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LIMNOLOGICAL PROFILE AND POLLUTION LEVELS OF DAL LAKE USING CARLSON'S TROPHIC STATE INDEX

MONISA MEHOOB, MASOOD UL HASSAN BALKHI, ADNAN ABUBAKR, IMTIYAZ QAYOOM* AND BILAL A. BHAT
Faculty of Fisheries, Rangil Ganderbal,
Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir - 190 006 (J&K)
e-mail: drimtiyazqayoom@skuastkashmir.ac.in

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***Corresponding author**

ABSTRACT
The limnological features and Trophic State Index (CTSI) was used to assess the trophic status of Dal Lake of Kashmir. The air and water temperatures of the lake recorded marked seasonal variation with the overall values of 14.39 ± 1.69 ºC and 13.57 ± 2.38 ºC respectively. Depth (3.14 ± 0.14 m) and transparency (1.93 ± 0.07 m) of the lake were found maximum at site D. TDS and TSS showed an increasing trend from winter to autumn with overall mean values of 159.31 ± 9.20 mgL^{-1}and 102.51 ± 6.45 mgL^{-1} respectively. pH of the lake was found alkaline throughout the study while as the mean dissolved oxygen concentration was recorded 6.94 ± 0.13 mgL^{-1}. Specific conductivity and free carbon dioxide showed average concentrations of 229.76 ± 11.49 μScm^{-1} and 2.067 ± 0.46 mgL^{-1} respectively. Average ammonia concentration recorded in the lake was 201.61 ± 11.62 gL^{-1} with maximum mean value being observed at site C. Nitrate-nitrogen concentrations were found raised in spring (428.09 ± 28.9μScm^{-1}) and autumn (459.11 ± 22.03 μScm^{-1}) than winter and summer. The total phosphorous concentration of the lake was on the higher side (378.49 ± 20.22 μScm^{-1}) during the study. Both orthophosphate and total phosphorous concentrations showed an increasing trend from colder to warmer months. Carlson's Trophic State Index was greater than sixty on almost all sites. Thus the study made reflected that the Lake is categorized as eutrophic and needs proper management.

INTRODUCTION

Eutrophication is a serious concern for ecologists which has profoundly led the deterioration of natural waterbodies leading to the alterations in their biodiversity. Although associated with the enrichment of system due to nutrient loading, the trophic state concept focuses on variables that are directly or indirectly related to primary productivity (*i.e.*, algae and aquatic plants) (Dodds and Cole, 2007). The natural eutrophication process varies with respect to the sites within the waterbody, their nutrient load (increase in nitrogen and phosphorous content), biodiversity and various other factors like geomorphology and climate. However, the anthropogenic and cultural interventions have pervaded effects on the productivity leading to the significant changes in the structure and function of aquatic ecosystems. Because of the complex nature of eutrophication, an increasing number of studies are directed toward broader scale analyses of lakes and reservoirs threatened by this environmental problem. Such analyses involve not only physical and chemical parameters, but also the trophic state indices and their relationship with morphology, land use, and land occupation (Nõges *et al.*, 2003; Fraterrigo and Downing, 2008; Taranu and Gregory-Eaves, 2008; Nõges, 2009; Liu *et al.*, 2010). Human activities act as stimulus for accelerated eutrophication, often associated with the increase in phytoplantonic and algal growth; worsen the status of portable water, flora, fauna, recreation and tourism. Various workers have worked in the field relating the causes of eutrophication with the limnology of lakes (Basavarajappa, *et al.*, 2010; Sharma and Kotwal, 2011 and Sharma and Chandrakiran, 2011)

Carlson's Trophic State Index (TSI) is an attempt to provide a quantitative index for classifying lakes as oligotrophic, mesotrophic or eutrophic using three parameters', viz. Secchi Transparency (determining turbidity of a waterbody), chlorophyll-a concentrations (determining algal bloom in a waterbody) and total phosphorous (nutrient supply for algal growth) independently. The TSI can be a valuable tool for lake management, but it is also a valid scientific tool for investigations where an objective standard of trophic state is necessary (Carlson, 1977).

Dal is a multi-basined shallow lake of Kashmir valley and second largest in the state. Being an urban lake and an attractive tourist destination, the lake is facing profound anthropogenic pressure leading to the impairment in the water quality, shift of biodiversity and increase in the nutrient level of the lake. Scientific estimations life of Dal Lake is 154 +/-12 years with no conservation efforts more than 50000 people live within Dal lake hamlets 25-30 MLD of sewage finds its way into the lake annually (Khan, 2015). Therefore the study undertaken aimed to assess the present limnological profile and trophic status of the lake using Carlson's Trophic State Index (TSI) of Dal Lake

MATERIALS AND METHODS

The study was carried out for a one year for all seasons in four basins viz. Hazratbal (site A), Bod Dal (site B), Gagribal (site C) and Nagin (site D) basins representing different ecological habitats of the lake. Three sub-sites were chosen from each basin for collection of water samples. At site 1, Dhobi Ghat (A_1) Telbal Nalla (A_2) and Oont Kadal (A_3) were chose as sub-sites where as Char Chinar (B_1) Karpora (B_2) and Centaur Lake View (B_3) for (site B), Kabootar Khana (C_1) Nehru Park (C_2) and Dalgate (C_3) for Site C and Nagin Littoral (D_1) Nagin Limnetic (D_2) and Nagin Outlet (D_3)

Physical parameters like air temperature, water temperature, depth and transparency were determined at the time of sampling. For other parameters including free carbon-dioxide, conductivity, total dissolved solids, total suspended solids, ammonical nitrogen, total phosphorous, orthophosphate, nitrate nitrogen and chlorophyll-*a*, the water samples were collected in one litre polyethylene bottles distinctly marked and cautiously closed to prevent any intake of air. For dissolved oxygen, water samples were collected in separate glass stoppered bottles as per the standard procedures of APHA (2005).

Trophic state index

The trophic state of the different sites was estimated by calculating the TSI based on Carlson's index as follows

$$\text{Carlson's TSI} = \frac{[\text{TSI(TP)} + \text{TSI(CA)} + \text{TSI(SD)}]}{3}$$

a. TSI (Trophic State Index) for Chlorophyll a (CA):

TSI = 9.81 In Chlorophyll a (μg/l-1) + 30.6

b. TSI (Trophic State Index) for Secchi Depth (SD):

TSI = 60-14.41 In Secchi Depth (meters)

c. TSI (Trophic State Index) for Total Phosphorous (TP):

TSI = 14.42 In Total Phosphorous (μg/l) + 4.15

Where, TSI is Carlson Trophic State Index and in is natural logarithm.

RESULTS AND DISCUSSION

The average air temperatures of Site A, Site B, Site C and Site D recorded were 12.14±1.08°C, 13.69±1.12°C, 15.56±1.20°C and 16.19±1.23°C respectively during different seasons with an overall Mean±SE of 14.39±1.69°C. The season-wise mean temperature depicted increasing trend from winter to summer with a significant ($p<0.05$) variation between the seasons. In this study, air temperature found higher than the surface water temperature of the lake can be attributed to the strong hydrogen bonding between water molecules which require considerably large magnitude of energy for temperature rise. These findings are in accordance with Baruah (1998) and Hulyal and Kaliwal (2011). The average water temperature of different basins of the lake ranged from 9.29±0.82 °C to 12.40±0.92 °C with no statistically significant ($p>0.05$) variation in the mean water temperatures between the seasons. Unlike summers, the lower water temperature in winter is attributed to cold, low ambient temperature and shorter photoperiods (Ganai and Parveen, 2014).

Depth of Dal Lake was recorded 1.93±0.05 m, 2.13±0.11 m, 1.50±0.09 m and 3.14±0.14 m at Site A, Site B, Site C and Site D respectively, with an overall Mean±SE of 2.17±0.15 meters. The variation in the mean was maximum at Nagin basin (3.14±0.14m) and minimum (1.50±0.09 m) at Gagribal basin differing with each other significantly ($p<0.05$). Winter recorded minimum depths probably due to reduced inflow of water from feeder canals into the lake which have been found considerably dry during the season. Similar findings have been published by Bhat and Yousuf (2004). Depth has been found associated with the seasonal patterns of primary production of lakes, found highest in rainy seasons when lakes have maximum seasonal depth and lowest turbidity Lind and Lind

Table I : Seasonal Variation in Physico-chemical Parameters of Different basins of Dal Lake, Kashmir.

Paramete R	Haz	Winter Bod	Gag	Nag	Haz	Spring Bod	Gag	Nag	Haz
A.T	5.0±0.28	4.94±0.1	6.38±0.34	6.0±0.28	13.3±0.8	14.83±1.33	17.22±1.60	18.16±1.52	21.44±0.24
W.T	3.21±0.23	3.26±0.2	3.77±0.50	4.14±0.3	10.48±0.74	13.17±1.27	14.27±1.29	14.44±0.9	15.61±0.2
Depth	1.87±0.08	2.04±0.1	1.44±0.20	2.95±0.2	1.87±0.08	2.06±0.2	1.45±0.1	3.16±0.29	1.84±0.13
Transp.	1.34±0.05	1.60±0.2	1.33±0.20	2.04±0.1	1.51±0.07	1.52±0.2	0.92±0.1	1.92±0.15	1.31±0.07
TDS	106.55±5.97	156.22±12.15	119.77±4.2	103.22±4.13	142.22±6.1	164.88±15.22	146.88±2.22^{A}	149.88±2.43^{A}	155.44±4.69^{A}
TSS	72.0±2.51	102.66±13.84	80.55±2.9	78.66±1.60	79.77±1.50	113.0±17.5	81.77±2.19	78.88±3.11	89.66±2.53
pH	7.711±0.1	7.92±0.1	7.98±0.18	8.23±0.13	7.97±0.09	8.26±0.14	8.32±0.22	8.61±0.14	7.65±0.10
Cond	278.66±210.42	221.0±34.98	169.77±170.21	294.22±11.36	210.55±20.26	240.0±32.49	229.11±33.78^{AB}	312.11±24.28	182.11±13.15
DO	7.38±0.20	7.53±0.3	7.61±0.17	7.6±0.25	6.97±0.2	7.05±0.4	6.66±0.1	7.13±0.25	5.84±0.08
CO2	1.33± 0.33	1.55±0.29	1.11±0.35	0.83±0.4	1.38±0.5	1.67±0.8	2.0±1.0	0.22±0.22	4.88±1.69
Ammonia	194.88±160.42	122.17±6.98	234.17±6.14	235.03±29.44	212.14±17.09	136.44±8.59	238.16±10.49	205.37±21.27	239.62±28.53
Nitrate	456.02±650.86	265.28±27.81	545.97±350.26	402.10±48.87	471.67±75.85	302.93±27.95	577.03±32.45	360.72±39.2	445.71±38.1
Total Ph	272.46±280.68	296.8±37.35	386.46 ±4.81	6.0±0.28	284.8±25.73	335.91±46.47	338.68 ±12.71 ^{A}	484.41 ±43.61	323.02±30.8
Ortho Ph	53.27±5.15	43.22±4.78	50.33±4.3	4.14±0.3	53.15±3.91	45.14±3.79	49.51±4.14	48.33±4.7	56.37±5.1 2:00 AM

Table 1: Continu..

	Summer				Autumn	
Bod	Gag	Nag	Haz	Bod	Gag	Nag
22.33±0.44	24.33±00.92	24.61±0.86	8.83±0.9	12.66±1.02	14.33±1.0	16.0±1.15
17.45±0.61	17.44±00.31	17.88±0.35	7.85±1.0	10.15±0.98	10.91±0.8	13.15±0.9
2.1±0.2	1.46±0.17	3.14±0.30	2.13±0.11	2.33±0.23	1.66±0.19	3.30±0.31
1.53±0.25	1.01±0.14	1.76±0.16	1.40±0.0	1.68±0.24	1.25±0.12	2.0±0.15
178.44±18.07^{A}	157.11±2.38^{A}	167.33±2.72^{A}	157.0±9.95^{A}	252.16±27.69^{C}	214.16±9.81^{BC}	177.67±11.19^{AB}
122.22±17.46	92.0±3.57	105.0±3.17	119.5±3.6	162.0±17.66	142.5±7.69	120.0±3.9
8.35±0.21	8.55±0.21	8.78±0.10	7.86±0.07	7.95±0.10	7.83±0.10	8.08±0.06
203.55±21.11	169.77±24.1	170.11±5	280.0±22.17	235.66±21.35	213.66±19.92	266.0±180.61
6.72±0.54	6.4±0.15	6.15±0.23	7.53±0.05	6.76±0.19A	6.71±0.16	6.98±0.13
1.44±0.80	1.55±1.14	0.00±0.00	2.10±0.3	5.41±1.59	6.41±2.46	1.16±0.57
145.16±60.09	212.73±19.3	190.32±15.28	262.65±28.48	150.76±4.0	277.96±8.43	167.67±40.49
340.8±280.81	454.14±40.47	393.56±37.8	521.96±59.23	370.51±41.38	500.56±11.22	443.4±37.
360.46±24.19	290.6 ±17	485.82±48.76	418.66±53.33	418.63±39.79	350.91 ±6.89	492.06±41.28
48.62±3.02	49.25±4.96	51.73±7.13	59.33±8.1	54.95±5.57	49.4±	52.22±

Table II : Overall Limnological Profile of Dal Lake during different seasons.

PARAMETER	BASIN				TOTAL MEAN±SE
	HAZRATBAL	BOD-DAL	GARGRIBAL	NAGIN	
Air Temp (ºC)	12.14±1.08^{A}	13.69±1.12^{A}	15.56±1.20^{A}	16.19±1.23^{A}	14.39±1.69
Water Temp (ºC)	9.29±0.82^{A}	11.01±0.96^{A}	11.60±0.94^{A}	12.40±0.92^{A}	13.57±2.38
Depth (m)	1.93±0.05^{B}	2.13±0.11^{C}	1.50±0.09^{A}	3.14±0.14^{D}	2.17±0.15
Transparency (m)	1.39±0.03^{B}	1.58±0.11^{C}	1.07±0.07^{A}	1.93±0.07^{D}	1.49±0.08
T.D.S (mgL^{-1})	140.30±4.78^{A}	187.93±11.18^{A}	159.48±6.39^{A}	149.52±5.66^{A}	159.31±9.20
T.S.S (mgL^{-1})	90.23±3.30^{A}	124.97±8.84^{A}	99.20±4.82^{A}	95.63±3.27^{A}	102.51±6.45
pH	7.80±0.06^{A}	8.12±0.07^{AB}	8.17±0.10^{AB}	8.42±0.07^{B}	8.13±0.08
Conductivity(μScm^{-1})	237.83±11.82^{A}	225.05±13.69^{A}	195.58±12.57^{A}	260.61±12.16^{A}	229.76±11.49
D.O (mgL^{-1})	6.93± 0.13^{A}	7.02± 0.19^{A}	6.85± 0.71^{A}	6.96± 0.13^{A}	6.94 ± 0.13
Free CO2 (mgL^{-1})	2.42±0.50^{A}	2.52±0.55^{A}	2.77±0.78^{A}	0.55±0.20^{A}	2.067±0.46
Ammonia (?gL^{-1})	227.32±12.0^{BC}	138.63±3.65^{A}	240.91±7.04^{C}	199.6±10.34^{B}	201.61±11.62
Nitrate (?gL^{-1})	473.84±29.74^{C}	319.88±16.7^{A}	519.43±17.13^{C}	399.94±20.3^{B}	428.27±21.75
Total P (?gL^{-1})	324.73±19.88^{A}	352.96±19.56^{A}	341.66 ± 7.96^{A}	492.12±21.79^{B}	378.49±20.22
Orthophosphate(?gL^{-1})	55.53 ±2.79^{B}	47.98± 2.23^{A}	49.62± 2.15^{A}	50.06± 2.83^{A}	50.79± 1.02

**Superscripts in capital alphabets indicate significant ($p<0.05$) variation between sites in a row. Figures with same superscript in a row do not differ significantly ($p>0.05$).*

(2002). Contrary to it, present study marked highest depth during autumns owing to the floods which hit the Kashmir valley in early September.Transparency was recorded lowest in summer season due to higher planktonic growth leading to increased Chlorophyll–a (chl-a) (Kumar *et al.*, 2012). Moreover, high tourist inflow in summer months may be the probable cause of waste discharges into the lake reducing its transparency. A significant ($p<0.05$) variation among sites was observed in transparencies with mean transparencies of 1.39±0.03m, 1.58±0.11m, 1.07±0.07m and 1.93±0.07m in Site A, Site B, Site C and Site D respectively. At site $A_1$and site B, lower values of transparencies recorded is because of extensive washing of clothes by washer-men and inflow of waste waters including night soil from house boats in the two areas respectively.

The overall mean pH of the lake depicted an alkaline nature of its waters (8.13±0.08). The mean pH at Site A, Site B, Site C and Site D was 7.80±0.06, 8.12±0.07, 8.17±0.10 and 8.42±0.07 respectively. The raised pH value in the lake is linked to level of eutrophication (Njenga, 2005; Mathur *et al.*, 2008) and imbalance in carbon-dioxide, carbonate-bicarbonate equilibrium due to alterations in physico-chemical parameters of water (Trivedi *et al.*, 2009 and Sing *et al.*, 2015). The highest pH values in Nagin basin is probably due to higher

Table III : Trophic State of Dal based on Carlson's Index

S. No.	Sites	TSI for Chl *a*	TSI for Depth	TSI for Total Phosphorus	Carlson's TSI
1	Dhobi Ghat	56.21	53.04	90.07	66.44
2	Telbal Nalah	53.47	51.21	89.2	64.62
3	Oont Kadal	51.3	48.06	80.33	59.89
4	Char Chinar	56.32	44.75	86.67	62.58
5	Karpora	50.3	55.67	93.35	66.44
6	Centaur Lake View	55.33	49.17	83.72	62.74
7	Kabootar Khana	56.08	48.31	89.15	64.51
8	Nehru Park	47.63	57.98	87.4	64.33
9	Dalgate	53.94	58.89	88.09	66.97
10	Nagin Littoral	56.12	49.58	94.42	66.7
11	Nagin Limnetic	55.68	39.88	87.88	61.14
12	Nagin Outlet	56.71	42.88	96.87	65.48

Table IV: Trophic State Index Values and Classification of Lakes (Carlson, 1977)

TSI Values	Trophic State	Attributes
< 30	Oligotrophic	Clear water, oxygen throughout the year in the hypolimnion.
30-40	Oligotrophic	A lake will still exhibit oligotrophy, but some shallower lakes will become anoxic during the summer.
40-50	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer.
50-60	Eutrophic	Lower boundary of classical eutrophy:Decreased transparency, warm water-fisheries only.
60-70	Eutrophic	Dominance of blue-green algae, algal scum probable, extensive macrophyte problems.
70-80	Eutrophic	Heavy algal blooms possible throughout the summer, often hyper-eutrophic
>80	Eutrophic	Algal scum, summer fish kills, few macrophytes.

photosynthetic activity of phytoplanktons and macrophytes.

The season-wise pH values recorded at site A, site B, site C and site D were 7.96±0.07, 8.29±0.08, 8.33±0.10 and 7.93±0.04 during winter, spring, summer and autumn respectively. A high value of pH in summers is documented by many workers (Barman *et al*., 2015; Sunder, S. and Khatri, 2015) and is mainly due to increased photosynthetic assimilation of dissolved inorganic carbon by the planktons. A similar effect could also be produced by water evaporation through loss of half bound CO_2 and precipitation of mono-carbonate (Khan and Choudhary, 1994). The elevated pH levels of the lake during summers corresponded with the increased air and the water temperature indicating its positive relation with air and water temperatures. Using specific conductivity as an index, values higher than 200µS/cm have been used to represent higher levels of nutrient enrichment (Rawson, 1960).

In this study, an insignificant difference was observed in the mean conductivity values of site A (237.83±11.82 µScm^{-1}), site B (225.05±13.69µScm^{-1}), site C (195.58±12.57µScm^{-1}) and site D (260.61±12.16 µScm^{-1}). High levels of specific water conductivity as such, have been used to reflect pollution status as well as the trophic level of the lakes (Shastree, 1991). The seasonal overall specific conductivity values were 240.91±13.78µScm^{-1}, 247.94±15.0µScm^{-1}, 181.38±8.68µScm^{-1}and 248.83±10.75 µScm^{-1} during winter, spring, summer and autumn respectively. Highest conductivity was observed in autumn which could be due to high rate of decomposition of organic matter (macrophytes and animals) during this season. Higher specific conductivity values during autumn season have also been reported due to high pollution levels in water, resulting from the high nutrient loads of wastewater (Abdo, 2010). Present study revealed low conductivity values in summer season which might be due to locking up of nutrients in the macrophytes. Lower electrical conductivity in summer may also be due to diminution in the dissolved ions caused by the precipitation of calcium carbonate and other minerals carried out under high pH as a result of high productivity. This is in conformity with the findings of Trisal and Kaul ()1984) and Adnan (2010) who reported decalcification during summer under increased atmospheric temperature attributing to increased biological activity in the lakes of Kashmir Valley.

In the present investigation, mean dissolved oxygen concentration was recorded 6.96±0.13mgL^{-1}, 7.02±0.19mgL^{-1}, 6.85±0.71mgL^{-1} and 6.96±0.13mgL^{-1}, respectively at site A, site B, site C and site D. The mean dissolved oxygen concentration of these sites varied significantly ($p<0.05$) in different seasons. Among the basins, site C recorded the minimum (6.85±0.71 mgL-1) dissolved oxygen concentration.

The sub-sites C_1, C_2 and C_3 are the centers for water sports and shikara rides. Moreover, being heavily loaded with hotels, restaurants and street vendors these sites have allowed a continuous inflow of pollutants into the lake reducing its oxygen levels. The overall seasonal dissolved oxygen concentrations at site A, site B, site C and site D were 7.53 ± 0.11 mgL^{-1}, 6.95 ± 0.13 mgL^{-1}, 6.28 ± 0.15mgL^{-1} and 7.0 ± 0.87 mgL^{-1} during winter, spring, summer and autumn respectively. Highest values were recorded in winter and the lowest in summer season suggesting an inverse relation between dissolved oxygen and the temperature. Similar seasonal variations have been reported by Balkhi *et al*. (1984); Ibrahim *et al*. (2008) and Kumar and Jha (2015). Lower dissolved oxygen in summer as recorded in the present study may be due to the presence of sewage and other wastes of human and animal origin getting decomposed at a faster rate at higher ambient temperature thereby reducing the oxygen levels of water. The higher dissolved oxygen in winter, on the other hand, may be as a result of increased solubility of oxygen at lower temperature as has been suggested by Umerfaruq and Solanki (2015). The overall mean dissolved oxygen content of water was low (6.94 ± 0.13 mgL^{-1}) mirroring the intensity of pollution due to anthropogenic intervention into the domain of the lake.

The average free carbon dioxide concentrations recorded in different basins of the Lake ranged from 0.55 ± 0.20 mgL^{-1} to 2.77 ± 0.78 mgL^{-1}. The basin wise comparison showed no marked variation in the mean free carbon-dioxide concentrations, however, mean concentration at site D (0.55 ± 0.20 mgL-1) was relatively lower than the other basins. This may be due to heavy infestation of the area by macrophytes leading to complete consumption of the available free carbon-dioxide. High values of CO_2 were recorded during summer (1.97 ± 0.60 mgL^{-1}) and autumn (3.77 ± 0.81 mgL^{-1}) seasons while lower in winter (1.20 ± 0.18 mgL^{-1}) and spring (1.31 ± 0.36 mgL^{-1}) seasons. These observations are in agreement with the findings of Bharama and Korgaonkar (2015) and attributed to lower carbon-dioxide values of winter to the decrease in temperature which subsequently elevated the oxygen holding capacity of the waterbody due to increased photosynthetic activity by phytoplanktons. An increasing trend in the mean free carbon dioxide concentration from winter to autumn season was seen. Bahura (1998) and Telkhade *et al*.(2011) have reported direct relationship of free carbon dioxide with temperature and pH but an inverse relationship with dissolved oxygen which are similar to the findings of present investigation. In the present study, complete absence of free carbon- dioxide was recorded at many sites which could be due to its complete utilization in photosynthetic activity or as a result of its inhibition by the presence of appreciable amount of calcium carbonate in water as also reported by Kumar *et al*.(2010)

The average ammonia concentrations at site A, site B, site C and site D was recorded 227.32 ± 12.0μgL^{-1},138.63 ± 3.65μgL^{-1}, 240.91 ± 7.04 μgL^{-1} and 199.60 ± 10.34 μgL^{-1} respectively with an overall mean of 201.61 ± 11.62 μgL^{-1}. There was a significant ($p < 0.05$) difference in the ammonia concentrations of site B, site C and site D. Ammonia dissolves in water to form ammonium hydroxide and hydroxyl ions. These ammonium ions are readily taken up by aquatic autotrophs with preference over nitrates, thus usually preventing it to reach to toxic levels. The higher concentrations of ammonia are generally found in polluted waters (Shrivastava *et al*., 2015). The basins presented significant variation in their ammonia concentrations, maximum being recorded at site C (240.91 ± 7.04 μgl^{-1}), followed by site A (227.32 ± 12.0 μgl^{-1}). Higher concentrations found in Hazratbal basin (site A) may be due to activities like washing of clothes on the bank or bathing and swimming activities. Mwamburi (Mwamburi *et al*., 2007) reported high values (480 ± 158 μgl^{-1}) of ammonia at the discharge sites of lake's body and related it to the higher levels of organic matter present in it. Another reason for high levels of ammonia in the lake may be its release from the sediments under low oxygen levels at which nitrification of ammonia ceases and the absorptive capacity of the sediments is reduced (Wetzel 2001). The overall seasonal ammonia concentrations in the different basins recorded were 196.71 ± 11.42 μgL^{-1}, 198.03 ± 9.66 μgL^{-1}, 196.96 ± 10.84 μgL^{-1} and 214.76 ± 11.93μgL^{-1} during winter, spring, summer and autumn respectively. The highest values (214.76 ± 11.93 μgl^{-1}) were recorded in the autumn season while the other seasons presented no relative difference in ammonical-nitrogen concentration. Higher ammonia concentrationsin water has been related to the deterioration of water quality (Metcalf and Eddy, 2003) thus explaining the poor condition of the lake. A higher trend in the mean concentration of nitrate-nitrogen was observed in all the basins throughout the year with site A (473.84 ± 29.74μgl^{-1}) and site C (519.43 ± 17.13 μgl^{-1}) basins showing significantly higher values. Both the basins are densely populated and have an inflow of pilgrims and tourists, respectively throughout the year. The overall Mean ± SE of nitrate-nitrogen was recorded as 428.27 ± 21.75 μgL^{-1} at the different basins during different seasons of the year. Spring and autumn seasons showed slightly elevated levels of nitrate in comparison to cold season. This is in agreement with the findings of Bhattacharya *et al*. (2002) and Singh *et al*. (2013) who reported higher concentrations of nitrate during summer and lower concentrations in winter, respectively in upper stretch of Gangetic West Bengal and major rivers in Imphal. Higher levels of nitrate in the autumn season recorded in this study might be due to inflow of pollutants from the surrounding areas of the lake following extensive floods during September, 2014. High nitrate levels recorded during spring could be a result of high rainfall during which the surface runoff carrying fertilizers and other waste materials directly got access to the lake water. Similar observations have been made previously by many workers (Pedge and Ahirrao, 2013; Tamot and Sharma, 2006). Najeeb *et al*., 2014) who reported high nitrate values in Bhoj wetland and attributed it to the domestic sewage, agricultural runoff and decomposition of autochthonous matter. Comparatively lower nitrate concentrations recorded during winter season, in the present study might be due to lower input of pollutants as a result of reduced human interference in cold weather conditions. Presence of Phosphorous in excess of 30 μgl^{-1} in waterbodies is regarded as a major nutrient triggering eutrophication (Welch, 1980). Constant addition of even low levels of nitrogen and phosphorous to an aquatic environment could greatly stimulate algal growth (Zimba, *et al*., 2001). In the present study, highest mean concentration of total phosphorous was recorded in autumn (420.08 ± 20.59 μgl^{-1}). Phosphorous levels however, were not significant with respect to other seasons of the year which recorded concentrations of 365.49 ± 22.33 μgL^{-1}, 360.95 ± 20.91 μgL^{-1}, 364.97 ± 19.91 μgL^{-1}during winter, spring and summer respectively. The higher values in autumn may be attributed to increased levels to the decomposition processes during autumn. Average Total Phosphorous concentrations at site A, site B, site C and site D during different seasons were recorded as 324.73 ± 19.88 μgL^{-1},352.96 ± 19.56μgL^{-1},341.66 ± 7.96 μgL^{-1} and 492.12 ± 21.79 μgL^{-1} respectively. site D showed significantly higher values ($p < 0.05$) as compared to the other basins which can be explained by an improper sewage disposal system in this basin. Sharma (2015) linked the higher Phosphorous values of site D to the direct discharge of untreated human wastes from houseboats and illegal settlements adjoining the lake. An overall high mean concentration (378.49 ± 20.22μgl^{-1}) recorded in this study sounds alarming considering the normal values of phosphorous in the water bodies. Higher total phosphorous levels in water have been taken as indicative of pollution (Pathak and Mankodi, 2013; Abir, 2014) and thus our findings strongly suggest highly eutrophic status of the lake needing extensive remedial measures. The mean orthophosphate concentrations recorded in different sites of the Lake during different seasons was 50.79 ± 1.02 μgL^{-1}. There was a significant ($p < 0.05$) variation in Orthophosphate concentration at site A with respect to the other basins. This can be due to the fact that the area is located near sub-site A_1 where people wash clothes frequently passing on considerable amounts of detergents into the lake. Samrat *et al*. (2012) also linked higher orthophosphate concentrations to the use of detergents and dyes in the nearby areas which find their way into the waters. The overall seasonal orthophosphate concentrations during winter, spring, summer and autumn were 48.69 ± 2.46 μgL^{-1}, 49.03 ± 2.05 μgL^{-1}, 51.49 ± 2.57 μgL^{-1}and 53.97 ± 3.0 μgL^{-1} respectively with no significant ($p > 0.05$) variation amongst them. Values were high during warmer months and low in winter season. These observations are in agreement with the findings of Mukhtiar (2012) who attributed its seasonal variations to the death and decay of algae and other aquatic vegetations.

In the present investigation, an increasing trend in the concentration of Total Dissolved Solids (TDS) from winter to autumn was recorded which might not pose a serious problem to the aquatic life but may be suggestive of contamination with domestic waste water, garbage, fertilizer, etc as has also been observed by (Tiwari, 2005). The average TDS values recorded in site A, site B, site C and site D were 140.30 ± 4.78 mgL^{-1}, 187.93 ± 11.18 mgL^{-1}, 159.48 ± 6.39 mgL^{-1}and 149.52 ± 5.66 mgL^{-1} respectively with an overall Mean ± SE of 159.31 ± 9.20 mgL^{-1}.The continuous inflow of human and animal wastes into the lake with absence of proper drainage system coupled with the agricultural run-off might be responsible for the higher TDS values in the Bod Dal basin. Umerfaruq and Solanki (2015) linked the higher TDS values in lake water to the addition of dead organic substances contributed by the decomposition of aquatic plants and animals at high temperature during summer. The overall seasonal TDS concentration was observed to be 121.44 ± 5.06 mgL^{-1}, 150.97 ± 4.24 mgL^{-1}, 164.58 ± 4.80 mgL^{-1} and 200.25 ± 9.98 mgL^{-1} during winter, spring, summer and autumn respectively. The seasonal comparison revealed a significant difference between winter and autumn seasons ($p < 0.05$). Higher values recorded in autumn may be owing to the heavy rains and devastating floods of early September, 2014 in the valley. Heavy rains washed away higher regions of the city and caused tremendous inflow of human, animal and agricultural wastes into the lake resulting in elevated TDS concentrations. The Total Suspended Solids (TSS) was highest in autumn (136.0 ± 5.60 mg L^{-1}) and summer seasons (102.22 ± 4.88 mgL^{-1}) while lowest in the winter season (83.47 ± 3.97 mg L^{-1}). The higher values of TSS in summer and autumn seasons have been linked to the accumulation of different salts in water as a result of higher evaporation rates in the warmer months (Pedge, S.S. and Ahirrao, S.D. 2013). The results of the present investigation showed a positive correlation between TDS and TSS which was also reported by (Barman and Roy, 2015). The basins viz., site A, site B, site C and site D recorded an average TSS concentration of 90.23 ± 3.30 mgL^{-1}, 124.97 ± 8.84 mgL^{-1}, 99.20 ± 4.8 mgL^{-1} and 95.63 ± 3.27 mgL^{-1} respectively with no significant ($p > 0.05$) difference amongst them. However, like TDS, highest TSS values were recorded at site B owing to the higher pollution levels and fertilizer run-off from the surrounding areas in this part of the lake.

Trophic state index (TSI)

Carlson's Trophic State Index (TSI) has been used as an authentic measure for determining the eutrophic status of water bodies based on three independent variables. The TSI values of chlorophyll *a,* depth and total phosphorous were used to calculate the Trophic State Index (Table III) at different sites of Dal lake. These obtained TSI values were compared with Carlson's Trophic State classification criteria as given in Table IV. The results obtained indicated that the lake was in a eutrophic state at all sites, during the entire period of study. The highest TSI value (66.97) was recorded at sub-site C_3 while the lowest (59.89) was recorded at A_3. These high values of all the variables may be the result of constant inflow of nutrients and pollutants into the lake through the catchment areas leading to accelerated growth of phytoplankton biomass. The average TSI-TP was recorded greater (88.93) than the average TSI-Chl *a* (54.09) indicating increase in Phosphorous surplus in the water (Rahul *et al*., 2013). The results are similar to the findings of Carvalho and Kirika (2003) who reported a direct relationship between phosphorous content and the growth of phytoplankton leading to eutrophic conditions of the waterbodies.

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