

# Application of Remodeled Water Quality Indices and Multivariate Statistical Methods for the Appraisal of Water Quality in a Himalayan Lake

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## Research Article

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## Abstract

This study demonstrates and analyses spatio-temporal changes and trends of 15 water quality parameters that were arbitrated from the samples collected at 11 sampling locations during the water quality monitoring across the Dal Lake from September 2017 to August 2020. Further a revised WQI (named  $WQI_{min}$ ) was developed contingent on multiple regression modeling comprising six key parameters ( $NH_4-N$ , DO, COD, WT, TUB and  $NO_3-N$ ) so as to ease the course of action and lessen the systematic costs of the water quality assessment. The results signify that the general mean WQI value 81.9 and seasonal average WQI values ranges from 79.44 to 84.55. The quality of water showed seasonal variance, with lowest values in summer, succeeded by autumn and winter, and highest in spring. Moreover, the suggested  $WQI_{min}$  model contingent on the selected six critical parameters displayed execution in the evaluation of Dal Lake's water quality with  $R^2 = 0.99$ , RMSE value (5.48) and PE value of 6.34%. This manifested that the developed  $WQI_{min}$  model can be convenient and efficacious implement to control and determine Dal Lake's water quality. Further results showed that most of the nutrients were above the threshold value during the monitoring period, which is the leading cause of eutrophication at some places in the lake.

## Introduction

The most plentiful and copious commodity in nature is water, even though it is exploited as well. The easy availability and rentability of surface water have made it liable to pollution because of its handiness in disposal of wastewater and pollutants. Surface water is also debased due to some natural processes and anthropogenic forces which culminates into defacement and impairment of this water for industrial, drinking, recreation, agricultural and other purposes (Todd et al., 2012). Thus, a substantial need to evaluate surface water quality arises which results due to increased comprehension in public health, regarding the significance of water quality for portable use and source water quality in marine and aquatic life (Ouyang., 2005). Moreover, for systematic management and treatment of water resources, discernment and measurably assessing the trend of spatiotemporal variation in water quality becomes crucial (Wang et al., 2015). To indicate the acceptability and suitability of water for human consumption, the term "water quality" has been formulated which is further used in normative documents and various scientific publications that relate to the prerequisites for water resources "strategic" and "excellent" management (Parparov et al., 2006). In an aquatic ecosystem, water quality characteristics plays a pivotal role in determining water quality. Hence the difficulties related with examining the huge number of parameters and high variability due to natural and anthropogenic factors become the problem for the water quality monitoring ( Simeonov et al., 2002;Boyacioglu., 2006).

Water Quality data can be inspected by a number of methods that work according to the nature of samples, area of the study location and on the informational objective (Stigter et al., 2006). The large-scale research in this field has been conducted which is stipulated by a number of procedures developed for modeling, interpretations and categorization of monitoring data (Hamid et al., 2016). Water quality's traditional monitoring approaches are related to comparing the observed parameters with local prescriptive levels, which results in providing limited details on the comprehensive water quality (Pesce and Wunderlin., 2000). Water Quality Index is an ingenious way to help envisage and examine the issues pertaining to the quality of water. Proposed by Horton in 1965, for aquatic ecosystem evaluation, by appropriating ten most frequently applied water quality parameters like pH, alkalinity, DO, chloride, conductance etc. Horton. (1965) and since then it is extensively used and accepted in Asian, European, and African nations. With a global vision, the information of freshwater quality in recent years is easily acquired, through the WQI which is favorably used in determining the water quality of freshwater systems (Kannel et al., 2007; Banerjee and Srivastava., 2009; Avigliano and Schenone., 2016; Varol., 2020). WQI is considered as a practical approach which focuses on the important physicochemical parameters which in turn constitute the pollution status in a water body (Simoes et al., 2008). For WQI concept, in current times, many modifications and alterations have been contemplated via various experts and scientists (Dwivedi., 1997; Bhargava., 1998). Several national and international organizations have formulated a great number of Indices, like Brown's Water Quality Index, CCMEWQI, TWO-TIER WQI and Oregon Water Quality Index. And for the assessment of water quality in specific areas, these WQI's have been applied ( Dojlido et al., 1994;Lumb et al., 2002;Effendi et al., 2015;Sener et al., 2017;Zotou et al., 2020). Bascaron WQI developed by bascaron in 1979 has also been broadly used in many developing countries to monitor water quality of rivers and lakes because of the flexibility it offers in

weight adjustment and parameter selection. (Pesce and Wunderlin., 2000;Kannel et al., 2007;Wu et al., 2018). Besides, the indices also depend on the nature of water quality variables and their varying numbers as contrast to the respective levels and standards of a certain region. Thus, it is important to develop a modified WQI by taking into consideration the analytical cost and the time taken in examining the large number of parameters, so as to reduce the unnecessary parameters and hence lessen the analysis cost. Furthermore, high correlations between the WQI values based on reduced set of variables and actual WQI results have also been delineated, suggesting the suitability of WQI<sub>min</sub> model to describe and assess the changes in the water quality more affordably and effectually (Sanchez et al., 2007;Wu et al., 2018;Nong et al., 2020).

Dal Lake situated in Srinagar, considered as the most developed regions in the Union Territory of Jammu and Kashmir, becomes important both in terms of economic role besides providing portable water for the adjacent locality and hence in relation to ecological impact issues and its safe water quality, it has drawn huge controversy and discussion ever so often. In 1997, government of Jammu and Kashmir formed Lakes and Waterways development authority - an autonomous body to serve as an independent organization to look, run and preserve the Dal Lake's ecosystem in addition to other water bodies in the region. For national interest, various studies on Dal Lake have been carried out which has mostly focused on physical, chemical and biological variables also few have studied the land use influences (Najar et al., 2011;Basharat et al., 2013;Javaid et al., 2017;Rather and Dar., 2020). Furthermore, some studies have also labelled and determined the spatial-temporal changes in water quality of Dal Lake (Rather and Dar., 2020;Ahmad et al., 2020). Nonetheless, more studies are still necessary in this regard, for mentioned reasons: associated research were mainly carried out to examine the physio-chemical parameters of the Dal Lake and compare with the local standard and quality values. Some studies partly focused on drinking water quality index whereas comprehensive analysis, examinations and evaluation of the general surface water quality were seldom reported or outlined (Yawar et al., 2016). Some results, due to small data sets, had limitations in evaluation of the projects overall water quality (Mudasir et al., 2017). Additionally, there was no investigation in checking the critical water quality variables that largely affect the Dal Lake's water quality. Taking into account the mentioned aspects and gaps, 15 water quality parameters were selected by us, measured on a monthly basis, from the 11 water quality observation stations of Dal Lake from September 2017 to August 2020 to carry out a research on Dal Lake's water quality. The aim and objectives of the research were (1) to assess and illustrate the spatial-temporal water quality variations in each basin of the lake (2) to carry an extensive assessment of the water quality by applying WQI approach and (3) to perceive the crucial water quality variables and hence develop a WQI<sub>min</sub> model for elementary and economical water quality estimation.

## Materials And Methods

### Description of Study Area

The Dal Lake is located at an altitude of 1583m above mean sea level, in Srinagar city at 34°5' N and 74°50' E coordinates and is also the second largest lake in the union territory of Jammu and Kashmir (Rather and Dar., 2020). Four basins mainly encompass the Dal Lake comprising of Hazratbal basin, Nishat basin, Gagribal basin and Nigeen basin. Although among these, the Nigeen basin is taken as a separate lake as it is also linked and connected to Gilsar Lake through Nallah Amir Khan channel Unni K.S. (2002) and thereby in this study, Nigeen basin is not included. The total catchment area of Dal Lake is 337.17 sq km. which formulates about twenty times more than the area of the lake. A large perennial inflow channel, Telbal nallah, feeds the lake normally, it is a stream which comes from the Marsar Lake high up in the mountains draining the largest sub-catchment area of about 145 km<sup>2</sup> and puts up about 60–70% of the total inflow to the lake. There are also other smaller streams around the shore line that feeds the lake viz., Boutkal, Merakhsha nallah, Peshpaw nallah, etc., in addition to some contribution and benefaction from the groundwater. At Harzratbal Basin, the Telbal nallah with other small streams enters the lake, and finally from Gagribal basin drains into the river Jhelum. Dal lacks in depth, is a shallow, multi-basin lake with an area of about 25.76 sq. km, out of which open water area is not more than 16.78 sq. km. According to the recent estimations, each year about 327 million cum of water flow into the lake ecosystem out of which 270.34 million cum leave the lake through two outflow channels, and 25.92 cum are drawn and used for drinking purposes and the rest is lost through seepage, evapotranspiration, and suction dredging (Vision Document., 2018).

To understand and keep the track of the variations in water quality of Dal Lake in real-time, the Lakes and Waterways Development Authority, Government of Jammu & Kashmir (LAWDA) has built 11 water quality monitoring stations across the lake to collect and examine water samples on monthly basis. Increased comprehensive and in-detail particulars of these monitoring stations and their locations are laid out in Table. S1, (supplementary data)

Specimen measurement and collection of data:

The water quality data used in this project was procured from head of research laboratory Lakes and Waterways Development Authority (LAWDA) with official consent. The collected water samples are obtained from 11 water quality monitoring locations, on monthly basis, from September 2017 to August 2020 by officials of the research wing of LAWDA. The collection and the procedure used for sample assessment were according to the Standard Methods for the Examination of Water and Wastewater (APHA., 1995). Moreover, using a portable GPS system, geographic coordinates of sampling sites were noted down. A total of 15 parameters were studied which include pH, Electrical Conductivity ( $\mu\text{S}/\text{cm}$ ), water temperature (WT,  $^{\circ}\text{C}$ ), Turbidity (NTU), dissolved oxygen (DO, mg/L), Chemical oxygen demand (COD, mg/L), Ammoniacal-Nitrogen ( $\text{NH}_4\text{-N}$ , mg/L), Nitrate-Nitrogen ( $\text{NO}_3\text{-N}$ , mg/L), Total Phosphorus (TP, mg/L), Chlorides (Cl, mg/L), Ortho-Phosphate (OP, mg/L), Iron (mg/L), Calcium (Ca, mg/L), Sulphates ( $\text{SO}_4$ , mg/L) and Magnesium (Mg, mg/L). For each month, the sampling dates at all stations were pick out and organized by research team, and was established on weather conditions, making certain that the water samples collected were specifically done on clear or overcast days in order to cut back on the intercession of rainfall and other precipitations with subsequent data. The samplings were acquitted at the center and along the boundaries in each basin of the lake with 15-20cm depth at each location, below the water surface. EC, pH and WT were determined on-site with multi-parameter instruments. However, a separate DO bottles was used for fixing the DO on site ( modified Winkler's method) and were kept in travel ice boxes filled with ice packs ( $0-4^{\circ}\text{C}$ ). Further, for remaining parameters samples were collected in plastic bottles wherein these bottles were pre washed ( $> 750 \text{ mL}/\text{sample}$ ) and within 6 hours moved the samples straight away to the nearby situated research laboratory for additional examination. Permanent markers were used to label the site description on the bottles for all the samples in order to prevent misjudgment. More details of the chemical methods and instruments used and operated during analysis are recorded in Table.S2, (supplementary data).

Water Quality Index

The Eq. (1) is used to study and analyze the calculations for Water Quality Index, that was filtered and suggested by (Pesce and Wunderlin in 2000) as follows:

$$\text{WQI} = \frac{\sum_{i=1}^n (C_i P_i)}{\sum_{i=1}^n P_i} \quad (1)$$

where n is used to show the aggregate parameters involved in the research,  $C_i$  is used to depict the standardized value of  $i^{\text{th}}$  parameter, and weight of  $i^{\text{th}}$  parameter is denoted by  $P_i$ . The value of  $P_i$  varies from 1 to 4 depending on the effect of parameter on water quality (Table.3) and in previous studies, these values have been substantiated and verified (Kannel et al., 2007; Zhao et al., 2013; Wu et al., 2018). WQI value varies from 0 and 100, where the good water quality conditions are being represented by the high values. Based on the WQI scores there are five levels on which water quality is classified : a) bad (0–25), low (26–50), moderate (51–70), good (71–90) and excellent (91–100) (Dojlido et al., 1994; Jonnalagadda and Mhere., 2001). The WQI value was calculated every month at each monitoring station and was averaged down to obtain a final value. The  $\text{WQI}_{\text{min}}$  model, based on the critical parameters, is formed in order to promote easy and low-cost water quality assessment approach for Dal Lake that is selected by the stepwise multiple linear regression analysis and then calculated using Eq. (1). The parameter weights are fully considered here in the  $\text{WQI}_{\text{min}}$  model as opposed to traditional non weighted models since it performs better which are verified by studies ( Wu et al., 2018; Xizhi et al., 2020). The seasons autumn, winter, spring and summer as defined in this study analogous to periods from September to November, December to February, March to May, and June to August, respectively. Thus, the calculation for the seasonal WQI values for each basin of the lake was also carried out.

In the previous studies, in order to examine the water quality trends, the Mann-Kendall trend analysis is broadly applied (walker, 1991; Helsel and Hirsch., 1992; Jaagus., 2005; Misaghi et al., 2005). Computational procedure of the Mann-Kendall analysis was explained in (Mann., 1945) in detail. In Figure-2, different trends of water quality parameters have been exemplified from the results of Mann-Kendall test, as seen in this study. To test the normal distribution of water quality data, one-sample Kolmogorov-Smirnov test was carried out, and also Bartlett's test was done to check the homogeneity of variance prior to the statistical analysis. One-way (ANOVA) was carried out so as to decide if there are significant spatial variation in water quality parameters Table.2 (Varol., 2020). A statistical software R was used to carry out both the M.K test as well as ANOVA, via specific library functions. In this study, the  $WQI_{min}$  models for the Dal Lake were set and established using the following steps: (1) In order to obtain the critical water quality variables for  $WQI_{min}$  model, WQI value and  $C_i$  for every month at each monitoring station from (2017–2018) to (2018–2019) were appraised as “training data”. (2) then  $WQI_{min}$  was tested and evaluated for each station in (2019–2020) through coefficient of determination ( $R^2$ ), Root Mean Square Error (RMSE) and the Percentage Error (PE) (Nong., 2020). To encounter homogeneity of variance and normality conditions the data was log transformation (i.e.,  $\log(x + 1)$ ) before stepwise multiple linear regression analysis. OriginPro 2019 was used for the graphical abstracts.

## Results

### Water quality attributes

### Biological, physical and chemical parameters (WT, pH, DO, WT, COD and Turbidity)

The annual average concentrations of various water quality parameters are shown in Table 1. Basin wise mean concentrations, the monitoring location concentrations and the trend of 14 water quality variables in Dal Lake, are respectively shown in Table 2, Figures. 1 and 2. One way ANOVA tests showed that all parameters except water temperature and COD varied significantly among the 3 basins of the lake Table 2.

Table 1

Contrast of the changes in water quality variables of the Dal Lake from 2017–2018 to 2019–2020 (Avg.: Average; S.D.: Standard deviation; Max.: Maximum; Min.: Minimum.).

Parameters	Threshold*	2017–2018			2018–2019			2019–2020		
		Avg ± S.D	MAX	MIN	Avg ± S.D	MAX	MIN	Avg ± S.D	MAX	MIN
WT	N/A	17.246 ± 7.68	30	3.8	18.51 ± 8.37	30	3.8	18.33 ± 8.08	29	4
EC	N/A	265 ± 46.38	450	155	251 ± 30.32	382	196	225 ± 24.35	350	128
PH	6.5–8.5	8.04 ± 0.154	8.4	7.5	8.00 ± 0.21	8.4	7.3	8.01 ± 0.163	8.8	7.3
DO	6	6.7 ± 0.53	7.8	4.5	7.1 ± 0.58	8.7	4.3	6.8 ± 0.58	7.9	4
COD	10	20.36 ± 4.19	31	11	22.96 ± 6.03	42	10	18.26 ± 4.18	32	10
TURB	5	4 ± 1.99	15	1	3 ± 1.83	15	1	5 ± 2.09	18	1
NO <sub>3</sub> -N	45	0.472 ± 0.051	0.705	0.250	0.462 ± 0.034	0.565	0.347	0.511 ± 0.037	0.600	0.325
NH <sub>3</sub> -N	0.5	0.313 ± 0.148	1.26	0.086	0.241 ± 0.125	1.40	0.096	0.265 ± 0.120	1.31	0.101
TP	0.05	0.648 ± 0.223	2.38	0.250	0.618 ± 0.160	1.38	0.262	0.622 ± 0.169	1.5	0.293
OP	N/A	0.228 ± 0.090	0.792	0.084	0.186 ± 0.068	0.481	0.098	0.163 ± 0.028	0.485	0.072
Iron	0.3	0.295 ± 0.066	0.702	0.190	0.285 ± 0.055	0.473	0.128	0.314 ± 0.051	0.580	0.205
Chlorides	250	35.6 ± 5.78	65	20	38.8 ± 3.69	62	32	37.62 ± 4.48	65	29
Calcium	75	36.81 ± 3.09	48	29	37.91 ± 2.63	49	32	37.6 ± 2.72	48	30
Magnesium	30	4.17 ± 0.54	6	2.9	4.09 ± 0.47	6.5	3.3	4.22 ± 0.49	7	3
Sulphates	200	34.45 ± 4.70	52	24	36.7 ± 3.21	50	28	37.55 ± 3.66	59	29

\*Standards from the Environmental Quality Standards for Surface Water BIS/WHO and US EPA

Table 2  
Mean values of water quality parameters in different Basins of the Dal Lake and results of ANOVA.

		Basin			Significance test	
Variable	Unit	Hazratbal	Nishat	Gagribal	<i>F</i>	<i>P</i>
		Mean	Mean	Mean		
Ph		7.9 <sup>a</sup>	8.05 <sup>b</sup>	8.1 <sup>b</sup>	10.96	0.000
WT	°C	17.20	18.57	17.96	0.085	0.919
DO	mg/L	6.52 <sup>a</sup>	6.96 <sup>b</sup>	7.13 <sup>b</sup>	18.72	0.000
EC	μS/cm	269 <sup>a</sup>	240 <sup>b</sup>	232 <sup>b</sup>	31.43	0.000
TURB	NTU	6 <sup>a</sup>	3 <sup>b</sup>	3 <sup>b</sup>	32.29	0.000
NO <sub>3</sub> -N	mg/L	0.452 <sup>a</sup>	0.461 <sup>a</sup>	0.500 <sup>b</sup>	35.63	0.000
NH <sub>4</sub> -N	mg/L	0.012 <sup>a</sup>	0.125 <sup>a</sup>	0.050 <sup>b</sup>	13.94	0.000
TP	mg/L	0.755 <sup>a</sup>	0.600 <sup>b</sup>	0.535 <sup>b</sup>	22.32	0.000
OP	mg/L	0.228 <sup>a</sup>	0.187 <sup>b</sup>	0.165 <sup>b</sup>	15.91	0.000
IRON	mg/L	0.345 <sup>a</sup>	0.301 <sup>b</sup>	0.248 <sup>c</sup>	25.98	0.000
Cl	mg/L	40.47 <sup>a</sup>	37.32 <sup>b</sup>	34.63 <sup>c</sup>	31.66	0.000
SO <sub>4</sub>	mg/L	40.05 <sup>a</sup>	36.18 <sup>b</sup>	32.47 <sup>c</sup>	80.351	0.000
COD	mg/L	21.71	20.62	19.26	3.052	0.061
Ca	mg/L	39.6 <sup>a</sup>	37.4 <sup>b</sup>	34.5 <sup>c</sup>	26.39	0.000
Mg	mg/L	4.47 <sup>a</sup>	4.16 <sup>b</sup>	3.87 <sup>c</sup>	14.73	0.000

Values with different superscript letters in the same rows, for each variable, indicate statistical differences among sites at  $p < 0.05$  (Tukey's test).

Table 3

Parameters included in the water quality index calculation, relative weights and normalization factor.

Parameters	P <sub>i</sub>	Normalization factor (C <sub>i</sub> )										
		100	90	80	70	60	50	40	30	20	10	0
Water Temperature	1	21/16	22/15	24/14	26/12	28/10	30/5	32/0	36/-2	40/-4	45/-6	> 45/ <-6
pH	1	7	7-8	7-8.5	7-9	6.5-7	6-9.5	5-10	4-11	3-12	2-13	1-14
Turbidity	2	< 5	< 10	< 15	< 20	< 25	< 30	< 40	< 60	< 80	≤ 100	> 100
Conductivity	1	< 750	< 1000	< 1250	< 1500	< 2000	< 2500	< 3000	< 5000	< 8000	< 12,000	> 12,000
Dissolved oxygen	4	≥ 7.5	> 7	> 6.5	> 6	> 5	> 4	> 3.5	> 3	> 2	≥ 1	< 1
COD	3	< 5	< 10	< 20	< 30	< 40	< 50	< 60	< 80	< 100	≤ 150	> 150
Ammoniacal Nitrogen	3	< 0.01	< 0.05	< 0.1	< 0.2	< 0.3	< 0.4	< 0.5	< 0.75	< 1	≤ 1.25	> 1.25
Nitrate Nitrogen	2	< 0.5	< 2	< 4	< 6	< 8	< 10	< 15	< 20	< 50	≤ 100	> 100
Total phosphorus	1	< 0.01	< 0.02	< 0.05	< 0.1	< 0.15	< 0.2	< 0.25	< 0.3	< 0.35	≤ 0.4	> 100
Ortho-Phosphate	1	< 0.16	< 1.60	< 3.20	< 6.40	< 9.60	< 16	< 32	< 64	< 96	≤ 160	> 160
Calcium	1	< 10	< 50	< 100	< 150	< 200	< 300	< 400	< 500	< 600	≤ 1000	> 1000
Magnesium	1	< 10	< 25	< 50	< 75	< 100	< 150	< 200	< 250	< 300	≤ 500	> 500
Chloride	1	< 25	< 50	< 100	< 150	< 200	< 300	< 500	< 700	< 1000	≤ 1500	> 1500
Sulphate	2	< 25	< 50	< 75	< 100	< 150	< 250	< 400	< 600	< 1000	≤ 1500	> 1500
Measured NO <sub>3</sub> -N values were converted from mg N/l to mg NO <sub>x</sub> /l prior to using the cited normalization factors.												

Table 4

Models describing the WQI ( $\lg(\text{WQI} + 1)$ ) built using 264 entries from training dataset. Models' outcome through a regression analyses including all 14 variables observed in this study after normalization.

model	Linear model R <sup>2</sup> P
1	$1.804^{***} + 0.065^{***}\lg(\text{NH}_4\text{-N} + 1)$ .552 <0.001
2	$1.601 + 0.049^{***}\lg(\text{NH}_4\text{-N} + 1) + 0.122^{***}\lg(\text{DO} + 1)$ .777 <0.001
3	$1.351 + 0.046*\lg(\text{NH}_4\text{-N} + 1) + 0.112*\lg(\text{DO} + 1) + 0.147*\lg(\text{COD} + 1)$ .849 <0.001
4	$1.308 + 0.044*\lg(\text{NH}_4\text{-N} + 1) + 0.112*\lg(\text{DO} + 1) + 0.146*\lg(\text{COD} + 1) + 0.025*\lg(\text{WT} + 1)$ .868 <0.001
5	$1.165 + 0.042*\lg(\text{NH}_4\text{-N} + 1) + 0.107*\lg(\text{DO} + 1) + 0.126*\lg(\text{COD} + 1) + 0.027*\lg(\text{WT} + 1) + 0.096*\lg(\text{TU} + 1)$ .889
6	$1.019 + 0.042*\lg(\text{NH}_4\text{-N} + 1) + 0.112*\lg(\text{DO} + 1) + 0.133*\lg(\text{COD} + 1) + 0.028*\lg(\text{WT} + 1) + 0.095*\lg(\text{TU} + 1) + 0.065*\lg(\text{NO}_3\text{-N} + 1)$ .894 <0.001
n = 264.6.8 *P < 0.001.	

Table 5

Outcome of WQI<sub>min</sub> models from regression analysis obtained from training dataset (entries = 264).

Model	Paraments	R <sup>2</sup>	RMSE	PE(%)	P
WQI <sub>min1</sub>	NH <sub>4</sub> -N, DO, COD, WT	0.95	12.74	15	< 0.001
WQI <sub>min2</sub>	NH <sub>4</sub> -N, DO, COD, WT, TUB	0.98	8.76	10	< 0.001
WQI <sub>min3</sub>	NH <sub>4</sub> -N, DO, COD, WT, NO <sub>3</sub> -N	0.96	9.92	11.8	< 0.001
WQI <sub>min4</sub>	NH <sub>4</sub> -N, DO, COD, WT, TUB, NO <sub>3</sub> -N	0.99	6.8	8.01	< 0.001

At most of the stations the average annual pH values were above 8, with the maximum value of 8.8 occurred in 2019–2020 at D19 in the Nishat basin and the minimum value of 7.3 was measured in 2018–2019 at D2 in the Hazratbal basin (Table.1) indicating that the water in Dal Lake throughout the observation period remained in alkaline condition. The mean pH values were greater than 8 moving from Nishat basin towards Gagribal basin however it was less than 8 in the Hazratbal basin. The annual average DO concentrations observed at each station were above the prescribed standard (6 mg/L) (CPCB 2019). With minimum value observed in 2019 (4.0 mg/L), and the highest was also observed in 2019 (8.8mg/l). The DO concentrations were lowest at D2 in the Hazratbal basin while at all other stations DO concentrations were slightly higher than the standard value.(6 mg/l) (Figure-1) The mean pH and DO concentration did not showed any significant variation in Nishat and Gagribal basins. However mean pH and DO concentration in Hazratbal basin was 7.9 and 6.52 mg/l, respectively which was lower than the Nishat and Gagribal Basins. (ANOVA p < 0.001) (Table .2). From M-K test results, no station showed trend for DO except at D2 and D16 where a significant increasing trend was observed while for pH increasing and decreasing trend was observed at D16 and D14 respectively (Figure-2).

The maximum and minimum annual average water temperature (WT) measured were 18.5°C and 17.2°C, respectively. WT did not show any significant variation across the lake (P > 0.05). The annual mean EC value ranged from 225–265 µS/cm. The mean EC value did not differ significantly among Nishat and Gagribal basins however it was slightly higher in the Hazratbal basin (269 µS/cm) (p < 0.001) while there was significant downward trend observed in both the Hazratbal and Nishat basins however no trend was observed in the Gagribal basin (Figure-2).

The annual average concentrations of COD ranged from 18.3 mg/L to 23.0 mg/L. The maximum COD concentration of 42 mg/l was observed in (2018–2019) at D2 of the Hazratbal basin and the minimum value of 10 mg/l in (2019–2020) was detected at D14 of the Gagribal basin (Figure-1). Three stations D1, D4 and D5 showed a downward trend for COD and no trend was observed at other stations. The annual average turbidity was below the acceptable limit (5 NTU) (WHO .2011) (Figure-1) The mean turbidity in the Hazratbal basin was notably higher than values observed in other two basins ( $P < 0.001$ ) (Table.2).

## Nutrients (TP, OP, IRON, NO<sub>3</sub>-N, NH<sub>3</sub>-N)

The annual mean TP concentration during sampling period were higher than the standard value (0.05mg/l) (USEPA. 2015). The maximum concentration of TP was 2.38 mg/l, observed in (2018–2019) in the Hazratbal basin and the minimum values of 0.25 mg/l, was observed in (2017–2018) in the Nishat basin (Table.1). All the stations showed mean concentration higher than the standard value (0.05mg/l) (Figure-1). Among basins, the TP concentrations were highest in the Hazratbal basin and decreased as we moved towards the exit of the lake. Annual average OP concentrations varied from 0.228 to 0.163 mg/l, while the highest and lowest OP concentrations were noticed at D1 of the Hazratbal basin in (2017–2018) with value of 0.705 mg/L and at D13 of the Gagribal basin in (2019–2020) with value of 0.072 mg/L, respectively.

The iron concentrations ranged from 0.285 mg/L to 0.314 mg/L with maximum iron concentration of 0.702 mg/l observed at D1 of the Hazratbal basin and the minimum value of 0.128 mg/l detected at D5 of the Nishat basin. Overall, 63% (7/11) of the stations have iron concentrations slightly above the standard value (0.03mg/l) (BIS.2012) (Figure-1). There was a significant spatial difference in iron concentrations between the three basins with highest in the Hazratbal and lowest in the Gagribal basin ( $p < 0.001$ ). A notable increasing trend was observed at all stations in the Hazratbal basin and at D14 in the Gagribal basin however no trend was observed at other stations (Figure-2).

The annual average NO<sub>3</sub>-N values varied from 0.46 mg/l to 0.51 mg/l which are within the prescribed standard limits (45 mg/l) (BIS.2012). The annual average NH<sub>3</sub>-N values ranged from 0.24 mg/l to 0.31 mg/l with the maximum value of (1.40 mg/l) was observed at D2 of the Nishat basin in (2018–2019) and minimum concentration of NH<sub>3</sub>-N (0.086mg/l) was detected at D13 of the Gagribal basin in (2017–2018) (Table.1). Both the mean NO<sub>3</sub>-N and NH<sub>3</sub>-N concentrations were significantly higher in the Gagribal basin (ANOVA  $p < 0.001$ ).

## Other soluble ions (SO<sub>4</sub><sup>2-</sup>, Cl, Ca and Mg)

The annual mean sulphate concentration ranged from 34.5 mg/L to 37.6 mg/L The annual average chloride concentration, ranged from 35.6–38.8 mg/L. The max value of 59 mg/l for sulphate and 65 mg/l for chloride was observed in 2019–2020 at D2 in the Hazratbal basin (Table.1). Both sulphate and chlorides varied significantly across the three basins of the lake ( $p < 0.001$ ) (Table.2). An increasing trend was observed for SO<sub>4</sub><sup>2-</sup> in the Hazratbal basin at D1, D2 and D3 and in the Gagribal basin at G14. For Cl, a notable increasing trend were observed in the Hazratbal basin while other stations showed no trend at all (Figure-2).

The calcium concentration varied significantly among the three basins and a similar situation was observed for magnesium as well ( $p < 0.001$ ). Both the parameters were below the prescribed standard at all the observed station (Figure-1) and their annual average values ranged from 36.81 to 37.91 mg/L for Ca and 4.09– 4.22 mg/L for the Mg, respectively.

### Water quality evaluation through WQI method

The results of WQI displayed the annual, seasonal and station wise profiles of water quality changes in each basin of the Dal Lake (Figure- 3). In general, the Dal Lake's water quality was categorized as "good", with all the monitoring stations, from 2017 to 2020, showing mean WQI values greater than 80 except station D2 in the Hazratbal basin showing lower water quality index value 76.1 (Figure-3a) also from the seasonal WQI variations, the maximum and minimum seasonal mean WQIs were seen in spring 2019 and summer 2018, with values 84.6 and 79.4, respectively (Figure- 3b). The values than dropped from spring to summer, the maximum and the minimum WQI values were observed in spring and summer of every year.

From the annual profiles (Figure- 3c) the WQI variations in (2017–2018) varied from those observed in (2018–2019) and (2019–2020) showing that the Dal Lake's water quality has improved from 2017 to 2020 especially in the Nishat basin where lowest WQI of 80.1 was observed in (2017–2018) and highest WQI of 83.2 was observed in (2019–2020) this is due to the decrease in anthropogenic activities from 2019 as the area was under complete lockdown due to political disturbances in 2019, followed by the COVID-19 lockdown in 2020.

## Development And Assessment Of Wqi Model

Regression modelling is perhaps the most widely used predictive model because its mathematically concise, has a useful baseline and the results are easy to interpret. In multiple regression we are interested in finding which of the independent variables have the larger impact on the dependent variable. To numerically capture this measure of accuracy, we use  $R^2$  which can be interpreted as the %age of variation in Y (dependent variable) that is explained with change in X (independent variable).  $R^2$  is called the coefficient of determination. The larger the  $R^2$  the better the model fits. In order to evaluate the predicted accuracy, we are primarily interested in how the model will perform on the data not seen by the model. To do so we randomly divide the data into two parts 1) training set : used for fitting the models. 2) validation set: used for choosing among different models. This is called data partitioning. To evaluate the accuracy of validation set we use a measure called Root mean square error (RMSE) and Percentage error (PE).

From the training dataset the outcome from multiple linear regression (Table.4) depicts that  $\text{NH}_4\text{-N}$  makes the largest contribution to WQI having  $R^2 = 0.552$  ( $p < 0.001$ ), and the other parameters DO, COD and WT are introduced in the model in series and exceptionally improve the models with increase in  $R^2$  values to 0.777, 0.868 and 0.849, respectively. Additionally, two more parameters, TUB and  $\text{NO}_3\text{-N}$ , are chosen as the fifth and sixth variables that further help in improving the execution of the models. The performance of  $\text{WQI}_{\text{min}}$  models, via  $R^2$ , RMSE and PE was foreseen and is shown in (Table.5). The outcome, according to the regression model, showed that the  $R^2$  of the models are increased as the parameters are added. Furthermore, between the WQI and  $\text{WQI}_{\text{min}}$  values, established on the training dataset, differences were observed while closest correlations with the WQI was shown by  $\text{WQI}_{\text{min}4}$  model hence displayed the best performance (Figure-4) in addition to that  $\text{WQI}_{\text{min}4}$  showed the smallest RMSE and PE values between other models established on training dataset, suggesting that for the calculation of WQI of Dal Lake it was the most acceptable model. The analysis conducted on the testing data also proves that the  $\text{WQI}_{\text{min}4}$  displayed the overall best performance among other models with lowest PE and RMSE values of 6.34% and 5.48 (Figure-5) ( $R^2 = 0.99$ ,  $P < 0.001$ ), respectively.

## Discussion

### *Physiochemical and Biochemical assessment*

pH plays an important role in aquatic ecosystem as it affects aquatic life also very low and high pH is associated with corrosion. Range of the concentration of pH in our study indicate that water of Dal Lake remained in alkaline state during the study period as was observed by (Raj et al., 2014). Moreover, pH was usually higher in summer that may be attributed to runoff from catchment, as summer is associated with frequent rainfalls in the region. The lowest and the highest WT was observed in winter and summer respectively which indicates that the water temperature was consistent with the air temperature across the Dal Lake. Electrical conductivity is directly related to the dissolved solids concentration. The values of EC were within the prescribed limits at all the sampling stations. Higher EC was observed during autumn which may be attributed to lower water levels and high rate of decomposition in lake (Ahmad et al., 2020). The most important parameter to access water quality is DO as trophic status as well as the biological activities of aquatic ecosystem depends on DO (Granier et al., 2000). To ensure healthy aquatic life the value of DO should range from 4 to 6 mg/l (Alam et al., 2007). The concentration of DO was within the limits prescribed by BIS/WHO also DO values were lowest in summers and showed an increasing trend as we moved towards winter indicating that solubility of oxygen increases with decrease in temperature

(Solanki et al., 2009). Chemical oxygen demand is an important parameter in assessing the organic pollution of water body (Sun et al., 2016). The COD values were slightly lower in the Gagribal basin and higher in Nishat and Hazratbal basin which is due to agricultural runoff and presence of Sewage Treatment Plants in these basins (Najar et al., 2011). Higher values of turbidity were observed at station D1 and D2 of the Hazratbal basin during summer due to algae growth and excessive dredging at these stations. (Wu et al., 2007)

#### *Nutrient's assessment*

The limiting nutrient which leads to the eutrophication of fresh water systems is phosphorus (Rabalais., 2002; Vyas et al., 2006; Zhang et al., 2019). Dissolution of phosphate rocks and (apatite) weathering of minerals are considered to be the main source of phosphorus (Bingham et al., 2020). The concentration of TP in the current study was higher at each station and were well above the eutrophication control limit value (0.02mg/l) (Salade et al., 1997; wang and liang., 2015) the value has increased significantly according the findings of (Mushtaq et al., 2018) based on data from 2015. However, a consistent result was observed from the study of (Rather and Dar., 2020). Hazratbal and Nishat basins showed relatively higher values then what was observed in Gagribal basin this is due to the increased runoff through agricultural catchment area in these basins and nearby floating gardens as well.

Ammoniacal nitrogen is generally produced through microbiological deterioration of nitrogenous matter, in the trophogenic zone this is easily assimilated by plants (Rolando., 2003). From the current study the values of  $\text{NH}_4\text{-N}$  were consistent with the findings of (Najar et al., 2011; Mushtaq et al., 2018) however the values were highest in (2017–2018) and then decreased thereafter this may be due to the decrease in the anthropogenic activities like de-weeding and dredging operations that were not carried out during these periods (Wetzel.2001). The existence of nitrates in water bodies are usually influenced by nitrifying bacteria, organic and domestic sources pandit.(1993) in lakes the phytoplankton productivity is enhanced with an increase in the concentration of nitrates (pandit and Yousuf., 2002; Mlital et al., 2005) higher values of nitrates is an indication of nutrient enrichment in a water body. The nitrates concentration observed in this study were significantly higher than those observed by (Bhat et al., 2017; Mushtaq et al., 2018) the increased values may be attributed due to increased nitro-phosphate fertilizers being used in the adjacent agricultural farms also domestic waste are deposited into the lake from quarters (Mustapa et al., 2005) however the results were consistent with (Rather and Dar., 2020)

#### *Soluble ions assessment*

The main sources of ions in lake water are from atmospheric depositions, carbonic acid silicates besides the contributions from anthropogenic activities and weathering of carbonates (Sidle et al., 2000; Kalpana et al., 2013; Wayland et al., 2003) consequently the  $\text{SO}_4$  results from the leachable sulphate through use of fertilizers from non-point sources and also from anthropogenic sources via sulfuric salts coming from domestic wastewater (Varol and Davraz., 2015). Moreover, to assess the organic pollution by domestic sewage chloride is used as indicator (Chandrasekhar et al., 2003). In this study the concentrations of both  $\text{Cl}^-$  and  $\text{SO}_4^{2-}$  were below the BIS and WHO prescribed standards however the values were higher than those of (Najar et al., 2011; Mushtaq et al., 2018) this is because of the increased no of STPs that are functioning around the lake. Calcium originates from disintegration of carbonate minerals. On the other hand, ferromagnesian minerals and dolomite are considered to be the primary source of magnesium in fresh wastewaters (Singh et al., 2012). In this study both Ca and Mg values were within the standards of WHO/BIS also Ca was the dominant cation and were in accordance with (Rather and Dar., 2020). In fresh water bodies of Kashmir, the concentration of Ca and Mg are correlated with population of plankton most commonly Cyanophycean ( Bhat and Pandit., 2003).

#### *Assessment of water quality using WQI*

The overall surface water quality of Dal Lake was evaluated in the study since comprehensive study on the surface water quality of dal lake has not been carried out except (Yawar et al., 2016). The special, seasonal and annual profiles of WQI values are shown in (Figure- 3) based upon the calculation the water quality of dal lake has been at good level throughout the monitoring period indicating that the water quality of dal lake has improved compared to the study carried out by Yawar et al.

(2016) this is because of the strict management and the pollution control by the lakes and waterways development authority. From the special profiles on the WQI (Figure- 3a). The station D2 in the Hazratbal basin showed the lowest water quality index value this is because of the increased anthropogenic activities mainly agricultural activities around this station Sener et al. (2017) however all other stations showed similar trend of WQI. From the seasonal profiles (Figure- 3b) the WQI values were slightly higher in summers which is because Dal Lake is subjected to high anthropogenic stress as most tourists visit Dal lake during summers. The annual profiles (Figure- 3c) clearly depict that the water quality of lake has improved from (2017–2018) this is because the state has been under lockdown the 2019 because of political disturbance in the area followed by a national lockdown in 2020 due to COVID pandemic which decreased the anthropogenic stress on the lake (Sun et al., 2016).

#### *Development of WQI<sub>min</sub> model for Dal Lake*

In order to assess the water quality using WQI method it requires need to measure and analyze large number of parameters. Thus, keeping in mind, the limited budgets available for the environmental protection in developing countries analytical cost and time-consuming analysis of large parameters will play a pivotal role in WQI acceptance (Ongley., 1998;Sun et al., 2016). So, it is imperative to pull out parameters that is explaining majority of the variation in the water quality data and thus can be used to provide a quick and reliable WQI results. Stepwise multiple regression analyses were used to obtain key parameters and hence develop a WQI<sub>min</sub> model for the water quality evaluation of Dal Lake. Based upon the results six crucial parameters (NH<sub>4</sub>-N,DO,COD,WT,TUB and NO<sub>3</sub>-N) explained majority of variance in water quality data and hence were selected in developing the final model that displayed excellent performance in the water quality assessment of Dal Lake. The parameters involved in the development of WQI<sub>min</sub> model should explain the overall characteristics and variations of water quality in addition reduce the cost of analysis (Pesce and Wunderlin, 2000). The first parameter selected that contributed highly to the WQI value in training dataset was NH<sub>4</sub>-N. DO have the second most expository power and was selected as second parameter followed by COD, WT, TUB and NO<sub>3</sub>-N. Additionally the selected six parameters can be easily measured and thus are favorable for Dal Lake's water quality assessment .

The selected parameters from our study also played a major role in developing WQI<sub>min</sub> model in other study areas (Wu et al., 2018;Kocer and sevgili., 2014) explained that ammoniacal nitrogen was an important parameter in assessing the water quality of Lake Taihu Basin, (china) and Esen Stream (Turkey) respectively. Also, in Dongjiang River (China) NH<sub>4</sub>-N and NO<sub>3</sub>-N played an important role in the development of WQI<sub>min</sub> (Sun et al.2016). For aquatic life DO plays an important role and has been used in several studies for the establishment of WQI<sub>min</sub> model (Pesce and Wunderlin., 2000; Kannel et al., 2007;Wu et al., 2018;Nong et al., 2020). In order to assess the water quality of Aksu river Sener et al. (2017) COD played an important role also similar findings were reported in (Debels et al., 2005). Moreover, the use of turbidity in the establishment of WQI<sub>min</sub> model has also been reported in (Wu et al., 2018).

## **Novelty, Challenges And Way Forward**

From the comprehensive analysis of Dal Lake's water quality, our study can describe and answer to few criticisms on the Dal Lake's water quality, showing a good evidence that Dal Lake's water quality is currently maintained at a good level. However, previous studies concluded different results where investigations were mostly related to the WQI explaining drinking water quality of the Dal Lake (Najar et al., 2011;Javaid et al., 2017). Keeping in mind, the limited budgets available for the LAWDA the WQI<sub>min</sub> model developed in this study based on few critical parameters can play an important role in assessing the water quality of Dal Lake more quickly and economically. There is a scope to further test the developed WQI model by selecting the different monitoring sites across the Dal Lake so as to check the reliability of the model for future prediction that will indeed help in the effective management of Dal Lakes water quality. Also, the increased nutrient concentrations especially TP and NH<sub>4</sub>-N has resulted in the eutrophication at some places in the lake which is to be managed and controlled effectively and should be of the utmost priority for the research division of LAWDA in future. In addition, considering the national importance of Dal Lake, heavy metal analysis, algal proliferation and analysis on micropollutants possibly be needed in future.

## Conclusion

In this research, WQI approach was used to determine the Dal Lake's water quality. A total of 14 water quality parameters were selected in this study. The results showed that majority of the parameters varied significantly between the three basins of the lake (except of WT and COD). The Dal Lakes water quality was overall "Good" throughout the monitoring period and the water quality has improved from 2017 to 2020. From the special profiles of WQI Gagribal basin showed the higher water quality and the Hazratbal basin the lower water quality compared to the three basins. Additionally, the water quality displayed distinct seasonal variation, with the lowest values in summer and the highest WQI values in spring. The seasonal variation in water quality were attributed to land use and anthropogenic activities. The results obtained were acceptable and proved that the water quality of Dal Lake has improved because of the constant efforts from the LAWDA. Moreover, the WQI<sub>min</sub> model developed in this study consists of six variables viz Ammoniacal nitrogen, Dissolved oxygen, Chemical oxygen demand, Water temperature, Turbidity and Nitrate nitrogen displayed excellent performance in explaining the Dal Lake's water quality. The selected parameters are easy to measure and thus can be used for the quick, cost-effective and reliable results on the water quality of Dal Lake. The model presented can play an important role and can be used as a useful baseline in the future monitoring also it is proposed that effective management of eutrophication should be of concern in future research.

## Declarations

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### Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Availability of data and materials

The data sets used and/or analyzed during the present study are available from the corresponding author on reasonable request.

### Funding

Not applicable.

### Ethics approval and consent to participate

Not applicable.

### Consent for publication

Not applicable.

### Credit author statement

**Mozim Shafi** : Experiments, Data collection and Analysis, Draft writing. **Chander Prakash**: Revision and Supervision. **Khalid Muzamil Gani**: Conceptualization, Writing- Reviewing, Editing, Finalization.

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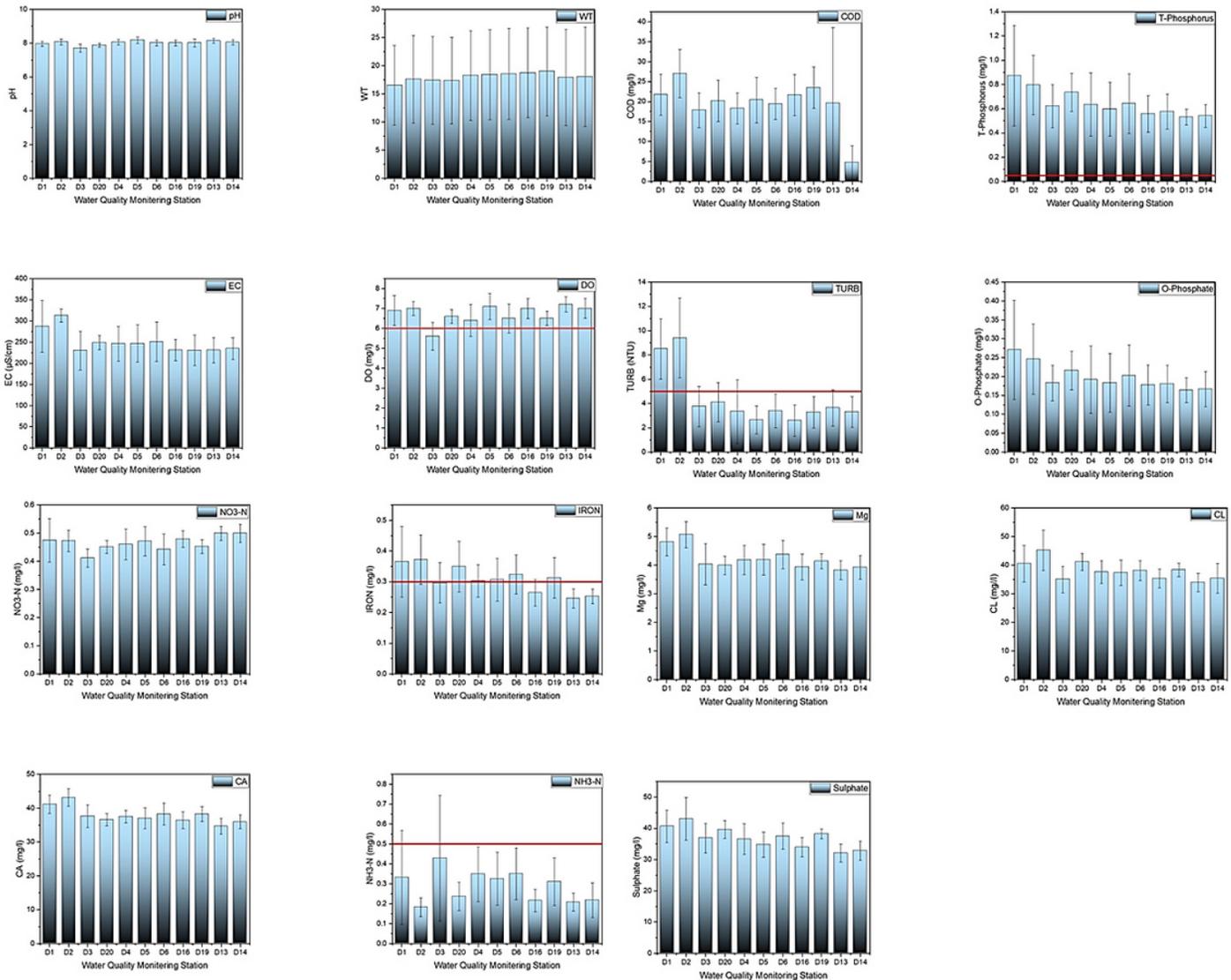
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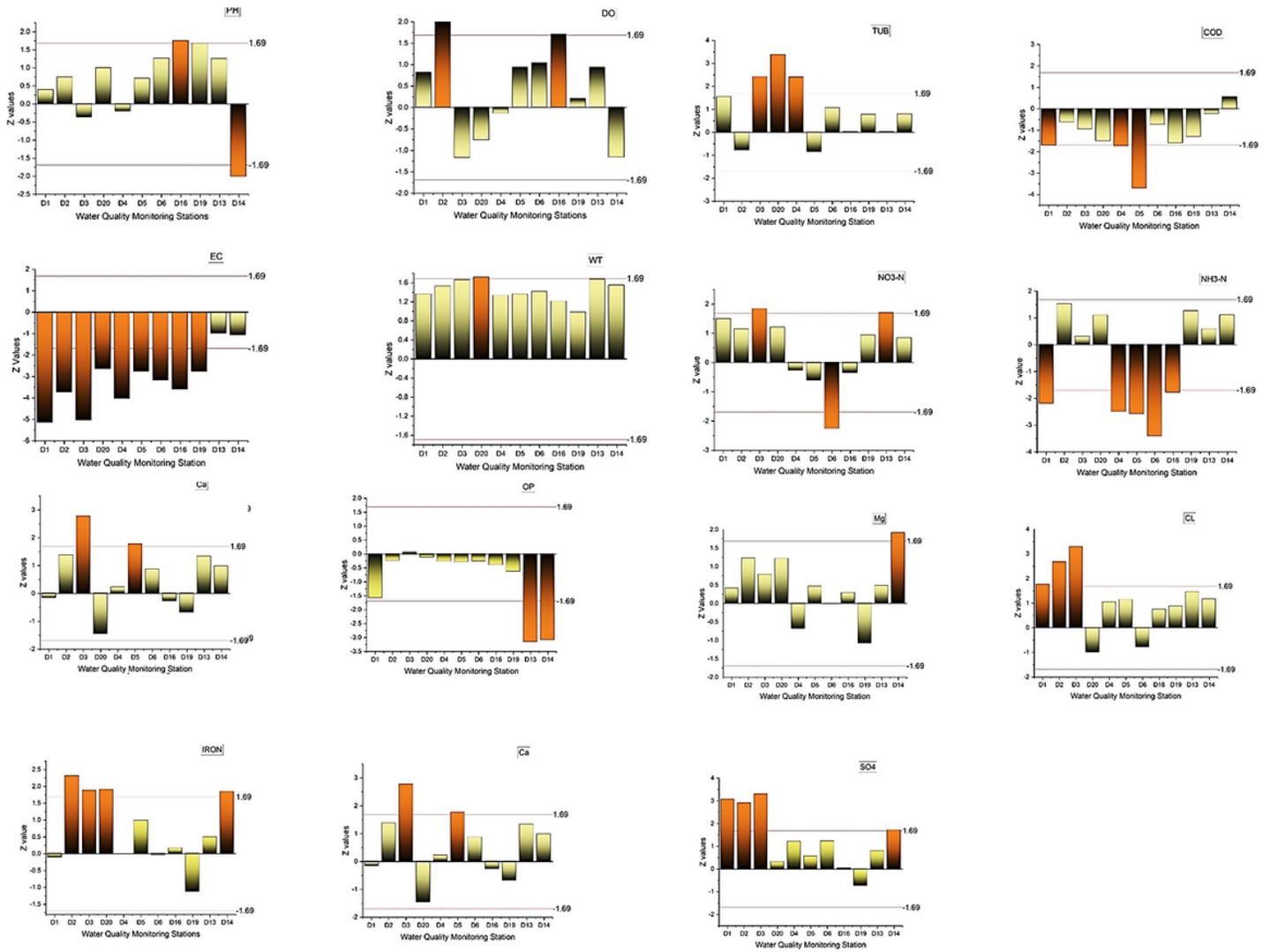
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## Figures



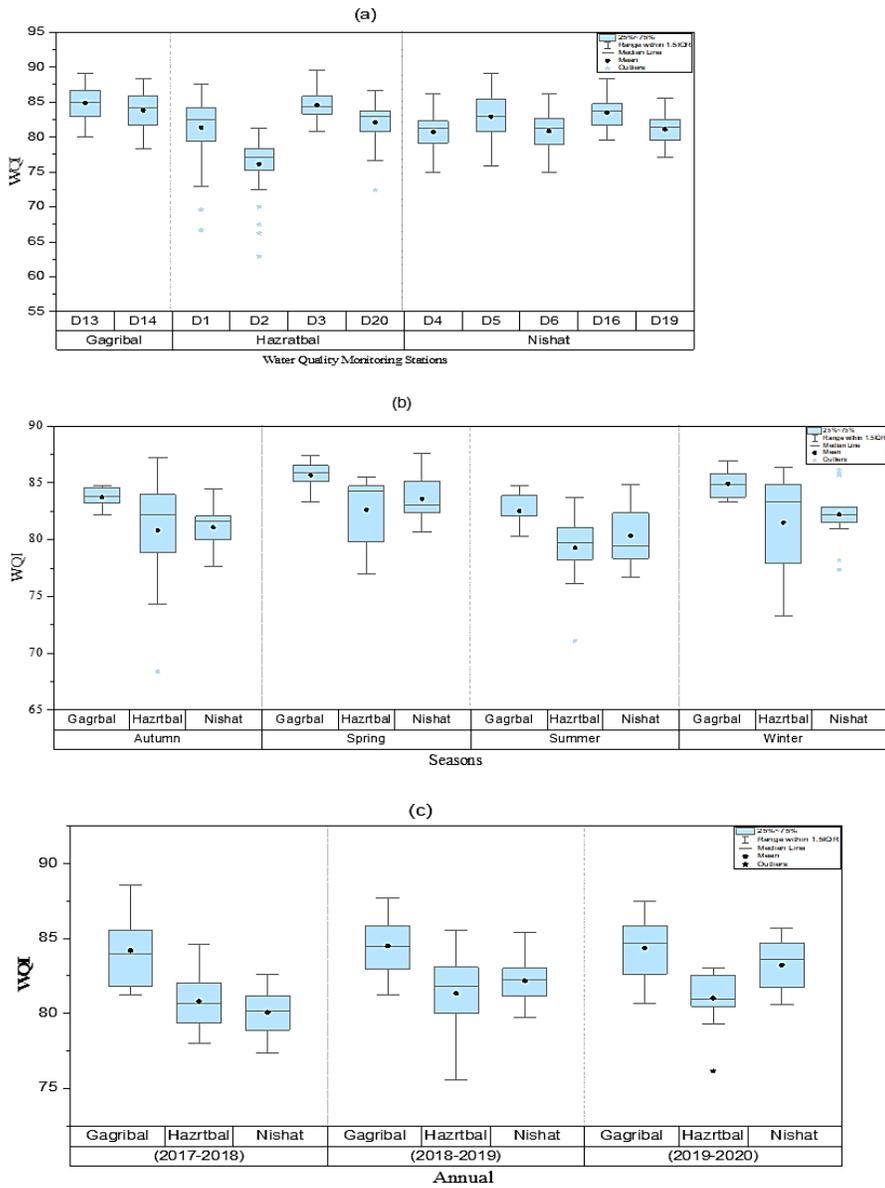
**Figure 1**

Mean concentrations and standard deviations for 15 water quality parameters for each monitoring locations in Dal Lake from 2017-2018 to 2019-2020. (\*Horizontal red line represents threshold value.)



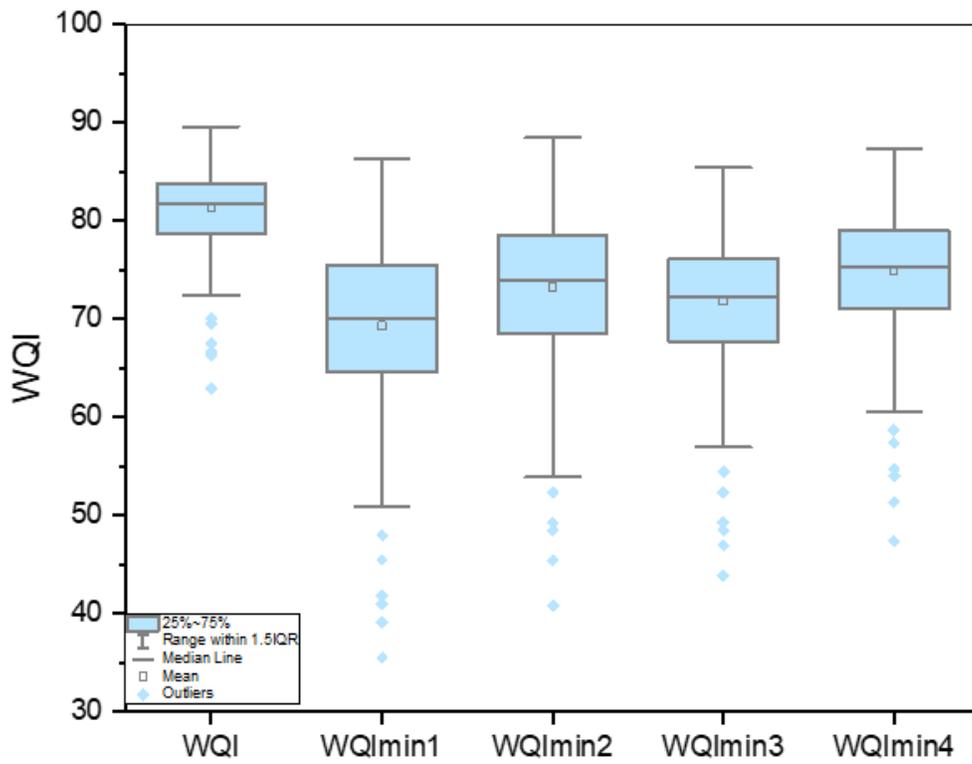
**Figure 2**

The results of Mann-Kendall test for 15 water quality parameters for each water quality monitoring station in the Dal Lake from 2017-2018 to 2019-2020



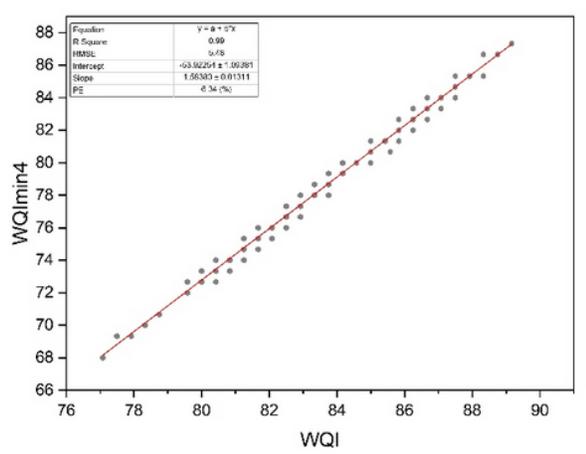
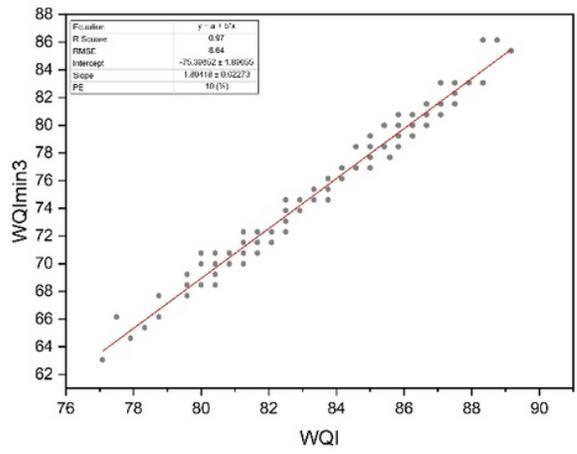
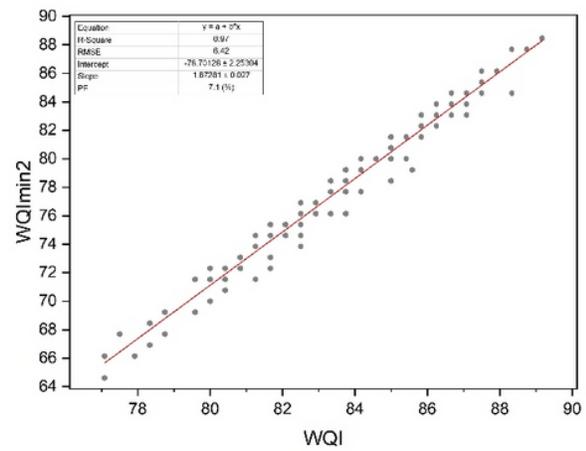
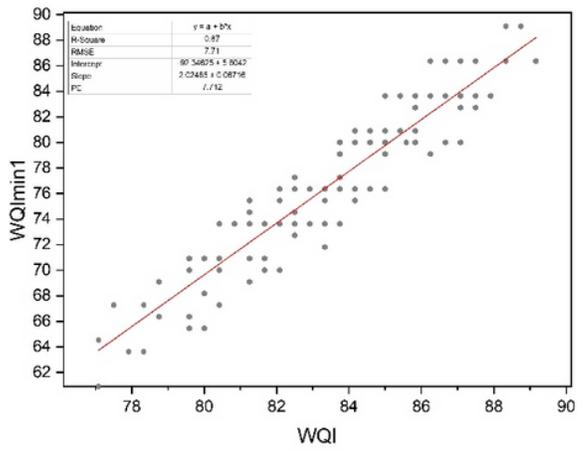
**Figure 3**

Spatial (a), Seasonal (b) and Annual (c) variations of the water quality index (WQI) in each basins of the Dal Lake from (2017-2018) to (2019-2020).



**Figure 4**

Contrast of WQI and WQImin estimates from training dataset (the parameters selected for the WQImin models are shown in Table 5).



**Figure 5**

Contrast of WQI and WQImin estimates from testing dataset (the parameters selected for WQImin models are displayed in Table 5).

## Supplementary Files

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