Received: 8 November 2023 | Accepted: 30 December 2024 | Published online: 22 February 2025
DOI: 10.59797/ijsc.v52.i3.181

ORIGINAL ARTICLE
Indian Journal of Soil Conservation

Water quality assessment of river Ganga in downstream area to Kanpur city

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Handling Editor :
Dr Raman Jeet Singh

Key words:
Correlation
Kanpur
Physiochemical parameter analysis
River Ganga
Statistical analysis

ABSTRACT

The sacred river Ganga in Kanpur city, Uttar Pradesh, India, underwent physio-chemical analysis in the month of Nov 2022. Three samples from each of the ten locations in Kanpur city were collected over two days and analyzed various physicochemical parameters: temperature, pH, total alkalinity (TA), biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), total dissolved solids (TDS), chlorides, electric conductivity (EC), nitrate, and total hardness (TH). Pearson correlation analysis was conducted in SPSS to examine relationships between these parameters. The investigation highlights significant trends in water quality parameters along different sites. The Bithoor site exhibited better DO levels (7.32 mg L^{-1}) and a slightly alkaline pH (8.31), indicating relatively healthier water conditions. In contrast, the Sarsaiya ghat site maintained stable BOD (22.25 mg L^{-1}), chloride levels (16.99 mg L^{-1}), and alkalinity (450.15 mg L^{-1}), suggesting a more buffered but still impacted ecosystem. The Jajmau site showed the highest levels of BOD (38.78 mg L^{-1}) and TDS (270.78 mg L^{-1}), coupled with an elevated pH of 8.67 and chloride concentration of 21.12 mg L^{-1}, pointing to higher organic pollution and industrial effluents. A notable negative correlation was observed between DO and other water quality parameters, reinforcing the trend of declining oxygen levels with increasing pollution. Conversely, pH, temperature, COD, BOD, TA, TH, TDS, chloride (Cl^-), EC, sulfate (So_4^{2-}), and nitrate (No_3^-) exhibited positive correlations, demonstrating a progressive deterioration of water quality from upstream to downstream. The Ganga river's water quality needs to be routinely checked to conduct appropriate treatment. The findings hold critical relevance for environmental policymakers, offering evidence-based insights for the development of sustainable water resource management strategies. Addressing the pollution of the Ganga is essential to restore its sanctity and safeguard public health, support aquatic ecosystems, and ensure long-term socio-economic sustainability.

1 | INTRODUCTION

Ganga river, originating from the Gangotri glacier in India's central Himalayas, is a vital waterway spanning 2,525 kms from Gaumukh to the Bay of Bengal (Singh *et al.,* 2020). It flows through several states, including Uttarakhand, Uttar Pradesh, Bihar, and West Bengal, passing by numerous urban centers, such as Kanpur, Allahabad, Varanasi, and others, before finally reaching the Bay of Bengal. Despite its cultural significance and role as a lifeline for millions, the Ganga faces severe challenges due to pollution from urbanization, industrialization, overpopulation, and agricultural activities. This pollution, including the disposal of animal corpses and industrial waste, degrades the water quality and threatens human health and the river's ecosystem. Efforts to mitigate these issues have proven insufficient, leading to a continued deterioration of the Ganga's water quality, especially in cities like Kanpur and Varanasi. Although some localized improvements have been observed (Haleem *et al.,* 2022), the overall health of the river remains compromised, highlighting the urgent need for more effective measures to protect and restore this iconic waterway (Haentjens, 2017).

Kanpur, located in Uttar Pradesh's industrial area, lies along the banks of the Ganga. It is a city with a large number of polluting industries, including leather processing and other harmful sectors, which contribute approximately 20% of the total pollution in the river. As Uttar Pradesh's leading industrial center, Kanpur is heavily populated. While the Ganga has traditionally been considered a sacred river in Kanpur, it is regrettably true that it is now greatly polluted by the residents of the city. The city is most famous for its leather manufacturing, but it also has many textile mills and chemical factories that contribute to the pollution of the Ganga by dumping waste. The quality of surface water has deteriorated due to various human activities, including industrial processes, agricultural runoff, and urbanization, as well as environmental factors like climate and rainfall. Many human remains and countless animal carcasses are cast into the river in hopes of spiritual rejuvenation. Furthermore, domestic and industrial waste adds to the pollution. Numerous tanneries, slaughterhouses and distilleries exacerbate the pollution problem. In Uttar Pradesh, waste discharges have been found to exceed the available river water levels, especially before the annual monsoon. Physio-chemical factors can help explain the water quality, and consequently, the assessment of the physio-chemical parameters of Ganga water is conducted by various researchers.

The contamination of the Ganga river by industrial effluents, sewage, and other pollutants poses significant risks to public health. Waterborne diseases such as cholera, typhoid, and dysentery are prevalent in communities residing along the riverbanks, leading to increased morbidity and mortality rates. Pollution in the Ganga river threatens the delicate balance of its aquatic ecosystem, endangering numerous species of flora and fauna. The discharge of toxic chemicals and heavy metals disrupts the river's natural biodiversity, leading to a decline in aquatic life and the degradation of habitat quality. The Ganga river's polluted waters adversely affect agricultural productivity in the surrounding areas (Singh *et al.,* 2023). Irrigation with contaminated water results in reduced crop yields and compromised food safety, impacting the livelihoods of millions of farmers who depend on the river for irrigation (Chand *et al.,* 2023). Singh (2019) revealed alarming deterioration in the health of the Ganga river, with declining water quality across the city. The pH remained alkaline, while maximum hardness (328 mg L^{-1}) and TDS (367.82 mg L^{-1}) indicated high inorganic pollution. Decreasing DO levels, along with high BOD and COD, confirmed the presence of both biodegradable and non-biodegradable materials waste.

The Bureau of Indian Standards (BIS) evaluated the Ganga river's suitability for drinking and other purposes. It found that while parameters like Na^+ and K^+ remained consistent across samples from five ghats, three parameters (NO_3^-, B, and Cl^-) exhibited an increasing trend (Singh *et al.,* 2023). Kushwaha and Srivastav (2023) observed that total coliform counts were negatively correlated with key parameters like DO (-0.628), BOD (-0.983), COD (-0.194), TH (-0.549), nitrate (-0.955), calcium (-0.918) and magnesium (-0.279). These findings provide valuable insights for informed decision-making in managing river pollution. A state of environment report for Uttar Pradesh states that 9-12% of Uttar Pradesh's overall disease burden is attributable to pollution in the Ganga coliform bacterial limits also exceed 200,000 MNP, and 6.4 million people in Uttar Pradesh suffer daily from health effects related to water pollution (Mallikarjun, 2003). According to the CPCB survey report, the overall management of municipal sewage is inadequate. Significant amounts of solid waste, including animal carcasses and human remains, fertilizers, pesticides used in agriculture, industrial wastewater, and other substances, are discharged into the river daily.

HIGHLIGHTS

- Impact of a north Indian industrial town, Kanpur, on water quality of river Ganga monitored.
- Water quality significantly deteriorated in a 16 km stretch investigated, exceeding the permissible limits for BOD, COD and TH.
- Correlations among the water quality parameters observed.

This study provides a unique contribution by presenting a comprehensive multisite analysis of the Ganga river's water quality in Kanpur, covering ten locations and multiple physicochemical parameters. It goes beyond basic descriptive statistics by utilizing statistical correlation methods to assess spatial variations in water quality, offering new insights into pollution distribution and its ecological impact. The study emphasizes actionable, policy-relevant recommendations, such as site-specific strategies for pollution control and infrastructure development. Additionally, it integrates public health and ecological concerns, advocating for an integrated river basin management approach. By identifying localized pollution hotspots and considering temporal variations, this research delivers a more nuanced and actionable understanding of the challenges facing the Ganga river.

2 | MATERIALS AND METHODS

2.1 | Study Area Selection and Sampling Design

The Ganga river, stretching from upstream to downstream of Kanpur city, was designated as the study area. Ten sampling points were selected at regular intervals along the river to capture spatial variations in physicochemical parameters based on the study area's length and anticipated variability in water quality, ensuring representative sampling. Three sample units were collected from each ghat for testing. The physico-chemical characteristics were evaluated (APHA, 2012).

2.2 | Study Area

Kanpur, often referred to as the "Manchester of the East," is the major industrial center of Uttar Pradesh. It is located between 26.84°N latitudes and 80.94°E longitudes on the west bank of the Ganga river, covering an area of 3155 km². The city is a crucial hub for the leather, textile, and chemical industries, significantly contributing to the industrial effluents discharged into the river. The Jajmau area has a dense cluster of approx. 402 tanneries (Boruah, 2022), which release high concentrations of organic and inorganic pollutants, including heavy metals and toxic chemicals, into the river. The Ganga river in this region receives an estimated 1.3 billion liters of waste per day, including 260 ML of industrial effluent and runoff from 6 mt of fertilizers and 9,000 tons of pesticides used in agriculture within the basin (Markandya and Murty, 2004). This extensive pollution load severely affects water quality, aquatic life, and public health. The Ganga river was studied over a stretch of 16 km, from Kanpur to Jajmau. A total of eight sampling stations were selected: Bithoor town, Brahmavat ghat, Ganga bairaj, Rani ghat, Bhairav ghat, Parmat ghat, Sarsaiya ghat, Gola ghat, Massacre ghat, Ganga ghat jajmau, and Siddhnath ghat jajmau (Fig. 1 and Table 1). The selection of these sites allows for a comprehensive analysis of pollution trends, ranging from relatively less contaminated upstream locations to heavily impacted downstream sites near industrial and sewage discharge zones.

TABLE 1 Sampling locations and their coordinates

S.No.	Sampling location name	Coordinates
1	Brahmavart ghat (S1)	26°61'N, 80°27'E
2	Ganga barrage (S2)	26°50'N, 80°31'E
3	Bhairav ghat (S3)	26°49'39"N, 80°32'75"E
4	Rani ghat (S4)	26°49'N, 80°30'E
5	Permat ghat (S5)	26°29'N, 80°20'E
6	Sarsaiya ghat (S6)	26°28'N, 80°21'E
7	Gola ghat (S7)	26°35'89"N, 80°22'35"E
8	Massacre ghat (S8)	26°45'N, 80°38'E
9	Ganga ghat, Jajmau (S9)	26°43'80"N, 80°40'93"E
10	Siddhnath ghat (S10)	26°46'N, 80°35'E

The twelve different physiochemical characteristics were determined by analyzing the collected samples from the locations: temperature, pH, EC, TDS, alkalinity, TH, Cl, DO, BOD, COD, SO_4 and No_3.

2.3 | Data Collection and Laboratory Analysis

Collect water samples at each sampling point using standardized protocols and equipment to maintain consistency. Measure physicochemical parameters and record metadata such as sampling date, time, and geographical coordinates of each sampling point. Transport collected water samples to the laboratory under controlled conditions to prevent contamination or alteration. Analyze water samples for physicochemical parameters using standardized laboratory methods and equipment. Ensure quality control measures are implemented during laboratory analysis to minimize errors and ensure the reliability of results. Safety precautions were taken for fellow workers from possible toxic substances that can penetrate through the skin and eyes and, in the case of vapours, also through the lungs.

2.4 | Sampling and Analysis

Water samples were collected from various sites along the Ganges river in Kanpur, including Brahmavart ghat, Ganga bairaj, Rani ghat, Bhairav ghat, Parmat ghat, Sarsaiya ghat, Gola ghat, Massacre ghat, Ganga ghat jajmau, and Siddharth ghat. The water quality in the Ganga river is significantly affected by seasonal variations and diurnal fluctuations,

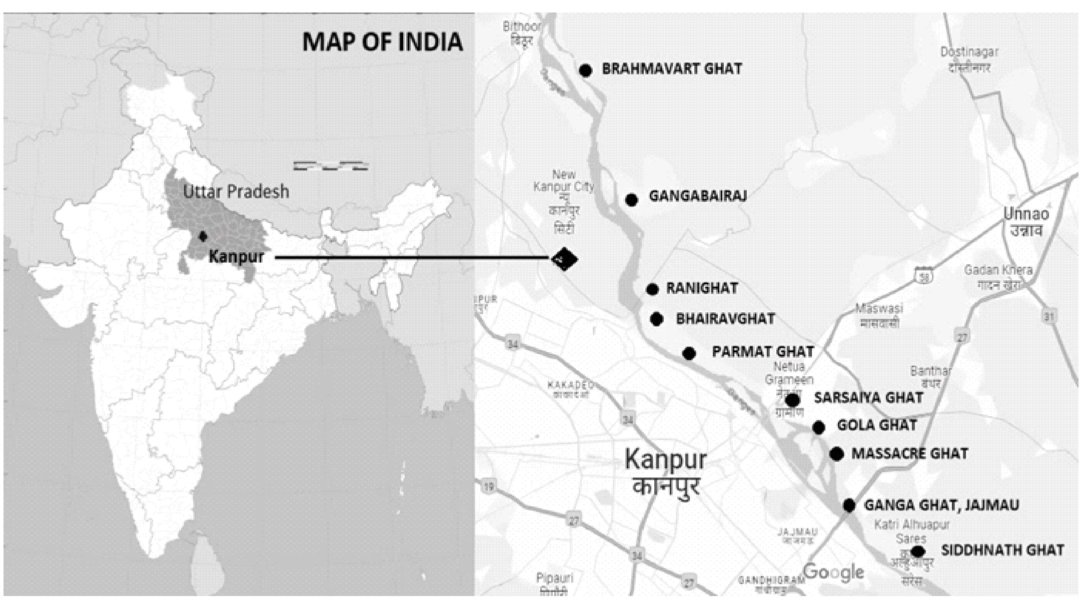

FIGURE 1 Water sampling locations downriver of Kanpur city

necessitating precise sampling protocols. To account for these variations, water samples were collected at multiple time points during the winter season, ensuring a comprehensive assessment of pollution trends. Sampling occurred around midday (12:00-2:00 pm) to capture fluctuations in DO, temperature, and other key parameters influenced by biological activity, industrial discharge cycles, and daily water usage patterns. Samples were acquired from approx. 2 cm deep in specific areas of the river. After spending a few minutes at each sampling site, about six liters of water from each location were gathered in glass bottles. Before sampling, the bottles were cleaned three times with deionized water and then rinsed with 10% v/v HNO_3. Surface water samples were collected directly from the riverbank into sample containers while facing upstream to avoid disturbing the bottom sediments. The samples were transported aseptically and kept at 4°C for later evaluation. A thermometer, a pocket digital pH meter, a TDS meter, and an EC meter were used to measure the water's temperature, pH, TDS and EC during sampling. Parameters such as chloride, DO, BOD and COD were analyzed in the lab using various established techniques (APHA, 2012). IBM SPSS statistics is a comprehensive data management, analysis and visualization software. Within SPSS statistics, the data editor serves as the primary interface for entering, viewing, and manipulating data. Pearson correlation analysis was performed using the IBM SPSS statistical data editor, which systematically investigates correlations between data variables. This type of analysis is critical because it employs correlation comparisons to demonstrate how changes in one physicochemical or quality characteristic of water influence other parameters, either positively or negatively.

3 | RESULTS AND DISCUSSION

3.1 | pH

The pH of the river water increased gradually downstream from 8.31 to 8.67, with the mean pH being 8.4 ± 0.436 (Fig. 2). The use of more alkaline detergents in homes and alkaline materials in tannery effluent have both been linked to the apparent rise in pH. The water pH showed strong positive correlations with all water quality parameters except for DO, with which pH displayed a strong negative correlation. The observed pH values suggest that the river's water quality falls within the range of moderately basic conditions. The variations in pH across different sampling locations highlight the localized influences of anthropogenic activities, particularly those related to domestic and industrial sources. The positive correlation between pH, TA and TDS suggests that higher pH values are associated with increased alkalinity and mineral content in the water. This correlation highlights the importance of monitoring these parameters collectively to assess overall water quality and potential impacts on aquatic ecosystems. Furthermore, the variations in pH correlations with other parameters across different sampling locations provide insights into localized pollution sources and environmental dynamics. For instance, the higher correlation between pH and DO at S2 compared to S10 indicates potential differences in oxygenation processes or pollutant inputs at these sites. Similarly, the inverse correlations between pH and parameters such as BOD and TDS highlight the complex interactions between pH and pollutant concentrations in the river. The stronger negative correlation between pH and BOD at S10 suggests higher organic pollution levels in this area compared to S2, where the correlation is weaker.

3.2 | Temperature

The maximum water temperature recorded during the study period across all sample locations was 28.1°C at S10, while the lowest temperature was noted at S1, with a mean of 25.25ºC ± 5.85 (Fig. 3). TDS, BOD, chloride, EC and nitrate all demonstrated a significant positive correlation with water temperature. DO and BOD are both influenced by temperature. Similar patterns were reported earlier (APHA, 2012). Atmospheric temperature and weather conditions were the primary factors contributing to the variation. The highest correlation between temperature and TDS occurred at S5 (r = 0.929), while the lowest was at S10 (r = 0.83). The temperature and BOD exhibited the highest correlation at S1 and the lowest at S4. The correlation among pH, temperature, and TA is notably negative for water DO. It is evident that DO negatively correlates with temperature; this inverse

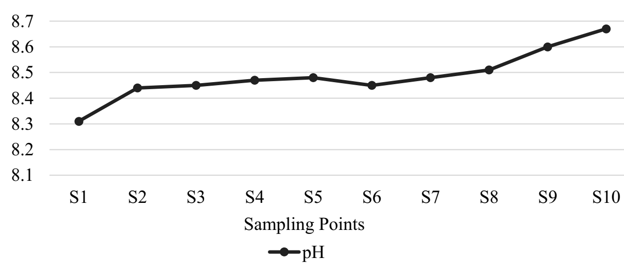

FIGURE 2 Mean pH at ten sampling points

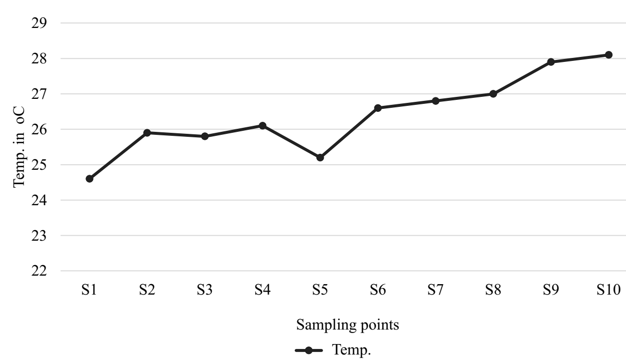

FIGURE 3 Mean water temperature at ten sampling points

relationship arises because warmer water holds less DO and becomes more saturated with oxygen. The correlation between temperature and pH peaked at S10 (r = -0.89) and reached its lowest point at S6 (r = -0.621).

3.3 | Electrical Conductivity (EC)

In this study, the range of EC was 272-451 µS cm^{-1}, with an average of 311.19 ± 65.94 µS cm^{-1} (Fig. 4), which is well below the threshold limit of 800 µS cm^{-1}. Sites S1 and S10 indicated the minimum and maximum values, respectively, due to their proximity to populated and industrial areas. The EC and nitrate exhibited a substantial positive association, with the maximum correlation at S10 (r = 0.846) and the minimum at S1 (r = 0.737). The greater the dissolved solids value, the more ions there are in the water (Arya *et al.,* 2013).

3.4 | Total Dissolved Solid (TDS)

The range of TDS in the study fluctuated from 181 to 270 mg L^{-1}, with a mean of 216±33.34 (Fig. 5). The minimum value was recorded at sampling site S1 (BRAHMAVARAT), while the maximum value was at S10 (SIDDHNATH). The TH of the water quality constraint illustrated the impact of dissolved minerals, with S10 (SIDDHNATH) showing the greatest prevalence in the current investigation. TDS are a critical indicator of water quality, reflecting the presence of various inorganic constituents dissolved in the water. The observed TDS values indicate fluctuations in the concentration of dissolved minerals across different sampling locations. The mean TDS value falls within the acceptable range for freshwater bodies, indicating a moderate level of inorganic contamination in the water system under study. However, the variability in TDS concentrations highlights spatial differences in pollution sources and environmental conditions. The lowest TDS concentration recorded at S1 (BRAHMAVARAT) suggests relatively lower levels of dissolved minerals in this area, possibly due to reduced anthropogenic activities or natural variations in geological formations. Conversely, the highest TDS concentration observed at S10 (SIDDHNATH) indicates elevated levels of inorganic contaminants, likely influenced by nearby industrial or agricultural activities. TH, often associated with dissolved minerals such as calcium and magnesium, serves as another important parameter for assessing water quality. The prevalence of high TH at site S10 (SIDDHNATH) underscores the impact of dissolved minerals on overall water quality in this location. Elevated TH levels can have implications for various water uses, including drinking water supply and industrial processes. High TDS affects other aspects of water, such as flavor, hardness, corrosion properties, and the osmoregulation of freshwater organisms (Kothari *et al.,* 2021).

3.5 | Dissolved Oxygen (DO)

The surface water's DO ranged from 7.3 to 4.99 mg L^{-1} (Fig. 6). A strong negative correlation was observed between DO and BOD, TDS, chloride, EC, nitrate, and sulfate. Another author reports similar results (Sawyer *et al.,* 2000). The correlation between DO and TDS was maximized at S10 and minimized at S7, supporting the hypothesis that low DO typically corresponds to high TDS values. DO and chloride revealed maximum and minimum correlations at S10 and S6, respectively. It plays a role in determining whether water is suitable for use in household, agricultural, or industrial settings. The role of DO in defining an aquatic system's water quality requirements is significant (Kumar *et*

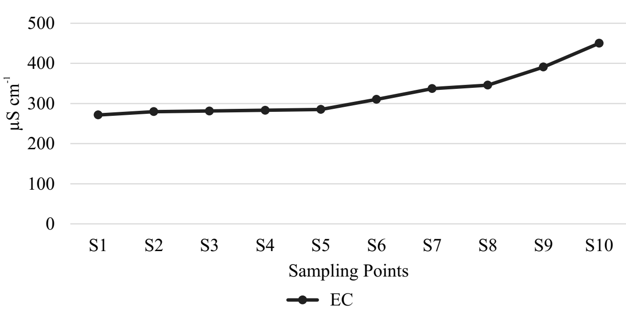

FIGURE 4 Mean electrical conductivity (EC) at ten sampling points

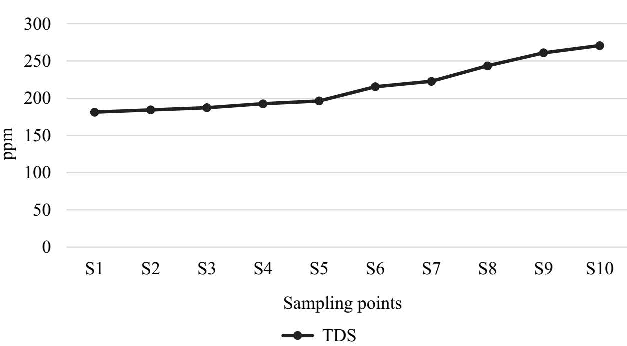

FIGURE 5 Mean total dissolved solids (TDS) at ten sampling points

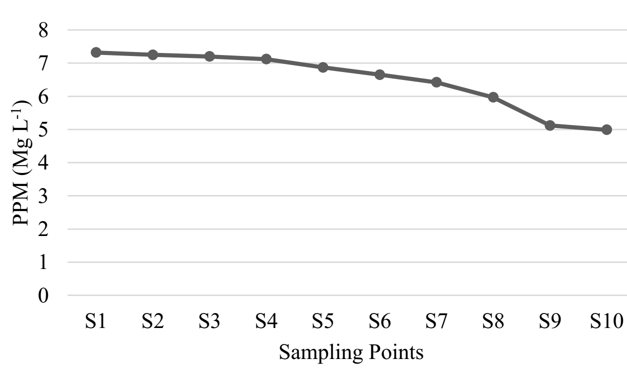

FIGURE 6 Mean dissolved oxygen (DO) at ten sampling points

al., 2023). DO is a crucial indicator of organic contaminants and water quality in the water body.

3.6 | Biological Oxygen Demand (BOD)

BOD in surface water in our study ranges from 10.57 mg L^{-1} to 38.8 mg L^{-1}, with a mean of 19.6 ± 8.09 (Fig. 7). S1 had the minimum BOD value, while S10 recorded the maximum value. The maximum and minimum correlation values for BOD versus TDS were observed at S10 (r=0.950 and r=0.751, respectively). BOD versus chloride correlation values peaked at GH1 (r=0.853) and at GH6 (r=0.614), both of which exceeded the upper limits permitted by BIS14 and WHO15 drinking water regulations (Pandey *et al.,* 2014). BOD is a crucial parameter for assessing water quality, particularly regarding organic pollution and its impact on aquatic ecosystems. The wide range of BOD concentrations observed across sampling sites suggests spatial variability in organic pollution sources and environmental conditions. The higher BOD levels indicate increased organic matter in the water, which can lead to oxygen depletion and negatively affect aquatic life. The maximum BOD concentration recorded at S10 highlights the potential influence of anthropogenic activities, such as industrial or municipal discharge, in contributing to organic pollution in the water system. The correlation analysis between BOD and TDS revealed strong positive correlations, particularly at S10, indicating a relationship between organic pollution and dissolved mineral content in the water. This suggests potential interactions between organic and inorganic pollutants, which can further exacerbate water quality issues. This indicates potential contamination of surface water sources with chloride ions, possibly from industrial discharges or agricultural runoff.

3.7 | Chemical Oxygen Demand (COD)

The COD sharply increased after the first sampling point and breached the critical limit of 50 ppm at all nine downstream sampling points (Fig. 8). The COD calculates surface water contamination and indicates organic pollution, with high levels of industrial discharge, agricultural runoff, and sewage. Elevated COD can cause oxygen depletion, habitat degradation, and harm aquatic life. COD variation indicates different pollution sources and conditions, with higher levels linked to industrial or municipal discharge versus less human activity. Correlation analysis with other water quality parameters offers insights into pollution sources; positive correlations with BOD and TDS suggest organic pollutants and similar sources.

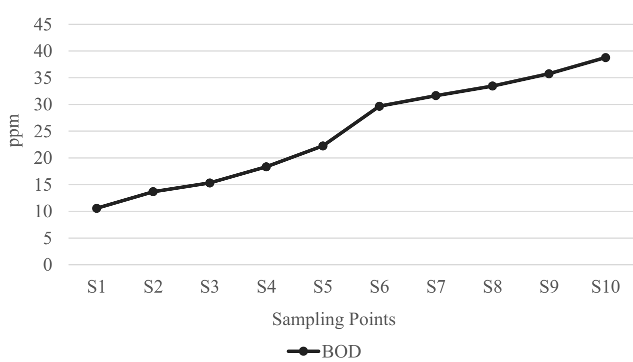

FIGURE 7 Mean biological oxygen demand (BOD) at ten sampling points

3.8 | Chlorides

A comparison of chloride and EC revealed a maximum correlation at S6 (r = 0.877) and a minimum correlation at S5 (r = 0.529), with the least chloride detected at S4 and the most also at S4. All observed values (Fig. 9) met the acceptable range set by BIS and WHO drinking water standards (Hale *et al.,* 2006). Chloride concentrations in water bodies are significant due to their potential impacts on aquatic ecosystems. High chloride levels may stem from various sources, including industrial discharge, agricultural runoff, and natural geological processes. In particular, irrigation water may present elevated chloride levels, posing a risk to aquatic organisms. The correlation analysis between chloride and EC underscored spatial variability in the relationship between these parameters across different sampling sites. The strongest correlation was noted at

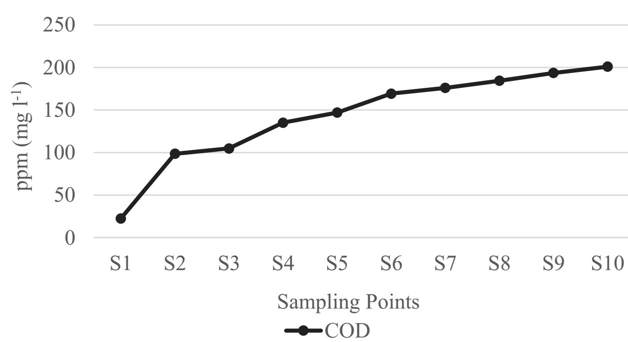

FIGURE 8 Mean chemical oxygen demand (COD) at ten sampling points

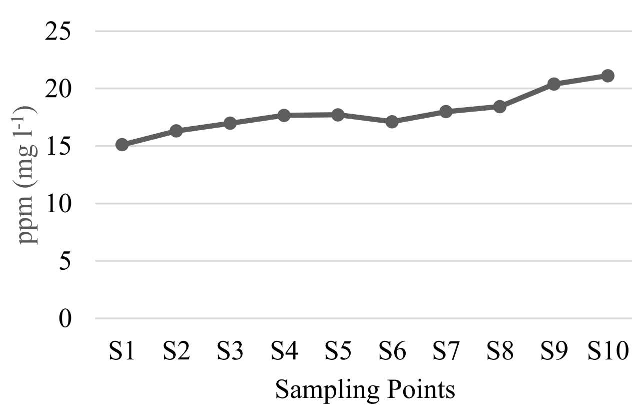

FIGURE 9 Mean chloride at ten sampling points

Sarsaiya ghat (S6), indicating a notable positive relationship between chloride and EC. The recorded chloride concentrations adhered to the permissible range established by drinking water standards set by the BIS and the WHO. Compliance with these standards is essential for ensuring the safety and quality of drinking water for human consumption.

3.9 | Total Hardness (TH)

The TH, caused by the presence of calcium and magnesium bicarbonates, sulfate, chloride, and nitrates, rapidly increased after the third sampling point and remained elevated beyond a desirable limit of 300 ppm but did not exceed the critical limit of 600 ppm (Fig. 10). Geological characteristics, land use practices, and anthropogenic activities in the surrounding area influence TH. Higher TH levels may indicate the presence of dissolved minerals from sources such as limestone deposits, agricultural runoff, or industrial discharges. The variability in TH concentrations across sampling sites underscores the spatial heterogeneity of water quality within the study area. Areas with intensive agricultural or industrial activities may exhibit elevated TH levels compared to less impacted sites. TH can affect various water uses, including drinking water supply, agricultural irrigation, and industrial processes. High TH levels may lead to scaling in water distribution systems, reduced soap effectiveness, and potential impacts on aquatic ecosystems.

3.10 | Alkalinity

Alkalinity levels progressively increased downstream from 238 to 277 mg L^{-1}, with a mean of 273 ± 24.68 mg L^{-1} (Fig. 11). These levels exceeded the desired water quality threshold of <200 ppm but remained well below critical limits of >600 ppm. The alkalinity of water is influenced by the presence of hydroxides, carbonates, and bicarbonates.

3.11 | Sulfate

Despite a significant progressive increase in sulphate concentration in river water from the first to the tenth sampling point, it remained well within the desirable limits of < ppm throughout the study area (Fig. 12). High concentrations of sulphate are often associated with dehydration, catharsis, and gastrointestinal discomfort (Eugene *et al.,* 2012).

3.12 | Nitrate

Only trace amounts of nitrates were present in the 16 km stretch of the river investigated (Fig. 13). Nitrate is a widespread contaminant in water bodies, primarily from agricultural runoff, sewage discharges, and fertilizer use. This indicates that neither sewage nor agricultural runoff is a significant pollution source in the investigated area. The

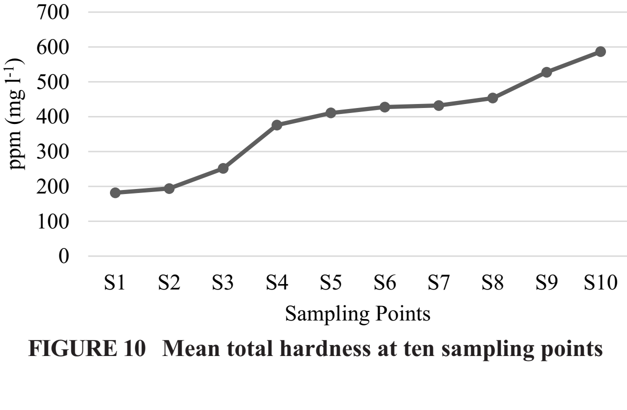

FIGURE 10 Mean total hardness at ten sampling points

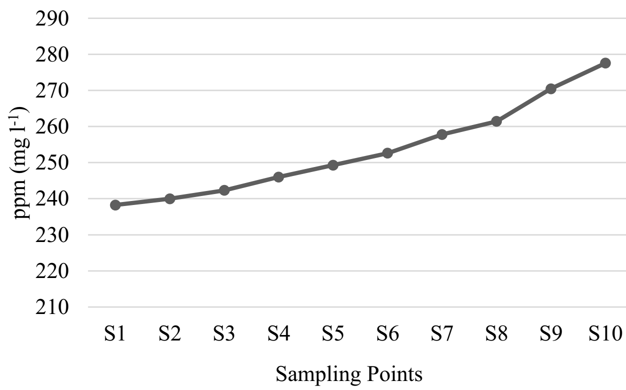

FIGURE 11 Mean alkalinity values of three samples collected from ten locations

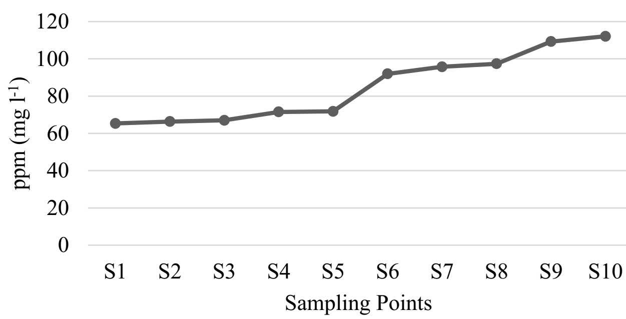

FIGURE 12 Mean sulphate values of three samples collected from ten locations

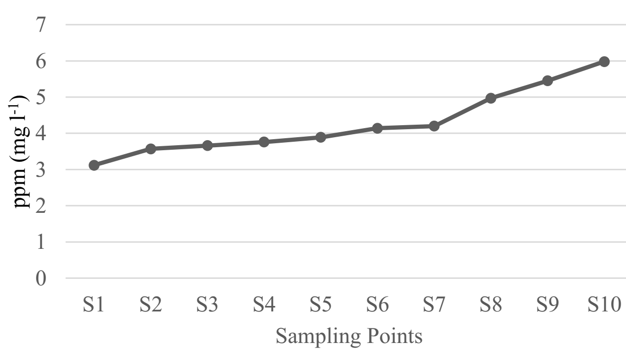

FIGURE 13 Mean nitrate values of three samples collected from ten locations

variation in nitrate concentrations across sampling sites reflects the spatial diversity of pollution sources and environmental conditions.

3.13 | Correlation

Significant relationships between various physicochemical parameters of Ganga water were identified, illuminating their interdependencies and potential pollution sources. Notably, strong positive correlations were observed between several pairs of parameters, indicating shared origins or influences within the water system. Specifically, a high positive correlation was evident between BOD and COD (0.93), TDS and NO_3^- (0.99), as well as between COD and both TDS (0.87) and TH (0.93). Additionally, a significant positive correlation was noted between EC and temperature. These findings suggest a common industrial or waste water source contributing to the elevated levels of these pollutants in the Ganga river. Further analysis revealed noteworthy negative correlations, particularly concerning DO. The negative correlation coefficient (-0.88) between DO and various parameters such as BOD, TDS, chloride, EC, nitrate, phosphate and magnesium underscores the importance of DO as a vital indicator of water quality (Table 2). As DO values decrease, the concentrations of these pollutants tend to increase, emphasizing the potential impact on aquatic ecosystems and human health (Kumar *et al.,* 2023). These results highlight the complex dynamics of water quality in the Ganga river and underscore the need for comprehensive pollution control measures and sustainable management practices to protect this vital resource for future generations (Chidiac *et al.,* 2023).

Industrial zones like Jajmau demonstrate stronger correlations among parameters such as BOD, COD and TDS due to untreated industrial effluents that contribute both organic and inorganic pollutants. Similarly, urban sites such as Sarsaiya ghat, characterized by prevalent untreated sewage, exhibit higher correlations between BOD and chlorides. Geographical factors also play a significant role; downstream sites experience stronger correlations due to the cumulative impact of upstream pollution, while upstream sites, closer to the river's source, tend to show weaker correlations owing to better dilution and natural purification processes. Seasonal variability, such as reduced water flow during dry seasons, can concentrate pollutants and enhance correlations between parameters like TDS and temperature. Furthermore, regions with intense agricultural activities demonstrate stronger correlations between nitrates and chlorides due to fertilizer runoff, while urbanized areas display higher correlations between BOD and TDS as a result of waste discharge. River morphology also influences correlations; shallow, slow-flowing regions typically show stronger associations between TDS and hardness due to sediment deposition, whereas faster-flowing areas reveal weaker correlations because of dilution effects. These spatial variations in water quality correlations reflect the combined influence of local pollution sources, hydrological conditions, and land use. Understanding these factors is crucial for developing targeted strategies to manage river pollution.

The findings emphasize the urgent need for stronger enforcement of water quality standards along the Ganga river to tackle pollution from industrial effluents and untreated sewage. Policies like the National Mission for Clean Ganga (NMCG) should be reinforced with clear pollution reduction targets. Monitoring water quality using automated sensors and ensuring public transparency is essential for effective management. Investment in wastewater treatment

TABLE 2 Heat map correlation in different physicochemical parameters of water sample

	pH	Temp	EC	TDS	Alkali.	TH	Cl^-	NO^{3-}	SO^{4--}	BOD	COD	DO
pH	1											
Temp	0.8965	1										
EC	0.895077	0.907811	1									
TDS	0.872659	0.928639	0.964211	1								
Alkali.	0.911726	0.918338	0.971857	0.988125	1							
TH	0.871041	0.839115	0.846581	0.899608	0.937936	1						
Cl^-	0.981296	0.900621	0.922155	0.917834	0.952922	0.916729	1					
NO^{3-}	0.938174	0.930783	0.968265	0.982037	0.982302	0.897224	0.9582	1				
SO^{4--}	0.814423	0.929425	0.930821	0.978307	0.966623	0.902251	0.865967	0.933808	1			
BOD	0.829605	0.898509	0.881601	0.950539	0.954926	0.950257	0.869725	0.917106	0.974587	1		
COD	0.857298	0.865892	0.747355	0.829652	0.856353	0.928286	0.856121	0.837086	0.850927	0.930603	1	
DO	-0.89206	-0.90933	-0.97092	-0.98937	-0.98493	-0.88317	-0.93764	-0.98253	-0.95326	-0.91454	-0.79143	1

Perfect Positive Correlation (Degree of Correlation 1)	Very High Positive Correlation (0.9 to 0.99)	High Positive Correlation (0.7 to 0.89)
Very High Negative Correlation (-0.9 to -0.99)	High Negative Correlation (-0.7 to -0.89)	

infrastructure, particularly in industrial and urban areas, is vital to decrease contamination. River basin management strategies must prioritize the protection of aquatic ecosystems, including habitat restoration and pollution mitigation. Public awareness campaigns and community engagement are crucial for fostering support for pollution control measures. A collaborative approach involving local authorities, industries, NGOs, and the public is necessary to address the complex challenges of river pollution effectively.

4 | CONCLUSIONS

Assessing the physicochemical properties of the Ganga river in Kanpur highlights the profound challenges posed by pollution, which significantly impacts its water quality, which is a critical resource for drinking and religious practices. The presence of ten sampling points across a 16 km stretch emphasizes the extent of monitoring required to address the issue comprehensively. Our investigation revealed correlations between various physicochemical characteristics of water samples, influenced by both direct and indirect factors such as sewage effluents and agricultural runoff. The alarming levels of pollutants, including BOD and COD, indicate a substantial influx of toxic effluents into the river, posing a serious threat to local communities and aquatic life. Moreover, the negative correlation observed with DO emphasizes the detrimental impact of human-related activities on water quality. This underscores the urgent need for effective pollution control measures and sustainable management practices to mitigate the degradation of the Ganga river. Despite visual inspections revealing discrepancies in correlation patterns, the overall findings stress the pressing need for concerted efforts to address pollution sources and protect the health and integrity of the Ganga river ecosystem. Key recommendations for policymakers include enforcing stricter pollution control regulations, investing in wastewater treatment infrastructure, implementing real-time water quality monitoring, promoting public awareness, and safeguarding aquatic ecosystems. Future research should focus on long-term water quality trends and the impact of climate change, evaluate pollution control technologies, and identify pollution hotspots to ensure the preservation of this invaluable natural resource for future generations.

ACKNOWLEDGEMENTS

Authors sincerely thank the Director of Naraina Vidyapeeth Engineering and Management Institute for their support in this study. We also acknowledge the laboratory staff and all individuals who supported our work directly or indirectly.

DATA AVAILABILITY STATEMENT

The data supporting this study's findings are available with the corresponding author.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

AUTHOR'S CONTRIBUTION

MKS: conceived and designed the experiments performed the experiments, analysed the data, prepared figures and/or tables, and authored or reviewed drafts of the paper. VD: supervision and editing.

REFERENCES

APHA. 2012. Standard methods for the examination of water and waste water. In: Eaton AD, Clesceri LS, Greenberg AE, editors. 22nd ed. Washington: APHA, ISBN 978-087553-013-0, 1360p.

Arya, S. and Gupta, R. 2013. water quality evaluation of Ganga river from up to downstream area at Kanpur city. *J. Chem. Cheml. Sci.,* 3(2): 54-63.

Boruah T. 2022. Kanpur tanneries and its environmental impacts: The Jajmau case. *Int. J. Sci. Res. (IJSR)*. 11(3). DOI: 10.21275/SR22326 150707.

Chand, S., Kingsly, I.T., Kumar, A. and Bharaty, A. 2023. Causes and consequences of conflicts in surface irrigation: Micro level study from Northern India. *Indian J. Soil Cons.,* 51(1): 50-56. DOI: 10.59 797/ijsc.v51.i1.149.

Chidiac, S., El Najjar, P., Ouaini, N. 2023. A comprehensive review of water quality indices (WQIs): history, models, attempts, and perspectives. *Rev. Environ. Sci. Biotechnol.,* 22: 349-395, https://doi.org/10.1007/s11157-023-09650-7.

Eugene, W.R., Rodger, B.B., Andrew, D.E. and Lenore, S.C. 2012. Standard methods for the examination of water and wastewater. American Public Health Association, American Water Works Association, Water environment federation, 22nd edn Washington DC, USA Google scholar.

Haleem, H., Dixit, M., Nissa, K. and Yadav, V. 2022. A study on physico-chemical parameters of Ghodha Pachad dam in Bhopal district (MP) India. *Int. J. Appl. Res.,* 8: 100-103. 10.22271/allresearch.2022.v8.i12b.10376.

Haentjens, T. 2017. The influence of monsoon & the impact of polluting cities on the ecological status of Ganga River. Antwerp University.

Hale, R.L. and Groffman, P.M. 2006. Chloride effects on nitrogen dynamics in forested and suburban stream debris dams. *J. Environ. Qual.,* 35(6): 2425-32. doi: 10.2134/jeq2006.0164.

Kothari, V., Vij, S., Sharma, S.K. and Gupta, N. 2021. Correlation of various water quality parameters and water quality index of districts of Uttarakhand. *Environ. Sustain. Indic.,* 9: 100093, https://doi.org/10.1016/j.indic.2020.100093.

Kumar, D. and Singh, B.B.P. 2023. Water quality parameters and ecological status of eutrophicated Taj Baj pond Hajipur (Vaishali). *Res. J. Sci. Tech.,* 15(2): 88-4, doi: 10.52711/2349-2988.2023.00015.

Kushwaha, G.J. and Srivastav, S. 2023. Water quality assessment of Kuwano river, Basti (UP) India, with reference to statistical analysis. *Environ. Cons. J.,* 24(4): 221-230, https://doi.org/10.36953/ECJ.23222605.

Mallikarjun, Y. 2003. Pollution levels in Ganga alarming. The Hindu.

Markandya, A. and Murty, M.N. 2004. Cost-benefit analysis of cleaning the Ganges: some emerging environment and development issues. *Environ. Dev. Econ.,* 9(1): 61-81, doi:10.1017/S1355770X03001013.

Pandey, R., Raghuvanshi, D. and Shukla D.N. 2014. Assessment of Physico-chemical parameter of river Ganga at Allahabad concerning WQI. *IJIR Set.,* 3(9): 16339-16349.

Sawyer, C.N., McCarty, P.L. and Parkin, G.F. 2000. Chemistry for environmental engineering 4th edition. Tata McGraw-Hill Publishing Company Limited.

Singh, R.K., Gupta, A. and Kumar, M. 2023. Water management for supplemental irrigation based on rainfall characteristics of Ranchi district, India. *Indian J. Soil Cons.,* 51(1) 41-49 DOI: 10.59797/ijsc.v51.i1.148.

Singh, Y.V., Bharteey, P.K., Singh, K., Borah, S.R., Kumar, A., Pal, S. and Barla, F.X. 2023. Assessment of water quality in Ganga river ghats of Varanasi district, Uttar Pradesh, India. *Int. J. Environ. Clim. Chan.,* 13 (5):231-39. https://doi.org/10.9734/ijecc/2023/v13i51764.

Singh, M. 2019. Analytical study and water quality assessment of the Ganges from up to downstream in Kanpur. 10.13140/RG.2.2.11394.66240.

Singh, V., Ngpoore, N.K., Chand, J. and Lehri, A. 2020. Monitoring and assessment of pollution load in surface water of river Ganga around Kanpur, India: A study for suitability of this water for different uses. *Environ. Tech. Innov.,* 18: 100676.

How to cite this article: Savita, M.K. and Dwivedi, V. 2024. Water quality assessment of river Ganga in downstream area to Kanpur city. *Indian J. Soil Cons.,* 52(3): 267-276.