EPH–International Journal of Science & Engineering
Published by: E-Pub Solutions Private Limited
ISSN (Online): **2454-2016**
Volume 12 Issue 03 August 2026
DOI:10.67772/xg3zqe52

INTERRELATIONSHIPS AMONG NUTRIENT ENRICHMENT, OXYGEN DYNAMICS, AND WATER QUALITY FOR SUSTAINABLE SURFACE WATER MANAGEMENT

Dr.Pooja sahu[1]

[1]Assistant professor; (Pharmacology)Dravyaguna department; management of lifestyle disorder; Betul; Om Ayurveda Medical College ,betul ,M.P. Contact no.8818874743; Mail id misthyo41024@gmail.com; Orcid id -000900043694; Pin code -460001

Article History:
Article Type: Research
Received Date: **06/07/2026**
Revised Date: **08/08/2026**
Accepted Date: **16/08/2026**
Published Date:**26/08/2026**

Keywords: Nutrient enrichment; Dissolved oxygen; Surface water quality; Eutrophication; Sustainable water management

ABSTRACT
Surface-water quality is increasingly influenced by nutrient enrichment, oxygen-demand processes, and localized pollution pressures, making integrated assessment essential for sustainable water management. This study examined the interrelationships among ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, phosphate, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and supporting physicochemical indicators across three monitoring locations and seasonal categories. A total of 36 observations were analyzed using descriptive statistics, Pearson correlation, simple linear regression, and Kruskal-Wallis tests. The results revealed pronounced spatial variability, with Jabalpur showing the highest mean concentrations of ammonia, nitrite, nitrate, phosphate, and COD. Significant spatial differences were observed for all major nutrient and oxygen-related variables, whereas seasonal differences were not statistically significant. Strong positive associations were found between nitrite and phosphate and between several nutrient indicators and COD. In contrast, nitrate showed only a weak relationship with dissolved oxygen, explaining approximately 3.5% of DO variability. These findings indicate that oxygen dynamics are shaped by multiple interacting environmental and physicochemical factors rather than nutrient concentration alone. The study highlights the importance of spatially targeted monitoring and integrated nutrient-oxygen assessment for effective and sustainable surface-water management.

1. Introduction

Surface-water systems are vital to drinking water, agriculture, biodiversity, fisheries, industry, and ecosystem functions; however, water quality is increasingly jeopardized by nutrient inputs, organic pollution, hydrological alteration, and increased human activity. Therefore, water-quality degradation is not measured by any individual chemical constituent but by interacting physical, chemical and biological processes that affect the overall condition and ecological capacity of rivers, reservoirs and interconnected aquatic systems (Chapman et al., 2020). Excessive loading of nitrogen and phosphorus is among these pressures and can be significant because nutrient enrichment can lead to increased primary production, change biological communities and increase eutrophication in freshwater systems (Kapsalis & Kalavrouziotis, 2021).

Eutrophication is a big problem in sustainable management of surface water as increased nutrient levels can affect the productivity of the algae, the breakdown of organic matter, oxygen level and the stability of the water. Nutrient concentration, oxygen condition and physicochemical variables have been shown to provide complementary information on ecological degradation in eutrophic freshwater systems, with water-quality indices showing this (Menberu et al., 2021). Nutrient enrichment in river-estuary systems can result in significant spatial variations in nutrient availability and phytoplankton production, which are important links between nutrient cycling and dissolved oxygen (DO) (Wang & Zhang, 2020).

The dissolved oxygen parameter is one of the most informative indicators of the condition of aquatic ecosystems due to the fact that it reflects the combined effects of biological respiration, photosynthesis, degradation of organic matter, reaeration, temperature and hydrological processes. Phosphorus, dissolved oxygen, biochemical oxygen demand and phytoplankton are highly linked processes in catchment scale water-quality dynamics that have been demonstrated using integrated modelling (Crossman et al., 2021). But the effects of nutrient loading are not the only factors that influence oxygen concentrations, and river morphology, channel conditions, flow characteristics and atmospheric exchange can significantly alter DO behaviour (Hutchins et al., 2021). The biochemical oxygen-demand assimilative capacity may also change as a result of rising temperature, which leads to increased concern under changing climatic conditions as described by Chapra et al. (2021).

Nitrogen compounds (ammonia, nitrite and nitrate) and phosphate are important indicators of nutrient enrichment and anthropogenic pressure. Spatial nutrient assessments show that surface-water networks can have very different nutrient conditions due to land use, wastewater discharge, hydrological connectivity, and pollutant transport. (Chen et al., 2022) Evaluating eutrophication increasingly involves not just one nutrient indicator or threshold, but simultaneous consideration of conventional nutrient indicators and temporal oxygen behaviour (Burkholder et al., 2022).

Hydrological connectivity also adds complexity to nutrient dynamics as nutrient inputs may lead to re-distribution and changes in water quality in receiving aquatic ecosystems (Koue, 2024). Eutrophication modelling has been synthesized recently, highlighting the need to consider nutrient concentrations, dissolved oxygen, physical and chemical conditions, spatial variability, and temporal trends when assessing surface water quality (Liu et al., 2025). The identification of eutrophication drivers is not sufficient; the mechanisms by which the nutrient loading affects oxygen demand and ecosystem processes and water-quality responses must be understood to direct sustainable nutrient management (Khalili & Moridi, 2025). In recent years, spatiotemporal evaluations also have shown that the levels of nutrient enrichment and eutrophication within the same aquatic system can be quite different at different sites, further emphasizing the importance of spatial variability in monitoring and management practices (Li et al., 2025).

The objective of the present study is to investigate the interrelationship between nutrient enrichment, oxygen dynamics and surface water quality conditions. It includes ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, phosphate, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, and other physicochemical parameters at various monitoring sites and in various seasons. Specific goals include describing nutrient and oxygen-related water-quality conditions, detecting spatial and temporal nutrient and oxygen-related water-quality variability, measuring associations between nutrient and oxygen-demand parameters, assessing the relationship between nitrogen-related parameter nitrate and oxygen-related parameter dissolved oxygen, and determining if there is significant water-quality parameter variation between monitoring locations and seasons. The analysis should create an integrated evidence base for sustainable monitoring and management of surface water.

2. Methodology

2.1 Research Design and Data Structure

The design of this study was quantitative, secondary data and the objective was to study the interrelationship between nutrient enrichment, oxygen dynamics and physicochemical characteristics of surface water. There were 36 observations and 33 variables recorded for each month in Analytical data with three monitoring locations such as Anuppur, Dindori, and Jabalpur. The number of observations at each monitoring location was N = 12 and the overall sample size was N = 36 and balanced spatially (Dilip, 2024).

The monitoring period began in April and ended in March the following year. The data were grouped into seasonal categories in the source data for use in seasonal analysis. These resulted in sample sizes of Summer (n = 12), Monsoon (n = 15) and Winter (n = 9). 36 observations were used in the analysis with no observations removed due to missing data for the principal variables.

This analysis was limited to three aspects of surface-water quality: nutrient enrichment, oxygen related conditions, and supporting physicochemical conditions. The spatial and seasonal variability was examined along with the statistical associations among these components.

2.2 Variable Selection and Operationalization

Ammonia N, Nitrite N, Nitrate N and Phosphate were the main nutrient-enrichment parameters. The following parameters were chosen for them to reflect the surface water nutrient load of nitrogen and phosphorus. The dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) were the oxygen related variables. DO indicated the availability of oxygen in the water while BOD and COD indicated biological and chemical oxygen-demand properties, respectively.

Other physicochemical variables were also considered in the descriptive assessment, because they provide additional information about chemical balance and ionic concentration and about suspended or optically active material, namely pH, specific conductivity and turbidity. The original numerical measures were left unchanged. All tables and figures report the variables in the units as they are provided in the source data; the analytical file did not explicitly define all units used for variables.

2.3 Descriptive, Spatial, and Seasonal Analysis

Descriptive statistics were calculated for the selected nutrient, oxygen-related, and physicochemical variables. For each parameter, the arithmetic mean, standard deviation, minimum, and maximum were calculated across all N = 36 observations,

$$\bar{X} = (\Sigma X_i) / N$$

where X_i is the observed value and N = 36. The sample standard deviation was calculated using the N - 1 denominator.

$$SD = \sqrt{[\Sigma(X_i - \bar{X})^2 / (N - 1)]}$$

Three divisions (Anuppur, Dindori and Jabalpur) were formed for the spatial analysis and the mean values were calculated for each division. The denominator for each monitoring location is n = 12. Ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, phosphate, DO, BOD, and COD location-specific means were derived.

The mean values were calculated for the seasonal analysis using the numbers of the observations in each seasonal category: Summer (n = 12), Monsoon (n = 15), and Winter (n = 9).

2.4 Correlation, Regression, and Group-Difference Analysis

The Pearson product-moment correlation coefficient was used to evaluate the relationship between ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, phosphate, DO, BOD and COD for all 36 observations. Two tailed significance tests were used to evaluate all correlation tests. $p < 0.05$ was considered as statistical significance and higher p values $p < 0.01$ and $p < 0.001$ were considered as stronger significance level.

Nitrate nitrogen and dissolved oxygen were quantified and visualized against each other in a simple ordinary least-squares regression model. Dissolved oxygen (DO) was used as the dependent variable and nitrate nitrogen (NO3-N) was used as the independent variable:

$$DO_i = \beta_0 + \beta_1(NO_{3i}) + \varepsilon_i$$

All 36 observations were used for the regression. The coefficient of determination (R^2) was used to express model explanatory power. A regression line was fitted to the data to determine the correlation; the R^2 value for this regression was 0.035 and the Pearson correlation value between nitrate nitrogen and DO was r = 0.186. When a simple linear regression is made with only one predictor and intercept, R^2 = r2, which means that the regression and the correlation are mathematically consistent.

Only a few variables associated with nutrients and oxygen had skewed distributions and significant differences between monitoring sites; therefore, spatial and seasonal comparisons were made using the Kruskal-Wallis H test instead of one-way ANOVA. Ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, phosphate, dissolved oxygen, BOD and COD were tested separately. The three groups were Anuppur (n = 12), Dindori (n = 12) and Jabalpur (n = 12) for the spatial comparison. The groups were divided into Summer (n = 12), Monsoon (n = 15) and Winter (n = 9) for seasonal comparisons. The significance of the results obtained was evaluated at the 5% level. No post-hoc pairwise comparisons were done or reported as the Results section only reports overall differences among the three groups.

2.5 Data Quality, Statistical Criteria, and Ethical Considerations

The data were screened for completeness, consistency of variables, consistency of categorical labels, and availability of nutrient and oxygen related variables that were needed for the statistical analysis. There were no missing variables or cases to be imputed in the analytical data set as there were 36 complete observations for all variables selected. Where necessary, labels were standardized to be consistent for monitoring locations; all numerical measurements were not changed for analysis.

For all the statistical analysis a two-sided significance level of $\alpha = 0.05$ was used. Where appropriate, exact p-values were reported, otherwise values < 0.001 were given as $p < 0.001$. Correlation significance was denoted as *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$. The descriptive statistics were presented to three decimal places, as are the results in this section.

Only pre-existing observations of environmental monitoring were used in the study and were not identified. There were no human subjects, animals, personal information, clinical interventions, or experimental manipulations. Therefore, informed consent and participant-specific ethical approval did not apply to this secondary environmental-data analysis.

3. Results

3.1 Descriptive Characteristics of Nutrient and Water-Quality Parameters

The data collected consisted of 36 observations equally spread over 3 locations Anuppur, Dindori and Jabalpur. The descriptive statistics for the principal nutrient, oxygen-related and physicochemical variables have been given in Table 1. The overall mean was highest for the nitrate nitrogen (0.419 ± 0.350), followed by ammonia nitrogen (0.155 ± 0.253), nitrite nitrogen (0.087 ± 0.145), and phosphate (0.077 ± 0.164) among the nutrient indicators. There was also a relatively large range for nitrate nitrogen, from 0.140 to 1.500, suggesting the presence of significant variability between sampling observations.

Mean dissolved oxygen (DO) was 7.456 ± 0.609, with values ranging from 5.700 to 8.500. The mean biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were 1.214 ± 0.624 and 8.753 ± 5.567, respectively. Specific conductivity and turbidity also varied, indicating that there were different physico-chemical conditions between the monitoring sites.

Table 1. Descriptive statistics of selected nutrient and water-quality variables

Parameter	Mean	SD	Minimum	Maximum
Ammonia nitrogen	0.155	0.253	0.006	0.900
Nitrite nitrogen	0.087	0.145	0.000	0.490
Nitrate nitrogen	0.419	0.350	0.140	1.500
Phosphate	0.077	0.164	0.000	0.600
Dissolved oxygen	7.456	0.609	5.700	8.500
BOD	1.214	0.624	0.100	2.600
COD	8.753	5.567	2.000	24.000
pH	7.637	0.326	6.670	8.510
Specific conductivity	281.711	111.212	196.300	829.000
Turbidity	4.253	2.874	1.000	16.300

Note: Values are reported in the units provided by the original source data.

3.2 Spatial and Seasonal Variability in Nutrient Enrichment and Oxygen Conditions

A spatial difference was found between the three monitoring sites. The mean concentration of all four nutrient indicators was significantly higher in Jabalpur as indicated in Table 2. Tenfold ammonia nitrogen was found as 0.438 in Jabalpur whereas only 0.011 was detected at Anuppur and 0.014 at Dindori. Analogously, mean N-NO3 went up from 0.238 at Anuppur and 0.252 at Dindori to 0.767 at Jabalpur. Phosphate showed an unusually high spatial variation between its mean values at Jabalpur, Anuppur and Dindori which were 0.226, 0.002 and 0.005 respectively.

Table 2. Mean nutrient and oxygen-related parameters by monitoring location

Parameter	Anuppur	Dindori	Jabalpur
Ammonia nitrogen	0.011	0.014	0.438
Nitrite nitrogen	0.013	0.010	0.238
Nitrate nitrogen	0.238	0.252	0.767
Phosphate	0.002	0.005	0.226
Dissolved oxygen	6.733	7.992	7.642
BOD	0.650	1.483	1.508
COD	5.425	6.500	14.333

This spatial nutrient gradient is clearly illustrated in Figure 1, where Jabalpur consistently exhibits the highest nutrient concentrations. The results therefore indicate a substantially greater nutrient burden at Jabalpur relative to the upstream monitoring locations.

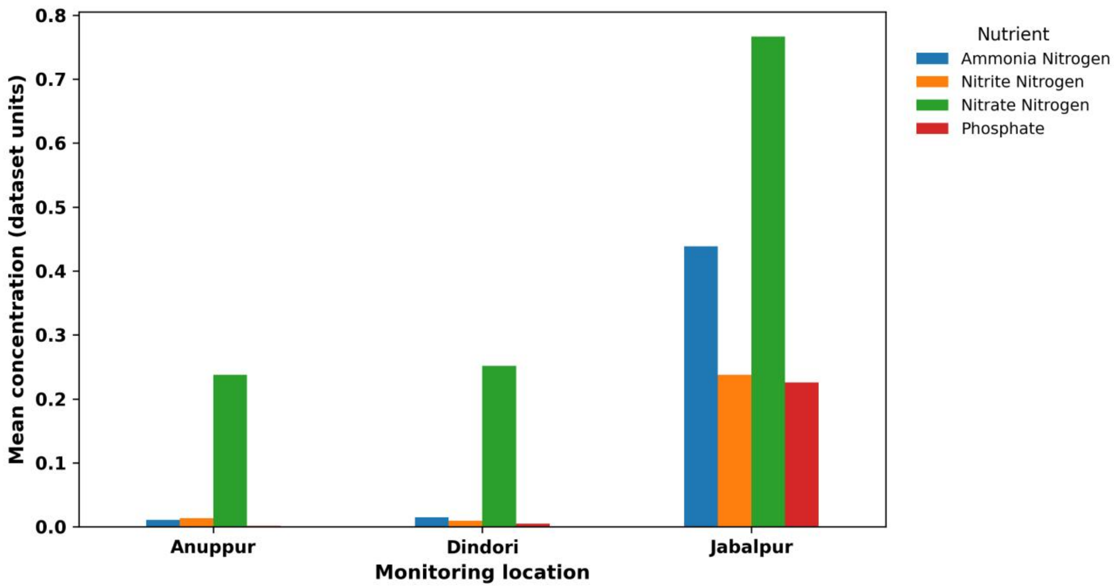

Figure 1. Spatial variation in nutrient enrichment

Oxygen indicators were also found to be different across the locations. The highest average DO concentration was recorded in Dindori whereas the lowest mean DO concentration was recorded in Anuppur. The high level of COD was found at Jabalpur (14.333) as compared to Anuppur (5.425) and Dindori (6.500) indicating high oxidizable pollutant load at Jabalpur.

The seasonal changes in oxygen related parameters were relatively small. Mean DO went up from summer to 7.275 to monsoon to 7.467 to winter to 7.678 as presented in Figure 2. The average BOD was 1.208, increased to 1.127 during monsoon and 1.367 during winter and COD was 7.508 in summer, 8.987 in monsoon and 10.022 during winter.

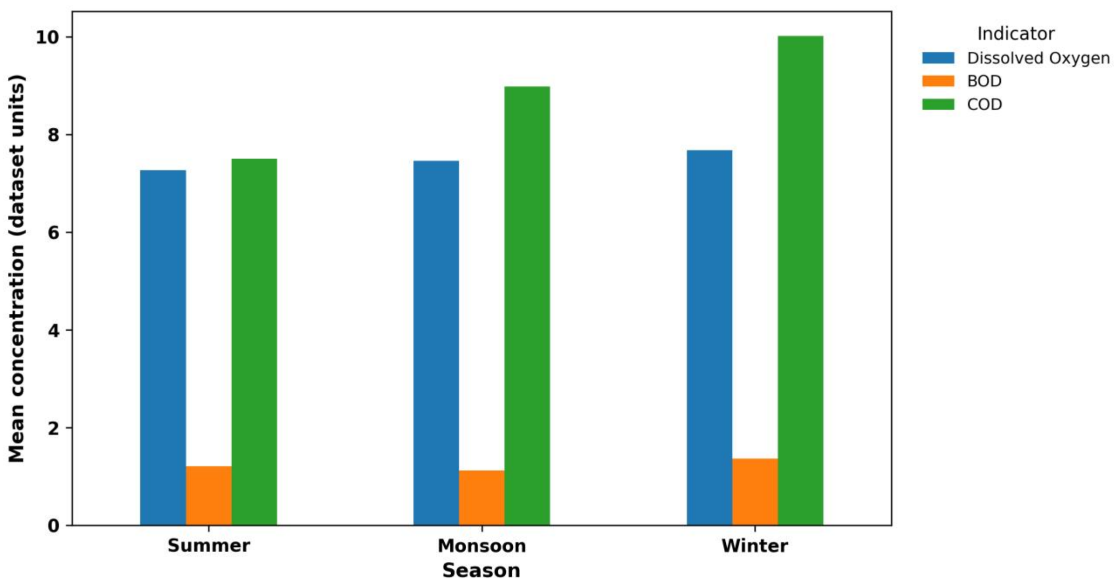

Figure 2. Seasonal variation in oxygen-related water-quality indicators

The monthly pattern presented in Figure 3 further shows that DO remained relatively stable over the annual sampling cycle, generally between approximately 7.1 and 7.8, whereas BOD exhibited a gradual tendency to increase during the later winter months, reaching its highest monthly average in March.

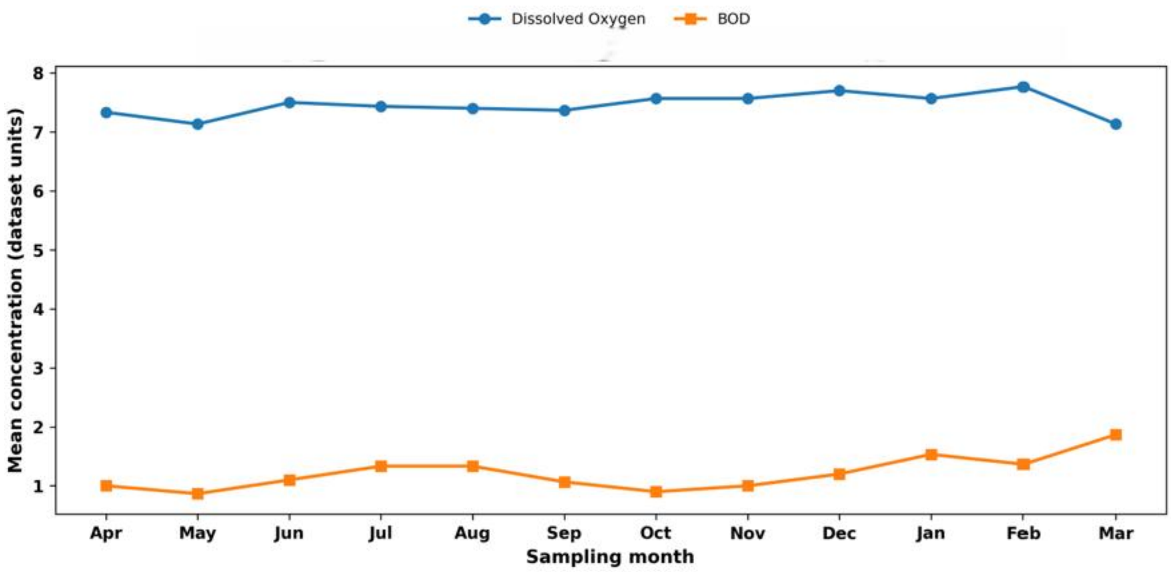

Figure 3. Monthly dynamics of dissolved oxygen and biochemical oxygen demand

3.3 Interrelationships Among Nutrients, Dissolved Oxygen, BOD, and COD

Pearson correlation analysis was performed to explore correlations between nutrient enrichment and measures of oxygen quality. The correlation matrix is shown in Table 3. There were positive relationships between a few nutrient variables that were strong. The greatest correlation was between nitrite nitrogen and phosphate ($r = 0.897$, $p < 0.001$), indicating that they have a similar trend. Nitrite nitrogen was also strongly correlated to COD ($r = 0.758$, $p < 0.001$) and phosphate was positively ($r = 0.717$, $p < 0.001$) correlated with COD.

Ammonia nitrogen was moderately correlated with nitrite nitrogen ($r = 0.553$, $p < 0.001$) and COD ($r = 0.505$, $p = 0.002$). Also, nitrate nitrogen was found to have a positive correlation with COD ($r = 0.489$, $p = 0.002$), suggesting that increased nutrient concentrations were generally linked to higher COD.

Table 3. Pearson correlation matrix for nutrient and oxygen-related water-quality variables

Variable	NH3-N	NO2-N	NO3-N	Phosphate	DO	BOD	COD
NH3-N	1.000						
NO2-N	0.553***	1.000					
NO3-N	0.395*	0.433**	1.000				
Phosphate	0.441**	0.897***	0.315	1.000			
DO	0.120	0.118	0.186	0.145	1.000		
BOD	0.287	0.208	0.258	0.218	0.414*	1.000	
COD	0.505**	0.758***	0.489**	0.717***	0.305	0.414*	1.000

Note: NH3-N = ammonia nitrogen; NO2-N = nitrite nitrogen; NO3-N = nitrate nitrogen; DO = dissolved oxygen; BOD = biochemical oxygen demand; COD = chemical oxygen demand. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

The direct relationships of individual nutrient parameters, however, to DO were weak. Nitrogen in the form of nitrate showed a positive weak correlation with DO ($r = 0.186$, $p = 0.277$), whereas ammonia, nitrite and phosphate nitrogen were only weakly correlated with DO ($r = 0.120$, $p = 0.313$; $r = 0.118$, $p = 0.316$; $r = 0.145$, $p = 0.284$, respectively). A poor relationship between nitrate and DO is plotted in Figure 4. The correlation coefficient for the fitted trend was $R^2 = 0.035$ which only accounted for a portion of the variance in dissolved oxygen concentration and suggested that the trend observed in the data was not explained solely by nitrate.

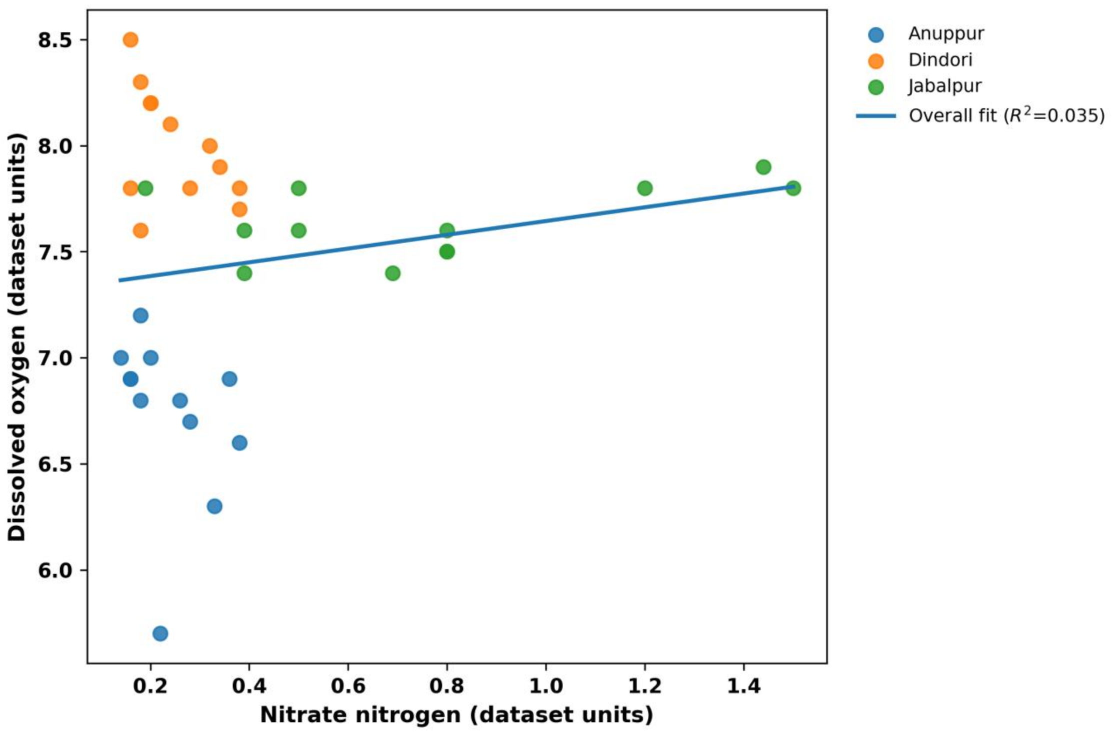

Figure 4. Relationship between nitrate enrichment and dissolved oxygen

Interestingly, DO was moderately and positively correlated with BOD ($r = 0.414$, $p = 0.012$). This result indicates that oxygen conditions in the monitored water system were influenced by multiple interacting spatial and physicochemical factors rather than by a simple inverse nutrient-oxygen relationship.

3.4 Statistical Differences Across Locations and Seasons

As several nutrient variables were highly skewed and showed significant differences in the between-location variance, non-parametric Kruskal-Wallis tests were used to compare the three monitoring locations and three seasonal categories. These results are summarized in the Table 4.

There were statistically significant spatial differences for all nutrients and oxygen-related indicators measured. Ammonia nitrogen differed significantly across locations ($H = 25.351$, $p < 0.001$), as did nitrite nitrogen ($H = 24.817$, $p < 0.001$), nitrate nitrogen ($H = 18.947$, $p < 0.001$), and phosphate ($H = 26.156$, $p < 0.001$). The dissolved oxygen also showed a significant difference among monitoring stations ($H = 27.526$, $p < 0.001$). Significant location effects were additionally observed for BOD ($H = 12.321$, $p = 0.002$) and COD ($H = 17.420$, $p < 0.001$).

Table 4. Kruskal-Wallis tests for spatial and seasonal differences

Parameter	**Location H**	**Location p**	**Season H**	**Season p**
Ammonia nitrogen	25.351	<0.001	0.806	0.668
Nitrite nitrogen	24.817	<0.001	2.077	0.354
Nitrate nitrogen	18.947	<0.001	3.181	0.204
Phosphate	26.156	<0.001	1.693	0.429
Dissolved oxygen	27.526	<0.001	1.788	0.409

BOD	12.321	0.002	0.245	0.884
COD	17.420	<0.001	2.315	0.314

The tested parameters did not show statistically significant seasonal differences (all $p > 0.05$) in contrast. Therefore, the results suggest that spatial location was a significant factor in explaining nutrient enrichment and water quality conditions related to oxygen when compared to the available observations and broad seasonal classification. Overall, the results indicate that nutrient enrichment, especially at Jabalpur, was highly correlated with high COD concentration, while the DO concentration had a more complicated pattern, which did not have a direct relationship with nutrient concentration.

4. Discussion

The results show that there was significant spatial variation within the surface waters in relation to nutrients and oxygen-related parameters. Jabalpur had significantly higher ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, phosphate and COD concentrations in comparison to Anuppur and Dindori, suggesting a high concentration of nutrients and oxidizable pollutants at Jabalpur monitoring site. In similar assessments for eutrophic systems, nutrient increases have been found to be associated with changes in dissolved oxygen, but the relationships vary widely with local environmental conditions (Hanjaniamin et al., 2023).

The large-scale spatial variability of all nutrient and oxygen related variables are consistent with the notion that DO and other water-quality characteristics can differ significantly within connected river networks due to varying pollution pressure, hydrology, channel form and environmental setting (Zhang et al., 2022). Spatial variations in oxygen conditions have also been linked to multi-level hydrological, biogeochemical and anthropogenic controls in complex, highly urbanized river systems instead of a consistent catchment response (Ma et al., 2024). This aligns with the present finding that location had a greater statistical influence on water-quality characteristics than seasonal classification.

There were strong interconnections between nutrient variables. The very high correlation between nitrite N and phosphate suggests that these constituents could be transported along the same channels, could originate from the same pollution sources or be hydrologically controlled. Nutrient enrichment has been found to create significant spatial and temporal variability in oxygen levels in aquatic systems, especially in places where nutrient inputs lead to increased biological production and decomposition of organic matter (Coffin et al., 2021). The temporal and spatial variability of DO patterns within the same aquatic complex is also reflected in long term monitoring (Espinosa-Díaz et al., 2021).

The positive correlations of some of the nutrient parameters with COD are particularly significant. Nitrogen (as nitrite) and phosphorus (as phosphate) had significant positive correlation with COD, and moderate positive correlation with ammonia and nitrate, respectively. This implies enrichment in the monitored system was simultaneously related to an increase in chemically oxidizable material and not as a standalone water quality stress. Similar spatiotemporal studies have revealed very often strong spatial organization of phosphorus and water-quality degradation, with pollutants inputs and catchment processes (Varol, 2020). Nutrient enrichment can also be from a hydrologically connected source that varies among contiguous water bodies, leading to differences in water-quality response (Dunn et al., 2023).

A weak correlation and an R^2 of 0.035 were observed for nitrate nitrogen and dissolved oxygen, compared to other variables. Compared to other variables, nitrate nitrogen had a weak correlation and an R^2 of 0.035 with dissolved oxygen. This means that nitrate is not a reliable indicator of oxygen. STDOs are well recognized to be sensitive both to simultaneous physical and biological controls and to a change of temperature, mixing, respiration, photosynthesis and hydrodynamics (Testa et al., 2024). This weak nitrate-DO relationship does not mean that nutrient enrichment is not ecologically relevant, but rather that oxygen dynamics is a multicausal process.

This positive association between DO-BOD that is observed here also reinforces the fact that oxygen relationships may not be linear when measurements are taken at a variety of sites that contain some variability. Experiments on nutrient reduction have demonstrated that responses to oxygen and pH can be nonlinear and subject to other ecosystem processes (Wang et al., 2024). Oxygen dynamics also show the complex coupling of eutrophication, mixing, climatic variations and ecosystem metabolism in long-term observations (Dordoni et al., 2024).
Although moderate descriptive variations were observed across seasons, the differences were not statistically significant for DO, BOD and COD. These results are reasonable when considering local hydrology and site characteristics are more important than the general categories of season. Changes in hydrology, induced by management actions, can significantly affect oxygen status and eutrophication responses even at the same water body level (Matsuzaki et al., 2023). Further, temperature and flow have been determined as significant river oxygen controls and further consideration of hydrological information in future monitoring is important (Yavuz, 2025). Eutrophic lake studies are also recent examples that show that DO is not only influenced by nutrients, but also by the interplay of ecological and environmental forcings (Zhang et al., 2025).
Taken together, the results suggest that nutrient and pollution control should be the primary focus of sustainable surface-water management, and should be a spatially targeted approach especially where nutrient enrichment and high COD concentrations co-occur. Regular monitoring should incorporate nutrient species, DO, BOD, COD, physicochemical parameters and hydrology in order to consider the interactions of these processes when informing management decisions for surface-water quality.

5. Conclusion

The present analysis shows that there is a close interplay between nutrient enrichment, oxygen dynamics and overall surface-water quality, which are, however, spatially heterogeneous. High concentration of ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, phosphate and COD was seen at Jabalpur with clear differences among the three monitoring locations. These results suggest that the localized nutrient and pollution pressures can have a more pronounced impact on water quality than the seasonal variations. The nutrient variables were also well correlated with each other, especially nitrite nitrogen with phosphate, and some nutrient indicators were positively related with COD. The relationship between nitrate nitrogen and dissolved oxygen (DO) was, in contrast, weak and nitrate only accounted for a small fraction of the variation in DO. This implies that oxygen dynamics are not only related to nutrient concentration, but to a combination of interacting factors. The large spatial variation seen for all major nutrient and oxygen-related variables and the lack of significant seasonal variation further justify the need for site-specific monitoring. Rational overall sustainable surface-water management should focus on the control of pollution at the target area, monitoring nutrient species and other physicochemical variables, and on integrated assessment of hydrological and environmental status. This can help to better identify changing water-quality conditions early and implement better nutrient-rich surface-water system management.

References

1. Burkholder, J. M., Kinder, C. A., Dickey, D. A., Reed, R. E., Arellano, C., James, J. L., et al. (2022). Classic indicators and diel dissolved oxygen versus trend analysis in assessing eutrophication of potable-water reservoirs. Ecological Applications, 32(4), e2541.
2. Chapman, P. J., Kay, P., Mitchell, G., Pitts, C., & Holden, J. (2020). Surface water quality. In Water resources: An integrated approach (pp. 99-150).
3. Chapra, S. C., Camacho, L. A., & McBride, G. B. (2021). Impact of global warming on dissolved oxygen and BOD assimilative capacity of the world's rivers: Modeling analysis. Water, 13(17), 2408.
4. Chen, X., Strokal, M., van Vliet, M. T., Fu, X., Wang, M., Ma, L., & Kroeze, C. (2022). In-stream surface water quality in China: A spatially-explicit modelling approach for nutrients. Journal of Cleaner Production, 334, 130208.
5. Coffin, M. R. S., Knysh, K. M., Roloson, S. D., Pater, C. C., Theriaul, E., Cormier, J. M., et al. (2021). Influence of nutrient enrichment on temporal and spatial dynamics of dissolved oxygen

within northern temperate estuaries. Environmental Monitoring and Assessment, 193(12), 804.
6. Crossman, J., Bussi, G., Whitehead, P. G., Butterfield, D., Lannergard, E., & Futter, M. N. (2021). A new, catchment-scale integrated water quality model of phosphorus, dissolved oxygen, biochemical oxygen demand and phytoplankton: INCA-Phosphorus Ecology (PEco). Water, 13(5), 723.
7. Dilip, M. (2024). Narmatha water quality [Data set]. Kaggle.
8. Dordoni, M., Barth, J. A., & Wassenaar, L. I. (2024). Long-term dynamics of dissolved oxygen and isotopic composition in Lake Erie and Lake Ontario: Implications for eutrophication and ecosystem health. Journal of Great Lakes Research, 50(6), 102447.
9. Dunn, R. P., Krask, J. L., Pinckney, J. L., & Smith, E. M. (2023). Contrasting trends in water quality between adjacent ocean- and river-dominated estuaries: Evidence for marsh porewaters as a source of nutrient enrichment? Limnology and Oceanography, 68(9), 2040-2058.
10. Espinosa-Diaz, L. F., Zapata-Rey, Y. T., Ibarra-Gutierrez, K., & Bernal, C. A. (2021). Spatial and temporal changes of dissolved oxygen in waters of the Pajarales complex, Cienaga Grande de Santa Marta: Two decades of monitoring. Science of the Total Environment, 785, 147203.
11. Hanjaniamin, A. E., Tabrizi, M. S., & Babazadeh, H. (2023). Dissolved oxygen concentration and eutrophication evaluation in Yamchi dam reservoir, Ardabil, Iran. Applied Water Science, 13(1), 9.
12. Hutchins, M. G., Qu, Y., & Charlton, M. B. (2021). Successful modelling of river dissolved oxygen dynamics requires knowledge of stream channel environments. Journal of Hydrology, 603, 126991.
13. Kapsalis, V. C., & Kalavrouziotis, I. K. (2021). Eutrophication-A worldwide water quality issue. In Chemical lake restoration: Technologies, innovations and economic perspectives (pp. 1-21). Springer International Publishing.
14. Khalili, R., & Moridi, A. (2025). A comprehensive review of eutrophication in water resources: From identifying contributing factors to proposing management strategies. Interdisciplinary Journal of Civil Engineering, 1(1), 36-49.
15. Koue, J. (2024). Impact of riverine inputs on nutrient dynamics and water quality in enclosed water bodies. Terrestrial, Atmospheric and Oceanic Sciences, 35(1), 19.
16. Li, H., Zhang, H., Duan, L., Liu, Q., Li, D., Huang, J., et al. (2025). Spatiotemporal variations in water quality parameters and assessment of the current status and challenges of eutrophication in Lake Dian. Ecological Indicators, 177, 113821.
17. Liu, H., Zhang, Y., Lin, Y., & Zhou, X. (2025). A comprehensive review of eutrophication simulation and assessment in surface water: Analysis and visualization. Environment, Development and Sustainability, 1-33.
18. Ma, R., Chen, Z., Wang, B., Xu, C., Jia, Z., Li, L., & Hu, J. (2024). Spatiotemporal variations and controlling mechanism of low dissolved oxygen in a highly urbanized complex river system. Journal of Hydrology: Regional Studies, 52, 101691.
19. Matsuzaki, S. I. S., Kohzu, A., Tsuchiya, K., Shinohara, R., Nakagawa, M., Fukumori, K., et al. (2023). Water-level drawdowns can improve surface water quality and alleviate bottom hypoxia in shallow, eutrophic water bodies. Freshwater Biology, 68(2), 229-244.
20. Menberu, Z., Mogesse, B., & Reddythota, D. (2021). Evaluation of water quality and eutrophication status of Hawassa Lake based on different water quality indices. Applied Water Science, 11(3), 61.
21. Testa, J. M., Liu, W., Boynton, W. R., Breitburg, D., Friedrichs, C., Li, M., et al. (2024). Physical and biological controls on short-term variations in dissolved oxygen in shallow waters of a large temperate estuary. Estuaries and Coasts, 47(6), 1456-1474.
22. Varol, M. (2020). Spatio-temporal changes in surface water quality and sediment phosphorus content of a large reservoir in Turkey. Environmental Pollution, 259, 113860.
23. Wang, H., Codiga, D. L., Stoffel, H., Oviatt, C., Huizenga, K., & Grear, J. (2024). Effect of nutrient reductions on dissolved oxygen and pH: A case study of Narragansett Bay. Frontiers in Marine Science, 11, 1374873.
24. Wang, J., & Zhang, Z. (2020). Phytoplankton, dissolved oxygen and nutrient patterns along a

eutrophic river-estuary continuum: Observation and modeling. Journal of Environmental Management, 261, 110233.
25. Yavuz, V. S. (2025). Impact of temperature and flow rate on oxygen dynamics and water quality in major Turkish rivers. Scientific Reports, 15(1), 22830.
26. Zhang, F., Shi, X., Zhao, S., Arvola, L., Sun, B., Hao, R., et al. (2025). Dissolved oxygen dynamics in a shallow eutrophic lake: Quantify critical eco-environmental effects. Ecological Indicators, 179, 114190.
27. Zhang, W., Rong, N., Jin, X., Meng, X., Han, S., Zhang, D., & Shan, B. (2022). Dissolved oxygen variation in the North China Plain river network region over 2011-2020 and the influencing factors. Chemosphere, 287, 132354.