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Spatio-Temporal Assessment of Dissolved Oxygen Dynamics and Organic Pollution in the Urban Stretch of the Gomti River, Lucknow

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Abstract

The present study provides the detailed spatio-temporal analysis and statistical assessment of three pertinent water quality parameters such as dissolved oxygen (DO), chemical oxygen demand (COD), and biochemical oxygen demand (BOD) in the urban reach of Gomti River at Lucknow for the period of 2023–2024. Four sites were selected based on the level of contamination due to combined anthropogenic, industrial and residential activities and monthly surface water samples were collected. The concentrations of the parameters were determined using standard analytical methods and the data were analyzed using statistical techniques such as multiple linear regression, descriptive analysis and Pearson correlation. The results revealed a high BOD (9.07 mg L^{-1}) and COD (39.86 mg L^{-1}) which indicates high extent of organic and chemical pollution and continuously low values of DO (mean: 3.15 mg L^{-1}) below the biological level required to support the aquatic organisms. During the summer months, dissolved oxygen was substantially reduced due to increased microbial activity, lower flow and warmer temperatures. BOD and COD were found to have a significant positive correlation ($r = 0.734$) which indicates their contribution to pollution severity. DO was found to have significant negative correlations with BOD ($r = -0.404$) and COD ($r = -0.480$). Regression analysis ($R2 = 0.579$, $p < 0.001$) shows that organic load has a significant influence on the COD variability, and BOD is the major determinant factor. Spatial variability revealed high levels of pollution due to untreated sewage and industrial effluents and the need for better treatment, regulation, monitoring and restoration.

Keywords: Dissolved oxygen; Biochemical oxygen demand; Chemical oxygen demand; Spatio-temporal variation; Organic pollution; Gomti River

Introduction

A body of water's quality is governed by its physio-chemical and biological components. The physicochemical characteristics of water in a given area are determined by a complex interplay between natural and artificial influences (Singh et al., 2020; Matta et al., 2020). Rivers are fundamental to ecological stability, sustaining biodiversity while meeting domestic, agricultural, and industrial water requirements. In many developing regions, however, rapid urban expansion, industrial growth, and increasing population pressure have led to a marked decline in river water quality (Wang and He, 2022).

Among commonly used indicators, dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) are considered reliable measures for evaluating organic pollution and overall ecosystem condition in freshwater environments (Lv et al., 2024). Dissolved oxygen plays a vital role in maintaining aquatic life and reflects the functional status of a water body. In contrast, elevated BOD and COD levels indicate increased organic and oxidizable pollutant loads, largely derived from sewage discharge, industrial effluents, and urban runoff. A simultaneous decrease in DO alongside rising BOD and COD suggests intensified microbial activity and oxygen consumption, ultimately resulting in ecological imbalance and habitat deterioration (Singh et al., 2025). The Gomti River, an important tributary of the Ganga River system, flows through the rapidly urbanizing city of Lucknow and experiences continuous anthropogenic stress. Discharge of untreated municipal waste, solid waste accumulation, and industrial inputs have progressively impaired water quality within its urban stretch (Verma, 2025). Additionally, Seasonal variations and increased human activities also affected BOD levels, putting more pressure on the aquatic ecosystem and reducing the availability of dissolved oxygen for the aquatic organisms (Mishra, 2019). Similarly, the chemical oxygen demand (COD) was always higher than the permissible limits, indicating the presence of high concentration of biodegradable and non-biodegradable organic and inorganic pollutants. Higher levels of COD were particularly noticed in the places where industrial effluents were discharged, underscoring the impact of inadequately treated or untreated wastewater discharge (Srivastava & Srivastava, 2023). Moreover, Organic Pollution Index (OPI) evaluations suggest a significant likelihood of eutrophication, with excess nutrient enrichment and deteriorating water quality conditions. Cluster analysis was used to classify the monitoring sites into specific water quality groups and facilitate the understanding of the ecological condition of the river and the distribution of pollution sources in different locations (Son et al., 2020). Rivers are the main source of inland water for domestic, industrial and agricultural use, often carrying large amounts of municipal sewage, industrial effluents and runoff from agricultural fields in the rainy season (Singh et al. 2004; Hu et al. 2012). The river has been polluted by the discharge of domestic waste, biodegradable organics, nutrients and agricultural waste (Dimitrovska et al., 2012).

The BOD & COD values increased simultaneously indicating a significant correlation between the organic pollution load and the degradation of water quality. The domestic sewage and industrial effluents are the major contributors for the degradation of river ecosystem. Furthermore, identified Gomti River as the largest recipient of untreated sewage and noted that inadequate wastewater-treatment efficiency was contributing to deterioration of surface-water quality and aquatic habitats. In order to repair and preserve the ecological health of the Gomti River, these conditions underscore the necessity of bolstering wastewater treatment facilities, enhancing sewer connectivity, and guaranteeing efficient monitoring of effluent discharge (Gautam et al., 2018). Although periodic monitoring efforts exist, a comprehensive spatio-temporal assessment supported by statistical analysis remains necessary to better understand pollution behaviour and parameter interactions (Singh and Tung, 2025). In this context, the present study was undertaken to (i) evaluate spatial and seasonal variations in DO, BOD, and COD in the urban reach of the Gomti River during 2023–2024, (ii) analyse interrelationships among these parameters using correlation and regression techniques, and (iii) assess the influence of organic load on COD dynamics. The outcomes are expected to contribute to evidence-based strategies for effective river management and pollution mitigation.

Materials and methods

Study Area

Gomti River is a major alluvial tributary of the Ganga River. It originates from Gomat Taal (Fulhar Lake) in Pilibhit District, Uttar Pradesh, India and flows for about 900 km before joining the Ganga River near Saidpur in Ghazipur District (Fan et al., 2010; Feher et al., 2016; Khan et al., 2020). The river has an important role for domestic water supply, irrigation, fisheries and ecological processes throughout its basin. The present study was carried out in the urban stretch of the Gomti River flowing through the capital city of Uttar Pradesh, India (26.8467°N, 80.9462°E). Lucknow has an area of approximately 2,528 km2 and is located at a mean elevation of 123 m from sea level. The city heavily relies on the Gomti River for drinking water, agricultural activities, and other ecosystem services. Lucknow is one of the major metropolitan centres in north India. In the last few decades, the environmental conditions of the Gomti River basin have been significantly altered due to rapid urbanization, industrialization, population growth, tourism development, infrastructure expansion and land-use change. Increased anthropogenic pressures on river ecosystem have been attributed to establishment of industries, pharmaceutical units, construction projects and conversion of agricultural and forest lands for urban development (Fan et al., 2010; Garizi et al., 2011; Kumar et al., 2017). As a result, large quantities of domestic sewage, industrial effluents and urban runoff are being discharged into the river, adversely affecting the water quality and ecological integrity. To assess the spatial variations in water quality and levels of contamination, four sampling sites were selected along the Lucknow stretch of Gomti River on the basis of surrounding land-use characteristics and potential pollution sources. Daliganj Bridge is a highly polluted urban zone characterized by dense urban settlements and large sewage discharge. Kudiya Ghat is moderately urbanized and also influenced by religious and recreational activities. The Mohan Mikin site is near industrial establishments and receives inputs of industrial effluent while Pakkapul is affected by mixed residential and commercial discharges. These sampling sites collectively represent a gradient of anthropogenic disturbances and allow for a comprehensive assessment of the physicochemical characteristics and pollution status of Gomti River within the urban landscape of Lucknow.

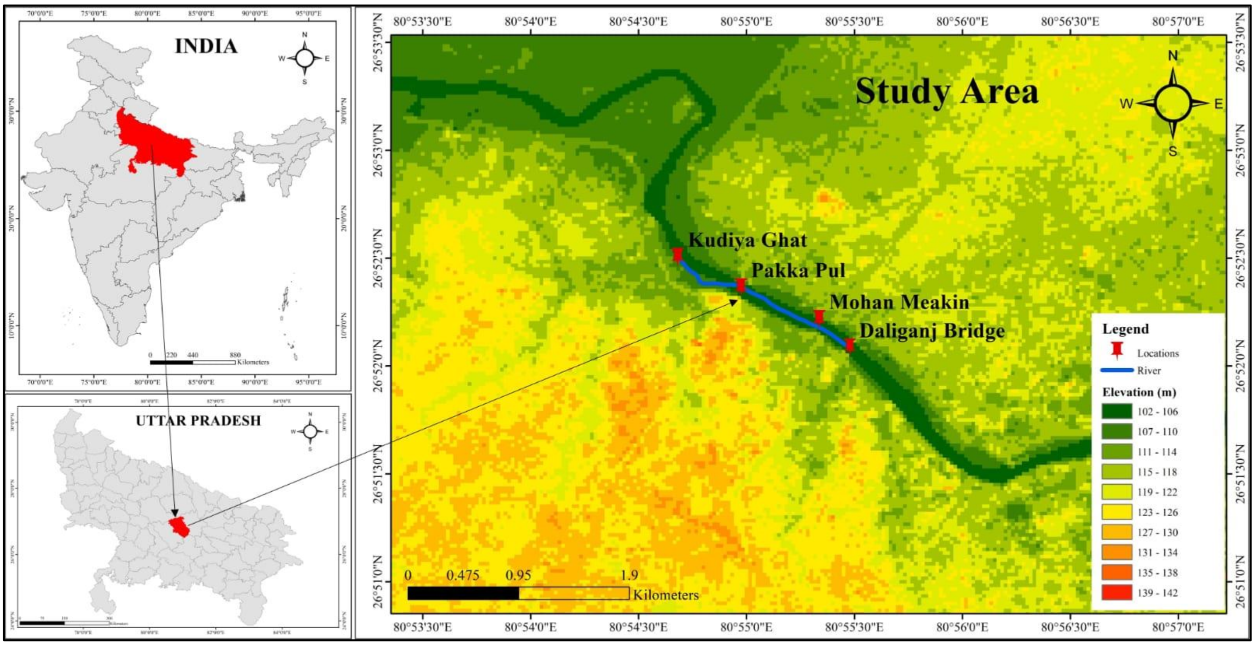

Fig. 1. Location map of the study area in Uttar Pradesh, India, showing sampling sites along the river stretch in Lucknow. The map includes sampling locations at Kudiya Ghat, Pakka Pul, Mohan Meakin, and Daliganj Bridge along the river course. The elevation gradient (m) is represented using a color scale, while the river is indicated in blue. Insets display the geographical position of the study area within India and Uttar Pradesh.

Sampling and Analytical technique

Surface water samples were collected monthly from January 2023 to December 2024 at all four locations, generating a total of 96 observations for each parameter. Sampling followed standard grab techniques, with water collected from the upper 0–30 cm layer using pre-cleaned, acid-washed polyethylene bottles. This depth was selected to represent the biologically active zone influenced by atmospheric exchange, microbial processes, and external inputs. Samples were transported to the laboratory in insulated containers and analysed immediately to minimize physicochemical changes and microbial alteration. Water quality assessment focused on key oxygen-related parameters, namely dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD), expressed in mg L^{-1}. Analyses were conducted following standard procedures recommended by APHA Standard Methods for the Examination of Water and Wastewater (24th Edition, 2023). DO (Method 4500-O), BOD_5 APHA Method 5210 B (5 days at 20°C) COD (APHA Method 5220). DO was determined using the Winkler iodometric titration method, BOD_5 was measured after a 5-day incubation at 20°C to estimate biodegradable organic load, and COD was analysed using the closed reflux titrimetric method to quantify total oxidizable pollutants.

Statistical Analysis

Statistical analysis was carried out for all the samples to determine the spatial and temporal variations in dissolved oxygen (DO), biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Descriptive statistics (mean, standard deviation) were computed to evaluate the spatial and temporal variability. The relationship of DO, BOD and COD were studied through Pearson correlation analysis. Significance was tested at 1% and 5% levels. The combined effect of DO and BOD on COD was assessed using multiple linear regression analysis based on the following model:

$$COD = \beta_0 + \beta_1(DO) + \beta_2(BOD)$$

Model performance was assessed using the coefficient of determination (R^2), adjusted R^2 and analysis of variance (ANOVA) where regression coefficients were significant at $p < 0.05$. All statistical analyses were carried out using SPSS (Version 26).

Results

Spatial Variation of DO, BOD, and COD in the Gomti River

The spatial distribution of dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) exhibited noticeable variation among the sampling locations during both 2023 and 2024. As shown in Fig. 2 (2023) and Fig. 5 (2024), DO concentrations remained consistently low throughout the study area, ranging from 2.91 to 3.34 mg L^{-1}. The highest DO concentration was observed at Kudiya Ghat, whereas the lowest value was recorded at daliganj Bridge. The consistently low dissolved oxygen levels are indicative of oxygen depleted conditions and significant organic pollution stress in the urban stretch of Gomti River. These conditions are typically related to organic matter decomposition and enhanced microbial respiration, which worsen oxygen depletion in aquatic ecosystems. The spatial distribution of BOD in 2023 (Fig. 3) and 2024 (Fig. 6) indicated high concentrations at all sampling sites, indicating the persistent presence of biodegradable organic pollutants. High BOD values indicate significant contributions of domestic sewage, municipal wastewaters and organic waste to the river system. The increase in organic loading increases the microbial activity resulting in higher oxygen demand and thus lower dissolved oxygen. The negative relationship between DO and BOD shows the influence of organic pollution on the ecological status of the river.

Fig. 4 (2023) and Fig. 7 (2024) demonstrated that the COD concentration remained at high concentrations during the entirety of the study period. The increased COD values Indicates the presence of both biodegradable and non-biodegradable contaminants from untreated sewage, urban runoff and different anthropogenic sources. The high COD values along with high BOD concentrations indicate that the river is subjected to a broad spectrum of organic and inorganic pollutants. These conditions reflect the state of the river ecosystem under ongoing pollution stress and diminished self-purification ability. the spatial distributions of DO, BOD and COD were predominantly consistent when comparing the two academic years. The locations with low DO concentrations in Fig. 2 and Fig. 5 were generally associated with high BOD and COD values in Fig. 3, Fig. 4, Fig. 6, and Fig. 7 which demonstrated the adverse effects of organic and chemical contamination on water quality. Fig. 8 and 9 show the variation of dissolved oxygen (DO) concentration of Gomti River for the period of 2023–2024 for the monthly and yearly basis. Generally, dissolved oxygen was high in winter and low in summer due to the higher temperatures, low water flow and the increased microbial activity that utilizes oxygen. Kudiya Ghat recorded relatively high levels of dissolved oxygen whereas Daliganj Bridge showed low levels consistently indicating higher pollution stress. Dissolved oxygen increased marginally during monsoon months due to dilution and increased aeration. 2023 and 2024 showed similar trends, suggesting that oxygen concentrations in the river were largely uniform. The low dissolved oxygen concentrations indicate the continued organic pollution and poor water quality of the urban stretch of the Gomti River. The observed spatial variations are indicative of the fact that anthropogenic activities have a significant effect on the water quality of the Gomti River, resulting in poor ecological conditions of its urban stretches.

Correlation Analysis

The Pearson correlation matrix among dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) is presented in Table 1. The analysis revealed significant negative correlations between DO and BOD ($r = -0.404$, $p = 0.004$) and between DO and COD ($r = -0.480$, $p = 0.001$), indicating that increasing organic and chemical pollution levels are associated with reduced oxygen availability in the river water. In contrast, a strong positive correlation was observed between BOD and COD ($r = 0.734$, $p < 0.001$), indicating that the two parameters respond in a similar fashion to pollution inputs and increase in proportion to increasing loads of contaminants. The observed strong correlations among these parameters point out the significant influence of organic pollution on the oxygen dynamics and the overall water quality of the Gomti River.

Descriptive Statistics

As presented in Table 2, the mean dissolved oxygen concentration was 3.154 ± 0.942 mg L^{-1}, indicating relatively low oxygen availability throughout the study period. In contrast, the mean BOD concentration was 9.071 ± 1.056 mg L^{-1}, reflecting a considerable biodegradable organic load in the river system. Similarly, COD exhibited a mean value of 39.860 ± 4.988 mg L^{-1}, indicating the presence of substantial quantities of oxidizable pollutants. Variations in BOD and COD concentrations indicated variations in pollution inputs between sampling locations and seasons. The descriptive statistics indicate that the urban section of the Gomti River is affected by persistent organic and chemical pollution leading to deteriorated water quality conditions overall.

Multiple Linear Regression Analysis

The performance of the multiple linear regression model is presented in Table 3, while the corresponding analysis of variance (ANOVA) and regression coefficients are provided in Tables 4 and Tables 5, respectively. The model produced an R^2 value of 0.579 and an adjusted R^2 value of 0.560, indicating that approximately 57.9% of the variation in COD was explained by the combined effects of DO and BOD. The ANOVA results in Table 4 demonstrated that the regression model was statistically significant ($F = 30.905$, $p < 0.001$), confirming the suitability of the selected predictor variables for explaining COD variability.

The regression coefficients presented in Table 5 yielded the following predictive equation:

$$COD = 15.885 - 1.160(DO) + 3.046(BOD)$$

The coefficient associated with DO was negative and statistically significant ($\beta = -1.160$, $p = 0.044$), indicating that higher dissolved oxygen concentrations are associated with lower COD values. Conversely, BOD exhibited a positive and highly significant effect on COD (β = 3.046, $p < 0.001$), showing that increases in biodegradable organic material greatly improve the river's chemical oxygen demand. BOD showed maximum impact on COD suggesting the dominant impact of organic pollution on the water quality in the urban stretch of Gomti River.

Spatial variation of mean DO, BOD, and COD concentrations at four sampling sites of the Gomti River during 2023.

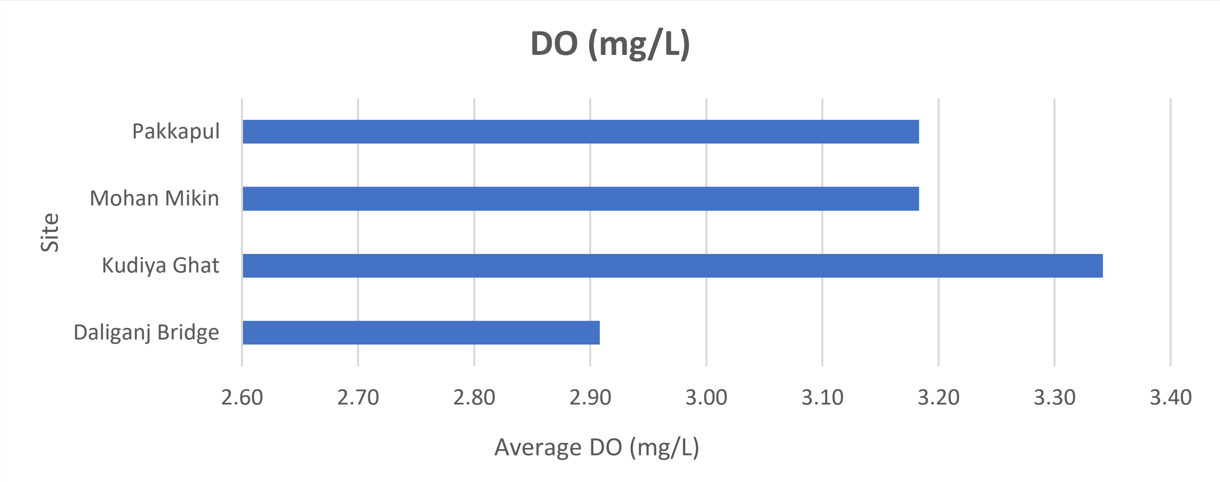

Fig. 2. Spatial variation in mean dissolved oxygen (DO) concentrations at four sampling locations of the Gomti River during 2023.

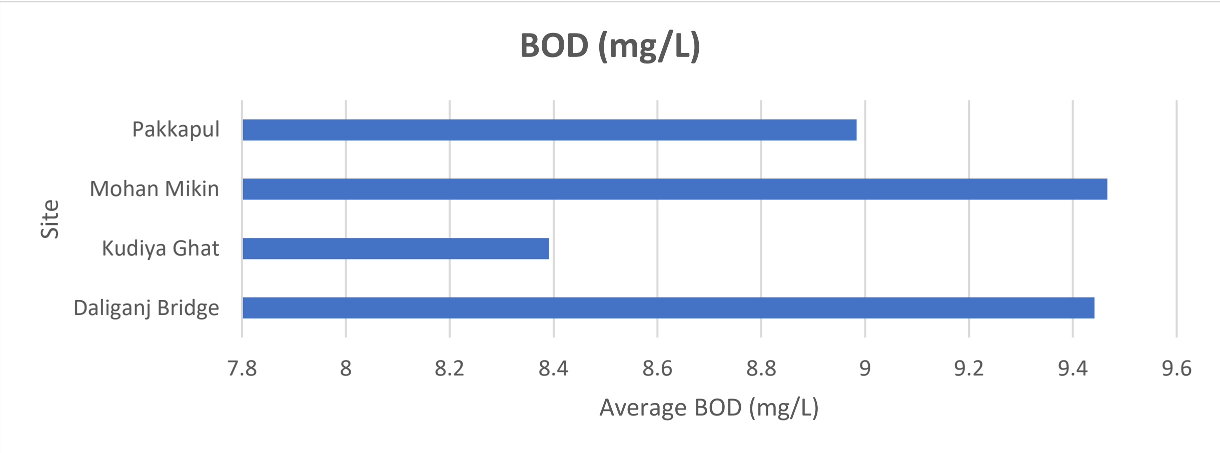

Fig. 3. Spatial variation in mean biochemical oxygen demand (BOD) concentrations at four sampling locations of the Gomti River during 2023

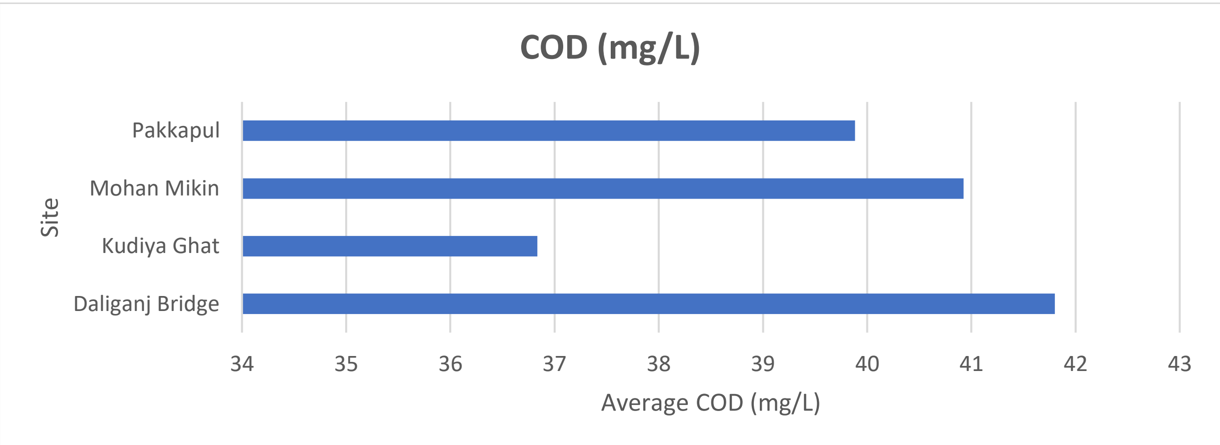

Fig. 4. Spatial variation in mean chemical oxygen demand (COD) concentrations at four sampling locations of the Gomti River during 2023.

Descriptive statistics showed that the average biochemical oxygen demand (BOD) was 9.07 mg/L with a standard deviation of 1.06, indicating significant organic pollution and moderate variability. The average is 39.86 mg/L and the standard deviation is 4.99. This shows that there is a big chemical pollution burden and there is a large difference between observations. The mean value of DO was 3.15 mg/L (standard deviation 0.94). It is a low value of dissolved oxygen and signifies that the oxygen is not sufficient in the water for the aquatic organisms to survive. This indicates that the water quality conditions were poor during the study period.

Spatial variation of mean DO, BOD, and COD concentrations at four sampling sites of the Gomti River during 2024.

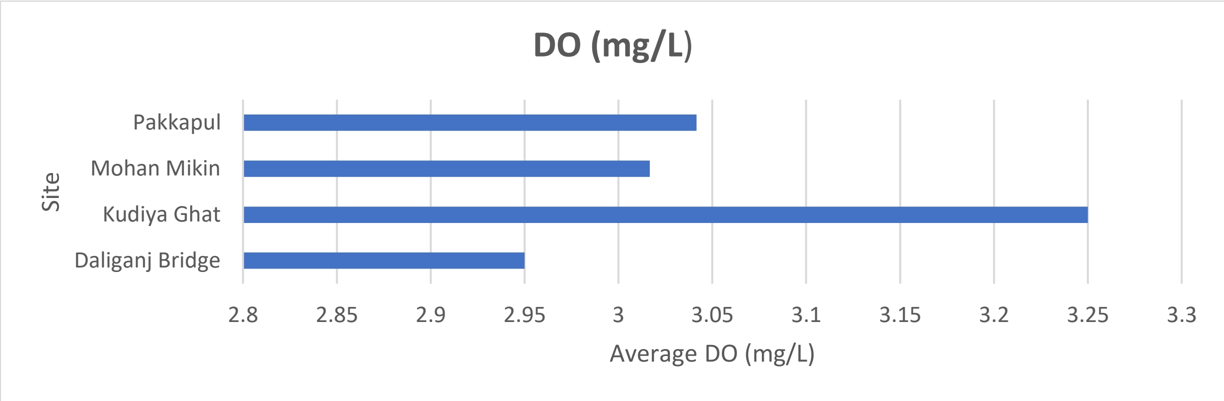

Fig. 5. spatial variation in mean dissolved oxygen (DO) concentrations at four sampling locations of the Gomti River during 2024

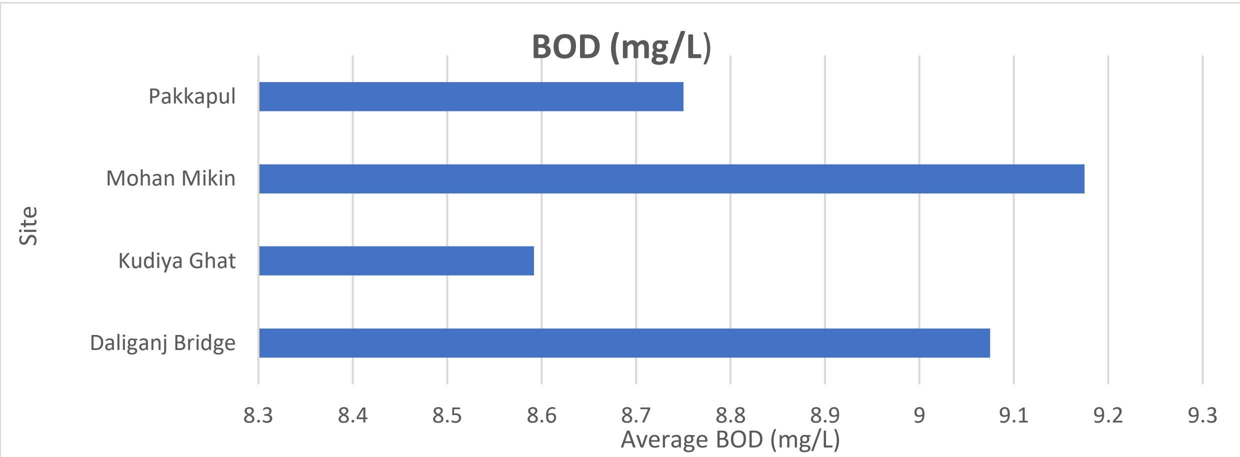

Fig. 6. Spatial variation in mean biochemical oxygen demand (BOD) concentrations at four sampling locations of the Gomti River during 2024

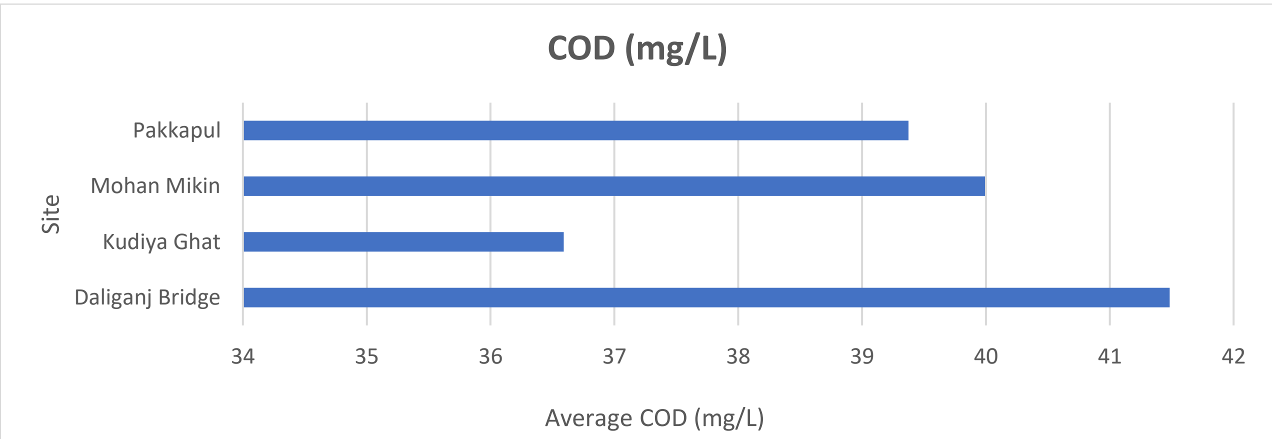

Fig. 7 Spatial variation in mean chemical oxygen demand (COD) concentrations at four sampling locations of the Gomti River during 2024

Discussion

The current study, validated by existing literature, conclusively demonstrates that the Gomti River experiences considerable anthropogenic stress, most notably attributable to the incessant discharge of untreated sewage, industrial effluents, and agricultural runoff. The river has high levels of biochemical oxygen demand (BOD) and chemical oxygen demand (COD), especially in urban areas. This is because untreated wastewater and industrial inputs are polluting the water with a lot of organic matter. As a result, the levels of dissolved oxygen (DO) drop sharply, and they often get so low that they can't support aquatic life (Dutta et al., 2011; Kushwah et al., 2023; Singh et al., 2025).

Variation of DO level on various gomti river sites over the years

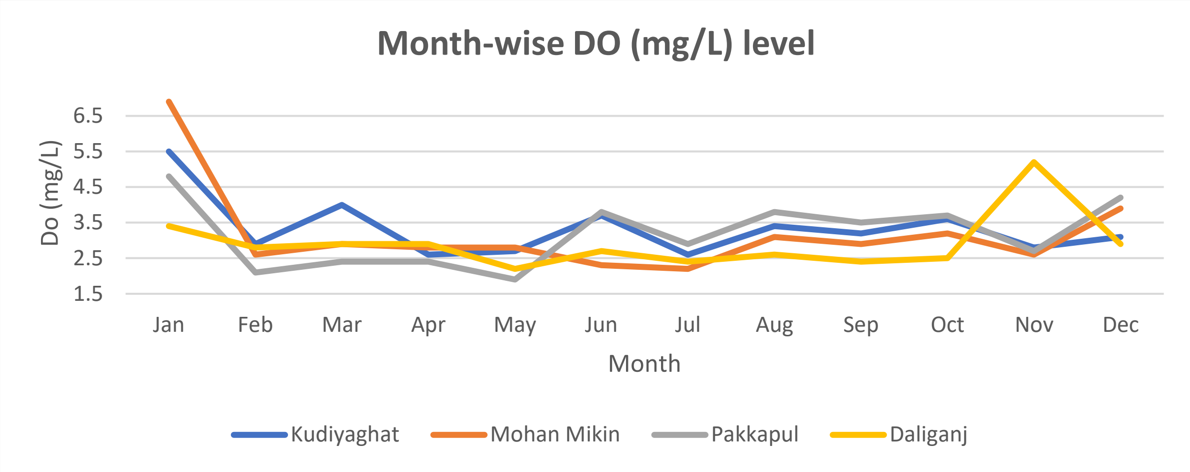

Fig. 8. Monthly variation in dissolved oxygen concentrations at four sampling locations of the Gomti River during 2023–2024

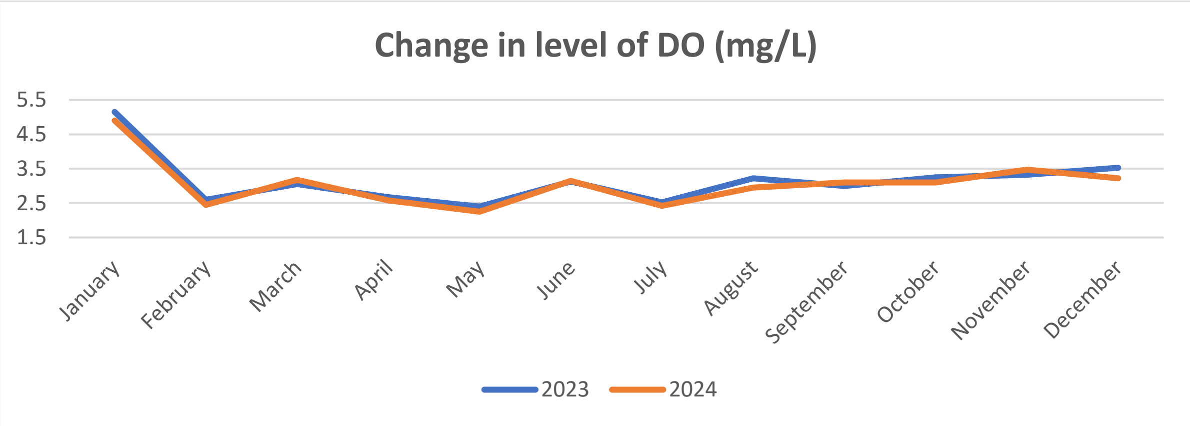

Fig. 9. Comparative monthly variation of dissolved oxygen concentrations during 2023 and 2024.

Table 1. Pearson correlation matrix showing relationships among DO, BOD and COD in the Gomti River during 2023–2024.

Correlations				
		DO (mg/L)	BOD (mg/L)	COD mg/L
DO (mg/L)	Pearson Correlation	1	-.404**	-.480**
	Sig. (2-tailed)		.004	.001
	N	48	48	48
BOD (mg/L)	Pearson Correlation	-.404**	1	.734**
	Sig. (2-tailed)	.004		.000
	N	48	48	48
COD mg/L	Pearson Correlation	-.480**	.734**	1
	Sig. (2-tailed)	.001	.000	
	N	48	48	48
**. Correlation is significant at the 0.01 level (2-tailed).				

Table 2. Descriptive statistics of water quality parameters in the Gomti River during 2023–2024.

Descriptive Statistics			
	Mean	Std. Deviation	N
BOD (mg/L)	9.071	1.0565	48
COD mg/L	39.860	4.9877	48
DO (mg/L)	3.154	.9421	48

Table 3. Model summary statistics of the multiple linear regression model predicting COD from DO and BOD concentrations in the Gomti River during 2023–2024.

Model	R	R^2	Adjusted R^2
	0.761	0.579	0.560

Table 4. Analysis of variance (ANOVA) for the multiple linear regression model.

ANOVA					
Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	676.628	2	338.314	30.905	<0.001
Residual	492.607	45	10.947		
Total	1169.235	47			
a. Dependent Variable: COD mg/L					
b. Predictors: (Constant), BOD (mg/L), DO (mg/L)					

Table 5. Regression coefficients showing the influence of DO and BOD on COD.

Model	Unstandardized Coefficients		t	Sig.
	β	Std. Error		
(Constant)	15.885	5.508	2.884	0.006
DO (mg/L)	-1.160	0.560	-2.072	0.044
BOD (mg/L)	3.046	0.499	6.100	0.000

Dissolved oxygen (DO) and biochemical oxygen demand (BOD) are important parameters for organic pollution and health of river (Kumar et al., 2017b) reported the dissolved oxygen content of the Gomti River ranged from 6.21 to 8.81 mg/L with higher values in winter and lower values in summer. The BOD values ranged from 1.54 to 2.68 mg/L and increased downstream due to release of untreated sewage and accumulation of organic matter. obtained similar findings in the Jakara River, where very low dissolved oxygen contents suggested serious organic pollution and deterioration of water quality. The authors also observed a strong positive correlation between BOD5 and COD ($r = 0.899$, $p < 0.05$) but a negative correlation with DO for both parameters (Mustapha et al., 2013). The results show that with increased organic pollution there is an increase in oxygen demand leading to a decrease in dissolved oxygen and a deterioration of the health of the aquatic ecosystem. These studies collectively demonstrate that anthropogenic loads, especially untreated domestic wastewater and organic waste, exert significant influence on the dynamics of dissolved oxygen, biochemical oxygen demand and chemical oxygen demand in river systems.

Moreover., Unplanned urbanization and cultural practices, like idol immersion, make pollution worse by adding household waste, feces, and plastic trash (Kumar et al., 2017b). These combined inputs have led to consistently high BOD and COD levels, which is a clear sign of a lot of organic contamination (Verma, 2025; Ojha, 2024; Divya and Archana, 2024; Das et al., 2024). As a result, lower DO levels lead to less oxygen, worse habitats, and negative effects on aquatic biodiversity. Recent assessments further corroborate severe organic pollution with critically low DO and elevated BOD/COD in Lucknow stretch (Singh et al.,2025).

Statistical analysis indicates these findings, indicating a significant negative correlation between dissolved oxygen (DO) and pollution indicators (biochemical oxygen demand (BOD) and chemical oxygen demand (COD)), as well as a robust positive relationship between BOD and COD. These results indicate that organic matter loading is a significant factor regulating water-quality decline. Regression analysis shows that the changes in COD are mostly caused by changes in organic pollution, which shows how these two things are linked. Seasonal trends, especially the drop in DO levels in the summer, can be explained by higher temperatures, lower flow rates, and more microbial activity, all of which speed up the use of oxygen. these results agree with what was found in earlier studies of the Gomti River. A long-term study (2013–2017) using the Water Quality Index (WQI) found that the river water was poor to unsuitable, with values between 71.11 and 165.33. This shows that the pollution stress is severe and long-lasting (Krishan et al., 2022).

Conclusion

The present study showed that the urban stretch of Gomti River is facing continuous organic pollution as indicated by low dissolved oxygen (DO) and high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) throughout the year 2023-2024. Average DO (3.15 0.94 mg L^{-1}), BOD (9.07 1.06 mg L^{-1}) and COD (39.86 4.99 mg L-1) suggest poor water quality as DO concentration is less than the level needed to support healthy aquatic ecosystems.s Spatial analysis revealed that Daliganj Bridge consistently exhibited the highest pollution levels, with the lowest DO and highest BOD and COD concentrations, whereas Kudiya Ghat showed comparatively better water quality. Seasonal assessment further demonstrated that DO Declined markedly during the summer months because of elevated temperature, reduced river flow, and increased microbial oxygen consumption, while slight improvements were observed during the monsoon due to dilution and enhanced aeration. Statistical analysis showed that DO and BOD ($r = -0.404$, $p = 0.004$) and DO and COD ($r = -0.480$, $p = 0.001$) were significantly negatively correlated, while BOD and COD were strongly positively correlated ($r = 0.734$, $p < 0.001$), indicating that increased organic pollution directly leads to the depletion of oxygen. In the multiple linear regression analysis, DO and BOD explained 57.9% of the variation in COD ($R^2 = 0.579$), with BOD being the most important predictor of

COD (β = 3.046, $p < 0.001$). These results conclusively show that organic pollution is the major cause for the deterioration of water quality in Gomti River. The study highlights the need for urgent improvement in sewage treatment, stricter regulations on the release of industrial effluent and ongoing surveillance of water quality to improve the ecological health of the Gomti River. Adopting integrated river basin management approaches and regularly assessing key water quality indicators will be crucial to restoring ecosystem health and sustainably managing this important freshwater resource.

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ZS: Conceptualisation, Methodology, Investigation, Formal analysis, Data curation, Writing – original draft; **SSA:** Conceptualisation, Supervision, Validation, Writing – review & editing; **SN:** Investigation, Methodology, Data curation, Validation; **SG:** Formal analysis, Statistical analysis, Data interpretation, Visualisation; **AK:** Sample collection, Laboratory analysis; **MM:** Resources, Writing – review & editing. All authors have read and approved the final manuscript.

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