria are a broad category of bacteria naturally present in the environment, including soil, vegetation, and feces. While not all coliforms are harmful, their presence in water indicates a possible breach in sanitary integrity and a high likelihood of pathogenic contamination, particularly when coupled with high fecal coliform counts. Total coliforms are often used as a baseline microbial indicator to assess water safety for drinking, bathing, and irrigation purposes.

According to CPCB guidelines, the permissible limit for total coliforms is:

- Class A (drinking water): must be absent in 100 ml,
- Class B (bathing water): ≤500 MPN/100ml.

In the Yamuna River dataset (2012–2023), total coliform levels ranged from 2,706 MPN/100ml (2013) to 37,443 MPN/100ml (2021). The data shows a consistently high and worsening trend, especially after 2017, with the 2020–2022 period exceeding safe bathing standards by over 70 times. Even the lowest recorded value (2,706 in 2013) was 5x above the CPCB bathing threshold.

The sharp increase in microbial load aligns with findings by [5] and [**1**], who both reported extremely high coliform loads in the Delhi stretch, caused primarily by direct sewage discharge, non-functional STPs, and stormwater mixed with wastewater. As [3] noted, more than 18 drains are directly emptying into the river in Delhi, and less than 50% of the generated sewage is even partially treated. Seasonal overflow during monsoons and poor septic management in rural fringes also contribute to this microbial surge.

High total coliform counts are a public health hazard, especially in downstream cities like Agra and Mathura, where river water is used for religious activities, agriculture, and in some cases, drinking water abstraction. Coliform-contaminated water increases the risk of enteric diseases and severely restricts the use of the Yamuna for even non-potable purposes.

The persistence of poor water quality in the Yamuna despite decades of intervention highlights the need for more robust mitigation strategies. Government-led programs such as the Yamuna Action Plan and the Namami Gange Mission have improved sewage treatment capacity and promoted riverbank rejuvenation, yet untreated domestic sewage and industrial effluents continue to dominate the pollution load. Strengthening enforcement of effluent standards, expanding decentralized wastewater treatment systems, and ensuring adequate environmental flows are critical to restoring the river's ecological balance.

Government action alone cannot restore the Yamuna without behavioral and community-level change. Citizens play a crucial role through:

- Reducing Household Pollution: limiting phosphate-rich detergents, segregating solid waste, and preventing direct disposal of domestic effluents into drains.
- Water Conservation Practices: rainwater harvesting, efficient irrigation, and greywater reuse reduce freshwater extraction and wastewater discharge.
- Religious and Cultural Practices: discouraging the dumping of idols, ashes, and ritual materials into the river, and instead promoting eco-friendly alternatives.
- Community-Driven Initiatives: NGOs and local groups have demonstrated success in riverbank clean-ups, decentralized wastewater treatment, and public awareness campaigns (e.g., "Meri Yamuna, Meri Dilli" initiative).

Mitigation requires a multi-pronged strategy:

- Upgrade urban and peri-urban sewer networks to ensure 100% connectivity
- Expand STP capacity to treat peak-flow volumes during the monsoon
- Implement secondary and tertiary disinfection in existing STPs (e.g., chlorination, UV)
- Use riverbank filtration for drinking water abstraction
- Enforce regular microbial testing along strategic stretches, including Palla, Nizamuddin, and Mathura-Vrindavan.

These steps are essential not just to restore river water usability but also to protect downstream populations from long-term microbial exposure.

4. Conclusion

This study analyzed the changes in the physico-chemical and microbiological parameters of the River Yamuna between 2012 and 2023. The results show considerable fluctuations in key indicators such as Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), conductivity, and coliform counts, highlighting persistent pollution levels despite some years of partial improvement.

While certain parameters, such as pH, remained relatively stable, high values of BOD and coliform counts indicate continuous anthropogenic pressures and inadequate wastewater management in the river basin.

Limitations of this study include reliance on secondary data sources, which may contain gaps or inconsistencies, and the focus on annual mean values, which may not capture short-term seasonal variations or localized pollution hotspots. Additionally, only selected physico-chemical and microbiological parameters were analyzed, leaving out other critical indicators such as heavy metals and emerging contaminants.

Future research should expand the scope of monitoring to include seasonal and site-specific variations and advanced pollutant categories. Integrating geospatial analysis, machine learning prediction models, and socio-economic data could provide a more holistic understanding of pollution drivers. Furthermore, comparative studies with other Indian rivers can help develop broader strategies for sustainable river management and policy intervention.

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