

# Assessment of seasonal variation in water quality of Dal Lake (Kashmir, India) using multivariate statistical techniques

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## Abstract

Seasonal variation in surface water quality of Dal Lake was assessed using multivariate statistical techniques. Water quality data collected from 4 sampling sites during 4 seasons was analysed for 13 parameters. Significant variation ( $p < 0.05$ ) in temperature, pH, EC, Ca, Mg, Na, K, DO, BOD<sub>5</sub>, COD, PO<sub>4</sub>-P, NH<sub>4</sub>-N and NO<sub>3</sub>-N of sampling sites during different seasons was observed. Cluster analysis grouped 4 sampling sites during 4 seasons into three clusters of similar water quality as relatively less polluted (LP), medium polluted (MP) and highly polluted (HP) sites. The principal component analysis/factor analysis applied to extract and recognize the factors responsible for water quality variations in four seasons of the year resulted in three principal components for each season accounting for 75.78%, 83.25%, 87.33% and 78.96% of total variance for winter, spring, summer and autumn seasons respectively. Parameters like NH<sub>4</sub>-N, NO<sub>3</sub>-N, BOD<sub>5</sub> and COD have strong positive loading whereas temperature and dissolved oxygen has strong negative loading. Thus, from the principal component/factor analysis it is clear that the domestic wastewaters, agricultural runoff and catchment geology play significant role in water quality variations in the Dal Lake for all the four seasons.

*Keywords: agricultural runoff, catchment geology, cluster analysis, Dal Lake, factor analysis, Kashmir valley, principal component analysis, seasons, wastewaters, water quality.*



## 1 Introduction

The quality of water at any point in a water body reflects several major influences, including the lithology of the basin, atmospheric inputs, climatic conditions and anthropogenic inputs [1]. Anthropogenic discharges constitute an invariable polluting source, while surface runoff is a seasonal phenomenon, largely affected by climate within the basin [2]. Seasonal variations in precipitation, surface run-off, ground water flow, interception and abstraction strongly affect lake volume and consequently the concentration of pollutants in a water body [3]. Human activities are major factors determining the quality of surface water through atmospheric pollution, effluent discharges, use of agricultural chemicals, eroded soils and land use [4]. These land use changes increase impervious surface resulting in storm runoff that negatively affect aquatic ecosystems and water quality [5]. Lentic systems with substantial agricultural and urban land use in their watersheds experience increased inputs and varying compositions of organic matter and nutrients mainly phosphates and nitrates from fertilizer application [6]. Hence monitoring is imperative for the sustainable management of these aquatic resources. However, with continuous monitoring generating a large and complex database of water quality [7], the application of multivariate analysis is a good technique for the interpretation of complex dataset as it allows a better understanding of the spatial variations in water quality [8].

The present study uses multivariate statistical techniques (cluster analysis, principal component analysis and factor analysis) to evaluate both similarity and differences in the physicochemical characteristics of water among the 4 basins of Dal Lake during four seasons, to discern water quality variables responsible for seasonal variation among them and to categorize them on the basis of pollution levels besides identifying the sources of pollution.

## 2 Materials and methods

### 2.1 Study area

Dal Lake, an urban lake situated towards the North-east of Srinagar, Kashmir, India, at an altitude of about 1,584 m above m.s.l, is tectonic in origin [9] and lies between 34°5'N and 34°9'N latitude and 74°50'E and 74°54'E longitude covering an area of about 11.50 km<sup>2</sup>. The lake is mainly fed by a large perennial inflow stream-Telbalnala, which drains the largest sub-catchment area of about 145 km<sup>2</sup> and contributes around 80% of the total inflow into the lake [10], and a number of small streams viz., Peshpawlnala, Shalimarnala, Merakhshanala, Harshikul situated around the shoreline besides the contribution from groundwater. The lake is divided into four basins: Hazratbal, Boddal, Nigeen and Gagribal (fig. 1). Nigeen basin is the deepest (maximum depth of about 6 m) and Gagribal basin the shallowest (maximum depth 2.5 m). The stream Telbalnala with other smaller streams enters the lake at Hazratbal basin.



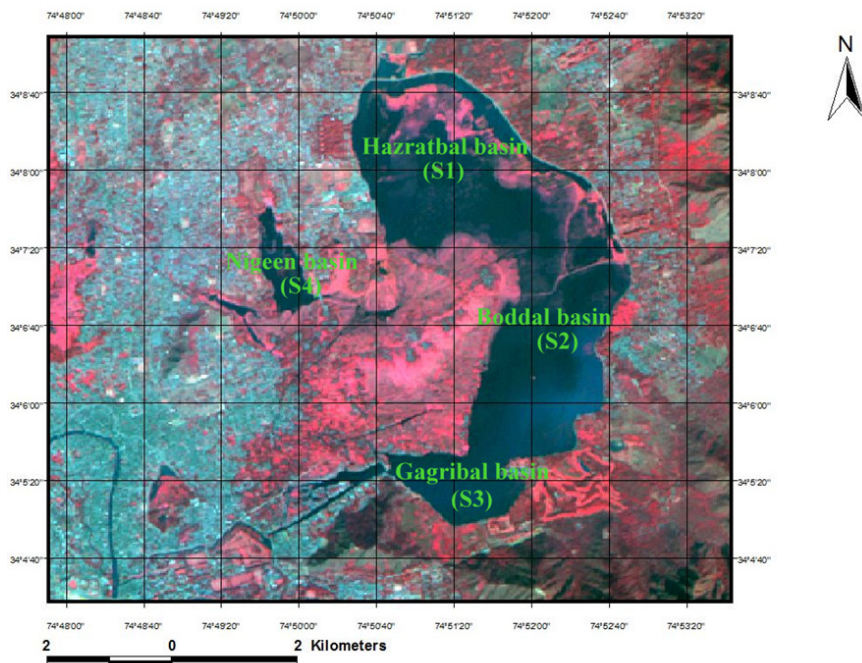


Figure 1: Outline map of Dal Lake showing sampling sites.

### 2.1.1 Sample collection and chemical analysis

Water samples were collected from the 4 sites- Hazratbal basin (S1), Boddal basin (S2), Gagribal basin (S3) and Nigeen basin (S4) every month during 2007-2009 and were kept in 1 L polyethylene plastic bottles which were prior cleaned with metal free soap, rinsed repeatedly with distilled water, soaked in 10% nitric acid for 24 hours and finally rinsed with ultrapure water. All water samples were stored in insulated cooler, taken on the same day to laboratory and kept at 4°C till further processing and analysis [11]. Water temperature (T) was measured in-situ during sample collection; pH and electrical conductivity (EC) were determined by pH meter and conductivity meter respectively. Calcium (Ca) and magnesium (Mg) concentrations were determined by the versenate method. Ammonical nitrogen ( $\text{NH}_4\text{-N}$ ) and nitrate nitrogen ( $\text{NO}_3\text{-N}$ ) was determined (spectrophotometer) by phenate method and phenyldisulphonic acid method respectively. Phosphate phosphorous ( $\text{PO}_4$ ) was determined (spectrophotometer) by molybdate method. Dissolved oxygen content (DO) and biochemical oxygen demand ( $\text{BOD}_5$ ) were determined using Winkler's method and chemical oxygen demand (COD) by dichromate method. Sodium (Na) and potassium (K) were analysed using flamephotometer.

### 2.1.1.1 Multivariate statistical methods

With the objective of evaluating significant differences among the seasons and among the sites for all water quality variables, two-way analysis of variance (ANOVA) at 0.05% level of significance was applied [12]. Lake water quality data sets were subjected to three multivariate techniques- Cluster Analysis (CA), Principal Component Analysis (PCA) and Factor Analysis (FA) [13]. All statistical analyses were performed using SPSS statistical software (Version 16) and graphs were plotted by using Sigma Plot software (Version 11.0). Bray-Curtis similarity was performed using PAST statistical software (Version 1.93).

Cluster analysis (CA) is a group of multivariate technique that classifies objects, so that each object is similar to the others in the cluster with respect to a predetermined selection criterion. Hierarchical agglomerative clustering is the most common approach, which provides intuitive similarity relationships between any one sample and the entire data set and is illustrated by a dendrogram, which provides a visual summary of the clustering processes, presenting a picture of the groups and their proximity, with a dramatic reduction in dimensionality of the original data [3].

Factor analysis (FA), which includes principal component analysis (PCA) is a technique applied to reduce the dimensionality of a dataset consisting of a large number of interrelated variables, while retaining as much as possible the variability presented in a dataset. This reduction is achieved by transforming the dataset into a new set of variables-the principal components (PCs), which are orthogonal (non-correlated) and are arranged in decreasing order of importance. Mathematically, the PCs are computed from covariance or other cross-product matrix, which describes the dispersion of the multiple measured parameters to obtain eigenvalues and eigenvectors. Principal components are the linear combinations of the original variables and the eigenvectors [14]. PCA can be used to reduce the variable numbers and explain the same amount of variance with fewer variables [15]. Factor analysis attempts to explain the correlation between the observations in terms of the underlying factors, which are not directly observable [16].

## 3 Results and discussion

### 3.1 Water quality characteristics

Physiochemical characteristics of water quality of the four sites (basins) of the Dal Lake during different seasons are given in fig. 2. The analysis of variance indicated significant variation ( $p < 0.05$ ) in temperature, pH, EC, Ca, Mg, Na, K, DO, BOD<sub>5</sub>, COD, PO<sub>4</sub>-P, NH<sub>4</sub>-N and NO<sub>3</sub>-N among the sites and among the seasons. Alkaline nature of water recorded during summer is attributed to increase in photosynthetic activity resulting in more consumption of carbon dioxide and it corroborates with earlier reports [17]. EC varied from 0.10 mS/cm at S2 during summer to 0.26 mS/cm at S1 during autumn reflecting on the nutrient load of the lake. Low value of PO<sub>4</sub>-P (166.87, 71.5, 114.5 and 114.2 µg/l), NO<sub>3</sub>-N (198.42, 147.5, 150.2 and 151.97 µg/l) and NH<sub>4</sub>-N (287.07,



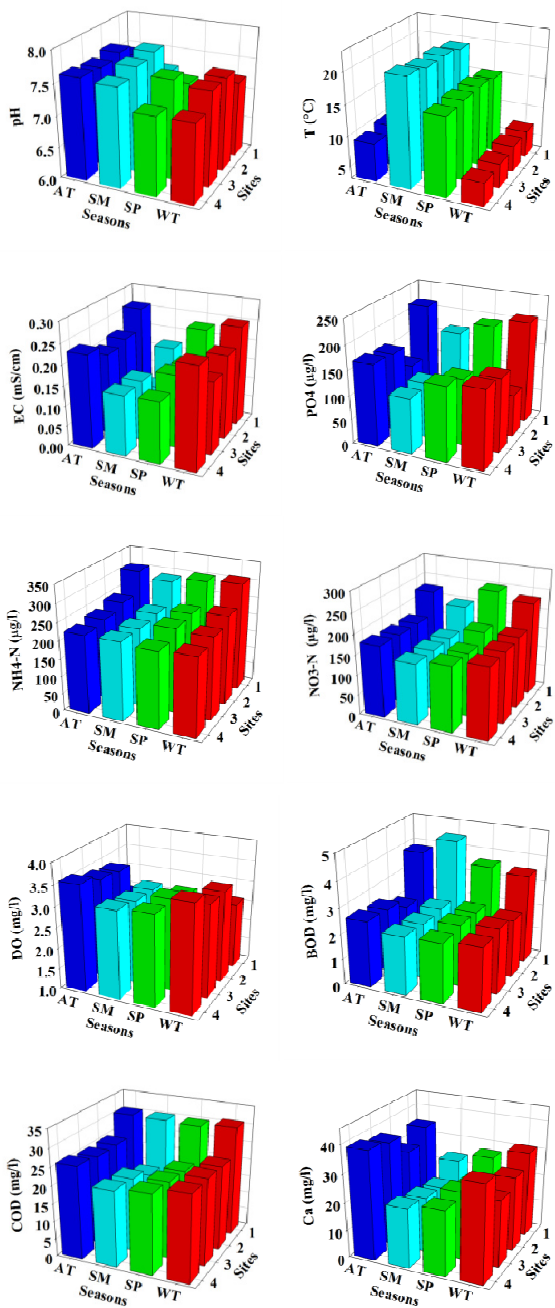


Figure 2: 3D graphs of physicochemical properties of water in the four basins (sites) of Dal Lake during different seasons.



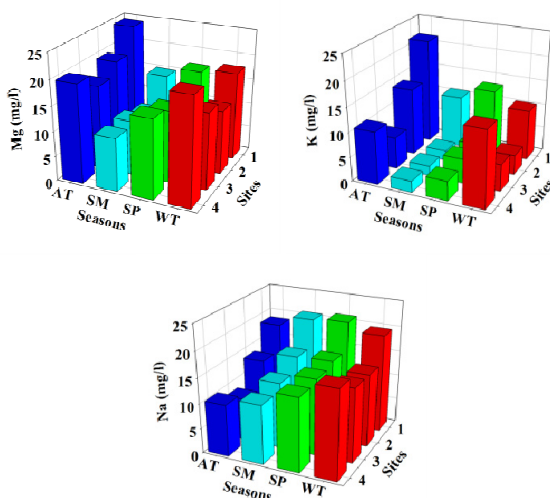


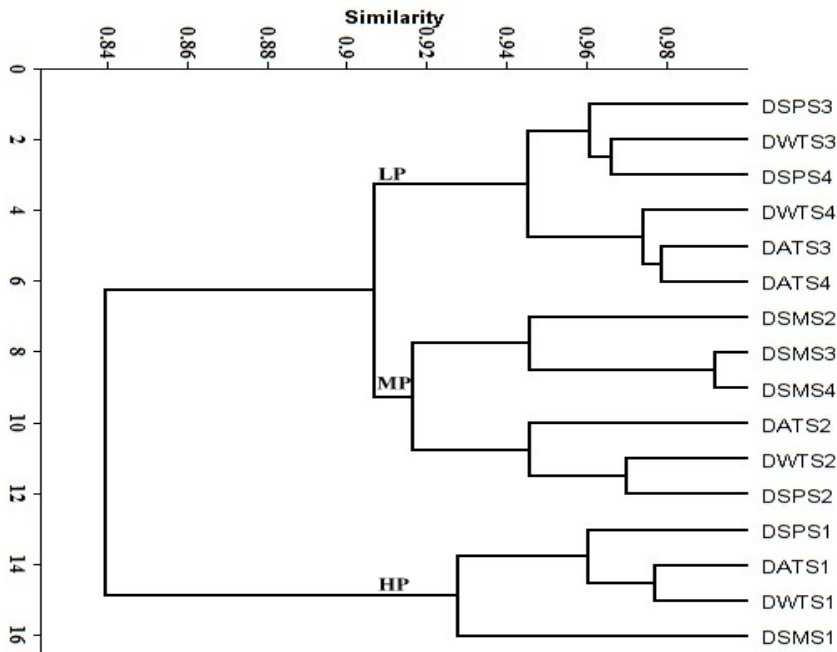
Figure 2: Continued.

227.33 and 221.1  $\mu\text{g/l}$ ) at S1, S2, S3 and S4 respectively was observed during summer, except at S4 for  $\text{NH}_4\text{-N}$  which was high during summer (223.57  $\mu\text{g/l}$ ). This is attributed to the release of wastewaters from house boats especially during summer. Low values of EC,  $\text{PO}_4\text{-P}$ ,  $\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  during summer could be attributed to the higher rate of assimilation by biota due to their peak growth [18].  $\text{BOD}_5$  and COD ranged from 2.07 mg/l at S2 during autumn to 4.47 mg/l at S1 (Hazratbal basin) during summer and 18 mg/l at S2 during summer to 31 mg/l at S1 during winter respectively. This corroborates with previous findings where COD higher in Hazratbal basin is attributed to agricultural runoff and domestic wastewater it receives [19]. Ca concentration varied from 18.5 mg/l at S2 during summer to 38.97 mg/l at S4 during autumn. Mg and K concentrations varied from 9.67 mg/l and 2 mg/l at S2 during summer to 24.25 mg/l and 21.5 mg/l at S1 during autumn respectively. However Na concentration was low (8.46 mg/l) at S3 during autumn and was 21.24 mg/l at S1 during spring. Among these Ca is the most dominant cation which is attributed to the predominance of lime rich rocks in the catchment area [20].

### 3.1.1 Cluster analysis

Cluster analysis resulted in a dendrogram (fig. 3) grouping all the four sampling sites during four seasons into three statistically significant clusters. Since we used hierarchical agglomerative cluster analysis, the number of clusters is decided by water quality. Site DATS4, DATS3, DWTS4, DSPS4, DWTS3 and DSPS3 form cluster 1 which comprises low polluted sites (LP). Site DSPS2, DWTS2, DATS2, DSMS4, DSMS3 and DSMS2 forming cluster 2 correspond as moderately polluted sites (MP) that receive agricultural runoff. Cluster 3 (DSMS1, DWTS1, DATS1 and DSPS1) corresponds to highly polluted sites

(HP), which receive domestic wastewaters, in addition to agricultural runoff. From the dendrogram it is clear that cluster 3 (Site 1) representing Hazratbal basin is the highly polluted basin of the Dal Lake during all the seasons, where as Nigeen and Gagribal basins (Site 3 and 4) are the least polluted ones. Boddal (Site 2) remains as a moderately polluted basin during all seasons. Though Gagribal (Site 3) and Nigeen (Site 4) remain as less polluted basins during spring, winter and autumn, they gets shifted to moderately polluted during summer (cluster 2). Since these two basins of the Dal Lake harbour the tourist house boats during peak summer tourist season, the release of waste water from these house boats results in higher pollution load of these basins during summer.



DWTS=Dal Winter Site, DSPS=Dal Spring Site, DSMS=Dal Summer Site, DATS =Dal Autumn Site, S1=Site1, S2=Site 2, S3=Site 3, S4=Site 4

Figure 3: Dendrogram of cluster analysis for sampling sites during different seasons based on the quality of surface water of Dal Lake.

### 3.1.1.1 Principal component analysis/factor analysis

Principal component analysis/factor analysis resulted in identification of significant water quality parameters. An eigenvalue greater than 1 considered significant [1] was taken as criterion for extraction of principal components required to explain the variance in the data. The different factors, total variance cumulative variance and component loadings for the three components derived from the PCA for different seasons are given in table 1. This analysis led to the

explanation of 75.78%, 83.25%, 87.33% and 78.96% variance in case of winter, spring, summer and autumn respectively. Factor loadings were classified [21] as “strong,” “moderate” and “weak,” corresponding to absolute loading values of  $>0.75$ ,  $0.75-0.50$  and  $0.50-0.30$ , respectively.

Biplots (1+2 components) of factor loading during different seasons are given in fig. 4. For the data set pertaining to winter season, among the three PCs, PC1 explaining 31.81% of the total variance has strong positive loading on  $\text{NH}_4\text{-N}$ ,  $\text{BOD}_5$ , COD,  $\text{NO}_3\text{-N}$  and strong negative loading on DO. PC1 signifies organic

Table 1: Seasonal factor loading values and explained variance of water quality of Dal Lake during different seasons.

Winter				Spring			
Parameter	PC1	PC2	PC3	Parameter	PC1	PC2	PC3
$\text{NH}_4\text{-N}$	0.89	-0.14	0.07	$\text{NH}_4\text{-N}$	0.82	0.33	0.19
$\text{BOD}_5$	0.90	-0.03	0.28	$\text{BOD}_5$	0.76	0.55	0.05
Ca	0.15	-0.26	0.84	Ca	0.71	-0.35	0.54
COD	0.81	-0.35	0.36	COD	0.88	0.29	0.14
DO	-0.84	0.16	0.16	DO	-0.25	-0.86	0.07
EC	-0.01	0.87	0.01	EC	0.12	0.51	0.72
K	-0.08	0.40	0.46	K	0.75	0.57	0.16
Mg	-0.01	0.26	0.77	Mg	0.84	0.00	0.04
Na	0.39	-0.35	0.70	Na	0.94	-0.13	0.19
$\text{NO}_3\text{-N}$	0.80	0.48	-0.03	$\text{NO}_3\text{-N}$	0.47	0.77	0.09
pH	-0.06	-0.87	0.24	pH	0.14	-0.78	-0.30
$\text{PO}_4$	0.53	0.54	0.17	$\text{PO}_4$	0.02	0.73	-0.10
T	0.18	-0.65	0.16	T	-0.26	0.09	-0.90
Eigenvalues	4.54	3.33	1.97	Eigenvalues	6.59	2.85	1.37
Tot. vari. (%)	31.81	25.44	18.51	Tot. vari. (%)	39.5	29.11	14.62
Cum. vari. (%)	31.81	57.26	75.78	Cum. vari. (%)	39.5	68.62	83.25

Summer				Autumn			
Parameter	PC1	PC2	PC3	Parameter	PC1	PC2	PC3
$\text{NH}_4\text{-N}$	0.95	0.18	-0.10	$\text{NH}_4\text{-N}$	0.91	0.22	0.08
$\text{BOD}_5$	0.91	0.31	-0.00	$\text{BOD}_5$	0.89	0.12	0.32
Ca	0.05	0.85	0.41	Ca	0.17	-0.55	0.21
COD	0.79	0.44	0.29	COD	0.83	-0.03	-0.29
DO	-0.97	-0.17	-0.03	DO	-0.95	-0.12	0.02
EC	0.33	0.85	-0.01	EC	-0.05	0.80	0.01
K	0.86	0.24	0.16	K	0.45	0.62	-0.09
Mg	0.77	0.02	0.39	Mg	0.71	0.57	0.19
Na	0.85	0.11	0.23	Na	0.41	0.81	0.00
$\text{NO}_3\text{-N}$	0.91	0.38	0.06	$\text{NO}_3\text{-N}$	0.79	0.26	0.44
pH	-0.25	-0.76	0.01	pH	-0.39	-0.82	-0.09
$\text{PO}_4$	0.75	0.41	-0.29	$\text{PO}_4$	0.62	0.04	0.62
T	-0.12	-0.14	-0.96	T	0.05	0.11	-0.92
Eigenvalues	8.32	1.73	1.29	Eigenvalues	6.61	2.26	1.38
Tot. vari. (%)	53.81	21.74	11.77	Tot. vari. (%)	41.03	24.61	13.31
Cum. vari. (%)	53.81	75.55	87.33	Cum. vari. (%)	41.03	65.64	78.96

Tot. vari. = Total variance, Cum. var. = Cumulative variance.







three PCs, the PC1 explaining 41.03% of the total variance has a strong positive loading on  $\text{NH}_4\text{-N}$ ,  $\text{BOD}_5$ , COD and  $\text{NO}_3\text{-N}$ , whereas strong negative loading on DO. PC1 represents organic pollution from wastewater [30]. PC2 is explaining 24.61% of total variance, has strong positive loading on Na, EC and strong negative loading on pH. Decomposing macrophytes have been linked with positive loading of Na and negative loading of pH [31]. Thus PC2 represents autochthonous factor. PC3, explaining 13.31% of total variance, has strong negative loading on T. Negative loading of T during autumn has been associated with seasonal variation [32]. PC3 represents seasonal variation. Thus from the principal factor analysis/component it is clear that the organic pollution from domestic wastewaters, seasonal variation, agricultural runoff and catchment geology are significant factors that contributed to water quality variations in four seasons.

## 4 Conclusion

Hierarchical cluster analysis grouped four sampling sites during four seasons into three clusters (LP, MP and HP) with similar water quality features. Inputs from domestic wastewaters and agricultural runoff are mainly responsible for high pollution levels at Hazratbal basin. Boddal basin is moderately polluted whereas Nigeen and Gagribal basins are less polluted basins. PCA/FA identified latent factors as  $\text{NH}_4\text{-N}$ ,  $\text{NO}_3\text{-N}$ ,  $\text{BOD}_5$ , COD, DO and T explaining 75.78%, 83.25%, 87.33% and 78.96% of total variance for winter, spring, summer and autumn seasons respectively, standing for domestic wastewaters, seasonal variation, agricultural runoff and catchment geology. Thus the existence of Dal Lake is threatened and implementation of environmental management plan for its restoration is warranted.

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