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RESEARCH ARTICLE

LIMNOLOGICAL STUDIES OF A FAMOUS HIMALAYAN LAKE: THE DAL LAKE (SRINAGAR, INDIA)

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ABSTRACT

The present study aims to analyse the physico-chemical properties of the Dal Lake Srinagar, India. Various physico-chemical and biological parameters were analysed, from January 2009 to December 2009, at eight different study sites on monthly basis by the standard methods. The maximum and minimum range of physico-chemical parameters were as: Air temperature 3.99-33.20 ^{o}C in January and July respectively, Water temperature 2.54 – 31.30 ^{o}C in January and July, Depth ranged from 1.54-2.26 m in December and August respectively, Turbidity index (Secchi-disc transparency) from 49.75 -74.38 cm in August and January, Total solids 198.25–345.38 mgL^{-1} in June and January, Total dissolved solids ranged from 88.38 -272.00 mgL^{-1} in October and January, Total suspended solids ranged from 57.25 – 148.13 mgL^{-1} in February and August respectively, pH were 8.32-8.84 in December and June, Conductivity was in the range of 289.75 µS L^{-1} in June and 427.13 µS L^{-1} in January, where as Dissolved oxygen was 4.69 mgL^{-1} in August and 7.14 mgL^{-1} in April, Chloride was in the range of 26.18 -39.11 mgL^{-1} in January and March respectively. Total alkalinity was 84.39 mg L^{-1} in June and 143.96 mg L^{-1} in January. Bicarbonate 77.09 mg L^{-1} in June and 143.10 mg L^{-1} in January, Carbonate 0.86 mg L^{-1} in January and 7.30 mg L^{-1} in June, Total hardness was 84.64 mgL^{-1} and 125.53 mg L^{-1} in June and January respectively, Calcium hardness was 84.75 mg L^{-1} in October and 96.13 mg L^{-1} in June and magnesium hardness 15.05 -21.33 mg L^{-1} in October and February respectively, Orthophosphate 233.75 -300.00 µg L^{-1} in November and February, Total phosphate was 998 -1442.75 µg L^{-1} in January and august, Iron was 217.38 µg L^{-1} in January and 341.38 µg L^{-1} in August, where as BOD and COD was 8.04 - 9.98 mg L^{-1} in April and August and 14.53- 18.73 mg L^{-1} in August respectively. The above mentioned results indicates that the lake is suffering from different kinds of pollutants from various sources, such as, sewage, agricultural runoff, house-boat wastes and encroachments. It is concluded, that this Lake is going towards more degradation and needs an immediate action through restoration by some new innovative techniques like Installation of more aeration units and catchment area analysis.

INTRODUCTION

Limnological studies on the polluted water bodies, which cannot be used as a source of drinking water, are of considerable importance. Such waters can be fruitfully used for recreational purposes and fisheries, if properly managed (Valecha *et al*., 1991, Dar *et al*., 2013). In order to have some idea of regional limonology and collection of baseline data for management, studies were initiated on the Dal Lake of Srinagar, which is situated in a thickly populated area of Srinagar city and is exposed to various human interferences (Pandit 1993). Stagnant water bodies have more complex and fragile ecosystems in comparison to running water bodies as they lack self cleaning ability and hence, readily accumulate greater quantities of pollutants. Increased anthropogenic activities in and around the water bodies damage the aquatic systems and ultimately the physico-chemical properties of water (Kavita *et al*., 2010). Physico-chemical factors are very important for growth of primary productivity (Lashari *et al*., 2009) and phytoplankton plays an important role in lake ecosystems as they produce oxygen and food, which sustains all other forms of life (Khan 2003 and Fathi 2001). In different types of lakes, changes in the phytoplankton community have long been recognized as providing a good indicator of the trophic status and environmental quality (Habib *et al*., 1997 and Silva *et al*., 2005). Furthermore, various physico-chemical parameters are responsible for controlling phytoplankton growth and reproduction (Teubner K. 2003). Hence the present study has been taken up to analyse the physico-chemical properties of water samples of Dal Lake, Srinagar (J&K).

MATERIAL AND METHODS

The water samples were collected regularly at monthly intervals from different study sites (Site I to VIII) in the lake (Fig. 1). Analysis of physico-chemical water samples were carried out by following the standard methods for examination of water and waste water (21st edition) 2005 published by APHA and Trivedy *et al*. (1987). Some of the variable

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parameters like pH, Dissolved oxygen (D.O), Air and Water temperature were determined at the field site during collection of the samples, where as the other parameters were analysed in the laboratory.

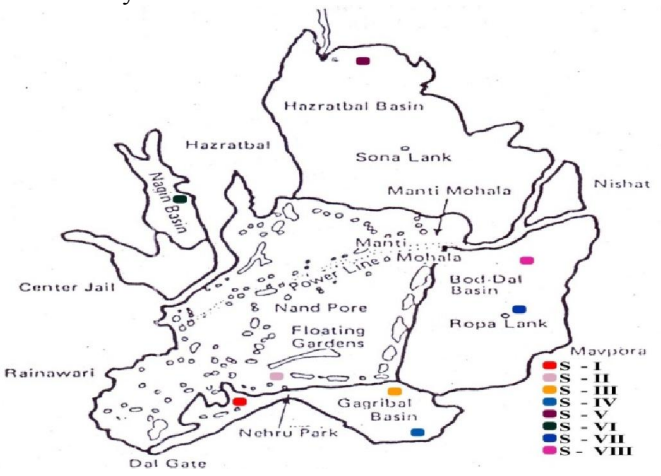

Figure 1. Map showing the different study sites of Dal Lake, Srinagar

RESULTS AND DISCUSSION

Evaluation of physico-chemical factors is basic to the understanding of the trophic status of that water body. Table 1 to 6 shows the mean physico-chemical values as well as the standard deviation (±SD) of the investigated sites of Dal Lake in 2009.

Temperature

One of the physical parameter which is directly related with chemical and biochemical reactions is temperature. In the present study the mean minimum and maximum air temperature ranged from 3.99±0.16 ^{o}C to 33.20±0.24 ^{o}C in January and July respectively. The change in atmospheric temperature brings corresponding changes in water temperature (Wetzel, 1975). In the present study the mean water temperature ranged from 2.53±0.11 ^{o}C to 31.30±0.28 ^{o}C in January and July respectively. The mean minimum and maximum depth ranged between 1.53±0.86 (m) to 2.25±0.92 (m) respectively. Water temperature is one of the most important limnological parameters that plays a prominent role in regulating nearly all other physico-chemical characteristics of the water as well as biological productivity (Wetzel, 1983) and also controls the nutrient input and turn over.

Transparency

Transparency plays an important role in light penetration. The higher the secchi disc transparency, the deeper the penetration of light and higher the rate of photosynthesis. Most workers have found higher transparency in winter and low in spring and summer (Zutshi and Vass, 1970). It is also due to suspension of phytoplankton in water (Zutshi *et al*., 1980). A similar trend was observed in the present study with the higher transparency of 91% recorded in January and the lowest 35% in August.

Total solids (TS)

In the present investigation the highest concentration was 455 mgL^{-1} in January and lowest was 134 mgL^{-1} in May. The mean minimum and maximum total solids ranged from 198.25±49.50 mgL^{-1} to 345.37±71.03 mgL^{-1} in June and January respectively. The total solids of water depend upon the concentration of suspended and dissolved solids. It indicates the increase in the concentration of the chemical elements and therefore eutrophication (Issac and Koul, 1989). The concentration of total solids recorded was in accordance with the precipitation and pollution load of the lake (Dar *et al*. 2013).

Table 1. Shows the mean values of physico-chemical characteristics of Dal Lake, Srinagar

Date/ Parameter		AT (^{o}C)	WT (^{o}C).	Depth (m)	Transparency
Jan.2009	Mean	3.99±0.18	2.54±0.12	1.71±0.82	74.38±10.38
Feb.2009	Mean	9.15±0.21	7.61±0.16	1.76±0.82	69.00±8.65
Mar.2009	Mean	17.84±0.25	16.14±0.16	1.85±0.86	68.13±9.63
Apr.2009	Mean	22.34±0.40	20.95±0.29	1.92±0.81	68.25±9.56
May.2009	Mean	27.56±0.32	26.20±0.24	2.07±0.84	62.13±9.40
Jun.2009	Mean	30.34±0.30	28.40±0.23	1.99±0.87	58.00±8.77
Jul.2009	Mean	33.20±0.26	31.30±0.30	2.03±0.91	58.25±10.70
Aug.2009	Mean	31.35±0.36	29.83±0.31	2.26±0.99	49.75±10.58
Sep.2009	Mean	28.33±0.30	26.81±0.32	1.97±0.93	57.75±10.83
Oct.2009	Mean	23.28±0.25	21.40±0.33	1.76±0.91	57.63±10.41
Nov.2009	Mean	17.35±0.24	15.54±0.26	1.63±0.87	63.50±10.16
Dec.2009	Mean	12.66±0.22	10.76±0.27	1.54±0.93	65.63±8.88

AT= Air temperature, WT= Water temperature, ± Standard error

Total dissolved solids (TDS)

The Total dissolved solids value ranged from 67 mgL^{-1} in September and 362 mgL^{-1} in January, where as the mean minimum and maximum value varied from 100.87±24.23 mgL^{-1} to 272±57.72 mgL^{-1} in September and January respectively. The higher concentration of dissolved solids was recorded in winter and lower in late summer due to the decreased water levels during winter resulting in the increased concentration of different salts in water.

Total suspended solids

The total suspended solids mean minimum and maximum during the study period was ranged from 57.25±16.13 mgL^{-1} to 148.12±23.99 mgL^{-1} in February and July respectively. This increased concentration of total suspended solids may be associated with the decreased concentration of dissolved oxygen. Generally the higher concentration of suspended solids observed during summer and the lower in winter, because of the high run-off rates during summer especially in rainy periods and water remaining calm during winter.

pH

The highest pH value observed was 9.90 in April and lowest was observed in May i.e., 7.18, where as the mean minimum and maximum pH value during the study period ranged from 8.31±0.31to 8.83±0.42 in December and June respectively. The high range of pH (7.18-9.90) indicates higher productivity of the water body. This is in accordance with the findings of Zafar (1964) and Vyas *et al*. (1989).

Conductivity

The present values of electric conductivity varied from 245 to 535 µS. The highest value was recorded in January and the lowest was recorded in June. The average mean highest and lowest conductivity values were 427.12±56.37 µS and

289.75±32.95 µS throughout the study period of one year in 2009. The electric conductivity of water depends on the concentration of ions and its nutrient status. The higher conductivity values may be due decomposition of organic matter, accumulation of ions owing to evaporation, biological turnover and interaction with sediments (Devi and Anandhi, 2009). Shastree *et al.* (1991) also reported that high level of conductivity reflects the pollution status as well as trophic levels of the lake.

considered as an indicator of eutrophication and pollution due to sewage (Chourasia and Adoni 1985).

Total alkalinity and Bicarbonates

The average mean total alkalinity values in the present study were ranged from 84.38±29.55 mgL^{-1} to 143.96±34.14 mgL^{-1} in the month of June and January respectively. Whereas the sites lowest and highest total alkalinity values were ranged

Table 2. Shows the mean values of physico-chemical characteristics of Dal Lake, Srinagar

Date/Parameter		TDS mg/L	TSS mg/L	pH	Conductivity(µS)
Jan.2009	Mean	272.00±61.71	73.38±17.26	8.51±0.35	427.13±60.27
Feb.2009	Mean	262.75±55.14	57.25±17.25	8.35±0.31	408.81±51.03
Mar.2009	Mean	212.38±53.37	84.13±24.68	8.62±0.73	388.75±45.16
Apr.2009	Mean	184.75±44.75	97.13±25.91	8.66±0.86	355.25±37.29
May.2009	Mean	126.75±40.98	81.63±32.07	8.64±0.89	326.06±36.84
Jun.2009	Mean	130.38±34.89	67.88±28.83	8.84±0.45	289.75±35.23
Jul.2009	Mean	106.50±27.28	111.50±30.43	8.69±0.66	304.56±31.91
Aug.2009	Mean	120.25±21.80	148.13±25.65	8.80±0.38	322.19±26.54
Sep.2009	Mean	100.88±25.90	105.63±32.74	8.69±0.39	344.63±26.86
Oct.2009	Mean	88.38±23.74	113.00±31.51	8.57±0.43	349.56±34.63
Nov.2009	Mean	136.00±19.78	125.63±20.46	8.48±0.51	366.88±31.95
Dec.2009	Mean	192.38±29.15	87.25±11.21	8.32±0.34	390.13±37.52

± Standard error

Table 3. Shows the mean values of physico-chemical characteristics of Dal Lake, Srinagar

Date/Parameter		D.O (mg/L)	Chloride (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)
Jan.2009	Mean	5.83±0.73	26.18±7.09	143.10±36.28	0.86±0.64
Feb.2009	Mean	5.65±0.43	33.58±13.77	134.83±35.21	2.11±1.80
Mar.2009	Mean	6.74±1.04	39.11±17.61	121.14±32.17	5.63±2.14
Apr.2009	Mean	7.14±1.06	34.70±14.75	105.05±35.66	4.80±2.93
May.2009	Mean	6.55±1.06	29.93±9.47	89.11±27.99	7.23±4.93
Jun.2009	Mean	5.95±1.24	31.28±13.72	77.09±30.89	7.30±2.66
Jul.2009	Mean	5.05±1.37	30.09±11.63	88.48±29.77	2.96±0.91
Aug.2009	Mean	4.69±1.32	27.79±10.27	98.98±32.22	3.71±1.27
Sep.2009	Mean	5.24±1.15	29.63±11.16	103.68±29.91	3.51±1.85
Oct.2009	Mean	5.21±0.89	31.96±10.23	104.64±30.52	4.26±1.72
Nov.2009	Mean	5.26±0.83	33.56±9.94	112.30±34.80	4.19±2.04
Dec.2009	Mean	5.28±0.76	35.55±10.07	124.21±34.84	2.16±1.81

± Standard error

Dissolved oxygen

The minimum and maximum dissolved oxygen values ranged from 2.50 and 8.80 mgL^{-1} in August 2009 and April 2009 respectively, whereas the average mean minimum and maximum values observed was 4.68±1.23 and 7.13±0.99 mgL^{-1} in August 2009 and April 2009 respectively. This may be due to vigorous photosynthetic activity of the auto-trophs (Phytoplankton and submerged vegetation). A decrease in D.O. content in summer may be due to increase in water temperature, which results in rapid rate of organic decomposition in the eutrophic water body. D.O. is also influenced by various factors such as temperature, photosynthetic activity and sewage input Jameel (1998). Low content of DO is also due to inorganic reductants like hydrogen sulphide, ammonia, nitrates, ferrous ion and other such oxidisable substances (Ara *et al*., 2003).

Chloride

The lowest and highest chloride values observed was 10.70 to 61.00 mgL^{-1} in July and March respectively. Whereas the average mean minimum and maximum values observed was 26.17±6.62 to 39.10±16.47 mgL^{-1} in January and March respectively. The increased concentration of chloride is from 52.8 to 210.2 mgL^{-1} in the month of June and January respectively. The annual mean bicarbonate values were ranged from 77.08±28.89 mgL^{-1} to 143.1±33.93 mgL^{-1} in June and January respectively, whereas the highest and lowest values in all the study sites ranged from 41.4 to 208.8 mgL^{-1} respectively. The high alkalinity values is a function of ion exchange i.e., Ca ions are replaced by Na ions and later contributed to alkalinity (Dar *et al*. 2013). This may also be caused due to evolution of CO_2 during decomposition of organic matter.

Carbonates

Low carbonate concentrations were recorded during the study period, that too mostly at less polluted sites; where carbonate alkalinity was almost nil and total alkalinity was due to the bicarbonate content only, because for carbonates there is tendency to get removed from polluted waters by precipitation or adsorption. The carbonate alkalinity in the present study ranged from 0.15 to 14.20 mgL^{-1} in January and May respectively. Whereas the mean annual highest and lowest values of carbonates recorded were 7.30 and 0.86 in June and January respectively.

Table 4. Shows the mean values of physico-chemical characteristics of Dal Lake, Srinagar

Date/Parameter		TH (mg/L)	CH (mg/L)	MH (mg/L)	Silicates (mg/L)
Jan.2009	Mean	125.53±14.85	94.38±13.06	19.43±4.61	6.49±1.30
Feb.2009	Mean	124.41±20.43	92.00±15.24	21.33±4.73	5.94±1.31
Mar.2009	Mean	125.05±17.41	89.25±11.59	16.05±3.96	5.35±1.26
Apr.2009	Mean	108.15±15.91	88.38±12.15	16.98±3.48	3.72±0.68
May.2009	Mean	88.96±20.31	90.75±12.70	16.78±3.92	4.06±0.99
Jun.2009	Mean	84.64±21.48	96.13±14.66	16.24±3.67	5.11±0.81
Jul.2009	Mean	89.63±22.06	91.25±12.15	16.18±3.66	6.94±1.02
Aug.2009	Mean	92.83±22.36	91.38±12.57	16.10±3.69	8.58±1.72
Sep.2009	Mean	100.28±21.24	91.75±14.16	15.31±3.68	7.88±1.52
Oct.2009	Mean	100.15±17.98	84.75±8.94	15.05±3.54	6.14±1.17
Nov.2009	Mean	108.18±18.89	84.88±8.81	16.17±3.68	5.43±1.14
Dec.2009	Mean	117.43±16.53	88.25±9.84	17.10±3.83	5.18±0.94

TH= Total hardness, CH= Calcium hardness, MH= Magnesium hardness, ± Standard error

Table 5. Shows the mean values of physico-chemical characteristics of Dal Lake, Srinagar

Date/Parameter		Ortho-phosphate (µg/L)	Total phosphate (µg/L)	Nitrate nitrogen (µg/L)	Ammonical nitrogen (µg/L)
Jan.2009	Mean	282.50±132.66	998.00±42.22	775.38±154.84	818.13±67.07
Feb.2009	Mean	300.00±106.74	1,073.63±9.71	807.88±140.04	844.63±69.27
Mar.2009	Mean	256.88±108.63	1,212.63±22.85	855.75±147.66	889.75±76.49
Apr.2009	Mean	293.75±116.09	1,268.50±14.88	888.88±146.48	936.88±83.09
May.2009	Mean	272.50±129.78	1,320.13±21.57	945.63±176.33	974.00±96.80
Jun.2009	Mean	288.75±120.73	1,418.50±23.86	995.63±210.87	1,008.63±123.83
Jul.2009	Mean	275.63±139.70	1,440.25±26.30	935.63±184.41	988.63±101.72
Aug.2009	Mean	273.75±133.78	1,442.75±41.84	856.25±160.18	949.13±82.69
Sep.2009	Mean	264.38±132.08	1,376.63±54.14	790.00±154.59	897.88±80.49
Oct.2009	Mean	245.63±118.58	1,275.38±51.41	757.50±172.25	871.50±79.88
Nov.2009	Mean	233.75±113.82	1,192.50±42.93	772.50±153.88	852.75±70.84
Dec.2009	Mean	238.75±123.08	1,095.63±25.13	775.00±158.38	833.00±69.37

± Standard error

Table 6. Shows the mean values of physico-chemical characteristics of Dal Lake, Srinagar

Date/Parameter		Iron (µg/L)	BOD (mg/L)	COD (mg/L)
Jan.2009	Mean	217.38±112.15	9.28±0.58	16.83±2.20
Feb.2009	Mean	222.50±77.46	9.34±0.32	16.91±0.87
Mar.2009	Mean	256.25±63.57	8.43±0.70	14.99±1.63
Apr.2009	Mean	279.00±94.44	8.04±0.95	14.53±1.85
May.2009	Mean	256.88±80.71	8.51±0.71	15.05±1.54
Jun.2009	Mean	217.50±100.92	9.09±0.88	16.80±2.17
Jul.2009	Mean	315.63±65.05	9.79±0.94	18.08±3.04
Aug.2009	Mean	341.38±72.53	9.98±0.94	18.73±2.37
Sep.2009	Mean	319.00±69.31	9.50±0.83	17.49±2.68
Oct.2009	Mean	292.25±57.57	9.53±0.64	15.99±1.34
Nov.2009	Mean	254.38±59.30	9.41±0.60	15.94±1.21
Dec.2009	Mean	234.75±69.27	9.34±0.63	15.94±1.63

± Standard error

Hardness

The mean annual lowest and highest values of total hardness values recorded were 84.63±20.09 mgL^{-1} to 125.53±13.89 mgL^{-1} in June and January respectively throughout the study period. Total hardness is mainly contributed by calcium and magnesium, which may be due the presence of lime stones and dolomites in the catchment area (Zutshi *et al*., 1980).The increase in calcium and magnesium hardness in water is mainly due to precipitation of calcium carbonate and by photosynthetic activity of primary producers.

Orthophosphate

The mean annual lowest and highest Orthophosphate values observed was 233.75 to 300 μgL^{-1} in November and February respectively throughout the study period. No definite trend was recorded for orthophosphate however the maximum orthophosphate values were recorded in winter and spring, whereas minimum orthophosphate values were recorded in autumn.

Total phosphate

The mean annual lowest and highest total phosphate values observed was 998 to 1442.75 μgL^{-1} in January and august respectively throughout the study period. Total phosphate records minimum value in winter and shows increasing trend towards summer up to august, where from shows decreasing trend towards winter. Similar trend has been observed by Dar *et al*. (2013) in Manasbal Lake, Srinagar.

Iron

The mean annual lowest and highest iron values observed was 217.38 $\mu g\ L^{-1}$ in January and 341.38 $\mu g\ L^{-1}$ in August respectively throughout the study period. The higher value of iron content may be due to the increased effect of domestic wastes and washing activities in the catchment area, as most of the detergents used contain trace elements of iron.

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

The mean BOD values fluctuated between 8.04 mgL^{-1} in April to 9.98 mgL^{-1} in August. Whereas the COD mean values

fluctuated between 14.53- 18.73 mg L^{-1} in April and August respectively. The BOD trend revealed comparatively high values during summer months. This may be attributed to the additional load of organic matter as a consequence of anthropogenic activities and domestic Sewage. Regular addition of organic matter in the lake water might have offered intense bacterial growth which consequently resulted in increased BOD level. On comparing the values it revealed that COD showed higher values in summer months. COD is an indicator for pollution strength of water (Koul, 1982). From the present study it is, therefore, concluded that the Dal Lake is undergoing rapid eutrophication under the increased human pressure in their drainage basins. Though the rate of eutrophication varies from one basin to other, yet the impact of human activities have been actually felt throughout the entire lake resulting in undesirable changes, being accompanied by wide environmental degradation. What is needed for the conservation of Dal lake ecosystems is to monitor the water quality over an extended period and to adopt long term restoration measures based on plans with ecological approach.

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