

Full Length Research Paper

Variations in the physico-chemical properties of Dal Lake, Srinagar, Kashmir

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Basic physical and chemical characteristics of the water in Dal lake Srinagar were determined. Surface water was sampled on monthly basis from June 2010 to April 2011. To determine the variations in physico-chemical parameters of Dal lake, a total of 21 physico-chemical parameters from six different site spread in four basins of lake was monitored. Our findings highlighted the deterioration of water quality in the lake due to anthropogenic activity in the lake and urbanization. The lake can be considered as eutrophic as evidenced by its shallow depth (1 to 4.5 m), low transparency (1 to 2.8 m), and higher concentrations of other nutrients such as phosphates, nitrates, sulphates and chloride. Pearson correlation coefficients were calculated to identify the strength of relation between the variables. The significant correlation was found among the temperature, depth, alkalinity, calcium, ammonia, nitrate and total phosphorus. Cluster analysis was additionally performed to obtain similarity between the sites.

Key words: Physico-chemical characteristics, Dal lake, anthropogenic activity.

INTRODUCTION

A lake is a reflection of its watershed and as watershed landscape, the topography, soil, geology and vegetation determines the kinds of materials entering into the lake that in turn reflect on its water quality (Dong et al., 2010). Nutrient enrichment of lakes is one among the major environmental problems in many countries (Oczkowski and Nixon, 2008). Though it stimulates the growth of plants (algae as well as higher plants), nutrient enrichment ultimately leads to deterioration of water quality and degradation of the entire ecosystem (Guyuan et al., 2011). In present times, the aquatic ecosystems worldwide are being severely altered or destroyed at a rate greater than ever known in the human history. Dal Lake (Lat. 34° - 06' N, 74° - 45' E, alt. 1581 m) situated in the heart of Srinagar, the summer capital of Jammu and

Kashmir State is under tremendous anthropogenic pressure for the last three decades. More than 50,000 people live within the lake itself in various hamlets besides living in houseboats. People use this lake, for personal purposes generating huge businesses out of it but producing numerous pollutant generating substances for it in the form of floating gardens and using fertilizers at large in the nearby paddy fields therefore these activities have deteriorated the lake ecosystem in diverse ways.

In recent decades, population growth, agricultural practices and sewage run-off from urban areas have increased nutrient inputs many folds than the level of their natural occurrence, resulting in accelerated eutrophication and pollution (Zan et al., 2011). However, this process is accelerated by excess nutrients from

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human activities and is called “cultural eutrophication” (Guyer and Ilhan, 2011). It is caused by excess plant nutrients (primarily N and P) disposed into lakes mainly as untreated or partially treated domestic sewage, runoff from agricultural fields and so on. The chemistry of lake water is a cumulative reflection of catchment geology, weathering and erosional processes as well as anthropogenic inputs. The concentration of the chemical constituents in water depends on the availability of the parent mineral for a particular constituent and its dissolving capacity. Since many lakes are sinks of agricultural runoff and municipal and industrial waste water discharges, they become enriched with nutrients, and associated heavy metals (Koussouris and Diapoulis, 1989).

Being an urban type lake, municipal and domestic effluents have altered the surface water composition of Dal Lake, leading to increased eutrophication (Hutchinson, 1973). The results indicate that the direct discharge of sewage from houseboats, interruptions to the flow of water, human encroachments, increase in population within the catchment area, etc, have resulted in the deterioration of water quality, prolific growth of aquatic macrophytes and siltation. Keeping in view, the ecological significance of water bodies in Kashmir like Dal Lake, the present investigation were undertaken to determine the variations in physicochemical characteristics of Dal Lake.

MATERIALS AND METHODS

Study area

The Valley of Kashmir is a lacustrine basin of the intermountain depression existing between the lesser and Greater Himalayas characterized by numerous aquatic ecosystems of great ecological and economic importance. Freshwater lakes of Kashmir Himalayas have important multistage components like source of drinking water, irrigation, navigation, fishery, agriculture, socioeconomic development and recreation. However, in recent decades, the lake ecosystem has changed drastically and come into exacerbated trend because of disturbances in the catchment areas. As a result of heavy anthropogenic pressures, the lake surface area is shrinking with deterioration of water quality. The main problem of these lakes is nutrient enrichment from catchment area in the form of domestic wastewaters (residential areas) and runoff from agricultural fields.

Six sampling sites were chosen for the determination of various physico-chemical parameters of water within the lake (Figure 1). Site I is located at a latitude 34° 08' 44.6"N and longitude 74° 50' 36.0"E near Habak STP where Bok kol enters in the Dal lake. The average depth of this site is 1.4 m. Site II is located within the centre of Hazratbal basin at latitude 34° 07' 47.4"N and longitude 74° 50' 38.0"E, having dense macrophytic growth and average depth of this site is 3.2 m. Site III is located in Nigeen basin (at latitude 34° 06' 53.1"N and longitude 74° 50' 07.3"E) near houseboats; this site is heavily impacted by direct drainage of sewage from house boats the average depth of this site is 2.4m. Site IV is located in dense floating garden area of Kandmohalla with average depth of 2.4 m, situated in Gagribal basin of lake at latitude 34° 05' 58.6"N and longitude 74° 50' 47.4"E). Site V is located with

the centre of Gagribal basin at latitude 34° 04' 54.8"N and longitude 74° 49' 52.0"E, having dense macrophytic growth and average depth of this site is 4.0 m. The last site VI is situated in Nishat Basin near Dock yard LAWDA at latitude 34° 07' 41.4"N and longitude 74° 52' 34.8"E; this site is regularly disturbed in summer months by manual dewatering processes. The average depth of this site is 3.0 m.

Sampling analysis

Sample collection and physico-chemical analysis water samples were collected monthly from 6 sites of Dal lakes from 2010 to 2011 and were kept in polyethylene plastic bottles that were prior cleaned with metal-free soap, rinsed repeatedly with distilled water, then soaked in 10% nitric acid for 24 h and finally rinsed with distilled water. All water samples were properly stored and taken on the same day to laboratory and stored at 4°C until processing and analysis (APHA, 1995). The parameters like pH, temperature, depth, and transparency were checked on spot while the parameters like free carbon dioxide, chloride, and alkalinity values were determined by APHA (1995). Nitrogen and phosphorus were calculated by Spectrophotometric method (Wetzel and Lichens, 2004).

Statistical analysis

The measured parameters varied over the years. The arithmetic means of each parameter were therefore calculated for each basin to obtain representative values for use in statistical analyses. The strength of relation between variables was ascertained using a Pearson correlation matrix of the data. Cluster analysis (CA) is a group of multivariate technique, which allows assembling objects based on the characteristics. CA classifies objects, so that each object is similar to the others in the cluster with respect to a predetermined selection criterion. Hierarchical agglomerative clustering is the most common approach, which provides intuitive similarity relationships between any one sample and the entire data set and is typically illustrated by a dendrogram (tree diagram). The dendrogram provides a visual summary of the clustering processes, presenting a picture of the groups and their proximity with a dramatic reduction in dimensionality of the original data (Shrestha and Kazama, 2007).

RESULTS

Physico-chemical parameters of water were analysed and assessed in order to understand and comprehend the variation of the various parameters amongst the lake basins. The results of various physico-chemical characteristics of the Dal Lake water sample for the one year are presented in the (Table 1). The air temperature varies from 4°C in December at site - VI to 28°C in July at site-II. Water temperature fluctuated between 1 to 25.5°C. The surface water temperature is one of the most significant parameters which control inborn physical qualities of water. The depth of water at a particular site in a water body is one of the major physical factors which act as a controlling factor for determining the water quality. Among the different sites, the maximum depth was 4.5 m and a minimum was 1 m. Water transparency is an important factor that controls the energy relationship

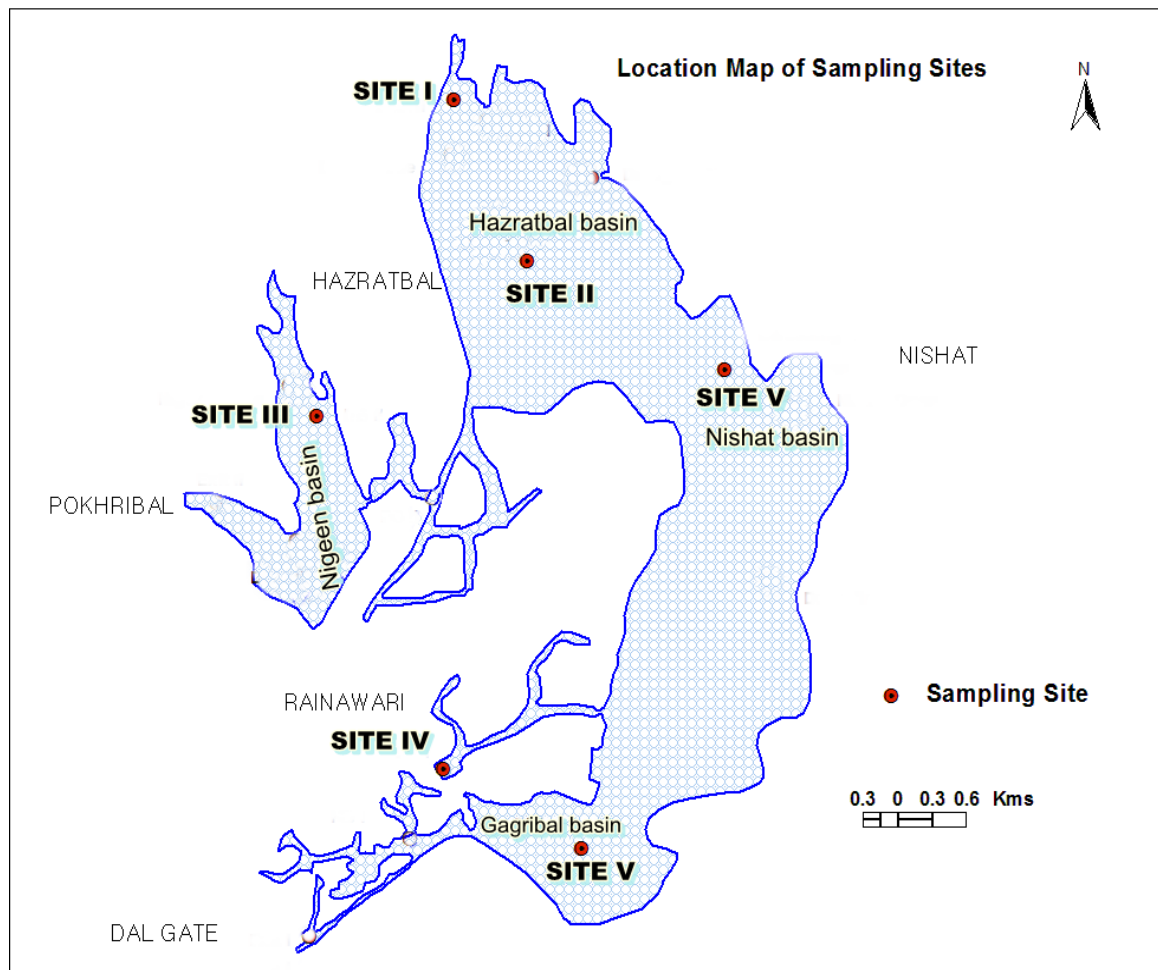


Figure 1. Map of Dal lake showing study sites.

Table 1. Spatio-temporal variation in physico-chemical parameters of different sites from June 2010 to April 2011 in Dal lake.

Parameter	Site	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Air temperature (°C)	I	26	28	27.5	15.5	17	9.5	6	7	8	15	15.5
	II	24	26	26	16.2	15	7.9	5.8	6.2	6.9	18	16
	III	27.5	27.5	27.5	16.6	16	7.5	7.2	7.3	7	21	19.2
	IV	32	21	20.7	14.9	14	7.4	6.7	7.5	8	19	19.5
	V	28.3	24	19	11.5	9.5	6.2	5.4	6	6.5	15	16.5
	VI	29	22	17	10	8	6.8	4	3.5	5.6	22	13.8
Water temperature (°C)	I	21	24	21.5	16	13	1	1	6	10.5	14.5	12.6
	II	19.3	23	22	15.8	14	4	4	5.3	8.5	13	14.5
	III	21	25.5	25	13.8	14	2.75	2.75	5.2	8.6	14	16
	IV	25	17	18	11	13.7	1.5	1.5	5	8.9	13	16.3
	V	24	18	15	9.5	8	4.5	4.5	5	8	14	15.9
	VI	24	17	14	8	7	3.5	3.5	3.2	9.1	15	12
Depth (m)	I	1.3	1.3	1.5	1	1	1	1	1	2.7	2.7	1
	II	2.5	2.5	3	4	4	2.9	4	4	2.9	2.9	2.5
	III	3	3	3	2.75	2.75	2.2	2.75	2.5	1.2	1.2	1.8
	IV	3	3	3	2.75	2.75	2.2	2.75	2.5	1.2	1.2	1.8
	V	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	2	2	4

Table 1.Contd.

	VI	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	1.5	1.5	2
	I	1	1	1	1	0.8	0.5	0.5	1	1.5	1	0.5
	II	2	1.5	2.5	2.5	1.5	1.5	2	2	1.8	1.8	1.5
Transparency (m)	III	2	1.8	1.3	1.5	1.8	1	1	1	0.5	1	1
	IV	1.5	2	1.5	2	2	2	1.5	1	1	0.3	0.5
	V	2.8	2.8	2.6	1.5	1	2.3	1	2.4	1	1	1.8
	VI	1.7	2.3	1.4	1.3	1	1.5	2	2	1	1	1.4
	I	7.4	7.5	6.9	6.8	7.4	6.9	8	8.3	8	8.2	7.6
	II	7.7	7.6	7	7	7.2	7	8.1	8.3	8.2	7.5	8.3
pH	III	7.8	7.2	7.2	7.6	7.5	7.3	7.2	7.8	8.5	8.1	7.5
	IV	7.8	7.2	7.6	7	7.2	7.4	7.8	8	8.2	7.5	7.6
	V	7.5	8.1	7.5	7	7	7.5	8	8.2	8.2	8.2	8.3
	VI	7.8	8.1	7.9	7.8	7.9	7.8	8	8.4	8.1	8.4	8.7
	I	200	200	142	245	250	220	160	230	210	260	340
	II	300	180	180	200	190	190	140	200	200	312	120
Conductivity ($\mu\text{s}/\text{cm}$)	III	100	240	178	180	180	190	230	200	210	388	360
	IV	100	220	193	195	180	180	220	180	200	382	380
	V	300	120	160	160	118	200	160	110	124	343	160
	VI	200	120	149	150	164	170	180	170	168	340	280
	I	3	4	6.4	6	6	6.8	3.2	3	6.4	4	3
	II	8	6	4	6	4	6	6	5	5	8	6
Dissolved oxygen (mg/L)	III	4.6	3	5.6	4.4	4.4	4.4	4.8	4	8	6.8	4.4
	IV	3	4	4	3	2.5	2.4	4	4	4	7.2	4
	V	6	4	4.8	4.8	5.2	6.2	6	4	6.8	5.6	6.6
	VI	4	4	8.2	4.4	4.4	4	6	4	8	7.6	4
	I	8	4	4	4	4	4	12	4	10	12	16
	II	4	6	14	8	18	4	4	4	10	0	4
Free Carbon dioxide (mg/L)	III	4	8	14	10	18	2	2	6	0	16	18
	IV	8	4	8	8	16	8	2	2	8	14	16
	V	0	10	10	8	10	4	4	2	6	10	4
	VI	2	4	4	8	12	4	4	0	4	10	0
	I	16	12	14	12	11	11	12	8	13	22	24
	II	23	14	14	14	20	20	11	11	9	18	16
Chloride (mg/L)	III	24	12	16	18	20	19	13	15	11	18	18
	IV	23	18	12	14	22	10	14	11	11	19	30
	V	21	16	12	12	20	17	9	12	10	23	16
	VI	14	12	6	13	20	17	13	11	9	12	24
	I	166	148	136	139	160	176	172	154	332	372	260
	II	48	30	60	60	100	116	190	160	140	52	60
Total alkalinity (mg/L)	III	142	148	142	142	124	160	168	148	316	120	110
	IV	142	136	154	157	102	140	154	124	344	152	148
	V	124	57	46	48	114	104	196	136	116	104	110
	VI	136	148	142	139	108	124	178	158	304	140	100
	I	506	600	308	84	63	96	182	200	166	118	118
	II	258	192	280	58	32	78	152	164	172	100	100
Total hardness (mg/L)	III	212	196	202	76	40	76	138	144	164	108	118
	IV	252	278	406	40	61	58	138	150	174	154	132
	V	164	214	268	38	27	38	98	88	120	118	114
	VI	232	286	252	58	46	64	146	140	138	114	144
	I	172	320	130	57	63	71	111	139	115	96	90
	II	147	142	130	21	32	40	88	113	120	63	63
Calcium hardness (mg/L)	III	107	102	132	27	40	50	76	103	115	100	94

Table 1. Contd.

	IV	107	125	279	33	61	29	82	103	115	99	102
	V	84	165	286	23	27	34	40	60	48	94	96
	VI	186	194	151	42	46	55	84	115	100	96	130
Ca²⁺ (mg/L)	I	65	110	52	23	25	28	44	55	46	54	36
	II	56	54	45	8	13	16	35	45	47	42	42
	III	41	39	153	11	16	18	58	41	46	40	38
	IV	41	40	112	13	25	12	33	41	46	39	41
	V	32	25	114	9	11	13	16	24	19	38	38
	VI	33	36	60	17	19	22	34	46	40	38	92
Mg²⁺ (mg/L)	I	81	86	43	7	6	6	17	15	12	5	7
	II	26	12	40	9	7	9	16	12	12	9	9
	III	25	22	17	8	7	6	15	10	12	2	6
	IV	35	37	31	6	5	7	14	11	14	13	7
	V	19	11	10	1	12	1	14	7	17	6	4
	VI	11	22	24	4	2	2	15	25	9	4	37
Ammonia (µg/l)	I	1200	282	430	280	95	120	0	0	10	10	130
	II	0	320	480	315	200	0	0	0	0	0	0
	III	0	375	320	140	0	130	0	0	175	120	120
	IV	0	358	350	160	705	220	0	0	45	205	120
	V	0	405	158	0	0	100	0	0	0	350	0
	VI	585	330	220	30	0	55	0	0	165	285	0
Nitrite (µg/l)	I	8	10	5	15	21	14	15	12	14	30	15
	II	7	10	35	5	5	48	8	10	5	15	10
	III	2	30	0	40	5	68	5	0	5	25	10
	IV	44	35	5	5	20	232	0	0	10	20	20
	V	10	50	55	10	205	20	0	0	0	0	10
	VI	85	10	5	5	10.5	12	52	10	20	20	15
Nitrate (µg/l)	I	125	55	190	440	815	280	250	285	1200	440	680
	II	550	82	1050	375	175	140	220	290	455	465	140
	III	180	100	225	60	90	58	185	255	600	1280	1430
	IV	195	230	110	280	150	85	90	145	145	145	1250
	V	80	135	45	525	70	205	285	145	65	50	120
	VI	75	125	145	70	560	235	120	185	160	1170	160
Orthophosphorus (µg/l)	I	75	4	0	63	111	0	3	20	170	85	100
	II	11	3	15	38	105	0	0	0	32	6	25
	III	19	0	4	13	60	8	10	35	51	6	160
	IV	25	0	0	25	0	16	0	0	11	6	125
	V	43	59	0	56	5	5	0	0	14	0	0
	VI	45	3	0	58	68	0	4	0	20	25	140
Total phosphorus (µg/l)	I	144	66	242	186	540	61	132	127	288	175	260
	II	132	180	127	136	443	40	26	3	55	483	123
	III	206	101	61	89	259	92	79	210	92	210	200
	IV	412	184	110	120	31	40	35	26	57	18	220
	V	57	105	206	160	13	53	0	5	120	215	65
	VI	120	61	131	107	131	18	48	22	120	83	265
Sulfate (mg/L)	I	2	8	1	4	34	4.5	4.5	6	5	4.2	4
	II	1	8.5	1	4	33	2.5	5	6	4	4	1
	III	2.2	21.5	1.5	13	2	3	7	8	2	3	4
	IV	1.5	20.5	1.5	4	5	0	3.5	3	3.5	4	1.5
	V	0	4	0	7	0	2	1	0	2	2	1
	VI	2	8.5	1	1	10	1	3	3	3	5	2

Table 1. Contd.

	I	4	3	2	8	5	5	3	4	4	5	8
	II	2	7	10	10	5	5	12	0	5	2	2
Silicate (mg/L)	III	5.8	4	20	4	8	8	3	0	3	5	2
	IV	1	4	2	3	5	5	2	0	2	2	6
	V	3	5	11	6	6	6	6	0	3	3	3
	VI	2	2	2	2	3	2	2	0	3	3	2

at different trophic levels. It is essentially a function of reflection of light from the surface and is influenced by the absorption characteristics of both of water and of its dissolved and particulate matter. The transparency ranged between 1 to 2.8 m during the study period. Considerable fluctuations in pH can be observed in natural water during day, season to season and within years because of exposure to the air and biological activities. The lake is characterized by highly alkaline pH during summer as well as in the winter season. The pH recorded during the present study (6.8-8.7) was indicative of the alkaline nature (mean value 7.7). pH showed great variations during the study period and the pH remained alkaline (7.0 to 7.8) from summer to autumn. The higher values of pH were recorded from winter to spring (8.0-8.7) from December to April. However, lower values of pH were recorded (6.8 to 6.9) at site-I in summer. Conductivity is a measure of capacity of substance or solution to conduct electric current. Conductivity determines the total dissolved solids in the water. The electrical conductivity varied from 100 388 $\mu\text{S}/\text{cm}$.

Dissolved oxygen concentration showed a gradual decrease with time at various sites. The higher values with maximum concentration of 8.2 mg/L was recorded in the month of August at site - VI, while the lower values of 3 mg/L was obtained at various sites in different months. Carbon dioxide concentration varied between 0 to 18 mg/L. The carbon dioxide concentration was also found to reduce with time. The concentration of chloride during the present study showed great variations from a lower value of 6 mg/L recorded at site - VI in the month of July and in comparison to it, the higher concentration of chloride of 30 mg/L was observed at site -IV in the month of April. It was observed during the present study that the monthly values of total alkalinity depict an increasing trend in winter months. Although the higher values of total alkalinity (372 mg/L) was found in the month of March at site- I, lower value (46 mg/L) was recorded at site - V in the month of August. Total hardness and calcium hardness showed a different variation in different months. In the case of total hardness, the highest value (600 mg/L) was observed at site - I in the month of July, while the lower value (32 mg/L) was found at site - II in October. Similarly, in the case of calcium hardness, the highest value (320 mg/L) was recorded at site -I in July and lowest value (21 mg/L) was noticed at site - II in the

month of October. It was observed during the present study that average monthly values of total and calcium hardness was found lowest from September to November and highest values were observed in the summer months. Calcium and magnesium followed the same pattern as total and calcium hardness. Ca^{2+} and Mg^{2+} ions showed gradual reduction in their concentration from September to November and start again increasing from December. However, the highest concentrations were observed in summer months.

A great variation was observed in ammonical nitrogen concentrations during the present study. It was observed that highest concentration of ammonical nitrogen (1200 $\mu\text{g}/\text{l}$) was found in June at site - I and lowest in winter months particularly in December and January (in trace amounts). The monthly mean values of ammonical nitrogen showed increasing trend with increasing mean values of water temperature and declines with the decrease in temperature. Nitrite nitrogen also depicts variations in its concentration at different sites during the present investigation. It was found during the present study that the highest concentration of nitrite nitrogen was found in the month of October (205 $\mu\text{g}/\text{l}$) at site - V and in November (232 $\mu\text{g}/\text{l}$) at site - IV due to rapid increase in its concentration because of some anthropogenic activities on these particular sites. It was also noticed that $\text{NO}_2\text{-N}$ depicts (in addition to above two sites) decreasing trend from summer months to winter and slightly increased from spring onwards. Nitrate nitrogen depicts great variations in its concentrations at different sites in different months. However, the highest values (1400 $\mu\text{g}/\text{l}$) were observed in the month of April at site -III and lowest values (45 $\mu\text{g}/\text{l}$) at site - V in August.

Phosphorous, is generally recognized as one of the key nutrients in the productivity of freshwaters as it is essential element determining fertility of lakes. The concentration orthophosphate phosphorus during the study period varied from trace amounts at different sites in different months to a highest of 170 $\mu\text{g}/\text{l}$ at site -I in February. The low orthophosphorous content in waters is due to the formation of an insoluble calcium-phosphate complex. The spatial and temporal variations in the total phosphate were much fluctuated. In general, lower concentrations were maintained in the winter months at all sampling sites. On the other hand, monthly concentration depicted a maximum of 540 $\mu\text{g}/\text{L}$ and a mini-

Table 2. Pearson correlation matrix for measured variables of all six sites of Dal Lake.

	Temp	Dep.	Trans	pH	Cond.	DO	CO ₂	Cl	TA	TH	C hrd	Ca ²⁺	Mg ²⁺	NH ₄	NO ₂	No ₃	OP	TP	SO ₄	
Temp																				
Depth	0.07																			
Trans	0.42	.794**																		
pH	-0.2	-0.6	-0.5																	
Cond.	0.12	-0.712*	-0.647*	0.37																
DO	-0	-0.724*	-0.619*	0.26	0.46															
CO ₂	0.3	-0.2	-0.4	-0.23	0.38	0.227														
Cl	0.41	-0.2	-0.2	-0.12	0.59	-0.09	0.47													
TA	-0.4	-0.623*	-0.603*	.662*	0.05	.619*	-0.2	-0.43												
TH	.674*	0.19	0.56	0.11	-0.22	-0.03	-0.3	-0.16	-0.1											
C hrd	.649*	0.08	0.44	0.19	-0.12	0.02	-0.2	-0.17	-0.1	.962**										
Ca ²⁺	0.52	-0	0.19	0.22	-0.01	0.194	0.02	-0.17	-0.1	.803**	.901**									
Mg ²⁺	.700*	0.35	.663*	0	-0.33	-0.2	-0.3	-0.06	-0.2	.965**	.881**	.679*								
NH ₄	.870**	0.29	.633*	-0.52	-0.13	-0.03	0.21	0.207	-0.5	.667*	.617*	0.45	.691*							
NO ₂	-0.1	0.17	0.17	-0.610*	-0.12	-0.15	0.09	0.342	-0.3	-0.29	-0.34	-0.4	-0.2	0.19						
NO ₃	0.09	-.797**	-.814**	0.43	.788**	0.553	0.6	0.423	0.28	-0.3	-0.14	0.1	-0.41	-0.3	-0.33					
OP	0.21	-0.4	-0.4	0.15	0.31	-0.01	0.53	0.572	0.07	-0.34	-0.29	-0.23	-0.26	-0.2	-0.13	.651*				
TP	.617*	-0.2	-0.2	-0.09	0.44	0.159	.827**	.706*	-0.3	-0.04	0.017	0.07	0	0.39	0	0.57	.651*			
SO ₄	0.09	0.31	0.2	-0.26	-0.22	-0.44	0.4	0.058	-0.3	-0.16	-0.14	-0.36	-0.06	0.19	0.22	-0.24	0.12	0.29		
DS	0.21	0.3	0.16	-.748**	-0.26	0.154	0.45	-0.04	-0.3	0.045	0.058	0.22	0.05	0.44	0.34	-0.09	-0.09	0.15	0.04	

Temp, Temperature; Dep, depth; Trans, transpiration. Cond, conductivity; DO, dissolved oxygen; CO₂, free carbon dioxide; Cl, chloride; TA, total alkalinity; TH, total hardness; C hrd, calcium hardness; NH₄, ammonia; NO₂, nitrite; NO₃, nitrate; OP, ortho-phosphorus; TP, total phosphorus; SO₄, sulphate DS, dissolved silica.

mum of 3 µg/L at sites-II and V in the month of January and December respectively. The values of sulphate depict a great variation during the study period. The concentration of sulphate varied from 1 mg/L to a highest of 20.5 mg/L. It was observed that the contrition of sulphate values showed irregular monthly changes. Dissolved silica also showed irregular variation in the present investigation period. The concentration of silica was found to be a minimum of 1 mg/L at site - IV in June to a maximum of 20 mg/L at site - III in the month of August.

Statistical analyses

Pearson correlation coefficients were calculated to obtain relations between the variables (Table 2). The temperature showed positively significant correlation with total hardness (r=0.674) and calcium hardness (r=0.649), ammonical nitrogen (r=0.870) and with total phosphorus (r=0.617). Depth was found positively correlated with transparency (r=0.794) and transparency depicted significant correlation with magnesium (r=0.663) and ammonical nitrogen (r=0.633). pH was was

positively strong correlated with total alkalinity (r=0.662) and conductivity with nitrate nitrogen (r=0.788). Similarly, other parameters were found to be positively strong correlated with one another such as, free carbon dioxide with total phosphorus (r=0.827), total hardness with calcium hardness (r=0.962), Ca²⁺ (r=0.803) and Mg²⁺ (r=0.965) and calcium hardness with Ca²⁺ (r=0.901) and Mg²⁺ (0.881). In addition, cluster analysis was performed to identify natural grouping in the sites (Figure 2). The site -II and Site -III and Site -IV and Site -VI were the closest clusters and are thus

Bray-Curtis Cluster Analysis (Group Average Link)

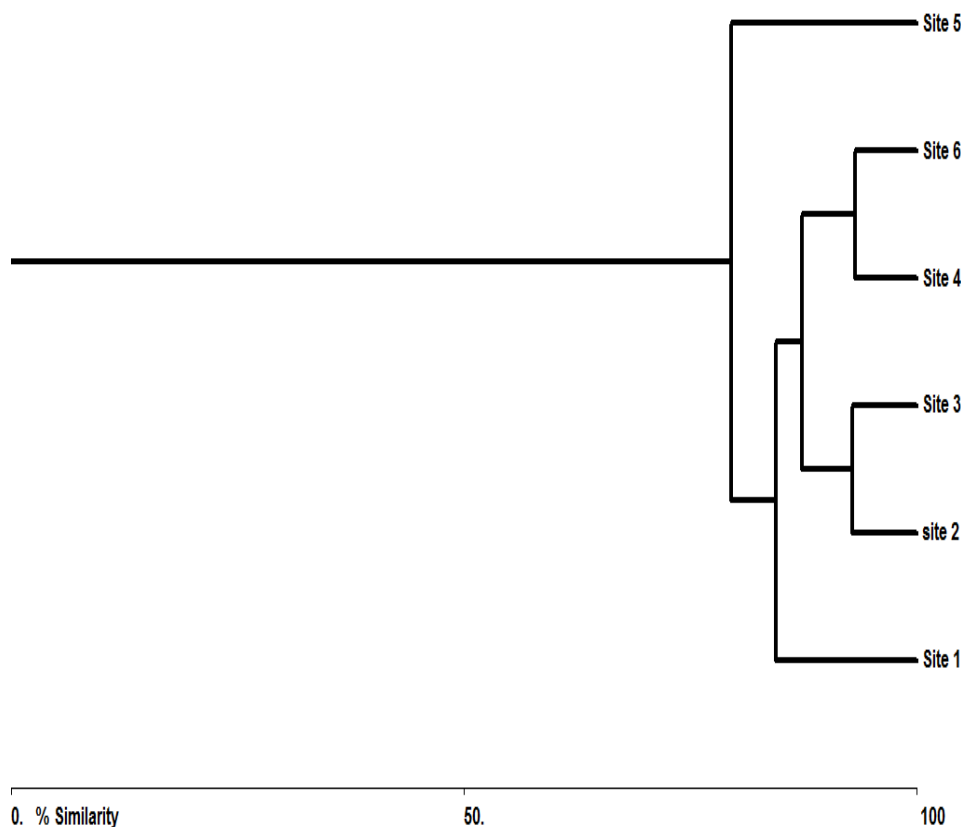


Figure 2. Cluster analysis dendrogram showing similarity between different sites.

the most similar to each other of all site. The site-I and site- V were found less similar with other sites and hence, not closely grouped with other site.

DISCUSSION

The surface water temperature of all sites follows closely that of the air temperature. The temperature variation recorded during the study period was optimal for normal growth and survival of aquatic organisms (Boyd, 1979). The depth of water at a particular site in a water body is one of the major physical factors which act as a controlling factor for determining the water quality. The lowest mean depth is an indication of an evolutionary process coinciding with higher trophic status of the lake as also opined by Rawson (1953) and Hayes (1957). During the study period, the Secchi disc transparency remains almost low at each site. Lower Secchi disc transparency could be as a result of anthropogenic activities which occur in Dal lake like dredging, dewatering, influence of floating gardens, etc. pH recorded in the present study was in alkaline range suggesting that the lakes were well buffered throughout the study period. pH range between 6.0 to 8.5 indicates productive nature of water body (Garg et al., 2010).

Electric conductivity depends upon the quantity of dissolved salts present in water (Gupta et al., 2008) and among the six sites the average conductivity varies from 178 to 223 μ s/cm. The dissolved oxygen in surface water comes from air or is produced by photosynthetic organisms like algae and plants in a water body. During the present study, the dissolved oxygen remain almost low at each site (Table 3); it may be due to highly eutrophic conditions of Dal lake. Depletion of dissolved oxygen in water probably is the most frequent result of certain forms of water pollution (Srivastava et al., 2009). The lower values of dissolved oxygen observed at site - IV could be due to cumulative effect of human activities like dumping of organic wastes from floating gardens where oxygen is used in decomposing these organic wastes. Oxygen level is depleted in water bodies due to decomposition of organic wastes (Mustapha and Omotosho 2005). The free CO₂ depicted well marked fluctuations at all the sites, registering a minimum mean value (4.7 mg/L at site VI) and a maximum in winter (8.9 mg/L at site III). The high value of the free carbon dioxide content is an indication of high degree of pollution, a fact also supported by Todda (1970) and Coole (1979) which related high value of free carbon dioxide content to high degree of pollution. The chloride content was observed

Table 3. The monthly mean values of physico-chemical parameters of different sites in Dal lake.

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Air temperature (°C)	15.9	15.3	16.8	15.5	13.4	12.9
Water temperature (°C)	12.8	13.0	13.5	11.9	11.5	10.6
Depth (m)	1.4	3.2	2.4	2.4	4.0	3.0
Transparency (m)	0.9	1.9	1.3	1.4	1.8	1.5
pH	7.5	7.6	7.6	7.6	7.8	8.1
Conductivity (µs)	223	201	223	221	178	190
Dissolved oxygen (mg/L)	4.7	5.8	4.9	3.8	5.5	5.3
Free Carbondioxide (mg/L)	7	7	9	9	6	5
Chloride (mg/L)	14	15	17	17	15	14
Total alkalinity (mg/L)	201	92	156	159	105	152
Total hardness (mg/L)	222	144	134	168	117	147
Calcium hardness (mg/L)	124	87	86	103	87	109
Ca ²⁺ (mg/L)	49	37	46	40	31	40
Mg ²⁺ (mg/L)	26	15	12	16	9	14
Ammonia (µg/l)	232	120	125	197	92	152
Nitrite (µg/l)	14	14	17	36	33	22
Nitrate (µg/l)	433	358	406	257	157	273
Orthophosphorus (µg/l)	57	21	33	19	17	33
Total phosphorus (µg/l)	202	159	145	114	91	101
Sulfate (mg/L)	7	6	6	4	2	4
Silicate (mg/L)	5	5	6	3	5	2

higher in summer months than in winter. Similar observations were also found by Jana (1973) and Govindan and Sundaresan (1979), according to them higher concentration of chloride in the summer period could be also due to sewage mixing, increased temperature and evaporation by water. As far as total alkalinity is concerned it varied greatly between the sampling sites, lesser values were observed in open water areas such as, at site - II and site - V. It was mainly due to bicarbonate ions, but carbonates made its presence in the months of March, August and October at site - III and VI. However, the site located in the floating garden area that is site - IV carbonates were not recorded at all. The alkalinity in floating garden area was only due to bicarbonate ions and not due carbonates ions (Siraj et al., 2006). Hardness of water is due to major cations present in the water body. Calcium and magnesium are principle cations that impart the hardness to water. Bicarbonates and carbonates of calcium and magnesium cause hardness in water because of hydrolysis and they are naturally change into cations. A natural hardness of water depends on geological nature of drainage basin. The values for total hardness during the present study period prevails greater variation in different months at different sites. The values of total hardness are much fluctuating from that of summer months to autumn months while as, in winter months the values also show similar trend as in summers. The mean value of hardness was maximum at site- I; it may be due to the outflow of

Sewage treatment plant at this particular site. Among the various cations, Ca²⁺ and Mg²⁺ were found almost abundant at all sites during the present study. Due to appreciable calcium and magnesium hardness, Dal lake can be classified as calcium rich (Ohle, 1934). Ca²⁺ and Mg²⁺ concentration of freshwater bodies of Kashmir Valley has been associated with thick population of plankton, especially Cyanophyceae (Bhat and Pandit, 2003). Ammonical nitrogen showed great fluctuations throughout the year at all the sites and ranged between maximum mean value of 232 µg/L and a minimum of 92 µg/L at site - I and site - V respectively.

Ammonical nitrogen showed during the present investigation gradual decrease in the months of December and January. After attaining the minimum values, the concentrations once again depicted an increasing trend. Such fluctuations in the values of ammonical nitrogen may be due to decomposition of organic matter into the lake as it is visited by many aquatic birds (Zuber, 2007). Organically polluted waters with high levels of NH₄-N, which is readily available as a nutrient for plant uptake may contribute to increased biological productivity (Sheela et al., 2011). The higher values of nitrite nitrogen may be due to use of fertilizers in floating garden as its high concentration was observed in these areas. The concentration of nitrate nitrogen and phosphates also showed great variations among various sites. The highest average value of nitrate and phosphate of 433 and 202 µg/L at site-I while the lowest average value of

157 and 91 µg/L at site-V respectively were observed during the present study period. Nitrate concentration could be due to the surface run off of nitro-phosphate fertilizers from nearby farm fields into the lake as well as domestic sewage from nearby residential areas. Phosphate enters the lakes through domestic wastewater, accounting for the accelerated eutrophication (Vyas et al., 2006). Increased concentration of phosphate and nitrate nitrogen in lakes resulted in enhanced productivity (Pandit and Yousuf, 2002). According to Rast et al. (1989), increase in nitrogen and phosphorus one or the other of which tends to limit productivity will lead to eutrophication. The sulphate is the third most abundant ion in the lake. The concentration of sulphate in Dal Lake fluctuated between 1 mg/L and 21 mg/L throughout the period of survey. The maximum mean sulphate concentration was recorded as 7 mg/L at site - I and minimum mean value was observed at site - V. The high concentration of sulphate at site - I may be due drainage of untreated sewage from sewage treatment plant into the lake. This agrees with Renn (1968) observation on the abundance of ions into the freshwaters. The source of the sulphate could probably be the mineral rocks that are present around the lake. Silica is the most abundant ion in the lake. Silica remains variable in different months at different sites in the present study. The mean values of silica ranged from a higher concentration of (6 mg/L) at site -III to a lowest concentration of 2 (mg/L) at site -VI. Its concentration could be due to decomposition of aluminium silicate minerals in rocks. The presence of the silica in the lake will promote the growth of diatoms- a major food producer of aquatic ecosystems. According to Sarwar (1986), the silicate content in the lake water gets depleted as it is taken up by the abundance of diatoms.

Conclusion

In conclusion, the lake is also productive and will support diverse number of organisms from phyto and zooplanktons, benthos to fishes and macrophytes going by the abundance of chemical ions needed for interconversion of energy and production of organic minerals present in the lake. It may be therefore, concluded that the water quality of Dal lake were observed polluted as a result of direct drainage of sewage from nearby residential areas and from inner side human habitation particularly houseboats. Current anthropogenic activities (dredging and dewatering operations, farming activities in floating gardens, etc.) in Dal lake are also responsible for deterioration of its water quality. The physico-chemical data obtained in this lake could be used as baseline and reference point when assessing further changes caused by natural or anthropogenic in this lake.

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