



SPATIAL AND TEMPORAL VARIATIONS IN WATER QUALITY PARAMETERS OF DAL LAKE

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Abstract

Dal Lake in the Kashmir Valley is an important freshwater ecosystem that harbours an excellent biodiversity. Nevertheless, the lake has experienced several degrees of ecological degradation and this is mostly brought about by human activities, which include dumping of domestic waste, tourism activities, and agricultural sewage. This paper elucidates the spatial and temporal changes in the water quality parameters of Dal Lake which discuss the impact of the same changes on the fish species *Pethia conchonius* and *Crossocheilus diplocheilus*. The parameters that were studied in the water quality included 11 parameters in which the results indicated that there was great spatial and seasonal differences where parameters like dissolved oxygen (DO), total hardness (TH) and total phosphorus (TP) showed significant differences. Correlation analysis by Pearson showed that there was strong correlation among significant water quality parameters and Principal Component Analysis (PCA) revealed the most effective factors in the trophic dynamics in the lake. Canonical Correspondence Analysis (CCA) revealed that such parameters of nutrients like NO₃-N and TP also have a significant impact on the fish assemblage. This research offers some useful information on the prevailing water quality situation in Dal Lake with a strong focus on the necessity to develop proper management and conservation measures that will allow reducing the current degradation trend and recover the ecological welfare of the lake.

Keywords: Dal Lake, Water Quality, Temporal Variations, Spatial Variations, Fish Diversity, *Pethia conchonius*, *Crossocheilus diplocheilus*, Eutrophication

1. Introduction

The Dal Lake located at the Kashmir Valley has been the subject of some of the limnological researches because it is highly biodiverse and has environmental importance. The lake falls within the north-eastern space of the Srinagar city and covers a catchment area of 337 sq. km and it has a surface area of 24 sq. km with an open water area of 10.5 sq. km (Rashid et al., 2017). This lake is fed by numerous streams including Telbal Nallah and Botkol making it a crucial element in the hydrology of the area (Ahmad et al., 2020). They maintain various aquatic organisms and also fish species like *Cyprinus carpio*, *Crossocheilus diplocheilus* and *Pethia conchonius* (Sultan et al., 2024). However, Dal Lake has many environmental issues despite its pivotal role in the environment, particularly in the quality of water contamination by human activities (Rather and Dar, 2020).

Some of the man-made problems that Dal Lake has encountered over the years include the problem of garbage abandoned by households and impacts of the tourism. The impacts of such stresses differ based on the place and one section of the lake is more exposed to the influences than another. As an example, Hazratbil, one of the areas close to the shrine, is among the most polluted spots because of household garbage, yet the Dalgate area is affected by houseboats pollution (Bhat et al., 2022). The fact of these variation of space and time as the quality of water is significant in the context of effective management and conservation of the ecological system in the lake. The past research has put emphasis on the importance of such water quality indices as temperature, beauty of pH, dissolved oxygen, and total dissolved solids (TDS) in establishing the characteristics of water systems (Najar and Khan, 2012). Thus, diversity and the population of fish species in the lake are influenced by the quality of water. Some of the affected species of water quality parameters include, pH, dissolved oxygen, the total phosphorus and nitrate



concentration, and seasonal and spatial variation of these parameters which are used as water quality parameters (*Pethia conchoni* and *Crossocheilus diplocheilus*). In order to compare the consequences of such fluctuations, researchers tend to employ a group of analytical techniques, such as such diversity measures as the Shannon-Weiner index and Simpson index that would help to quantify the richness and the evenness of species in various environments (Rather and Dar, 2020).

The study targets the review of the transition of space and time in the use of water quality parameters in Dal Lake with a keen interest to the effect that the transitions had on fish species *Pethia conchoni* and *Crossocheilus diplocheilus*. In the study to get access to a detailed overview of the ecological activity of Dal Lake, the interaction of the various factors of water quality and fish population is examined by taking a wide scope of statistics into consideration like correlation, principal component analysis (PCA), and canonical correspondence analysis (CCA).

2. Literature Review

2.1 Historical Changes and Water Quality Degradation in Dal Lake

Dal Lake, which used to be a pure body of water has in the recent decades suffered extensively as a result of the anthropogenic forces that has caused a lot of ecological degradation to the lake. Various studies have been able to record the degradation of its water quality and they point to urbanization, agricultural activities and the discharge of untreated and raw sewage into the lake. Rashid et al. (2017) underline that the nutrient loading and especially that of domestic waste is one of the factors that have greatly affected the nutrient balance of the lake, taking the lake towards the eutrophication path. The degree of transparency of the lake has significantly decreased over the last 40 years, and different parameters of water quality, such as dissolved oxygen (DO), have shown the gradual decline, whereas the values of different nutrients, including phosphates and nitrates, increased tremendously (Khanday et al., 2018). Specifically, the significant contributor to the nutrient pollution are agricultural runoff and bare sewage that increase an aquatic weed, *Eichhornia crassipes* (water hyacinth), that further contributes to the decrease in the water quality and biodiversity in the lake (Kumar et al., 2022).

Land use in Dal Lake catchment area has been severely felt. The growth of the urban area, especially in the regions near the lake, has enhanced the lake runoffs, which, consequently, have led to the growth of nutrient and sedimentation into the lake (Sabha et al., 2019). Moreover, the development of the lake periphery and encroachments have caused the destruction of wetlands to intensify the loss of aquatic life and increase the pollution pressure of the urban runoff (Mir et al., 2024). Since Dal Lake is still a significant part of the cultural and economic life of the area, knowing about these changes becomes a vital skill to construct sustainable control procedures which could reduce the current degradation and allow to recover ecological welfare of Dal Lake.

2.2 Physicochemical Conditions and Trophic Processes.

Dal Lake has been under different studies where physicochemical parameters have been used to determine its trophic condition and how human activities have impacted to its ecological health. The lake is termed as eutrophic and it contains high nutrient concentration, which favors heavy vegetation. Observations of the Trophic State Index (TSI) have discovered that Dal Lake is overtly eutrophic to hypereutrophic in the same way that it is excessive in nutrient contents, specifically nitrogen and phosphorus, necessary to trigger algal blooms (Qadir and Singh, 2019). Although such blooms initially sustain biodiversity, they will ultimately cause a drop in oxygen content within the water, which is counterproductive to the fishes and other organisms within the aquatic environment. Moreover, the biochemical oxygen demand (BOD) of the lake has been observed to be elevated in comparison to most of the other freshwater bodies especially in the summer months when decomposition of organic matter goes faster because of increased temperature levels (Amin et al., 2014).

One of the problems associated with the trophic condition of Dal Lake is the fluctuation in water quality parameters both between seasons and between space. As an illustration, the total dissolved solids (TDS) and electrical



conductivity (EC) are greater in winter whereas the values such as pH, alkalinity, and levels of dissolved oxygen have seasonal changes which are attributed to variation in temperature (Mushatq et al., 2013). The overall cause of seasonal change in water quality has been the interplay of both biological and abiotic processes and factors, which include photosynthesis and respiration and temperature and precipitation respectively (Bona and Lone, 2023). The seasonal fluctuation of the parameters described indicate that the management plans must be adaptable to the temporal and spatial trends of the water quality in the lake in order to be able to follow them. These seasonal variations with the trophic state, highlight the susceptibility of the lake to disruptions in climate and to human activity, a combination of which determine the ecological state of Dal Lake.

2.3 Land-Use Pressures, Non-Point Pollution, and Urban Pressures.

The immediate area of Dal Lake has undergone significant changes in land use over the last many decades resulting in significant effects in the quality of the water and the overall well being of the lake. The land use around the lake has contributed to the increase in runoff of the developed areas including thoroughfares, buildings, and agricultural areas and these increase the amount of nutrients in the lake. It has been shown that land-use change into an urban environment and the development of tourism infrastructure have broken the water cycle and increased pollutant transfer to the lake (Ahmed et al., 2017). This has led to high concentrations of the various nutrients like nitrogen and Phosphorus that promote the growth of the algae and emphasize on eutrophication. Furthermore, agricultural activities in the Dal Lake watershed have resulted into the leaching of chemicals, nutrients and soil particles into the lake, and therefore file it into a state that is abundant in nutrients (Bhat et al., 2022). The massive use of artificial fertilisers on the agricultural lands surrounding the lake is important in increasing the nitrate content in the water system that have been linked to a number of havocs in the environment on the aquatic life.

Non-point source pollution is a major challenge in the management of Dal Lake, which is typified by extensive pollution through urban runoff, agricultural runoff, and many other human activities (Rashid et al., 2017). Unlike pollution that has a specific source, such as a sewage discharge, pollution with a multifaceted and diffuse cause poses more management problems due to its widespread and discontinuous nature. The growing construction and agricultural practices on the Dal Lake have led to contamination accumulation over the years and this has led to gradual reduction in the quality of the water. Also, the construction of thoroughfares, housing, and homes near the lake has disrupted the natural filtration processes that wetlands and woodlands used to provide and caused more sediments and a reduced level of transparency in the water (Shah & Shah, 2013). The modifications do not only affect the quality of water but also threaten the high diversity of life in Dal Lake particularly aquatic organisms that require a uniform and clean water environment to sustain their life. The growing pressure on the watershed by the urban development presents the need to have strong land-use planning and pollution alleviating measures in ensuring that the ecological integrity of the lake is not compromised (Khanday, R.S.A., 2021).

3. Methods and Materials

3.1 Study Area

This study was done in Dal Lake, which is in the northeast of Srinagar city, in the Kashmir Valley and the latitude was 3400 -34 11N and the longitude was 7400 -24 53E. The lake has a total area of about 337 sq. km of catchment, and a surface area of 24 sq. km, as well as an open water area of 10.5 sq. km (Rashid et al., 2017). Dal Lake is a drainage system that is open and fed by the various streams especially the Telbal Nallah and Botkol springs and other smaller streams of the lake bed and its neighboring mountains forming springs (Qadri and Yousuf, 1980). There are two main outlets of the lake namely: Nallah Amir Khan and Dalgate. There is great faunal richness in the lake, in particular fish dominated by *Cyprinus caratio*, *Crossocheilus diplochilus*, *Schizothorax niger*, *S. curvifrons*, *Botia birdi*, *Pethia conchoni*, *Carassius carassius*, and *Gambusia holbrooki* (Ahmed et al., 2017; Bhat et al., 2022).

3.2 Design of Sampling

Five distinct sampling sites (S1 to S5) were selected to capture spatial variation in anthropogenic pressures:

- **S1 (Hazratbal):** A heavily polluted area adjacent to Hazratbal Shrine, impacted by domestic waste.
- **S2 (Dalgate):** Located near houseboats, this site receives waste generated from the houseboats.
- **S3 (Nishat):** A tourism-heavy area of Dal Lake.
- **S4 (Telbal):** Adjacent to the primary inflow channel (Telbal Nallah), this site experiences direct inflow from the stream.
- **S5 (Centre):** The least polluted site located at the center of the lake.

The water and fish samples were transported to the Fish Biology and Limnology Laboratory for further analysis.

3.3 Abundance of *Pethia conchonius* and *Crossocheilus diplochilus*

The abundance of these fish species was determined using various diversity indices:

- **Simpson's Index (Dominance):** Calculated to determine species dominance.
- **Shannon-Weiner Index (Richness):** Used to estimate species diversity.
- **Pielou's Evenness Index:** Assessed the distribution of individuals across species.
- **Catch per Unit Effort (CPUE):** Estimated the relative abundance of fish using the formula $CPUE = \frac{C}{F}$, where C represents catch and F represents fishing effort.

3.4 Population Dynamics and Population Structure

Several metrics were used to understand the population structure of *Pethia conchonius* and *Crossocheilus diplochilus*:

- **Length-Weight Relationship (LWR):** Determined using the equation $W = aL^b$, where W is weight, L is length, a is the intercept, and b is the slope.
- **Relative Condition Factor (Krel):** Calculated to evaluate the health condition of the fish.
- **Growth Parameters:** Asymptotic length (L_{∞}) and growth constant (K) were computed using FiSAT II software, based on the equation $L_t = L_{\infty}(1 - e^{-K(t-t_0)})$.
- **Mortality:** Natural mortality (M) was calculated using Pauly's equation. The fishing mortality (F) and total mortality (Z) were derived using the length-converted catch curve method. The exploitation ratio (E) was computed as $E = F/Z$.

3.5 Reproductive Biology

Reproductive parameters were assessed for both fish species:

- **Fecundity:** Estimated by counting the eggs in a subsample of gonads after extraction and fixation in formalin.



- **Gonado-Somatic Index (GSI):** Determined using the formula $GSI = \frac{\text{Gonad weight}}{\text{Body weight}} \times 100$ (Zin et al., 2011).
- **Sex Ratio:** Determined through gonadal examination and analyzed using chi-squared tests to compare observed and expected ratios.
- **Ova Diameter:** Measured under a microscope fitted with a camera (Magcam DC 10) to examine the maturity stages of ovaries.
- **Length at First Maturity (Lm):** Estimated by plotting the frequency of adult mature individuals against length class and fitting the data to a logistic function.

3.6 Impact of Water Quality on Fish Abundance

Water quality was monitored using various physicochemical parameters, as follows:

- **pH:** Measured using a Hanna HI98129 meter.
- **Dissolved Oxygen:** Measured using the Winkler's Iodometric method.
- **Temperature, TDS, EC, Alkalinity, Nitrate, Phosphorus:** Measured using Hanna HI98129 and other standard methods.
- **Biochemical Oxygen Demand (BOD):** Measured using the Winkler's Iodometric method (APHA, 2017).
- **Free Carbon Dioxide:** Titrimetric method.

The water quality data was analyzed using multiple statistical tests, including ANOVA, box plot analysis, principal component analysis (PCA), and cluster analysis to examine spatial and seasonal variations. The relationship between water quality and fish abundance was explored using Pearson correlation and Canonical Correspondence Analysis (CCA).

3.7 Statistical Analysis

Data were subjected to statistical analysis using:

- **MS-Excel 2019** for length-weight relationship and data presentation.
- **PAST 4.17** for diversity analysis.
- **SPSS Ver. 26** for water quality data analysis.
- **FiSAT II** for population dynamics and growth parameters.
- **Principal Component Analysis (PCA) and Cluster Analysis** for water quality data interpretation.

The results of statistical tests such as ANOVA and correlation were used to draw conclusions about the influence of water quality on the abundance and reproductive parameters of *Pethia conchonius* and *Crossocheilus diplochilus* in Dal Lake.

4. Data Analysis and Results

In September 2023, 11 different water quality parameters were subject to an extensive analysis. Table 4.1 represents the variation in different types of water quality parameters depicting the minimum and maximum parameters, the mean, and standard deviation. The data showed that the water of Dal Lake had minimum and maximum temperature of 4.0 °C and 27.1 °C respectively with the mean temperature of 16.4 ±1.0 °C. There were variable values in concentration of total dissolved solids (TDS) with the lowest value of 34.0 mg/L and maximum value of 160.0 mg/L giving an average of 93.1 ±26.9 mg/L. Electrical conductivity (EC) values were found to be as low as 80.0–340.0 µS/cm of electrical conductivity, averaging 192.0 ±53.3 of electrical conductivity. The pH was ranging between 7.1 and 9.2 with the average level at 8.0 ±0.3. The levels of the alkalinity varied with the lowest level of 50.0 mg/L, the highest level of 196.0mg/L, and the average levels at 121.8/31mg/L. Dissolved oxygen concentrations (DO) were measured and ranged as low as 4.0 mg/L, and as high as 9.8mg/L with the average of 7.21 mean plus or minus 1.1mg/L. The total hardness (TH) data were varied with a low of readings of 72.0 mg/L and all the highest with a value of 434.0 mg/L to give an average value of 195.8±83.1 mg/L. The levels of free carbon dioxide (FCO₂) were ranging as low as 1.0 mg/L with a maximum of 29.0 mg/L and an average of 12.12.56mg/L. There was a variation in the total phosphorus concentration, with the highest and lowest concentrations of 20.0 23 g/L and 1620.0 23 g/L respectively, and the mean value was 243.960.186g/L. The nitrates (NO₃-N) concentration was not constant as the lowest level was 40.0 0g/L and the highest one was 2098.0 0g/L, and the mean level of nitrates was determined as 574.0 og/L. The biochemical oxygen demand (BOD) had the lowest value of 1.0 mg/L and highest value of 8.4mg/L, and the mean was 3.7±1.7mg/L.

Table 4.1: Overall variation in the water quality parameters of Dal Lake

Parameter	Minimum	Maximum	Mean±SD
Water Temperature (°C) WT	4.0	27.1	16.4±6.9
Total Dissolved Solids (mg/L) TDS	34.0	160.0	93.1±26.9
Electrical Conductivity (µs/cm) EC	80.0	340.0	192.0±53.3
pH	7.1	9.2	8.0±0.3
Alkalinity (mg/L) Alk	50.0	196.0	121.8±31.0
Dissolved Oxygen (mg/L) DO	4.0	9.8	7.2±1.1
Total Hardness (mg/L) TH	72	434	195.8±83.1
Free CO₂ (mg/L) FCO₂	1.0	29.0	12.1±5.6
Total Phosphorus (µg/L) TP	20.0	1620.0	243.9±196.6
Nitrates (µg/L) NO₃-N	40.0	2098.0	574.0±467.9
Biochemical oxygen demand (mg/L) BOD	1.0	8.4	3.7±1.7

The acquisition of water samples was done in five different sampling locations during a period of 2 years. This data were aggregated and analysed with ANOVA, which was followed by Tukey Honest Significant Difference post-hoc examination whose results were presented in Table 4.2. The data shows that WT, TDS, EC, and pH did not vary significantly throughout the locations with the rest of the parameters having significant changes across the locations. Its maximum and minimum concentration of dissolved oxygen were 7.610mg/l and 6.714mg/l respectively at S4 and S1 respectively. At S4, the highest concentration of TH was reached, of 245.073.7mg/L and the lowest concentration was observed at S5, which was 144.052.3mg/L. It was observed that the total power was considerably high (411.4 302.4 8) at S1 and maximum (115.5 45.3 8) at S3. NO₃-N concentration was also unbelievably high at S4 843.0 3552.0 3 J/ and at S1, where the concentration was 738.3 3421.0 3 J/.

Table 4.2: Spatial variation in the water quality parameters of Dal Lake

Parameter	S1	S2	S3	S4	S5
Water Temperature (°C) WT	16.7±6.9 ^a	16.4±7 ^a	17.2±7.5 ^a	15.7±6.5 ^a	15.8±6.5 ^a
Total Dissolved Solids (mg/L) TDS	113.0±23.2 ^b	83.7±25.3 ^a	91.9±22.3 ^a	91.6±26.5 ^a	85.5±28.7 ^a
Electrical Conductivity (µs/cm) EC	233.5±46.6 ^b	173.4±46.6 ^a	175.7±43.6 ^a	193.9±52.6 ^a	183.4±56.4 ^a
pH	8.0±0.4 ^a	7.9±0.3 ^a	8.0±0.2 ^a	8.0±0.3 ^a	7.9±0.4 ^a
Alkalinity (mg/L) Alk	135.1±34.2 ^b	105.2±30.9 ^a	112.1± 28.8 ^{ab}	136.7±30.7 ^b	120.0±30.4 ^{ab}
Dissolved Oxygen (mg/L) DO	6.7±1.4 ^a	7.3±1.0 ^{ab}	7.2±0.9 ^{ab}	7.6±1.0 ^b	7.3±1.0 ^{ab}
Total Hardness (mg/L) TH	208.4±75.5 ^{bc}	203.1±96.6 ^{abc}	178.5±81.4 ^{ab}	245.0±73.7 ^c	144.0±52.3 ^a
Free CO ₂ (mg/L) FCO ₂	13.3±5.6 ^{bc}	10.9±4.3 ^{ab}	9.2±4.4 ^a	16.6±6.3 ^c	10.4±4.6 ^{ab}
Total Phosphorus (µg/L) TP	411.4±302.4 ^c	245.5±112.0 ^{ab}	115.5±45.3 ^a	297.8±155.7 ^{bc}	149.2±104.1 ^a
Nitrates (µg/L) NO ₃ -N	738.3±421.0 ^{bc}	379.2±302.4 ^a	462.8±393.4 ^{ab}	843.0±552.0 ^c	446.7±481.4 ^{ab}
Biochemical oxygen demand (mg/L) BOD	4.9±1.2 ^d	3.8±1.3 ^{bc}	3.2±1.2 ^b	4.8±2.0 ^{cd}	2.1±0.9 ^a

The values sharing the same superscripts in a row are statistically not significant (p>0.05)

These one-season water quality data of Dal Lake were summarized into four seasons spring (March, April and May), summer (June, July and August), autumn (September, October and November) and winter (December, January and February). During ANOVA, this data was thoroughly analysed and post-hoc test of the statistical significance was performed by Tukey using the name Honest Significant Difference (HSD), as is shown in Table 4.3. The presented data reflected that the overall dissolved solids and electrical conductivity was the highest during the winter months (TDS = 117.7±15.9 mg/L; EC = 240.1±27.0 µs/cm) and minimal in the autumn months (TDS = 70.1±20.9 mg/L; EC = 147.4±42.0 µs/cm). There was slight variation in the levels of pH, alkalinity, dissolved oxygen, FCO₂, and nitrogen nitrate among the different seasons. During the winter, TH was highest and was 272.2 pseudo -1-77.9 mannitol at 272.2 mg/L and lowest in summer at 152.9 pseudo -1-49.9 mannitol at 152.9 mg/L. On the other hand TP was found to have its highest in the spring with the value at 353.0±297.2 manage to express it in terms of 81/ larger units that is 353.0 / and the lowest in the autumn with the value at 152.7/larger units. Biochemical oxygen demand (BOD) showed a significant increase during the summer seasons, with the average BOD of 5.516mg/L and a significant decrease during winter seasons, with the average BOD of 2.310mg/L.

Table 4.3: Seasonal variation in the water quality parameters of Dal Lake

Parameter	Spring	Summer	Autumn	Winter
Water Temperature (°C) WT	17.2±3.5 ^b	24.5±1.3 ^c	16.2±4.4 ^b	7.3±2.3 ^a
Total Dissolved Solids (mg/L) TDS	102.1±20.3 ^b	82.6±22.6 ^a	70.1±20.9 ^a	117.7±15.9 ^c
Electrical Conductivity (µs/cm) EC	209.6±44.6 ^b	170.9±44.1 ^a	147.4±42.0 ^a	240.1±27.0 ^c
pH	8.1±0.3 ^b	7.9±0.2 ^{ab}	8.0±0.4 ^{ab}	7.8±0.3 ^a



Alkalinity (mg/L) Alk	130.8±24.5 ^b	104.7±25.5 ^a	105.8±32.4 ^a	145.9±30.1 ^b
Dissolved Oxygen (mg/L) DO	7.0±0.9 ^a	6.9±1.1 ^a	7.6±1.2 ^a	7.4±1.0 ^a
Total Hardness (mg/L) TH	158.4±45.0 ^{ab}	152.9±49.9 ^a	199.8±91.0 ^b	272.2±77.9 ^c
Free CO₂ (mg/L) FCO₂	15.8±4.3 ^b	11.8±7.3 ^a	9.4±5.0 ^a	11.3±3.3 ^a
Total Phosphorus (µg/L) TP	353.0±297.2 ^b	235.9±118.7 ^{ab}	152.7±55.5 ^a	233.8±179.0 ^{ab}
Nitrates (µg/L) NO₃-N	617.6±553.6 ^a	524.6±416.5 ^a	535.7±369.8 ^a	618.1±523.3 ^a
Biochemical oxygen demand (mg/L) BOD	3.8±1.2 ^b	5.5±1.6 ^c	3.4±1.3 ^b	2.3±0.8 ^a

The values sharing the same superscripts in a row are statistically not significant (p>0.05)

4.1 Correlation analysis of water quality data from Dal Lake

To investigate the nature of relationship between the various variables the water quality measures of Dal Lake were subjected to Pearson correlation test. The results of correlation analysis can be seen in Table 4.4 and Figure 4.1. TDS, EC, NO₃-N and Alk that had positive correlation among parameters were significant. Moreover, TP showed strong positive correlation with FCO₂, whereas BOD showed strong positive correlation with WT. On the other hand, correlation between water temperature and alkalinity and total hardness to water temperature showed a strong negative correlation. *Crossocheilus diplochilus* had a favourable correlation to the pH, FCO₂, TP, and NO₃ -N. On the other hand, *Pethia conchonius* had a positive relationship with water temperature and BOD, whereas having a negative relationship with TDS, EC, Alk, and NO₃-N.

Table 4.4: Pearson's correlation analysis of water quality parameters from Dal Lake

Parameters	WT	TDS	EC	pH	Alk	DO	TH	FCO ₂	TP	NO ₃ -N	BOD	<i>C. diplochilus</i>
WT												
TDS	-0.67*											
EC	-0.67*	1.00**										
pH	0.39	-0.36	-0.36									
Alk	-0.82**	0.96**	0.97**	-0.28								
DO	-0.64*	-0.14	-0.13	-0.20	0.09							
TH	-0.92**	0.55	0.55	-0.69*	0.66*	0.68*						
FCO₂	0.15	0.46	0.46	0.53	0.38	-0.71*	-0.44					
TP	0.08	0.56	0.56	0.43	0.47	-0.71*	-0.36	0.99**				
NO₃-N	-0.71*	0.90**	0.90**	0.02	0.95**	-0.01	0.44	0.60*	0.65*			

BOD	0.98**	-0.54	-0.55	0.23	-0.74*	-0.73*	-0.86**	0.16	0.12	-0.67*		
<i>C. diplochilus</i>	-0.25	0.21	0.22	0.77*	0.36	0.06	-0.14	0.63*	0.58	0.61*	-0.37	
<i>P. conchoni</i>	0.80**	-0.83**	-0.84**	-0.04	-0.93**	-0.18	-0.53	-0.47	-0.52	-0.98**	0.79*	-0.66*

* strong correlation

**very strong correlation

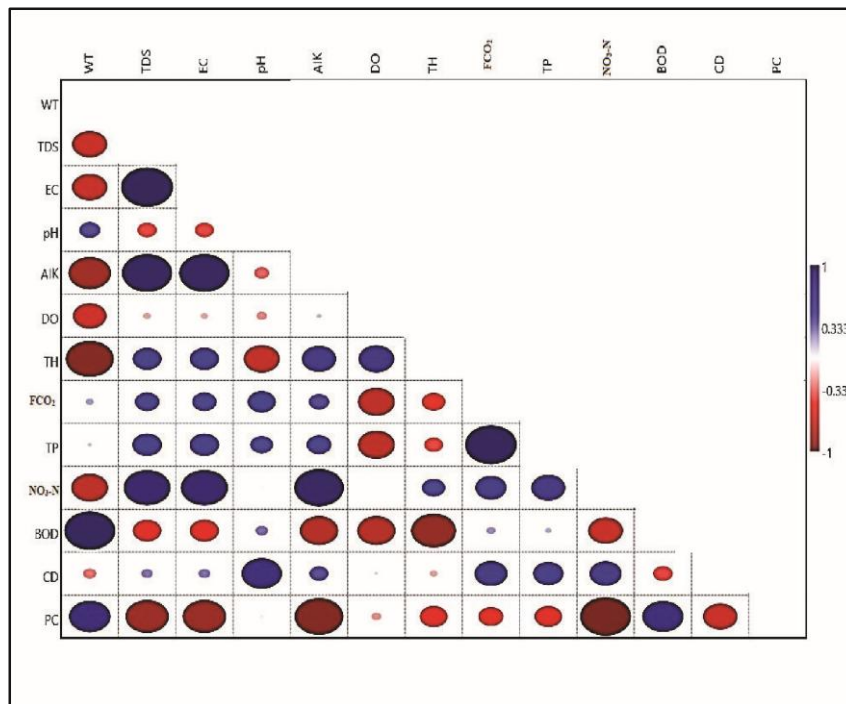


Figure 4.1: Pearson's correlation analysis of water quality parameters from Dal Lake

4.2 Cluster analysis of water quality data from Dal Lake

The data on the water quality analysis gave rise to two main clusters. S1 and S4 belonged to the first cluster, S2 belonged to the second cluster which was further subdivided into two sub-clusters: sub-cluster 1 (SC1) was composed of S5 and S3, and the second sub-cluster 2 (SC2) was S2. The dendrogram obtained after the cluster analysis is shown in figure 4.2.

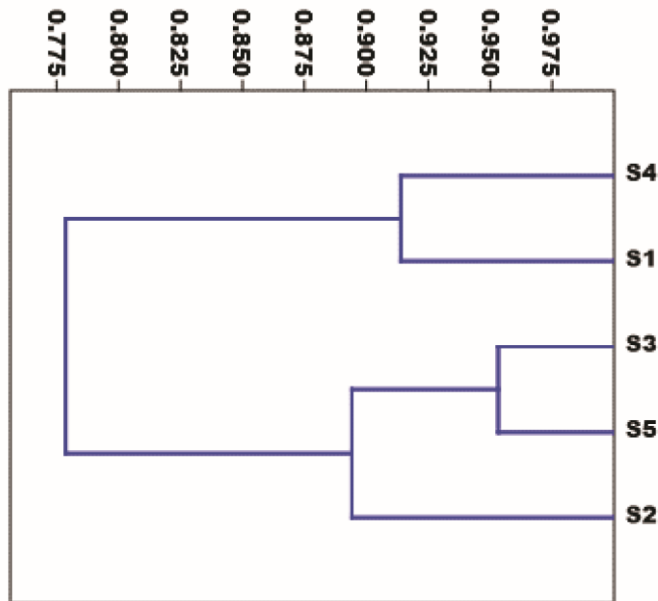


Figure 4.2: Cluster analysis of water quality parameters of different sites of Dal Lake

4.3 Violin and box plot analysis of water quality data from Dal Lake

The violin and box plots graphically presented the temporal aggregation of water quality data of Dal Lake by presenting the median, interquartile range and the entire numerical distribution of the data. The difference between the water temperature was significantly less during the period of summer months as compared to the changes in temperature witnessed in other seasons. There were marked deviations in the distributions on the TDS and EC, with a number of exceptions in the spring and fall seasons. Considering total phosphorus, an exceptionally high outlier was recorded in the spring period with little fluctuation being recorded in the autumn period. Figure 4.3 will depict the violin and the boxplots of the water quality parameters of the Dal Lake.

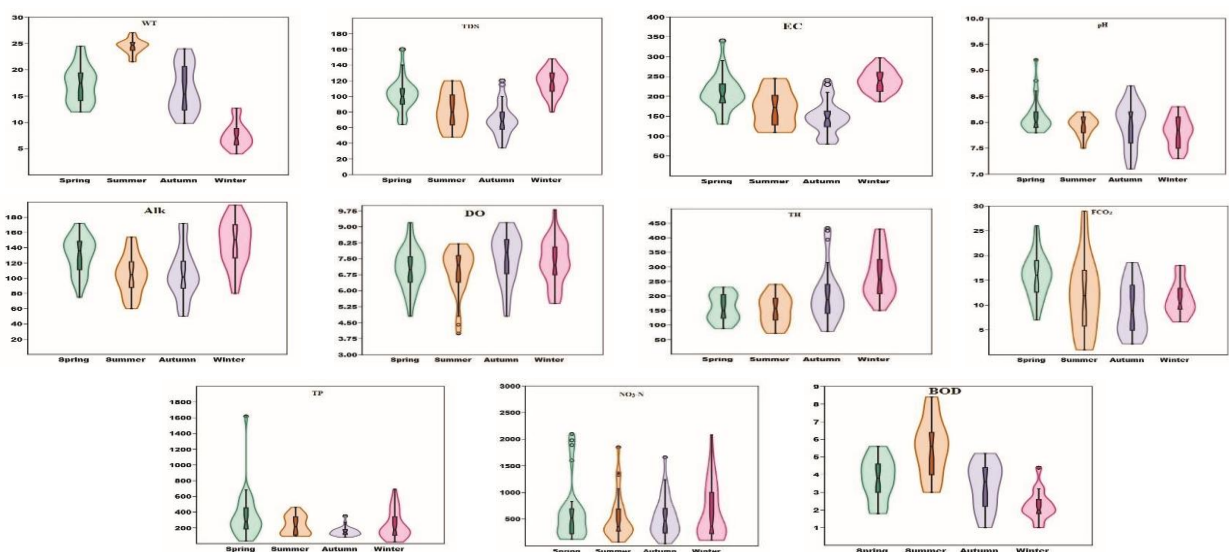


Figure 4.3: Violin and box plot analysis of water quality parameters from Dal Lake

4.4 Principal component analysis of water quality data from Dal Lake

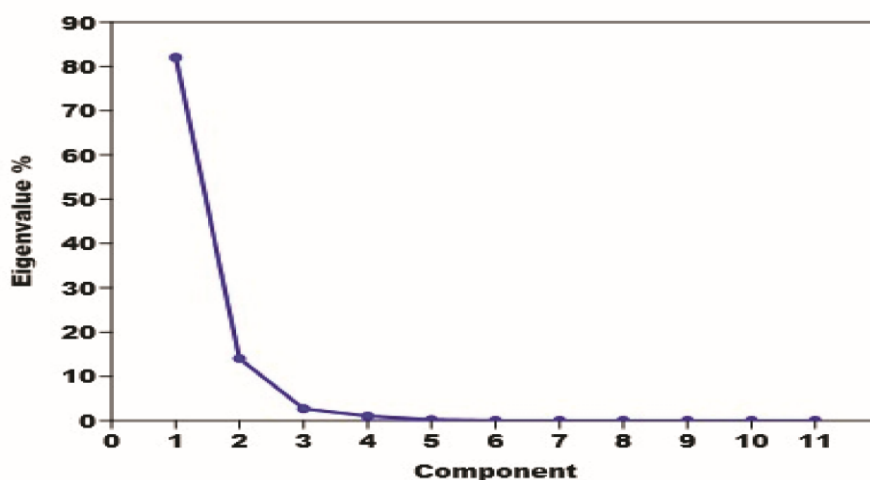


Figure 4.4: Scree plot of the eigen value of PCA for water quality parameters of Dal Lake

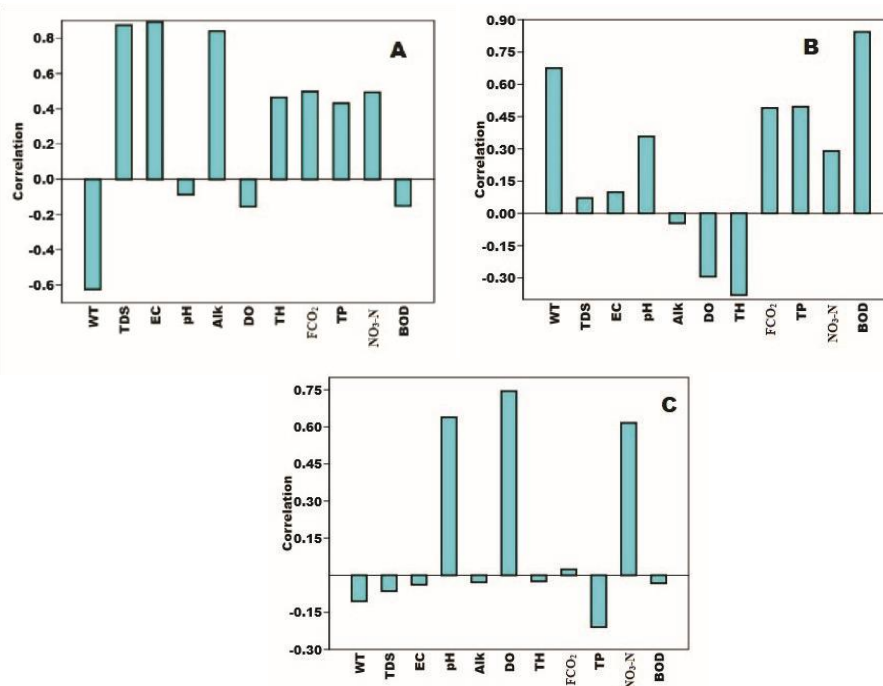


Figure 4.5: A, B and C represent the loading scores of first three principal components obtained by PCA of water quality parameters of Dal Lake.

The analysis of the data on the water quality parameters implied the use of principle component analysis, as a result of which the variables, which had the most significant impact on the water quality, were discovered. The scree plot and the loading scores are represented in figure 4.4 and figure 4.5 respectively. The loading scores reflected that PC1 had a strong positive relationship with total dissolved solids, electrical conductivity, and alkalinity with a moderate negative relationship with water temperature. On the other hand, PC2 shows a strong positive correlation with BOD and PC3 is a strong positive relationship with dissolved oxygen and moderate positive relationship with pH and nitrates.

4.5 Canonical correspondence analysis

In order to disfigure the relationship between the parameters of water quality and the structure of the fish species, the data on fish catches and water quality were subjected to canonical correspondence analysis. The analysis has indicated that the two axes, i.e, Axis 1, Axis 2, alone explained a remarkable 95.75 per cent of the observed variance in the fish assemblage of the Dal Lake. In the case of *Crossocheilus diplocheilus*, the CCA scatter plot depicts that NO₃-N, Alk, TP, TDS, EC, and FCO₂ are important environmental factors whereas in the case of *Pethia conchonius*, the determinants are BOD and WT. *Crossocheilus diplocheilus* showed a favourable response in Axis 2 and unfavourable response on Axis 1, contrary to, *Pethia conchonius* that showed positive responses on both axes. Figure 4.6 shows the relationship between aquatic environments and fish communities in the form of CCA plot.

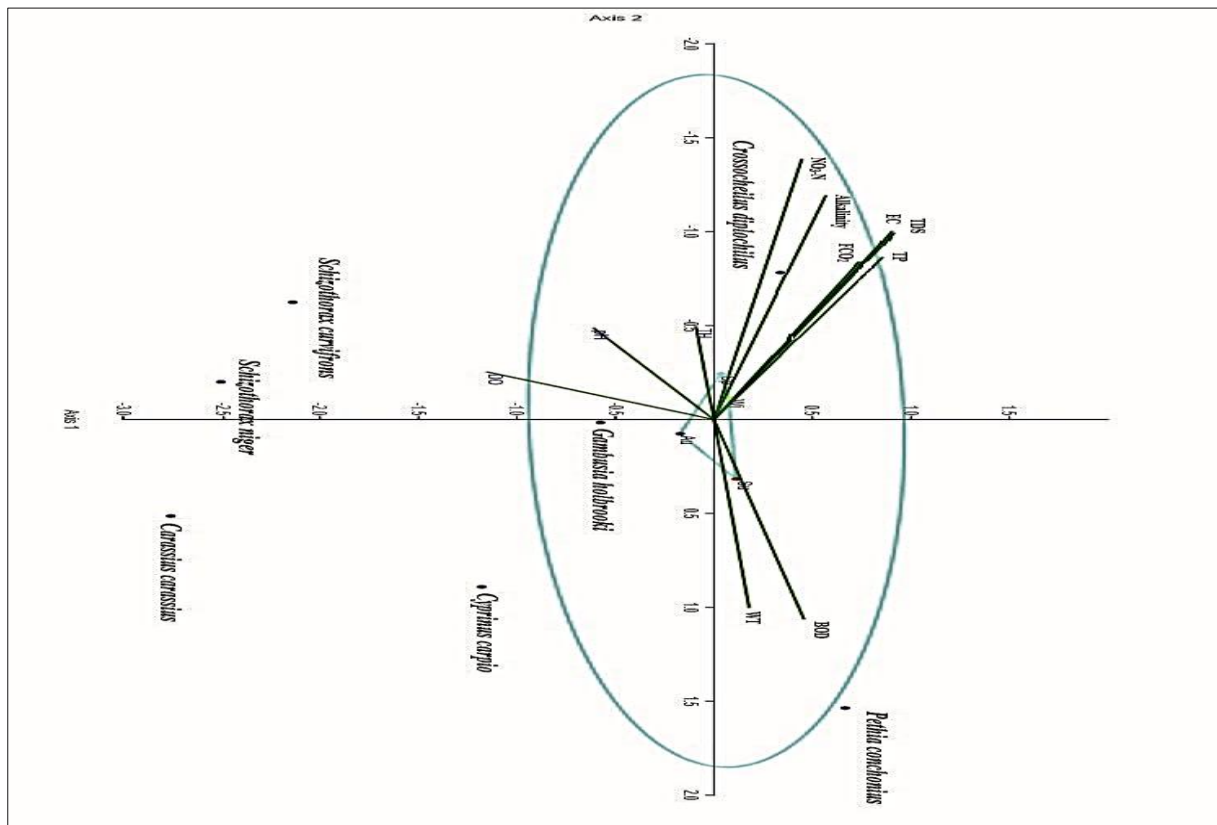


Figure 4.6: Canonical correspondence analysis (CCA) of the water quality parameters and fish assemblage of Dal Lake

5. Discussion

Conclusion of the current study will provide the general overview of the spatial and time dynamics of water quality parameters of Dal Lake and their effects to fishes, namely, *Pethia conchonius* and *Crossocheilus diplocheilus*. It has been revealed that there is much variability either in space or time which is caused by many anthropogenic and environmental factors that bring about the water quality analysis. Rashid et al. (2017) have also noted that Dal Lake is not an exception and some of the human activities that have contributed to the impairment of the water quality include domestic waste discharging, and tourism are among the factors. It is emphasized that the temperature of water, dissolved oxygen (DO), and the total dissolved solids (TDS) were also crucial parameters that determined the ecological dynamics of the lake in the past (Kumar et al., 2022). These findings are supported by the current study which expressed the fact that, even though there was no statistically significant difference between the values of certain water quality indicators, as TSS, electrical conductivity (EC), some other ones were found to vary spatially



and temporally DO, total hardness (TH) and total phosphorus (TP). These differences indicate the amounts of environmental stresses at each of the sampling sites e.g.: The pollution rates in such places as Hazratbil and Dalgate are even worse than in the relatively purer Centre place (Sabha et al., 2019). The results are comparable to the results achieved in such kinds of works and have observed that there are cases of eutrophication and excessive nutrient loads in Dal Lake especially in more urbanized areas (Saleem et al., 2015).

The parameters of water quality seasonal variation also supports the weakness of the lake to climate change and human activities. As it was noted by Bhat et al. (2022), the TDS and EC were maximal during the winter, probably because of the decreased amount of water in these seasons and variation of temperatures, whereas such parameters as pH and alkalinity did not vary significantly with the season. It was particularly notable in terms of seasonal changes in parameters like total phosphorus (TP), biochemical oxygen demand (BOD), and so on (Dey & Vijay, 2022). In one instance, the peaks of TP were observed in the spring which might be explained by the fact that more nutrients via agricultural runoff were released after the snowmelt and the consequent increased discharge of inflow streams (Qadri and Yousuf, 1980). It means that the processes of land-use, such as agriculture and urban development, are also having a direct effect on nutrient concentrations in Dal Lake, which is also reported by Ahmed et al. (2017) and Rashid et al. (2017). The elevation of the BOD in summer may be attributed to the augmentation of microbial action owing to the rise in temperature, which consequently leads to the enhancement of the microbial decomposition of organic matter contributing to the eutrophic lake even more (Ganaie et al., 2021).

In addition, correlation analysis described in Table 4.4 has indicated the existence of strong relationships among important water quality parameters. Indicatively, TDS, EC, NO₃-N, and alkalinity had positive correlations, and this fact is stated that there is always a tendency to co-vary among parameters in response to common surroundings including nutrient loading by both point and non-point sources (Parvez and Bhat, 2014). The fact that the Pearson correlation analysis revealed a significant positive relation between BOD and water temperature can also confirm the idea that the rise in temperature cause an increase in the microbial activity that increases the extent of organic matter decomposition (Kumar et al., 2022). The main component analysis (PCA) also identified the robust input of other parameters in the water quality of the lake, including TDS, EC, and alkalinity, supporting them as important eutrophication predictors in Dal Lake (Bhat et al., 2022). The canonical correspondence analysis (CCA) was used to explain 95.75 percent of the variance in fish assemblage that showed that the environmental factors such as NO₃-N, alkalinity, and total phosphorus significantly affected the distribution of fish species such as *Crossocheilus diplocheilus* and *Pethia conchonius*. This observation is in agreement with the past studies that have held the view that fish populations in Dal Lake are strongly correlated with fluctuations in water quality parameters, especially the parameters involving nutrient concentrations (Khanday, R.S.A., 2021).

The presented findings of the study are significant in the form of insights into the present-day condition of the water quality of Dal Lake, underlining the necessity of the further monitoring and management of the study conditions to be undertaken to address the spatial and time-related change in the parameters of water quality (Shah and Shah, 2013). The anthropogenic activities in question, including domestic waste discharge, agriculture, and tourism, are reflected in the degree of pollution in different areas of the lake (Bona and Lone, 2023). Besides, the seasonal variability in water quality parameters supports the importance of the lake to changes in the environment, especially climate and land use (Mushatq et al., 2013). In the future, specific measures should be taken to minimize nutrient loading, curb pollutants, and reestablish an ecological balance in Dal Lake so that the aquatic life can be sustainable and the local population will be able to receive the ecosystem services (Amin et al., 2014). Plans like enhanced waste management, tightening of agricultural runoff, and restoration of wetlands are very crucial in reducing the prevailing problems of the lake (Qadir & Singh, 2019). The results also point to the possibility of using the water quality parameters as the predictor of the ecological health that could help guide the further conservation measures that will be capable of protecting the biodiversity of Dal Lake (Mir et al., 2024).

6. Conclusion

This paper has indicated that there exist spatial and temporal changes in the water quality parameters of the Dal Lake



which affect fish species *Pethia conchonius* and *Crossocheilus diplocheilus*. The results reveal that the anthropogenic factors of the water quality have led to a severe water depletion through domestic waste, tourism, and agricultural run-offs, especially around Hazratbal and Dalgate. The differences in water quality parameters including the dissolved oxygen (DO), total phosphorus (TP), and nitrates at various seasons indicate that there is a complex interaction between the climatic conditions, land use, and human activities. In that regard, it is worth noting that the findings of the study have contributed to the importance of incessant monitoring and implementing specific interventions to regulate the nutrient loading, decrease pollution, and recover the ecological fitness of the lake. Consumerism Indicators of ecological situations, using water quality parameters as seen in this case, could be a crucial factor in movement towards the conservation of the biodiversity of Dal Lake in the future. Consequently, proper management of the waste materials, regeneration of the wetlands and tighter control of the farming activity are crucial measures towards alleviating the problems of the lake as well as making the lake sustainable to the forthcoming generation.

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