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# Multivariate Assessment of Gomaspan Reservoir Water Quality in Erbil, Iraqi Kurdistan Region

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## Abstract

Reservoir water quality in semi-arid catchments is shaped by short, intense runoff pulses and early impoundment effects. This study uses a mix of physicochemical and biological water quality measures to assess the water quality of the Gomaspan reservoir monthly using statistical analyses, including two-way ANOVA (Month, Site), Pearson correlations, PCA, and Bray–Curtis cluster analysis. Over the course of four months (November 2024 to February 2025), measurements were made of thirteen important water quality parameters at nine sample locations. These included air and water temperature, pH, EC, TDS, TSS, turbidity, $BOD_5$, DO, TN, TP, MPN, and chlorophyll-a. To evaluate pollution levels and establish a baseline for further monitoring, data were compared to WHO criteria. Good water quality was indicated by the Water Pollution Index (WPI) value of 0.52. Significant temporal and spatial variation were found in a number of factors using two-way ANOVA, most notably in temperature, microbial load, and nutrient content. PCA (first four PCs) explained 78.66% of the variance. Two-way ANOVA detected significant month and site effects ($p < 0.05$) for temperature, nutrients (TN, TP), and biological indicators (MPN, Chl-a). By grouping stations according to similarities in water quality, cluster analysis highlighted regional sources of contamination. For the sampled window only (Nov–Feb), most parameters met WHO guideline values, but pronounced temporal and site-specific variability indicates the need for a dry-season campaign (Mar–Sep) to characterize the full hydrological year.

## 1. Introduction:

Understanding spatial and temporal variations in river water quality and quantitatively evaluating the trend of changes are important to study and efficiently manage water resources [1]. The reservoir plays a crucial role in the local water supply system, which is mostly dependent on groundwater supplies and surface water from the Greater Zab River and its tributaries [2] [3]. These water resources must be managed effectively, particularly in light of urgent problems with water quality brought on by local industrialization, urbanization, and agricultural practices [4].

According to recent research, several anthropogenic causes, including the discharge of wastewater from homes and businesses, affect the quality of the water from the Gomaspan Reservoir, endangering both environmental sustainability and public health [5]. For example, untreated wastewater has been strongly connected to Erbil City's declining groundwater quality, indicating a serious pollution problem that has to be addressed right away. Understanding the complex dynamics of water quality parameters such as turbidity, pH, total dissolved solids (TDS), and the presence of heavy metals is critical for assessing environmental health [6].

Cumulative inputs from municipal wastewater and other waste discharges into connected streams and basins have resulted in generally polluted waters, as evidenced by widespread algal occurrences across rivers [7].

In addition to the direct impacts from water management practices, the Gomaspan reservoir itself poses unique challenges in water quality monitoring and assessment. Computational modeling techniques, such as Computational Fluid Dynamics (CFD), have begun to be used to analyze the reservoir's structural integrity and its effectiveness in managing potential cavitation, which can affect downstream water quality [8].

These approaches help comprehend the interrelatedness of reservoir operations and the necessary environmental standards to maintain water quality. The need for safe and clean water will increase as Erbil's population grows; hence, it is crucial to conduct continuous studies on the Gomaspan reservoir's water quality in order to inform future water management strategies. In order to improve water quality standards and ultimately ensure sustainable development in line with global water preservation goals, these studies highlight the necessity of a multifaceted strategy that integrates technological advancements, community engagement, and regulatory frameworks [3]. Essentially, data-driven evaluations that represent the current state of the water quality at the Gomaspan reservoir should be continuously incorporated into any future research or intervention in order to support well-informed decision-making. For instance, the interplay between temperature and parameters like BOD exhibits seasonal dependency, with a good correlation between temperature and BOD found in winter, indicating a temperature's influence on biological activity in that season [9], [10].

Furthermore, there's a noted lack of prior research on the water quality of specific bodies of water, such as the Gomaspan impoundment. Addressing this gap would involve applying comprehensive multivariate statistical techniques to evaluate seasonal variations, identify temporal and spatial patterns, and understand the similarities or dissimilarities between sampling sites within the reservoir [11]. Future studies should also aim to refine WQI parameter selection through expert judgment and statistical analysis, ensuring the index is both comprehensive and practical for specific regional needs. This would allow for a more accurate and context-specific assessment of water quality [8]. In the case of Gomaspan reservoir, which began operation in late 2024, an early assessment of its water quality provides valuable baseline data against which future changes can be measured. It also helps identify any immediate concerns, such as runoff pollution from the catchment or initial ecosystem responses, so that management strategies can be implemented proactively. Therefore, this study aims to investigate the monthly (temporal) variations of water quality parameters during the early wet-season window (November 2024–February 2025) and to assess water-pollution levels in the Gomaspan reservoir; the findings provide baseline information shortly after impoundment began and are not intended to represent the full hydrological year.

## 2. Material and Methods:

### 2.1 Study area:

Gomaspan Reservoir lies 30 km in the Erbil region of the Iraqi Kurdistan Region (Figure 1). The catchment is characterized by ephemeral/seasonal inflows responding to early wet-season rainfall covering approximately 132.5 km$^2$. The monitoring network comprised nine stations (S1–S9) distributed to represent inflow-proximal waters, mid-reservoir pelagic areas, near-dam/outlet conditions, and shorelines influenced by nearby settlements or agriculture. Station coordinates and elevation (m.a.s.l.) are listed in Table 3. The water body shows significant topographic variation, with elevations ranging from 800 m above sea level at the reservoir location to approximately 1900 m above sea level in the northern highland areas [12]. The reservoir site is characterized by precipitation levels between 300–400 mm annually according to Riksen, Ritsema analysis, whereas the upper part of the catchment area receives substantially higher precipitation, averaging approximately 1000 mm per year [13]. Based on meteorological data from Shaqlawa weather station spanning 15 years (1991-1992 to 2010-2011), the mean annual rainfall depth across the Gomaspan reservoir catchment area was recorded as 795.7 mm [12].

**Table 1.** Geographical location of the sampling stations.

| ID | Station | Latitude Degree | Longitude Degree | Elevation (m.a.s.l) |
|---|---|---|---|---|
| 1 | S1 | 36.28082166 | 44.3339395 | 820 |
| 2 | S2 | 36.28287378 | 44.3358287 | 820 |
| 3 | S3 | 36.28757169 | 44.3330642 | 824 |
| 4 | S4 | 36.28778335 | 44.3383817 | 821 |
| 5 | S5 | 36.28300314 | 44.3408544 | 823 |
| 6 | S6 | 36.28233871 | 44.3463835 | 824 |
| 7 | S7 | 36.27890687 | 44.3490784 | 819 |
| 8 | S8 | 36.28049759 | 44.3393443 | 814 |
| 9 | S9 | 36.27809896 | 44.3330722 | 806 |

### 2.2 Study Design and Sampling Process:

Sampling followed a monthly monitoring design across four consecutive months (Nov-Feb) shortly after the first impoundment. The dataset provides an early wet-season baseline and is not a full seasonal survey of the hydrological year. A total of 9 sampling stations were selected to fulfill the purpose of the study, and they were stratified by hydraulic function and pressure gradients (i) inflow-proximal (tributary mouth), (ii) mid-reservoir pelagic sites, (iii) near-dam/outlet zone, and

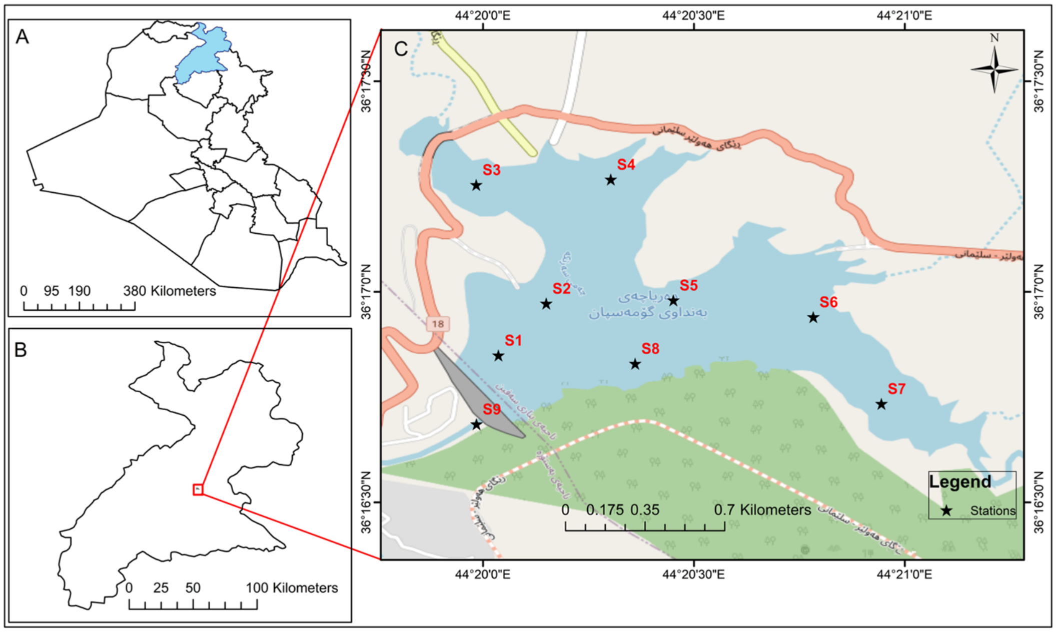


**Figure 1.** The map shows, A) Iraq; B) Erbil Governorate; and C) the study area with sampling stations.

(iv) near-shore areas influenced by settlements or agriculture. Additional criteria included access/safety and representativeness of the sub-catchment land use. Water samples were collected for four consecutive months (November 2024, December 2024, January 2025, and February 2025). Water parameters like water temperature, air temperature, EC, TDS, pH and DO were instantly noted on the field whereas other parameters like biological oxygen demand ($BOD_5$), total nitrogen (TN), total phosphorus (TP), TSS, Turbidity, Chlorophyll-a (Chl-a), most probable number (MPN) were determined in the laboratory (Table 2). The water samples were collected in 1-liter polyethylene bottles (LDPE) and then immediately transported to the laboratory, preserved in the refrigerator until the sample analysis. TP and TN were quantified by colorimetry; $BOD_5$ by 5-day incubation; MPN by membrane filtration with selective media; Chl-a by acetone extraction and spectrophotometry; major cations ($Na^+$, $K^+$, $Mg^{2+}$, $Ca^{2+}$) by standard ICP procedure [13].

**Table 2.** Geographical location of the sampling stations.

| ID | Parameter | Abbreviation | Unit |
|---|---|---|---|
| 1 | pH | pH | pH unit |
| 2 | Electrical Conductivity | EC | $\mu$S cm$^{-1}$ |
| 3 | Total Dissolved Solids | TDS | ppm |
| 4 | Air Temperature | Air T. | $^o$C |
| 5 | Water Temperature | Water T. | $^o$C |
| 6 | Dissolved Oxygen | DO | ppm |
| 7 | 5-day BOD | $BOD_5$ | ppm |
| 8 | Total Suspended Solids | TSS | ppm |
| 9 | Turbidity | Turb | NTU |
| 10 | Total Phosphate | TP | ppm |
| 11 | Total Nitrogen | TN | ppm |
| 12 | Most Probable Number | MPN | Index /1 mL |
| 13 | Chlorophyll a | Chl-a | mg m$^{-3}$ |

### 2.3 Water Pollution Index (WPI):

WPI was calculated using Equations 1 and 2, and the methodology is described by Hossain and Patra (14). In accordance with WHO guidelines (2022), EC, TDS, pH, $Ca^{2+}$, $Mg^{2+}$, $K^+$, and $Na^+$ were chosen and utilized to compute WPI. WHO has specified certain parameters and threshold levels for the protection of aquatic ecosystems, which are in line with the main ecological purpose of reservoir waters. The following formula was used in the first phase to determine the pollutant load (PLi) of ith parameter [14]:

$$PLi = \frac{Ci - 7}{Sib - 7)} \quad (1)$$

where Sib is the standard or maximum allowable limit for the corresponding parameter, and Ci is the observed concentration of ith parameter. The following formula [14] illustrates how to calculate the WPI, which has n variables (parameters), by adding up all of the pollutant loads and then dividing by n.

$$WPI = \frac{1}{n}\sum_{i=1}^{n} PLi \quad (2)$$

The resultant WPI values were categorized into four distinct pollution status classifications: highly polluted (>1), moderately polluted (0.75–1), good water quality (0.5–0.75), and excellent water quality (<0.5), providing a systematic framework for water quality characterization and environmental assessment.

### 2.4 Statistical Analysis:

All statistical analysis for this study was carried out using MS-Excel 2019 and R (v. 4.5.1). Descriptive statistics were reported as means and standard deviations. Two-way ANOVA was used to determine any significant difference between the means of water parameters between months and sampling stations. Individual PCA was applied to reduce the dimension of water parameters, where a dendrogram was used to look at the connection between sampling stations. Normality and homogeneity were checked (Levene) before data analyses. The study area map was created using ArcGIS 10.1.

## 3. Results and Discussion:

### 3.1 Descriptive statistics and two-way ANOVA:

The spatiotemporal fluctuation of several physicochemical and biological water quality indicators during four sample months (November 2024 to February 2025) (Figure 2) across nine stations (S1–S9) (Figure 3) in Gomaspan reservoir catchment was assessed using a two-way ANOVA (Table **??**). pH, DO, $BOD_5$, TDS, TSS, EC, TN, TP, chl-a, turbidity, MPN index, and air and water temperatures were among the parameters that were tested. There were statistically significant variations in air and water temperatures between sites and months ($p < 0.05$). November 2024 saw the greatest air temperature at S2 ($25\pm0.088^{o}$C), while February 2025 saw the lowest at S1 ($12.6\pm0.058^{o}$C). The water temperature showed a similar seasonal tendency, peaking in November and then declining in January and February. Although they varied significantly each month ($p = 1.1 \times 10^{-10}$), pH values were largely consistent among stations. From November to February, the pH steadily dropped, going from neutral to slightly alkaline in November (peaking at S9: $9.86\pm0.033$) to more acidic values in February (falling to S4: $7.36\pm0.012$).

DO levels did not change spatially, but they did change considerably with time ($p = 1.50 \times 10^{-08}$). November saw higher DO concentrations, which then decreased as February approached. $BOD_5$ concentrations, on the other hand, showed significant temporal variations ($p = 2.10 \times 10^{-10}$), peaking in November (S3: $485\pm1.453$ ppm) and falling in February (S3: $302\pm1.202$ ppm), indicating a greater rate of organic load decomposition as temperatures dropped. There were notable variations in EC and TDS between sites and months ($p < 0.001$). TDS sharply decreased in February after reaching a peak in November, particularly at S3 ($485\pm1.453$ ppm). Similar trends were seen in EC, which peaked in November (e.g., S3: $1.9\pm0.088$ $\mu$S/cm) and fell in February. Both spatial and temporal changes had a substantial impact on the concentrations of TN and TP ($p < 0.01$). January and February had the greatest TN levels, especially at S9 ($2.77\pm0.009$ ppm in January). In November and February, respectively, TP displayed large increases at S3 and S7 ($23.3\pm0.115$ and $5.85\pm0.009$ ppm), suggesting possible eutrophic conditions.

As a stand-in for phytoplankton biomass, chl-a showed significant spatial and temporal variability ($p = 2.10 \times 10^{-11}$). In November, elevated amounts ($23.3\pm0.115$ mg/m$^3$) were observed at S3, which is consistent with increased nutritional availability, especially for TP. There were notable monthly and station-based fluctuations in both turbidity and TSS. TSS peaked in November at S3 ($1.064\pm0.004$ ppm), while turbidity peaked in February at S4 and S8 ($8.554\pm0.003$ and $9.623\pm0.034$ NTU, respectively). These results suggest that in some months there may be sediment resuspension or influx. There were notable differences in the Most Probable Number (MPN) index between stations and months ($p = 1.30 \times 10^{-11}$). The highest microbiological loads, 11 MPN/mL and 13.9 MPN/mL, respectively, were recorded at S1 and S7 in February and November, indicating localized sources of fecal contamination.

**Table 3.** Number and percentages of Proteus spp in different clinical samples.

| | | Stations in Gomaspan Reservoir | | | | | | | | | P-value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Parameters | Months | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | p-station x months p-months p-station |
| Air T. | November-24 | 24± 0.12Aa | 25± 0.088Ba | 24± 0.12Aa | 22± 0.145Ca | 22± 0.153Ca | 24± 0.145Aa | 20± 0.24Da | 23± 0.233Ea | 24± 0.067Aa | 2.00E-16 |
| Air T. | December-24 | 19± 0.24Ab | 14± 0.252Bb | 3± 0.088Cb | 7± 0.231Db | 8.5± 0.153Eb | 6± 0.033Fb | 6± 0.167Jb | 14± 0.145Bb | 7± 0.058Jb | 2x10-5 |
| Air T. | January-25 | 6.7± 0.145Ac | 5.5± 0.12Bc | 5± 0.067Bc | 4.4± 0.145Bc | 5.2± 0.033Bc | 6.1± 0.088Ab | 10.3± 0.088Cc | 10.6± 0.115Cc | 11.6± 0.088Dc | 0.001 |
| Air T. | February-25 | 12.6± 0.058Ad | 8.9± 0.088Bd | 5.8± 0.145Cd | 6± 0.088Cd | 5.9± 0.088Cd | 5.1± 0.058Cc | 7.3± 0.058Db | 5.6± 0.033Cd | 8.6± 0.058Bd | |
| Water T. | November-24 | 16.5± 0.088Aa | 16.3± 0.153Aa | 13.7± 0.088Ba | 16.5± 0.088Aa | 17.2± 0.115Aa | 17.1± 0.058Aa | 16.4± 0.26Aa | 15.6± 0.186Aa | 16.1± 0.12Aa | 2.00E-03 |
| Water T. | December-24 | 11.1± 0.252Ab | 10.4± 0.12Bb | 7.1± 0.088Cb | 10.1± 0.153Bb | 11.6± 0.219Ab | 11.3± 0.233Ab | 11.4± 0.115Ab | 11.3± 0.088Ab | 7.8± 0.088Db | 0.011 |
| Water T. | January-25 | 6.8± 0.058Ac | 6.8± 0.088Ac | 4.8± 0.058Bc | 6.8± 0.115Ac | 6.5± 0.088Ac | 6.8± 0.115Ac | 8.7± 0.173Cc | 8.1± 0.12Dc | 7.7± 0.145Db | 0.7 |
| Water T. | February-25 | 9.5± 0.058Ad | 7.5± 0.088Bc | 5.9± 0.033Cd | 7.3± 0.153Bc | 7.1± 0.145Bd | 6± 0.12Cd | 7.5± 0.067Bd | 6.1± 0.145Cd | 6.5± 0.067Cc | |
| EC | November-24 | 820± 2.963Aa | 734± 1.202Ba | 768± 0.882Ca | 737± 0.882Ba | 759± 0.882Ca | 752± 0.882Ca | 745± 1.155Ca | 765± 1.202Ca | 666± 0.882Da | 2.00E-09 |
| EC | December-24 | 735± 1.202Ab | 743± 1.155Aa | 732± 0.882Ab | 746± 0.882Ab | 726± 1.155Ab | 745± 1.453Aa | 737± 1.453Aa | 721± 2.517Ab | 1084± 3.215Bb | 1.15E-06 |
| EC | January-25 | 673± 1.764Ac | 647± 1.453Bb | 619± 1.856Cc | 655± 2.887Bc | 646± 2.028Bc | 651± 1.764Bb | 651± 2.517Bb | 654± 1.856Bc | 901± 1.764Da | 4.61E-08 |

| | | Stations in Gomaspan Reservoir | | | | | | | | | P-value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Parameters | Months | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | p-station x months p-months p-station |
| EC | February-25 | 665± 1.155Ac | 657± 2.028Ac | 605± 1.856Bd | 650± 1.528Ac | 661± 1.528Ad | 654± 1.453Ab | 655± 1.528Ab | 658± 1.528Ac | 831± 2.646Cd | |
| pH | November-24 | 8.25± 0.015Aa | 8.19± 0.009Aa | 8.26± 0.009A | 8.23± 0.009Aa | 8.2± 0.01Aa | 8.23± 0.023Aa | 8.17± 0.018Aa | 8.13± 0.015Aa | 9.86± 0.033Ba | 2.00E-16 |
| pH | December-24 | 8.35± 0.022Aa | 8.27± 0.023Aa | 8.46± 0.026A | 8.3± 0.019Aa | 8.23± 0.012Aa | 8.28± 0.006Aa | 8.29± 0.006Aa | 8.23± 0.006Aa | 8.27± 0.015Ab | 1.10E-10 |
| pH | January-25 | 7.67± 0.012Ab | 7.65± 0.117Ab | 7.54± 0.057Ab | 7.51± 0.037Ab | 7.47± 0.131Ab | 7.44± 0.018Ab | 7.45± 0.012Ab | 7.47± 0.018Ab | 7.49± 0.015Ac | 0.538 |
| pH | February-25 | 7.43± 0.015Ac | 7.52± 0.023Ab | 7.48± 0.021Ab | 7.36± 0.012Ab | 7.43± 0.022Ab | 7.54± 0.018Ab | 7.51± 0.02Ab | 7.44± 0.015Ab | 7.45± 0.02Ac | |
| DO | November-24 | 7.4± 0.145Aa | 7.23± 0.012Aa | 7.91± 0.028Ba | 7.3± 0.067Aa | 7.22± 0.048Aa | 7.25± 0.026Aa | 7.77± 0.009Ba | 6.48± 0.012a | 7.62± 0.024Ba | 1.50E-08 |
| DO | December-24 | 6.97± 0.046Aa | 6.68± 0.003Bb | 8.87± 0.115Cb | 6.41± 0.033Bb | 7.04± 0.015Aa | 6.77± 0.037Ab | 7.43± 0.022Da | 6.85± 0.051Aa | 9.35± 0.044Eb | 1.12E-05 |
| DO | January-25 | 7.22± 0.006Aa | 6.78± 0.07Bb | 7.55± 0.02Ac | 7.12± 0.102Aa | 7.14± 0.185Aa | 7.33± 0.033Aa | 7.56± 0.02Aa | 6.89± 0.026Ba | 8.22± 0.072Cc | 0.128 |
| DO | February-25 | 4.96± 0.059Ab | 5.11± 0.047Ac | 5.22± 0.031Ad | 5.18± 0.021Ac | 5.09± 0.029Ab | 5.3± 0.035Ac | 5.02± 0.029Ab | 5.49± 0.029Bb | 4.99± 0.035Ad | |
| TDS | November-24 | 416± 0.577Aa | 369± 2.028Ba | 485± 1.453Ca | 363± 0.882Ba | 381± 2.028Da | 375± 2.082Ba | 370± 1.202Ba | 385± 1.202Da | 325± 1.453Ea | 2.10E-10 |
| TDS | December-24 | 367± 1.155Ab | 370± 0.577Aa | 365± 1.856Ab | 372± 2.603Ab | 362± 2.082Ab | 373± 1.764Aa | 366± 1.155Aa | 364± 2.333Ab | 537± 1.856Bb | 8.30E-07 |

| | | Stations in Gomaspan Reservoir | | | | | | | | | P-value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Parameters | Months | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | p-station x months p-months p-station |
| TDS | January-25 | 337± 1.528Ac | 321± 1.764Bb | 313± 1.202Cc | 328± 2.309Bc | 323± 0.882Bc | 325± 1.528Bb | 325± 1.732Bb | 327± 1.856Bc | 448± 1.155Dc | 5.27E-05 |
| TDS | February-25 | 332± 1.202Ac | 331± 1.856Ac | 302± 1.202Bc | 327± 1.155Ac | 330± 1.155Ad | 328± 0.882Ab | 325± 1.528Ab | 330± 0.882Ac | 415± 1.764Cd | |
| BOD5 | November-24 | 1.35± 0.019Aa | 2.01± 0.012Ba | 1.9± 0.088Ca | 1.59± 0.006Da | 1.55± 0.006Da | 1.13± 0.003Ea | 2.51± 0.012Fa | 1.39± 0.006Aa | 1.98± 0.006Ba | 1.80E-12 |
| BOD5 | December-24 | 0.72± 0.009Ab | 1.03± 0.006Bb | 2.58± 0.015Cb | 0.78± 0.009Ab | 1.04± 0.009Bb | 0.26± 0.012Db | 0.51± 0.012Eb | 0.02± 0.003Fb | 2.53± 0.009Cb | 0.0001 |
| BOD5 | January-25 | 1.7± 0.012Ac | 1.65± 0.012Ac | 2.03± 0.006Bc | 1.8± 0.012Ac | 1.41± 0.009Cc | 2.13± 0.012Dc | 1.78± 0.012Ac | 2.03± 0.009Bc | 2.77± 0.009Ec | 0.03 |
| BOD5 | February-25 | 0.16± 0.012Ad | 0.33± 0.009Bd | 0.31± 0.012Bd | 0.35± 0.012Bd | 0.609± 0.009Cd | 0.37± 0.015Bb | 0.88± 0.006Dd | 0.15± 0.006Ad | 0.14± 0.012Ad | |
| TSS | November-24 | 0.012± 0.001Aa | 0.004± 0.001Aa | 0.009± 0.001Aa | 0.005± 0.001Aa | 0.002± 0.001Aa | 0.003± 0.001Aa | 0.007± 0.001Aa | 0.004± 0001Aa | 0.011± 0.001Aa | 0.55 |
| TSS | December-24 | 0.023± 0.001Ab | 0.017± 0.001Aa | 0.021± 0Aa | 0.014± 0.001Aa | 0.017± 0.001Aa | 0.018± 0.001Aa | 0.01± 0.006Aa | 0.012± 0.001Aa | 0.004± 0.001Aa | 0.0002 |
| TSS | January-25 | 0.004± 0bAa | 0.001± 0.001Aa | 0.0035± 00.001Aa | 0.006± 0.001Aa | 0.004± 0.001Aa | 0.003± 0.001Aa | 0.04± 002Ab7 | 0.004± 0.001Aa | 0.004± 0.001Aa | 0.316 |
| TSS | February-25 | 0.021± 0.073Ab | 0.013± 0.001Aa | 0.016± 0.001Aa | 0.018± 0.001Aa | 0.02± 0.009Aa | 0.023± 0.001Aa | 0.029± 0.004Aa | 0.037± 0.001Aa | 0.021± 0.001Aa | |
| Turbidity | November-24 | 9.59± 0.015Aa | 5.28± 0.012Ba | 23.3± 0.115Ca | 4.87± 0.022Da | 3.65± 0.026Ea | 2.85± 0.015Fa | 11.69± 0.023Ga | 2.7± 0.115Fa | 12.83± 0.021Ha | 2.10E-11 |

| | | Stations in Gomaspan Reservoir | | | | | | | | | P-value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Parameters | Months | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | p-station x months p-months p-station |
| Turbidity | December-24 | 1.98± 0.022Ab | 1.69± 0.007Ab | 9.88± 0.015Bb | 2.62± 0.023Cb | 1.53± 0.015Ab | 1.66± 0.015Ab | 3.69± 0.009Db | 1.39± 0.009Ab | 0.98± 0.038Eb | 2.19E-09 |
| Turbidity | January-25 | 1.48± 0.009Ac | 1.52± 0.012Ab | 3.61± 0.017Bc | 1.55± 0.012Ac | 1.73± 0.012Ab | 1.31± 0.018Ab | 2.53± 0.018Cc | 1.25± 0.015Ab | 0.7± 0.088Dc | 1.97E-07 |
| Turbidity | February-25 | 1.59± 0.012Ac | 1.37± 0.015Ab | 7.32± 0.019Bd | 2.14± 0.006Cd | 2.08± 0.012Cc | 2.12± 0.003Cc | 5.85± 0.009Dd | 6.56± 0.342Dc | 2.91± 0.012Ed | |
| TP | November-24 | 0.22± 0.006Aa | 0.12± 0.009Aa | 0.31± 0.018Aa | 0.1± 0.29Aa | 0.08± 0.006Aa | 0.1± 0.007Aa | 0.27± 0.012Aa | 0.17± 0.006Aa | 0.18± 0.009Aa | 1.13E-04 |
| TP | December-24 | 0.06± 0.006Aa | 0.04± 0.009Aa | 0.16± 0.015Aa | 0.06± 0.012Aa | 0.02± 0.018Aa | 0.01± 0.015Aa | 0.07± 0.006Aa | 0.02± 0.009Aa | 0.04± 0.009Aa | 0.0004 |
| TP | January-25 | 0.08± 0.019Aa | 0.06± 0.015Aa | 0.1± 0.145Aa | 0.075± 0.002Aa | 0.07± 0.001Aa | 0.07± 0.003Aa | 0.06± 0.002Aa | 0.09± 0.001Aa | 0.07± 0.006Aa | 0.07 |
| TP | February-25 | 0.05± 0.012Aa | 0.05± 0.012Aa | 0.1± 0.018Aa | 0.06± 0.003Aa | 0.2± 0.017Aa | 0.05± 0.009Aa | 0.12± 0.015Aa | 0.16± 0.012Aa | 0.08± 0.245Aa | |
| TN | November-24 | 1.381± 0.009Aa | 1.525± 0.018Aa | 1.499± 0.004Aa | 1.606± 0.002Aa | 1.241± 0.089Aa | 1.63± 0.022Aa | 1.016± 0.001Ba | 1.346± 0.001Aa | 1.301± 0.004Aa | 1.50E-10 |
| TN | December-24 | 2.649± 0.021Ab | 2.006± 0.001Bb | 2.635± 0.002Ab | 2.571± 0.002Ab | 2.606± 0.032Ab | 3.957± 0.07Cb | 2.487± 0.011Db | 2.459± 0.003Db | 2.113± 0.002Bb | 1.10E-08 |
| TN | January-25 | 2.607± 0.003Ab | 2.703± 0.002Ac | 2.658± 0.003Ab | 2.675± 0.003Ab | 2.569± 0.006Ab | 2.597± 0.007Aa | 2.63± 0.018Ab | 2.557± 0.015Ab | 2.52± 0.038Ac | 0.37 |
| TN | February-25 | 2.215± 0.003Ac | 2.563± 0.006Bd | 2.568± 0.015Bb | 2.383± 0.008Bc | 2.702± 0.004bCc | 2.792± 0.004Cd | 2.529± 0.01Bb | 2.835± 0.006Cc | 2.485± 0.005Bc | |

| | | Stations in Gomaspan Reservoir | | | | | | | | | P-value |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Parameters | Months | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | p-station x months p-months p-station |
| Chlorophyll | November-24 | 0.535± 0.032Aa | 0.214± 0.023Ba | 1.064± 0.004Ca | 11.761± 0.058Da | 1.069± 0.008Ca | 2.031± 0.007Ea | 13.9± 0.057Fa | 13.9± 0.027Fa | 11.761± 0.023Da | 2.10E-10 |
| Chlorophyll | December-24 | 1.069± 0.004Ab | 1.068± 0.003Ab | 1.068± 0.004Aa | 2.138± 0.006Bb | 1.069± 0.001Aa | 1.065± 0.003Ab | 3.208± 0.001Cb | 1.069± 0.001Ab | 1.064± 0.003Ab | 1.77E-06 |
| Chlorophyll | January-25 | 1.069± 0.004Ab | 1.064± 0.182Ab | 1.069± 0.004Aa | 3.208± 0.001Bc | 2.138± 0.002Cb | 1.066± 0.003Ab | 2.134± 0.006Cc | 1.069± 0.003Ac | 1.069± 0.002Ab | 1.71E-06 |
| Chlorophyll | February-25 | 0.107± 0.005Ac | 1.066± 0.003Bb | 4.277± 0.02Cb | 8.554± 0.003Dd | 4.277± 0.003Cc | 1.069± 0.001Bb | 2.136± 0.005Ec | 9.623± 0.034Fd | 1.067± 0.004Bb | |
| MPN Index | November-24 | 1.5± 0.115Aa | 0.16± 0.029Ba | 0.29± 0.027Ba | 0.29± 0.044Ba | 0.29± 0.026Ba | 0.21± 0.02Ba | 0.03± 0.0Ca | 0.11± 0.017Ba | 0.03± 0.0Ca | 1.30E-11 |
| MPN Index | December-24 | 0.43±0.026Aa | 0.43± 0.018Aa | 2.4± 0.153Bb | 0.43± 0.012Aa | 2.4± 0.088Bb | 0.094± 0.002Aa | 4.6± 0.088Cb | 0.93± 0.023Aa | 0.23± 0.02Ab | 1.22E-05 |
| MPN Index | January-25 | 0.29± 0.015Aa | 0.36± 0.006Aa | 0.75± 0.024Aa | 0.43± 0.006Aa | 0.29± 0.015Aa | 2.4± 0.145Bb | 0.75± 0.018Ac | 1.2± 0.12Aa | 0.75± 0.012Ab | 0.0008 |
| MPN Index | February-25 | 11± 0.882Ab | 2.1± 0.145Bb | 0.36± 0.009Ca | 0.35± 0.022Ca | 0.11± 0.012Ca | 2.9± 0.088Bb | 11± 0.667Ad | 2.9± 0.208Bb | 0.35± 0.015Cb | |

Note 1. Differences among the stations displayed by capital letters in the same rows are significant.
Note 2. Differences among the months displayed by lower-case letters in the same columns are significant.

The temporal variations in water temperature align with typical seasonal trends observed in aquatic systems globally, where increasing temperatures in late fall and early winter typically decrease during the transition into early spring [15]. The significant fluctuations recorded in this study from November (25±0.088$^o$C at S2) to February (12.6±0.058$^o$C at S1) confirmed the influence of seasonal climatic changes on thermal patterns in freshwater bodies [16].

This temperature variation has subsequent repercussions on DO levels, as higher temperatures are generally correlated with lower oxygen solubility, creating potential hypoxic conditions in deeper or stratified water layers during colder months, particularly relevant given the observed decline in DO concentrations over this observation period [15]. The changes in pH from slightly alkaline conditions in November to more acidic environments in February are critical benchmarks that could indicate shifts towards eutrophic scenarios in the reservoir. Similar findings have emerged in other water quality assessments, where anthropogenic influences, along with seasonal variability, have been shown to correlate with pH alterations [17]. The observed dynamics in $BOD_5$ levels, peaking in November (485±1.453 ppm at S3) and decreasing in February (302±1.202 ppm at S3), speak to organic load decomposition processes that are influenced by environmental temperatures. This is reflective of patterns described in other studies, indicating a direct relationship between microbial activity and temperature, which can significantly alter organic matter breakdown mechanisms within aquatic systems [16], [18].

In terms of nutrient levels, TN and TP exhibited significant temporal and spatial fluctuations, with their highest concentrations indicating a shift towards potentially eutrophic conditions at various sampling stations. Specifically, TN levels peaked at S9 in January (2.77±0.009 ppm), while TP concentrations indicated spikes at S3 and S7 during November and February, respectively [17]. Chl-a concentrations serving as indicators for phytoplankton biomass displayed remarkable variability throughout the sampling months, with the highest levels recorded at S3 in November (23.3±0.115 mg/m$^3$). Such findings highlight the dependency of phytoplankton biomass on nutrient availability, particularly phosphorus, as discussed in numerous aquatic studies focusing on habitat productivity [19]. Turbidity and TSS measures similarly demonstrated substantial monthly and spatial fluctuations, indicating the pronounced influence of seasonal changes on sediment dynamics–potentially indicative of sediment resuspension events or stormwater runoff during periods of rainfall [20], [21]. The spikes recorded in turbidity at S4 and S8 during February suggest that monitoring sediment transport processes is essential for assessing water quality, especially in the context of maintaining acceptable conditions for aquatic life and drinking water uses [18]. The bacteriological assessment through the MPN index highlighted concerning trends in fecal contamination at S1 and S7, with values reaching 11 and 13.9 MPN/mL in February and November, respectively. These microbiological loads are alarming, pointing towards localized pollution sources that necessitate immediate attention to mitigate public health risks [22].

### 3.2 Correlations:

The correlation matrices analysis identified multiple significant relationships among the water quality parameters at Gomaspan reservoir catchment (Figure 4). EC showed a strong positive correlation with TDS (r = 0.97), signifying that ionic concentration is a principal factor influencing conductivity in the system. Moderate positive correlations were noted between EC and pH (r = 0.54), as well as between pH and DO (r = 0.46), indicating that elevated pH levels may correlate with enhanced oxygenation. DO demonstrated a strong positive correlation with $BOD_5$ (r = 0.80), presumably attributable to heightened microbial activity during the breakdown of organic waste. TSS exhibited a significant negative correlation with DO (r = –0.52) and $BOD_5$ (r = –0.61), indicating that elevated sediment concentrations may disrupt oxygen transport and biological functions. The pH-DO relation is consistent with photosynthetic CO2 uptake raising both pH and DO, while the negative TSS-DO and TSS-$BOD_5$ associations suggest mineral-dominated diluting biodegradable organic matter and attenuating light [7], [23], [24]. Turbidity showed a modest positive correlation with TP (r = 0.72), associating sediment-laden water with increased phosphorus concentrations, potentially attributable to adsorption-desorption processes. The hypothesis that nutrient enrichment and light scattering from particles affect algal productivity was supported by the moderate correlations found between chl-a and turbidity (r = 0.36), as well as TP (r = 0.33). However, TN showed largely poor or negative correlations with other measures, such as EC (r = -0.53) and TDS (r = -0.48), indicating that it might come from other sources or follow different biogeochemical routes than TP. Cluster analysis employing Bray-Curtis similarity (single linkage) categorized the nine sampling stations into discrete clusters according to their water quality profiles (Figure 5). Stations S1, S2, and S4 displayed analogous characteristics and constituted a single cluster, presumably affected by similar upstream or land-use factors. Stations S3 and S7, with heightened nutrient and chlorophyll-a concentrations, constituted a distinct group, signifying localized eutrophic conditions. Station S9 exhibited greater distinctiveness, perhaps attributable to its unique microbial and nutritional profile. The strong association between EC and TDS means the inherent relationship between the availability of ions in the water and the overall EC, which has implications for aquatic life. Elevated conductivity can indicate higher levels of dissolved salts, potentially affecting fish and other aquatic organisms through osmotic stress [25]. Furthermore, moderate correlations between EC and pH (r = 0.54) suggest that changes in ionic content also influence the acidity-basicity balance in the water system. Pre-

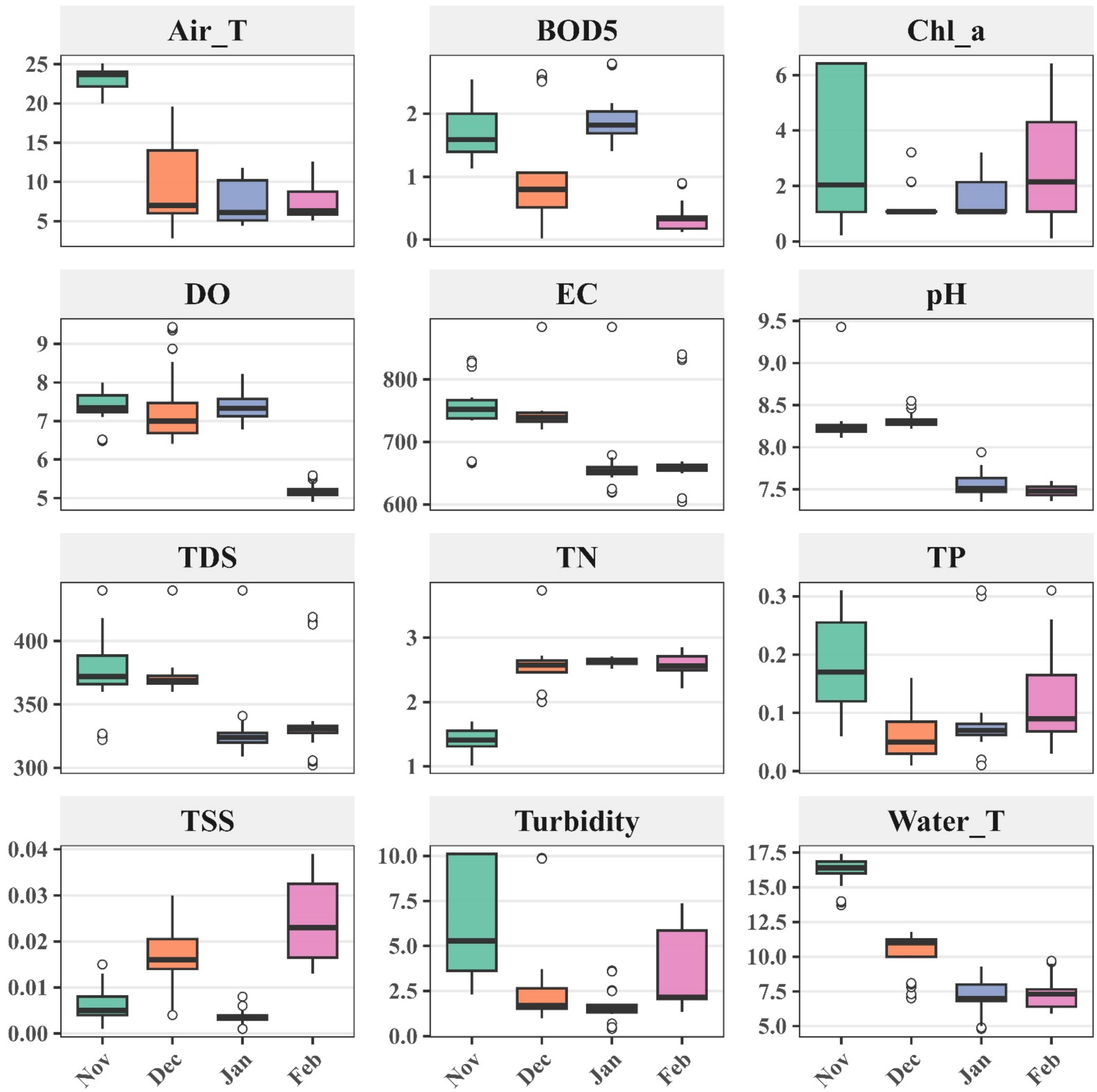


**Figure 2.** Boxplots of Air T., Water T., $BOD_5$, Chl-a, DO, EC, pH, TDS, TN, TP, TSS, Turbidity for four months during study period.

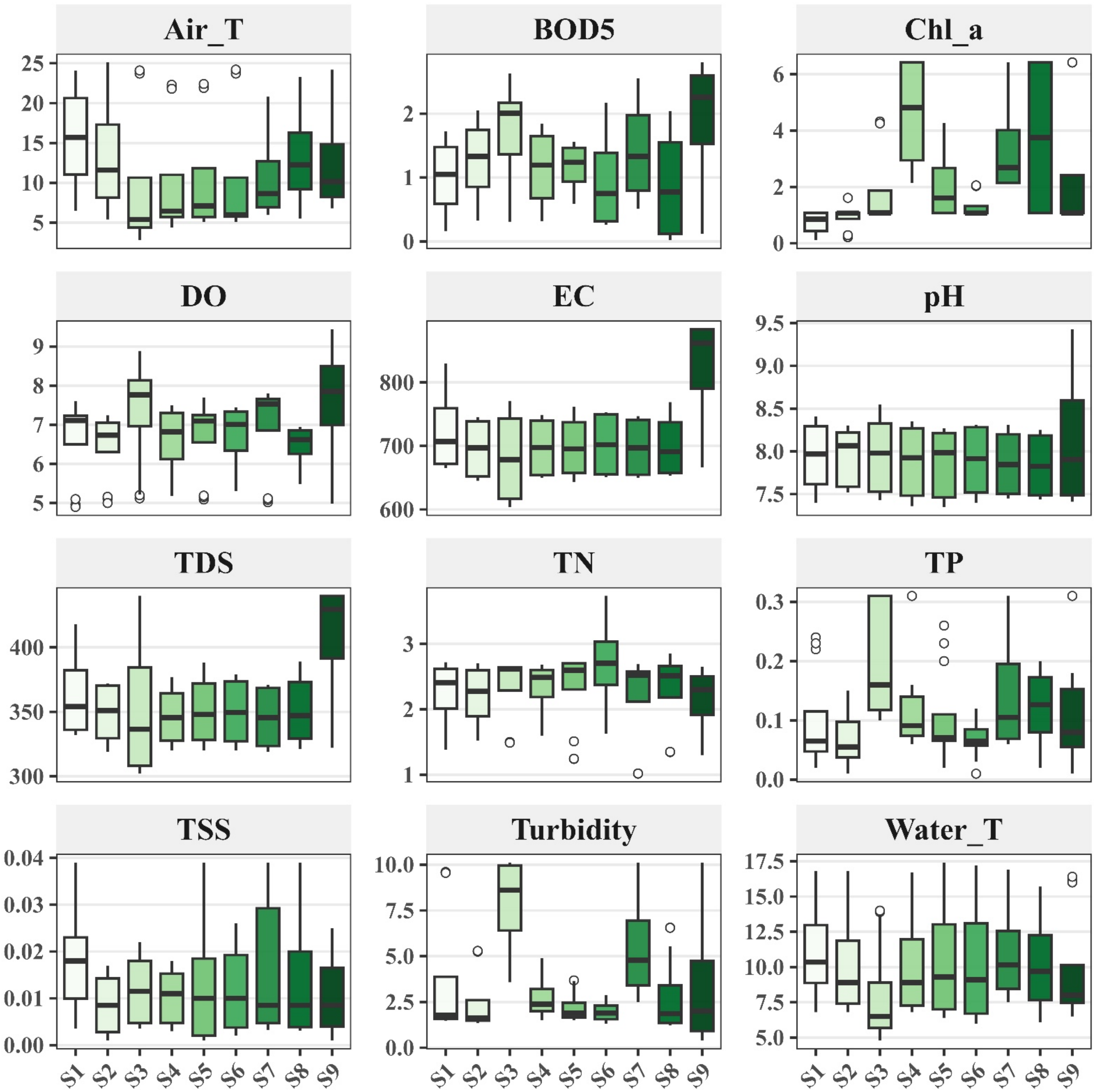


**Figure 3.** Boxplots of Air T., Water T., $BOD_5$, Chl-a, DO, EC, pH, TDS, TN, TP, TSS, Turbidity for nine stations during study period.

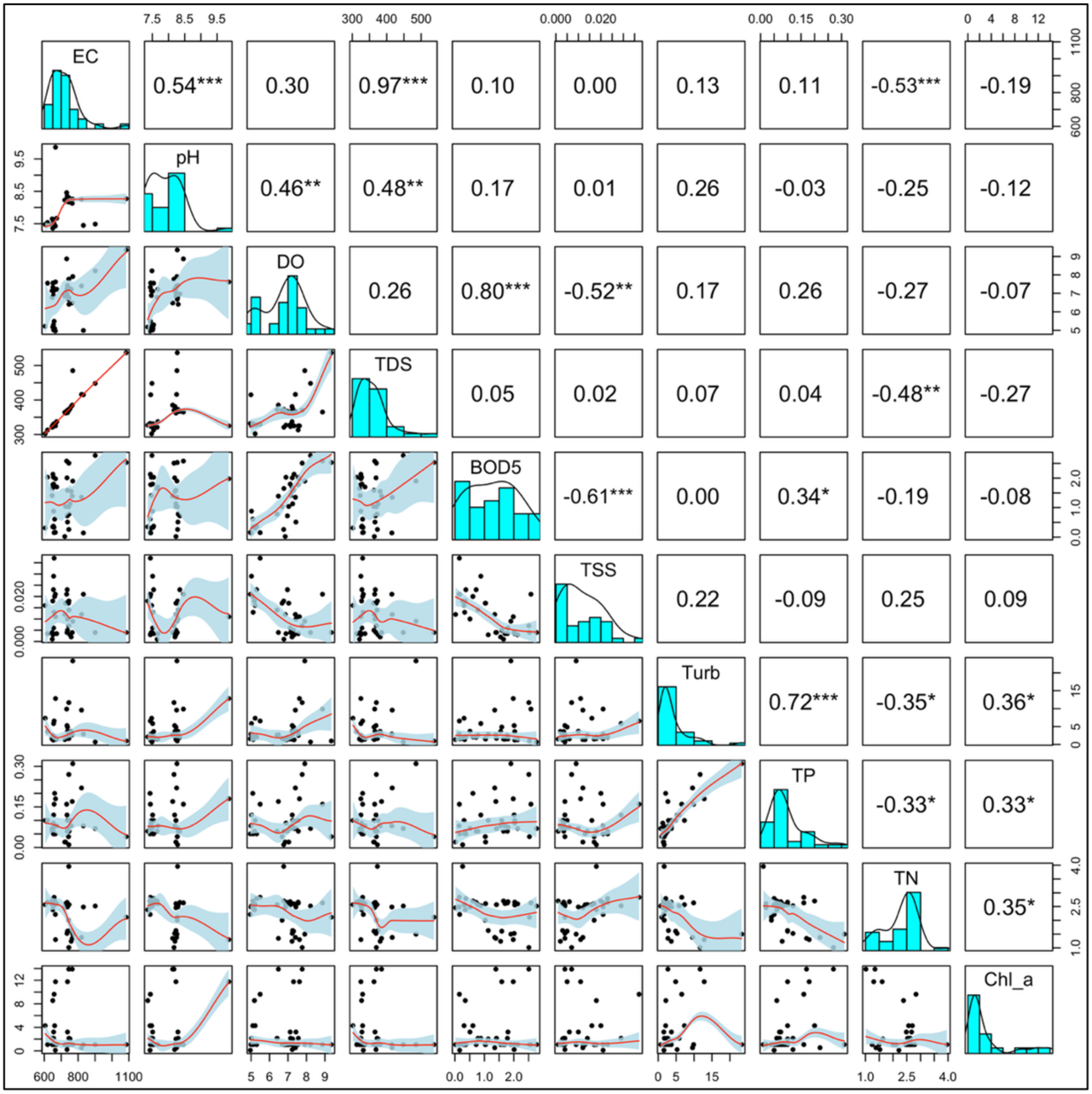

**Figure 4.** Correlation matrices between water parameters at Gomaspan reservoir catchment.

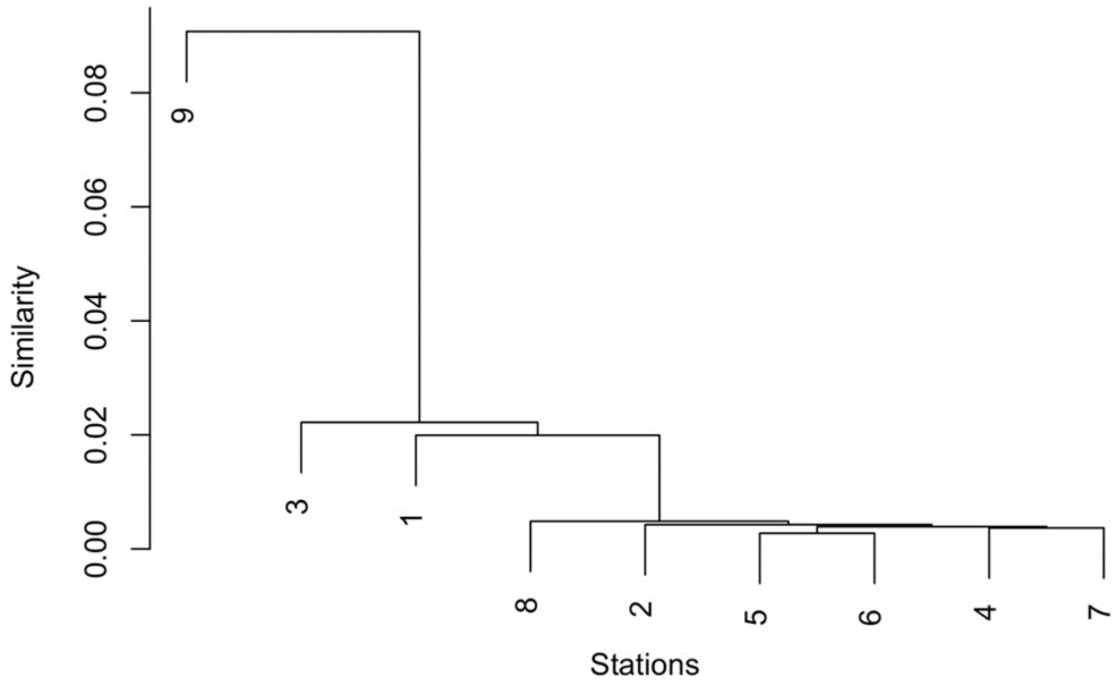


**Figure 5.** Bray-Curtis Similarity dendrogram (Single Linkage-Constrained) of the sampling stations.

vious studies have indicated that increases in salinity can alter the pH of freshwater bodies, leading to ecological changes [26]. The biological implications of higher pH levels may correlate with improved DO levels (r = 0.46), hinting at a complex interplay between various biological and chemical parameters that enhance aquatic habitat. The relationship of dissolved oxygen to $BOD_5$ presents a compelling link to the microbial processes occurring within the reservoir. A strong positive correlation (r = 0.80) suggests that as organic matter breakdown increases due to microbial activity, the availability of oxygen concurrently rises.

Turbidity presents another critical factor within the Gomaspan reservoir water quality profile. The modest correlation (r = 0.72) between turbidity and TP indicates that sediment-laden water might facilitate phosphorus concentration via adsorption-desorption processes. This correlation is critical as it aligns with findings from studies indicating how increased turbidity can exacerbate nutrient cycling, promoting algal blooms that adversely impact water quality [25]. The association between chlorophyll-a (chl-a) concentrations and turbidity (r = 0.36) and TP (r = 0.33) substantiates the hypothesis that nutrient enrichment and light scattering due to suspended particles directly affect algal productivity, which can lead to further complications in water quality parameters [27]. The negative associations identified between TSS with both DO (r = -0.52) and $BOD_5$ (r = -0.61) illustrate potential detrimental effects of sediment load on aquatic life. High sediment concentrations can physically impede oxygen transport and disrupt biological processes that rely on oxygen. Other studies have similarly shown that increased sedimentation alters habitat availability, impairs light penetration, and disrupts food web dynamics through the smothering of aquatic vegetation, which also serves to stabilize sediment and support numerous aquatic organisms [28].

### 3.3 Principal Component Analysis (PCA):

PCA is appropriate to address multicollinearity among parameters (e.g., EC – TDS) and to reduce dimensionality, revealing latent gradients (e.g., a nutrient/particle axis) that single-parameter tests cannot capture. To minimize dimensionality and identify the key factors of water quality fluctuations at the Gomaspan reservoir catchment, Principal Component Analysis (PCA) was used (Tables 4 and 5). According to the findings, the first four principal components (PCs) jointly explained 78.66% of the dataset's variance and had eigenvalues larger than 1. In particular, PC1 contributed 18.52%, PC3 accounted for 11.53%, PC4 added 9.56%, and PC1 explained 39.05% of the cumulative variance. These components showed that they captured most of the variability in the water quality parameters. Air temperature (-0.359), water temperature (-0.355), pH (-0.307), and DO (-0.296) had the greatest effects on PC1 in terms of variable contributions, indicating a strong link to processes involving thermal and oxygen. High positive loadings for turbidity (0.303), TP (0.331), and chl-a (0.353) were found in PC2, indicating light attenuation and nutrient-driven algal dynamics. Indicating interactions between organic matter and TSS, PC3 was inversely correlated with TSS (-0.462) and TDS (-0.481) and positively correlated with $BOD_5$ (0.347). Turbidity (0.487) and TP (0.482) both displayed significant positive loadings in PC4, confirming their co-variation. While the MPN index loaded most heavily on PC5 (0.682), TN had its highest loading in PC1 (0.366), indicating that a different component captures microbial variability.

**Table 4.** Presents the eigenvalues, total variance, and cumulative variance of the principal components.

| Component | Eigenvalue | Percent of Variance | Cumulative Percent |
|---|---|---|---|
| 1 | 5.076 | 39.048 | 39.048 |
| 2 | 2.407 | 18.519 | 57.567 |
| 3 | 1.499 | 11.533 | 69.1 |
| 4 | 1.242 | 9.556 | 78.655 |
| 5 | 0.862 | 6.632 | 85.287 |
| 6 | 0.757 | 5.826 | 91.113 |
| 7 | 0.6 | 4.618 | 95.732 |
| 8 | 0.176 | 1.357 | 97.089 |
| 9 | 0.158 | 1.213 | 98.302 |
| 10 | 0.093 | 0.717 | 99.019 |
| 11 | 0.071 | 0.55 | 99.569 |
| 12 | 0.044 | 0.341 | 99.91 |
| 13 | 0.012 | 0.09 | 100 |

Based on the principal components, the PCA ordination plot (Figure 6) shows the distribution of water quality samples over the course of four months, displaying distinct temporal clustering patterns. There was a noticeable change in the water quality conditions over time, as evidenced by the samples from November and December often grouping apart from those from January and February. Higher temperatures, DO, and nutrient concentrations were more strongly linked to the November and December samples, as evidenced by their closeness to variables like TP, chl-a, and BOD5. Samples from January and February, on the other hand, tended to correlate more with lower temperatures, higher microbial counts (MPN), and increased turbidity, which may indicate changes brought on by runoff events, organic load dynamics, or seasonal cooling. The spatial split along the catchment's first two principal components (PC1 and PC2) indicates how human activity and seasonal environmental conditions affect variations in water quality. The eigenvalue and loading results are supported by this visual differentiation, which confirms that organic pollution and nutrient enrichment are important factors influencing the aquatic environment's temporal patterns. The broad November spread reflects first-flush dynamics at the onset of rains-runoff mobilizes sediments and nutrients, raising turbidity/TP and occasionally Chl-a, with later months showing damped variability as flows stabilize. Spatially, higher variations near inflows indicated localized inputs, whereas mid-reservoir/near dam sites are more mixed and stable due to depth and residence time [29]. The first four principal components accounted for a significant 78.66% of the total variance, indicating the effectiveness of PCA in capturing key variables impacting aquatic health and quality. Notably, the strong contributions of air temperature, water temperature, DO, and pH to the first PC1 align with established findings in the literature that emphasize the critical role of temperature in shaping water quality through thermal stratification and oxygen levels [30], [31]. These findings accentuate the need to consider climatic influences on water bodies, especially in light of rising global temperatures and changing precipitation patterns [32].

**Table 5.** Principal component loadings of the 13 water quality parameters.

| Parameter | PC1 | PC2 | PC3 | PC4 | PC5 |
|---|---|---|---|---|---|
| Air Temperature | -0.359 | 0.194 | -0.07 | -0.309 | 0.216 |
| Water Temperature | -0.355 | 0.175 | -0.084 | -0.396 | 0.145 |
| EC | -0.231 | -0.344 | -0.476 | 0.009 | -0.169 |
| pH | -0.307 | 0.067 | -0.143 | -0.199 | -0.163 |
| DO | -0.296 | -0.373 | 0.13 | 0.172 | 0.03 |
| TDS | -0.263 | -0.284 | -0.481 | 0.152 | -0.123 |
| BOD5 | -0.265 | -0.283 | 0.347 | 0.331 | 0.195 |
| TSS | 0.209 | 0.327 | -0.462 | 0.184 | -0.239 |
| Turbidity | -0.263 | 0.303 | -0.054 | 0.487 | 0.001 |
| TP | -0.263 | 0.331 | 0.073 | 0.482 | -0.041 |
| TN | 0.366 | -0.194 | -0.035 | 0.128 | -0.242 |
| Chlorophyll a | -0.151 | 0.353 | 0.231 | -0.071 | -0.491 |
| MPN | 0.18 | 0.197 | -0.308 | 0.149 | 0.682 |

The distinct clustering observed in the PCA ordination plot, particularly the separation between samples from November-December and January-February, calls attention to the influence of seasonal variation in water quality parameters. During colder months, the correlation of lower temperatures with heightened microbial counts and turbidity may suggest the impact of organic load dynamics or runoff events typical of winter seasons [33], [34]. This is consistent with research indicating that increased runoff can lead to elevated turbidity and nutrient concentration due to the mobilization of sediments and organic matter [35]. Furthermore, the robust positive loadings for turbidity, TP, and chl-a in the second principal component (PC2) suggest a coupling between light attenuation and nutrient enrichment, potentially driving algal blooms–a phenomenon noted in various freshwater ecosystems undergoing

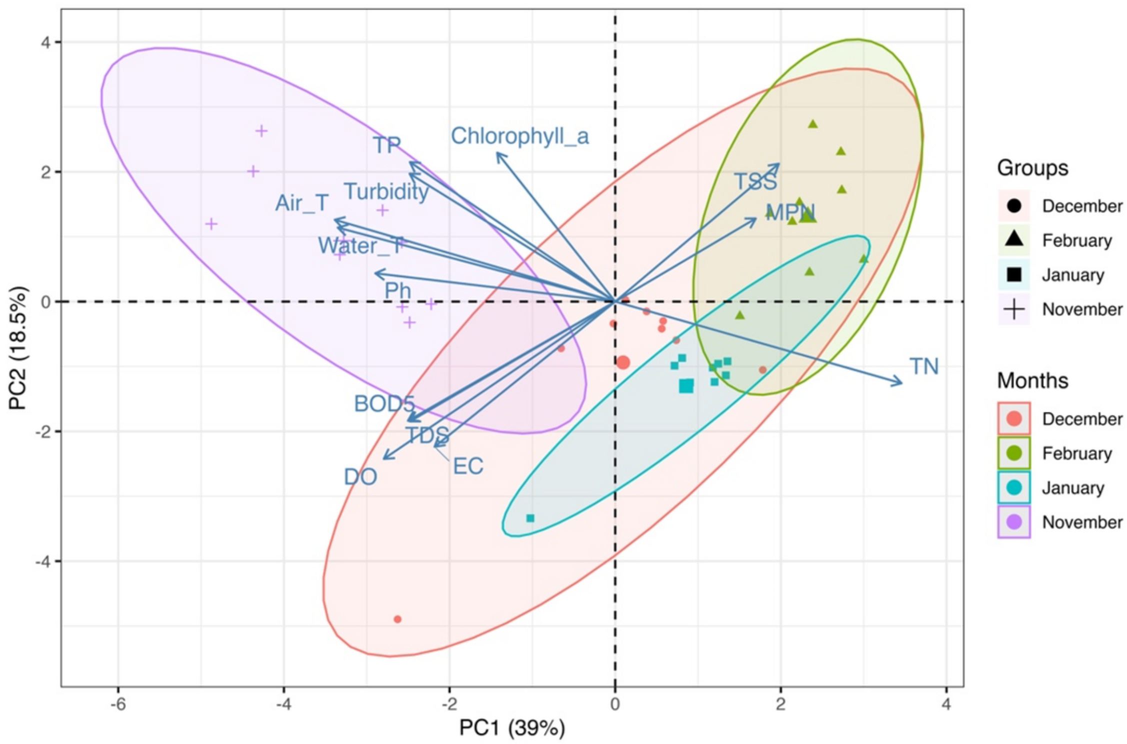


**Figure 6.** Individual PCA for water parameters for four months of the study duration.

nutrient loading [36], [37]. The seasonal differences noted in the study align with suggestions that freshwater ecosystems experience shifts in biotic interactions and nutrient cycling with changing temperatures and light availability [38]. Moreover, the interaction encapsulated in PC3, with its inverse correlation with TSS and TDS, while positively correlating with BOD5, indicates a complex relationship between organic pollution and nutrient cycling. This is indicative of eutrophication processes where organic matter inputs foster higher microbial activity, consuming oxygen and altering water quality [39]. Such interactions are critical for understanding microbial community dynamics and resultant water quality impacts in systems faced with nutrient enrichment. Lastly, the implications drawn from the high loading of MPN index in PC5 signal the necessity of considering microbial dynamics as a separate yet vital component of water quality fluctuation. Understanding the role of microbial populations in nutrient cycles, particularly in terms of their response to anthropogenic changes and seasonal variations, is vital in managing water quality effectively [40]. The overall findings from this study reinforce the notion that a multi-faceted approach, integrating both chemical data and microbial activity, is essential for comprehensive assessment and management of water quality in freshwater systems like Gomaspan reservoir.

### 3.4 Water Pollution Index (WPI):

The Water Pollution Index (WPI) was calculated for selected water quality parameters in the Gomaspan reservoir to assess the overall pollution status (Table 5). The WPI value was found to be 0.52, which is obtained from the average of the Ci-7/Sib-7 ratios for each parameter. This value indicates good water quality and falls within the acceptable range, suggesting that the water quality is suitable for domestic and agricultural use. Among the parameters assessed, the Ci-7/Sib-7 ratios were as follows: pH (0.61), EC (0.96), TDS (0.72), $Ca^{2+}$ (0.66), $Mg^{2+}$ (0.69), $K^{+}$ (0.02), and Na+ (0.01). While most parameters had positive ratios indicating acceptable levels, the negative values for $K^{+}$ and $Na^{+}$ reflect concentrations far below the WHO maximum permissible limits of 200 ppm, contributing insignificantly to the WPI.

According to Gomaspan reservoir's permitted WPI level, pollution levels are presently under control. This is in keeping with ideas presented in the literature that stress the value of communicating the condition of water bodies about different pollutants using comprehensive indices such as the WPI [41]. Contextualizing this metric within temporal and spatial dimensions is crucial, though. Studies conducted in several regions show that seasonal fluctuations in runoff and agricultural practices can cause episodic contamination episodes even in water systems with acceptable average quality [42]. As a result, ongoing monitoring is essential to guaranteeing that the quality

**Table 6.** Water Pollution Index (WPI) for the study area.

| ID | Parameter | Min | Max | Mean ± SD | Ci-7 | Sib-7 | Ci-7/Sib-7 | WPI | WHO |
|---|---|---|---|---|---|---|---|---|---|
| 1 | pH | 7.36 | 9.86 | 7.92 ± 0.51 | 0.92 | 1.5 | 0.61 | 0.52 | 6 - 8.5 |
| 2 | EC ($\mu$S cm$^{-1}$) | 605 | 1084 | 718 ± 89.95 | 711 | 743 | 0.96 | | 750 |
| 3 | TDS (ppm) | 302 | 537 | 361.44 ± 49 | 354 | 494 | 0.72 | | 500 |
| 4 | $Ca^{2+}$ (ppm) | 40.4 | 83.7 | 51.71 ± 3.48 | 44.71 | 68 | 0.66 | | 75 |
| 5 | $Mg^{2+}$ (ppm) | 32.4 | 49 | 36.46 ± 1.94 | 29.46 | 43 | 0.69 | | 50 |
| 6 | $K^{+}$ (ppm) | 2.56 | 4.73 | 3.13 ± 0.19 | -3.69 | 193 | -0.02 | | 200 |
| 7 | $Na^{+}$ (ppm) | 5.15 | 6.92 | 5.58 ± 0.28 | -1.42 | 193 | -0.01 | | 200 |

of the water stays constant over time. This draws attention to a significant suggestion made by the literature supporting the creation of long-term programs for monitoring the quality of water [43].

Furthermore, present agricultural practices and regulatory frameworks intended to minimize nutrient runoff and other contaminants may have an impact on the good water quality seen in Gomaspan reservoir. According to numerous studies, good management techniques are essential for preserving the integrity of water systems, especially in regions where increased nutrient loading has resulted from agricultural growth [44].

## 4. Conclusions:

A WPI finding indicates that the water quality in the Gomaspan reservoir is good. The water is generally safe for residential and agricultural use because the majority of physicochemical parameters are within WHO-acceptable limits. Nonetheless, there were statistically significant differences in water quality between months and sampling locations, especially in terms of temperature, nutrient concentrations (TN and TP), and biological markers like MPN and chlorophyll-a. Seasonal shifts, especially during the colder months, appear to influence microbial activity and turbidity levels, suggesting the influence of runoff and organic matter input. Multivariate analyses–including correlation matrices, PCA, and cluster analysis–revealed the interrelationships among parameters and helped identify key factors influencing water quality, such as nutrient enrichment and sediment resuspension.

Stations S3, S7, and S9 emerged as sites with elevated risk for localized eutrophication and microbial contamination, highlighting the need for targeted management strategies. This study establishes essential baseline data for future water quality assessments and underscores the importance of continuous monitoring, especially given potential pressures from urban expansion, agriculture, and climate variability. Implementing preventive measures and sustainable water resource management practices will be vital to ensuring the long-term integrity of the Gomaspan reservoir ecosystem.

The present dataset covers four consecutive months (November–February) and was designed as an early baseline shortly after reservoir operation commenced. While two-way ANOVA and PCA already revealed significant temporal effects within this window, year-round status–especially for an ephemeral/seasonal system–cannot be inferred without a dry-season campaign. We therefore recommend a dry-season (March–September) assessment to complete the hydrological picture and verify the persistence of patterns observed here.

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**Data Availability Statement:** All of the data supporting the findings of the presented study are available from corresponding author on request.

**Declarations:**
**Conflict of interest:** The authors declare that they have no conflict of interest.

**Ethical approval:** This research did not include any human subjects or animals, and as such, it was not necessary to obtain ethical approval.

**Author Contributions:** This work was carried out in collaboration between all authors. Sidra Q. Yassin contributed to the design of the study, collected samples and analyses, and wrote the paper with input from all authors. Siraj M. Abdulla conceptualized and contributed to the study design and implication of the study, visited the field for sample collection, and reviewed and edited the final manuscript draft. All authors read and approved the final manuscript.

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# تقييم متعدد المتغيرات لجودة مياه خزان كوماسبان في أربيل، إقليم كردستان العراق

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الخلاصة

جودة مياه الخزانات في مستجمعات المياه شبه الجافة تتشكل بواسطة نبضات الجريان السطحي القصيرة والشديدة وتأثيرات الحبس المبكر. تستخدم هذه الدراسة مزيجاً من المقاييس الفيزيائية والكيميائية والبيولوجية لجودة المياه لتقييم جودة مياه خزان كوماسبان على أساس شهري باستخدام التحليلات الإحصائية التي تشمل تحليل التباين ثنائي الاتجاه (الشهر، الموقع)، ومعاملات ارتباط بيرسون، وتحليل المكونات الأساسية ( *PCA* )، وتحليل العنقودية برايكورتيس. خلال فترة أربعة أشهر (نوفمبر 2024 إلى فبراير 2025 )، تم قياس ثلاثة عشر مؤشراً مهماً لجودة المياه في تسعة مواقع عينة. شملت هذه المؤشرات درجة حرارة الهواء والمياه، والأس الهيدروجيني، والتوصيل الكهربائي، وإجمالي المواد الصلبة المذابة، وإجمالي المواد الصلبة المعلقة، والعكارة، والطلب البيوكيميائي للأكسجين لخمسة أيام، والأكسجين المذاب، والنيتروجين الكلي، والفوسفور الكلي، والعدد الأكثر احتمالاً، والكلوروفيلاً. لتقييم مستويات التلوث وإنشاء خط أساس للمراقبة المستقبلية، تم مقارنة البيانات مع معايير منظمة الصحة العالمية. أشارت قيمة مؤشر تلوث المياه ( *WPI* ) البالغة 0.52 إلى جودة مياه جيدة. تم العثور على تباين زمني ومكاني كبير في عدد من العوامل باستخدام تحليل التباين ثنائي الاتجاه، وخاصة في درجة الحرارة، والحمولة الميكروبية، ومحتوى المغذيات. فسر تحليل المكونات الأساسية (المكونات الأربعة الأولى) 78.66% من التباين. اكتشف تحليل التباين ثنائي الاتجاه تأثيرات شهرية وموقعية معنوية ( $p < 0.05$ ) لدرجة الحرارة والمغذيات (النيتروجين الكلي، الفوسفور الكلي) والمؤشرات البيولوجية (العدد الأكثر احتمالاً، الكلوروفيلاً). من خلال تجميع المحطات وفقاً للتشابهات في جودة المياه، سلط التحليل العنقودي الضوء على المصادر الإقليمية للتلوث. بالنسبة للفترة المدروسة فقط (نوفمبر – فبراير)، استوفت معظم المعاملات قيم إرشادات منظمة الصحة العالمية، لكن التباين الزمني والموقعي الواضح يشير إلى الحاجة لحملة الموسم الجاف (مارسسبتمبر) لتوصيف السنة الهيدرولوجية الكاملة.

**الكلمات الدالة** :تقييم جودة المياه؛ خزان كوماسبان؛ مؤشر تلوث المياه ( *WPI* )؛ المعاملات الفيزيائية والكيميائية؛ تحليل المكونات الأساسية ( *PCA* ).

**التمويل:** لايوجد.

**بيان توفر البيانات:** جميع البيانات الداعمة لنتائج الدراسة المقدمة يمكن طلبها من المؤلف المسؤول.

**اقرارات:**

**تضارب المصالح:** يقر المؤلفون أنه ليس لديهم تضارب في المصالح.

**الموافقة الأخلاقية:** : لم تتضمن هذا البحث أي تجارب على البشر أو الحيوانات، بالتالي لم تكن من الضروري الحصول على موافقة أخلاقية.

**مساهمات المؤلفين:** تم تنفيذ هذا العمل بالتعاون بين جميع المؤلفين. ساهمت سدرة قوباد ياسين في تصميم الدراسة، وجمعت العينات والتحليلات، وكتبت الورقة البحثية بمساهمة من جميع المؤلفين. قام سراج محمد عبد الله بوضع المفهوم والمساهمة في تصميم الدراسة وتطبيق الدراسة، وزار الميدان لجمع العينات، وراجع وحرر المسودة النهائية للمخطوطة. قرأ جميع المؤلفين ووافقوا على المخطوطة النهائية.