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Seasonal variation of the water quality of Dal Lake and its tributaries in Srinagar City, Kashmir Valley, India

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This paper presents a study on the spatial and seasonal/temporal variation of the water quality of Dal Lake and its tributaries based on some physicochemical parameters (temperature, pH, EC, TDS, NO_3^--N , NH_3-N, total phosphorus, PO_4^{3-}, Na^+, K^+, COD, DO, BOD, oil and grease, Ca^{2+}, Mg^{2+}, total hardness, SO_4^{2}) and heavy metals (Cu, Fe, Mn, Pb, Cd, Zn, and As). Four inlets (Botkoul, Telbal Nallah, Pishpav Nallah, and Nallah Meerek Shah), two outlets (Dal Lock Gate and Nallah Aamir Khan), and five sampling sites within Dal Lake (Char Chineri, Nehru Park, Southeast SKICC, Northeast SKICC, and Near Karpora Lam) were selected as study sites during summer and autumn of 2020. The data reveals that in summer, temperature ranged from 14.10 to 23.60°C, pH (6.71 to 8.18), DO (2.09 to 7.34 mg/L), total phosphorus (0.33 to 0.49 mg/L), orthophosphate (0.26 to 0.31 mg/L), COD (26.67 to 80.00 mg/L) and BOD (3.42 to 9.11 mg/L) and these levels were higher than recorded in the autumn at most of the study sites. Conversely, in autumn, higher concentrations of TDS (74.67 to 449.67 mg/L), EC (113.33 to 640.00 µS/cm), NO_3^--N (0.85 to 1.78 mg/L), NH_3-N (0.79 - 2.18 mg/L), SO_4^{2-} (39.33 to 218.53 mg/L), oil and grease (0.07 to 0.16 mg/L), Ca^{2+} (15.01 to 126.83 mg/L), Mg^{2+} (11.91 to 141.51 mg/L) and total hardness (96.58 to 755.56 mg/L) were recorded at most of the study sites. Iron, Manganese, and Lead were higher during the summer, whereas Copper, Zinc, and Cadmium were higher during the autumn. The seasonal variation between most locations (study sites) and among parameters was statistically significant ($p \leq 0.05$), respectively. This implies the influence of spatiotemporal and environmental factors on the poor water quality of Dal Lake and its tributaries.

Key words: Dal Lake, heavy metals, physicochemical, seasonal variation, summer and autumn, tributaries.

INTRODUCTION

Dal Lake, situated in the northeast of Srinagar city, in the heart of Kashmir Valley, Himalaya, at 1583 m above sea level (Fazal and Amin, 2012) has faced a lot of problems in the past decades emerging from anthropogenic pressures like water extraction and pollution, runoff of fertilizers used in agricultural fields, population encroachment and solid waste pollution which has led to the deterioration in water quality, eutrophication and other consequences such as reduction in the aesthetic impact in tourism and a decrease in fish stocks (Bassi et al., 2018). The lake has been considered eutrophic as evidenced by its shallow depth (1 to 4.5 m), low

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transparency (1 to 2.8 m), and higher concentrations of other nutrients such as phosphates, nitrates, sulphates, and chloride (Mushtaq et al., 2013). The direct discharge of solid and liquid wastes from the settlements all along the Tailbal stream and other areas in the upstream area has led to degradation of water quality and health hazards to the communities living around the Dal Lake (Saleem et al., 2015). The organic and inorganic pollutant loads in the Dal Lake have accelerated the macrophytic growth, which in turn has reduced the water quality and biological oxygen demand (BOD) of the lake and hence has reduced the recreational and aesthetic appeal of the lake. Dal Lake's condition has gotten to a critical stage from the ecological angles and if appropriate management actions are not taken in the future, the lake will likely depreciate more and will soon turn into a hyper-eutrophic condition (Sharma et al., 2015). In their research on Dal Lake, Rather et al. (2016) pointed out that the lake is marching towards a hyper-eutrophic condition mainly due to enhanced levels of nitrogen forms. The results they obtained from a one-way ANOVA of nitrogen forms revealed that the data was overall significant ($p<0.05$) for Ammonia and Nitrite and insignificant ($p>0.05$) in the case of nitrate.

The local meteorological disturbances and the shallowness of the Dal Lake cause erratic fluctuations in physicochemical parameters and alter the biological balance of the lake water (Lone et al., 2017). Most of the parameters analyzed in Dal Lake show monthly and seasonal variation and higher concentration of nutrients are found closer to houseboat areas with microphytic growth indicating high load of organic pollution from catchment and habitations, compared to the open water areas (Bhat and Mudasir, 2012; Najar and Basheer, 2012). The water quality index (WQI) of four basins of Dal Lake including Hazratbal, Boddal, Nageen, and Gagribal in summer, winter, and monsoon viz. 102.66, 120.33, 109.35, and 101.35, respectively, indicated that the Dal Lake water is not fit for drinking (Kanakiya et al., 2014). The bio-accumulation of heavy metals in the surface water and sediments of Dal Lake has been extensively noted (Jeelani and Shah, 2006; Raja et al., 2013; Shah et al., 2021). The access of heavy metals to any water system is through consumer and industrial wastes, the weathering of minerals by acidic rain discharging heavy metals into rivers, streams, lakes, and groundwater. The toxicity of heavy metals damages or reduces the functions of the mental and central nervous systems, lowers energy levels, and destroys the blood composition, liver, kidneys, lungs, and other important organs in living organisms (Verma and Dwived, 2013).

Dal Lake is one of the famous lakes in India due to its tourists' attractions and its bountiful ecological, social, and economic importance. However, due to the increase in population, industrialization, and urbanization in and around the lake and its tributaries, the quality of the lake water is deteriorating continuously. Therefore, it is best to continually monitor it and its tributaries to have up-to-date knowledge of its status. This study will give an understanding of the status of Dal Lake and its tributaries concerning the seasonal variation of some physico-chemical parameters that were analyzed which would give a better idea to decision makers in connection to other studies that have been done to handle the pollution problems of Dal Lake seasonally and spatially.

MATERIALS AND METHODS

Study area

Dal Lake is situated between 34°04' – 34°11' N, 74°48' – 74°53' E in the northeast township of Srinagar in the heart of Kashmir Valley in the western Himalayas. The lake has a total area of above 23 km^2 of which approximately 12 km^2 is the total open water spread area (Saleem et al., 2015). Dal Lake is integral to Kashmir tourism and recreation, though it sustains commercial benefits from fisheries, water plant harvesting, and vegetable production in floating gardens. Human interference by way of settlement in the lake to facilitate pedestrian traffic and establishment of lake tourism by providing floating residences (houseboats) got accelerated in the past decades. The length of the lake is 7.44 km (4.62 miles) with a width of 3.5 km (2.2 miles). The average elevation of the lake is 1,583 m (5,190 ft). The depth of water varies from 6 m (20 ft) at its deepest in Nagin Lake to 2.5 metres (8.2 ft), the shallowest at Gagribal (Bhat et al., 2017). Dal Lake has many tributaries as shown in Figure 1, some inlets and some outlets. This research considered four (4) inlets, namely *Botkoul* (N 34.14°, E 074.84°), *Telbal Nallah* (N 34.15°, E 074.84°), *Pishpav* (N 34.14°, E 074.86°) and *Nallah Meerak Shah* (N 34.14°, E 074.87°), and two outlets which are *Dal lock gate* (N 34.08°, E 074.83°) and *Nallah Aamir Khan near Ashai Bridge* (N34.11°, E 074.84°). Within the lake, the following sampling points were considered, *viz*: *Char Chineri* (N 34.10°, E 074. 87°), *Nehru Park* (N 34.09°, E 074.85°), *Southeast section of Sher-e-Kashmir International Conference Centre-SKICC* (N 34.09°, E 74.86°), *Northeast section of SKICC* (N 34.09°, E 074.96°), and *Near Karpora Lam* (N 34.10°, E 074.87°).

Water sampling method

Water samples were collected in two seasons, summer (in July) and autumn (in October) once in each season. Pre acid-washed sampling bottles and 250 ml BOD bottles were carried along for sampling. Three replicates were taken at each sampling point. The samples were stored in a refrigerator at 4°C for preservation and analysis. Oxygen was fixed at the sampling sites for dissolved oxygen analysis, and the temperature was taken at the same sampling time.

Water analysis method

For analysing the various water physicochemical parameters (temperature, pH, EC, TDS, NO_3^--N, NH_3-N, total phosphorus, PO_4^{3-}, Na^+, K^+, COD, DO, BOD, oil and grease, Ca^{2+}, Mg^{2+}, total hardness, SO_4^{2-}), the methods given by APHA (2005) were adopted. Heavy metals (Cu, Fe, Mn, Pb, Cd, Zn, and As) were analysed using the procedure given by Sharma and Tyagi (2013) in accordance with APHA (2005).

Statistical analysis

The R software version 4.0.4 (2021-02-15) was used to analyse the

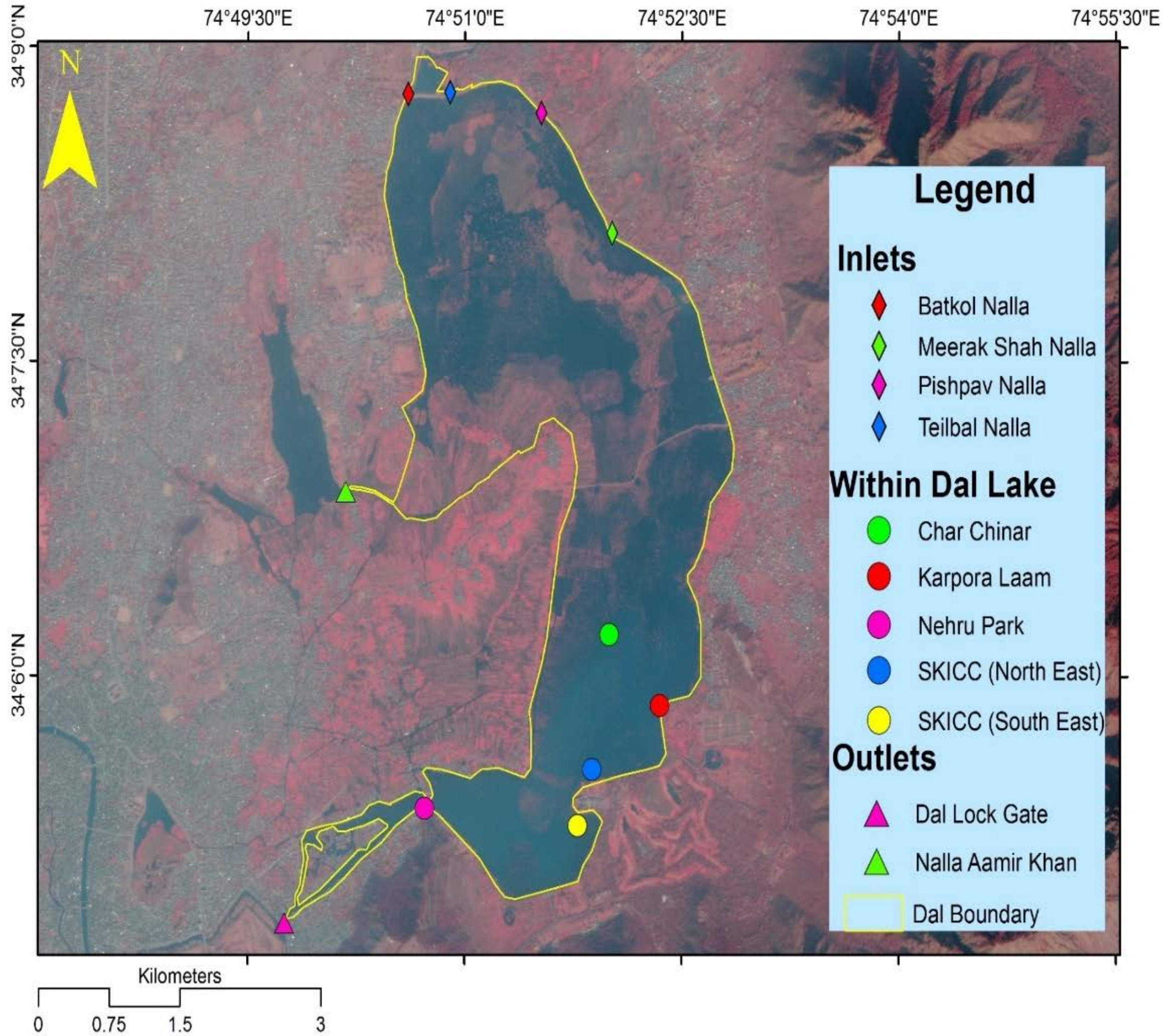

Figure 1. Digital map showing the water sampling sites.
Source: Authors Reserach Data, 2020

triplicate results of the physicochemical parameters. The Randomized Complete Block Design (RCBD) was employed for the analysis. A two-way analysis of variance (ANOVA) was used in the R software to get the critical difference (CD) of significance at $p \leq 0.05$ to determine whether there was a significant variation in physicochemical parameters between the two seasons and between locations/study sites. Correlation of the physicochemical parameters was done using the same software.

RESULTS AND DISCUSSION

Seasonal variation of physicochemical parameters

Table 1 shows the data of the first half of the physicochemical parameters analysed for their seasonal variation at the study sites. From the data, it was observed that the seasonal variation of all the parameters and between most locations (study sites) were statistically significant ($p \leq 0.05$). Higher temperatures and lower pH levels were obtained in the summer which can be related to the increase of the amount of energy striking any given place due to the suns' rays and the long sunshine hours (Science Reference Section, 2019). Due to the increasing temperature, water molecules vibrate and ionize to produce more hydrogen ions thus leading to a decrease in pH during the summer (Westlab, 2017). Total dissolved solids (TDS) and electrical conductivity (EC) were both lower at all the study sites in the summer than in the autumn. The reason for the low TDS and EC concentrations during the summer might be

Table 1. Seasonal variation of physicochemical parameters at the study sites.

Parameter	Seasons	Study sites											Mean (S)	Factors	C.D.	SE(d)
		Botkoul	Telbal Nallah	Pishpav Nallah	Nallah Meerek Shah	Char Chineri	Nehru Park	SKICC (Southeast)	SKICC (Northeast)	Near Karpora Lam	Dal Lock Gate	Nallah Aamir Khan				
Temperature	Summer	23.90	20.53	19.77	22.63	19.87	16.70	14.10	14.53	18.60	22.33	23.60	19.69	Season (S)	0.28	0.14
	Autumn	18.60	15.87	15.57	15.63	11.47	13.40	12.53	12.30	16.07	15.63	16.13	14.84	Location (L)	0.66	0.33
	Mean (L)	21.25	18.20	17.67	19.13	15.67	15.05	13.32	13.42	17.33	18.98	19.87		S × L	0.93	0.46
pH	Summer	7.22	7.16	6.71	6.86	7.01	7.79	7.11	6.73	8.18	6.86	6.85	7.13	Season (S)	0.08	0.04
	Autumn	7.23	7.35	6.80	7.10	7.00	8.19	7.39	7.49	8.33	7.59	7.04	7.41	Location (L)	0.20	0.10
	Mean (L)	7.22	7.26	6.75	6.98	7.01	7.99	7.25	7.11	8.25	7.22	6.94		S × L	0.28	0.14
Total Dissolved Solids (TDS)	Summer	385.67	292.33	230.00	218.00	87.33	87.67	105.67	102.33	98.67	53.67	99.00	160.03	Season (S)	5.87	2.90
	Autumn	449.67	345.00	242.67	246.33	86.00	99.00	140.00	103.00	81.00	74.67	174.00	185.58	Location (L)	13.76	6.80
	Mean (L)	417.67	318.67	236.33	232.17	86.67	93.33	122.83	102.67	89.83	64.17	136.50		S × L	19.46	9.61
Electrical Conductivity (EC)	Summer	596.67	436.67	356.67	353.33	146.67	133.33	170.00	160.00	153.33	93.33	156.67	250.61	Season (S)	6.05	2.99
	Autumn	640.00	536.67	373.33	383.33	126.67	156.67	206.67	160.00	123.33	113.33	250.00	279.09	Location (L)	14.19	7.01
	Mean (L)	618.33	486.67	365.00	368.33	136.67	145.00	188.33	160.00	138.33	103.33	203.33		S × L	20.07	9.91
Nitrate Nitrogen (NO_3–N)	Summer	0.95	0.78	0.72	0.70	0.78	0.81	0.77	0.81	0.84	0.87	0.91	0.81	Season (S)	0.02	0.01
	Autumn	1.78	1.65	1.11	1.52	1.02	0.94	0.85	1.04	0.95	0.95	1.11	1.18	Location (L)	0.04	0.02
	Mean (L)	1.36	1.21	0.91	1.11	0.90	0.88	0.81	0.92	0.90	0.91	1.01		S × L	0.06	0.03
Ammoniacal Nitrogen (NH_3-N)	Summer	1.24	1.17	1.19	1.35	0.83	0.95	0.80	0.86	0.91	0.97	0.84	1.01	Season (S)	0.03	0.01
	Autumn	1.83	2.18	1.66	1.34	0.79	0.89	1.18	1.06	1.27	1.14	0.98	1.30	Location (L)	0.07	0.03
	Mean (L)	1.54	1.67	1.43	1.35	0.81	0.92	0.99	0.96	1.09	1.05	0.91		S × L	0.09	0.05
Total phosphorus	Summer	0.43	0.37	0.40	0.44	0.35	0.37	0.45	0.49	0.42	0.39	0.33	0.41	Season (S)	0.01	0.004
	Autumn	0.35	0.33	0.39	0.33	0.32	0.34	0.30	0.31	0.32	0.33	0.31	0.33	Location (L)	0.02	0.01
	Mean (L)	0.39	0.35	0.40	0.38	0.34	0.36	0.37	0.40	0.37	0.36	0.32		S × L	0.03	0.01
Orthophosphate	Summer	0.29	0.27	0.27	0.30	0.26	0.31	0.29	0.31	0.29	0.30	0.28	0.29	Season (S)	0.003	0.001
	Autumn	0.28	0.30	0.31	0.29	0.26	0.28	0.27	0.27	0.28	0.29	0.26	0.28	Location (L)	0.010	0.003
	Mean (L)	0.29	0.29	0.29	0.30	0.26	0.30	0.28	0.29	0.29	0.30	0.27		S × L	0.010	0.005
Oil and Grease	Summer	0.10	0.08	0.04	0.14	0.05	0.05	0.06	0.04	0.08	0.10	0.12	0.08	Season (S)	0.01	0.004
	Autumn	0.16	0.14	0.15	0.14	0.07	0.08	0.08	0.09	0.12	0.12	0.10	0.11	Location (L)	0.02	0.010
	Mean (L)	0.13	0.11	0.10	0.14	0.06	0.07	0.07	0.07	0.10	0.11	0.11		S × L	0.03	0.012

Critical Difference (CD) significant at $p \leq 0.05$.
Source: Authors Reserach Data, 2020

due to the increasing growth of micro- and macro-phytes in high temperatures and their uptake of the nutrients and other ions at the different study sites (Srivastava et al., 2008; Rejmánková, 2011; Kinidi et al., 2017). The concentrations of TDS and EC in both seasons at all the sampling sites are controlled by variations of precipitation, radiation, temperature, and dilution (Beylich and Laute, 2012). Nitrate and ammoniacal nitrogen concentrations were higher in the autumn and lower in the summer season at most of the study sites, respectively. During autumn, due to the less warm months and reduced growth of aquatic plants, slow decomposition of organic matter by micro-organisms and reduced uptake of nutrients by aquatic plants might have led to the higher concentrations of nitrate and ammoniacal nitrogen. But during warmer months in the summer, organic matter is decomposed at a faster rate by microorganisms, and are also taken up faster by plants for their growth and therefore less nitrate and ammoniacal nitrogen in the summer season (Michaud, 1991; Quirós, 2003; Wang et al., 2010; Qian et al., 2020). Total phosphorus (TP) and orthophosphate (PO_4^{3-}) were higher during the summer than in the autumn at most of the sampling sites, respectively. This is due to the warmer temperatures in the summer which has a decreasing effect on dissolved oxygen, causing an increase in TP (Gibbons et al., 2020). Total phosphorus as noted by Shuvo et al. (2021) has an equal effect to the influence of the synergistic acts of climate variables (temperature, precipitation, cloud cover, and solar radiation). In order words, an increase in temperature (decrease dissolved oxygen) for example is favourable for the release of TP (Li et al., 2013 a). In regards to oil and grease, the summer season recorded lower concentrations at all the study sites than the autumn season. The higher temperatures in summer lead to the desorption of oil and grease from oil-water interfaces as they melt and coalesce thereby forming sediments (Binks and Rocher, 2009), thus reducing the oil and grease on the surface water into sediments. The discharge from the sewage treatment plants and urban runoff must have enhanced the concentration of oil and grease in both seasons at most of the study sites (Khan, 2016).

The seasonal variations of the rest of the physicochemical parameters are given in Table 2. From the data, it was also observed that the seasonal variation of all the parameters and between most locations (study sites) were statistically significant ($p \leq 0.05$). The data on sodium and potassium shows that all the study sites recorded higher mean concentrations of sodium and potassium in the autumn and lower concentrations in the summer. The reason for the lower concentrations of both mineral elements in the summer might be due to the warmer temperatures causing the excess growth of micro- and macro-phytes and their uptake of these minerals as nutrients (Moshiri, 1993; Salt et al., 1998; Zingelwa and Wooldridge, 2009). The direct discharge of effluents from sewage treatment plants must have enhanced the concentrations of sodium and potassium in both seasons (Skowron et al., 2018).

The chemical oxygen demand (COD) and biological oxygen demand (BOD) values ranged from 20 to 80 mg/L and 2.33 to 9.11 mg/L for both seasons, with the summer recording higher mean COD and BOD concentrations than the autumn at all/most of the study sites, respectively. Higher COD and BOD concentrations in the summer can be attributed to the greater quantity of organic matter from runoff of agricultural and domestic wastes, and effluents from sewage treatments plants (Latif et al., 2010; Ramachandra et al., 2014; Akaahan and Azua, 2016; Ling et al., 2017); the increased rate of oxygen consumption by microorganisms during decomposition of organic matter (Bhateria and Jain, 2016; Ramanathan and Amsath, 2018) and the chemical oxidation of organic matter as temperature increases at most of the study sites (Boyd, 1973; AOS, 2018). From the data (Table 2), the dissolved oxygen (DO) values ranged from 2.09 to 11.15 mg/L for both seasons. The summer season recorded lower DO levels than the autumn season at most of the study sites. This can be attributed to the increasing and decreasing of temperatures in the summer and autumn, respectively. In other words, warm water holds less oxygen in solution than cold water (Kelly and Green, 1997; Barman et al., 2015). Also, low dissolved oxygen can be attributed to excess nutrients especially phosphorus from sewage treatment plants, infiltration of cropland and urban stormwater runoff, and natural decay of vegetation (Joseph and Jacob, 2010: Ramachandra et al., 2014) which causes excess algal and phytoplankton growth, their die-off and decomposition also thus enhance low DO (MPCA, 2009; Biologist, 2016).

Sulphate (SO_4^{2-}) concentration ranged from 23.60 to 218.53 mg/L for both seasons. The lower concentration of sulphate in the summer than the autumn is due to the higher temperatures, accelerated growth of algae, and its uptake by micro- and macro-phytes as a nutrient (Zhao et al., 2021). Increasing temperatures also enhances microbial growth and thus increases their sulphate reducing capacity (Pellerin et al., 2020). Calcium and magnesium concentrations ranged from 24.11 to 140.18 mg/L and 10.15 to 141.51 mg/L, respectively. Notwithstanding, the summer concentrations of both calcium and magnesium were lower than the autumn concentrations. The lower calcium concentrations in the summer season can be attributed to its absorption by aquatic plants for strengthening their cell walls, maintaining pH, activating enzymes and hormonal response, improving water penetration, and resistance to diseases and environmental stress (Knight et al., 1997; Shi et al., 2002; Wang et al., 2019). In other words, it is an exceptional macronutrient with various but fundamental physiological roles in plant structure, signaling, and photosynthesis (Liang et al., 2009;

Table 2. Seasonal variation of physicochemical parameters at the study sites (continued).

Parameter	Seasons	Study sites											Mean (S)	Factor	C.D.	SE(d)
		Botkoul	Telbal Nallah	Pishpav Nallah	Nallah Meerek Shah	Char Chineri	Nehru Park	SKICC (Southeast)	SKICC (Northeast)	Near Karpora Lam	Dal Lock Gate	Nallah Aamir Khan				
Sodium	Summer	1.21	0.87	0.92	0.77	0.20	0.29	0.31	0.22	0.46	0.71	0.51	0.59	Season (S)	0.02	0.01
	Autumn	1.27	0.68	1.14	0.47	0.24	0.47	0.68	0.39	0.27	1.03	1.06	0.70	Location (L)	0.04	0.02
	Mean (L)	1.24	0.78	1.03	0.62	0.22	0.38	0.50	0.31	0.37	0.87	0.79		S × L	0.06	0.03
Potassium	Summer	2.12	1.55	1.09	1.72	0.16	0.29	0.18	0.19	1.11	0.79	0.15	0.85	Season (S)	0.02	0.01
	Autumn	2.23	1.24	1.36	1.06	0.20	0.50	0.39	0.33	0.65	1.70	0.46	0.92	Location (L)	0.05	0.02
	Mean (L)	2.18	1.39	1.22	1.39	0.18	0.40	0.28	0.26	0.89	1.25	0.31		S × L	0.06	0.03
Chemical Oxygen Demand (COD)	Summer	80.00	43.33	40.00	65.00	26.67	66.67	40.00	56.67	50.00	63.33	76.67	55.30	Season (S)	3.37	1.66
	Autumn	55.00	30.00	45.00	53.33	20.00	21.67	38.33	40.00	30.00	45.00	68.33	40.61	Location (L)	7.89	3.90
	Mean (L)	67.50	36.67	42.50	59.17	23.33	44.17	39.17	48.33	40.00	54.17	72.50		S × L	11.16	5.51
Dissolved Oxygen (DO)	Summer	2.50	3.24	2.09	3.00	4.54	6.58	5.38	2.92	7.01	7.34	6.59	4.65	Season (S)	0.08	0.04
	Autumn	3.78	6.31	6.85	8.15	6.60	10.29	10.80	11.15	9.33	8.60	4.96	7.89	Location (L)	0.18	0.09
	Mean (L)	3.14	4.78	4.47	5.57	5.57	8.43	8.09	7.04	8.17	7.97	5.78		S × L	0.25	0.12
Biological Oxygen Demand (BOD)	Summer	9.11	5.26	7.32	8.32	3.42	5.04	4.88	5.31	4.44	4.44	5.10	5.69	Season (S)	0.22	0.11
	Autumn	8.67	5.30	4.52	2.33	4.56	2.52	2.45	2.95	3.57	4.61	7.26	4.43	Location (L)	0.51	0.25
	Mean (L)	8.89	5.28	5.92	5.33	3.99	3.78	3.67	4.13	4.01	4.53	6.18		S × L	0.73	0.36
Sulphate (SO_4^{2-})	Summer	94.40	35.40	45.60	41.07	29.08	23.87	24.13	24.93	33.53	23.60	58.45	39.46	Season (S)	1.29	0.64
	Autumn	218.53	128.73	47.93	53.13	90.73	39.33	39.67	42.20	43.20	42.13	70.80	74.22	Location (L)	3.02	1.49
	Mean (L)	156.47	82.07	46.77	47.10	59.91	31.60	31.90	33.57	38.37	32.87	64.62		S × L	4.27	2.11
Calcium	Summer	140.18	27.08	70.83	47.92	31.25	74.70	69.35	59.226	24.11	45.83	45.54	57.82	Season (S)	1.25	0.62
	Autumn	109.13	16.58	75.52	126.83	69.47	56.69	69.02	88.516	84.03	70.14	15.01	71.00	Location (L)	2.92	1.44
	Mean (L)	124.66	21.83	73.18	87.38	50.36	65.70	69.18	73.871	54.07	57.99	30.28		S × L	4.14	2.04
Magnesium	Summer	91.34	20.30	42.80	10.15	41.49	42.29	30.20	65.37	29.50	35.59	54.96	42.18	Season (S)	1.23	0.61
	Autumn	16.43	33.25	65.27	71.51	56.87	137.00	11.91	12.74	13.59	141.51	14.40	52.22	Location (L)	2.87	1.42
	Mean (L)	53.88	26.77	54.04	40.83	49.18	89.64	21.06	39.05	21.55	88.55	34.68		S × L	4.06	2.01
Total hardness	Summer	724.94	150.93	352.56	161.42	248.25	360.14	297.20	416.08	181.24	260.49	339.16	317.49	Season (S)	4.51	2.23
	Autumn	340.17	177.78	456.41	610.26	406.84	703.42	221.37	273.50	265.81	755.56	96.58	391.61	Location (L)	10.58	5.23
	Mean (L)	532.56	164.36	404.49	385.84	327.55	531.78	259.29	344.79	223.52	508.02	217.87		S × L	14.96	7.39

Critical Difference (CD) significant at $p \leq 0.05$.
Source: Authors Reserach Data, 2020

Gilliham et al., 2011). On the other hand, the lower magnesium levels in the summer can be related to the warmer temperatures and therefore much uptake of magnesium by aquatic plants for photosynthesis. This is because for plants to perform properly the enzymes in their cells require magnesium, which plays a very vital role as the central atom in the chlorophyll molecule that governs plant photosynthetic process (Levitt, 1954; Premier Tech, 2021a). During autumn, the death and decomposition of some aquatic plants enhanced the magnesium content at most of the study sites (Ranjbar and Jalali, 2012). Agricultural runoff from catchment areas and floating gardens runoff in Dal Lake might have enhanced the concentration of calcium and magnesium at most study sites (Mushtaq et al., 2018). The concentration of total hardness for both seasons ranged from 96.58 to 755.56 mg/L. Due to lower calcium and magnesium concentrations in the summer at most of the study sites, total hardness concentration was also lower in the summer and higher in the autumn at most of the study sites. This is due to the fact that total hardness is the amount of dissolved ions especially calcium and magnesium in the water. In addition to the factors causing an increase in calcium and magnesium concentrations and therefore total hardness, the discharge of agricultural and residential wastes and effluents from sewage treatment plants also enhances the total hardness of water (Ishaq and Kaul, 1989; Mushtaq et al., 2018).

Seasonal variation of heavy metals

Table 3 shows the data on the seasonal variation of heavy metals at the study sites. The data shows that Copper (Cu) ranged from 0.00 to 0.190 ppm and it was absent in the summer, but present in the autumn season at all the study sites, respectively. Whereas, Zinc (Zn) ranged from 0.011 to 0.998 ppm and was only present in lower concentrations at few study sites in the summer, but was present in higher levels at all the study sites in the autumn. Cadmium (Cd) was absent at all the study sites during the summer season, and present at only a few of the study sites, viz. Nallah Meerek Shah (0.379 ppm), Char Chineri (0.529 ppm), and Dal lock Gate (0.214 ppm) in the autumn season. The absence and lower concentration of Cu, Zn, and Cd in summer at all/most, respectively of the study sites could be due to their excessive uptake by the growing micro- and macro-phytes and other aquatic organisms during higher temperatures, and their sedimentation at the study sites (Maine et al., 2001; Vigneault and Campbell, 2005; Kim and Kim, 2016; Wojtkowska et al., 2015; Costa et al., 2018). Bashir (2020) reported that a high concentration of Cu was found in aquatic macro-phytes during summer than in autumn, also she found higher concentration of Cu in sediments during summer than in winter (lower temperatures). The increased concentration of Cu, Zn, and Cd during autumn could be related to the death and decomposition of some aquatic plants and the release of nutrients (Showqi et al., 2018). The presence of Cd at the few study sites might be due to natural load from rocks in their watersheds, refuse dumps, and sewage sludges (Ravera, 1984).

Also, the data (Table 3) points out that iron (Fe) was present at most of the study sites during the summer ranging from 0.0 to 3.8 ppm and absent at all the study sites in the autumn season. Lead (Pb) was present at all the study sites in both seasons ranging from 0.050 to 0.220 ppm, with higher levels in the summer. The higher levels of Fe and Pb in the summer could be due to the availability of iron and lead at lower pH in the summer causing their uptake by aquatic organisms especially plants (Metzger, 2005; Premier Tech, 2021b), and their release from sediments into the surface water (Li et al., 2013b). Also, this could be related to higher water temperatures, low dissolved oxygen, and reducing conditions in the catchment area (Durand et al., 1994; Ekström, 2016). Increasing dissolved organic matter might also be another cause of higher iron concentration in the summer. Iron has been reported to have a very strong association with dissolved organic matter because they both originate and are transported from organic soils (Oni et al., 2013; Sarkkola et al., 2013). Manganese (Mn) ranged from 0.221 to 1.594 ppm in summer and 0.320 to 0.400 ppm in autumn. The presence of Mn in both seasons at all the sampling sites can be attributed to its uptake by aquatic plants for respiration, chloroplast formation, photosynthesis, pathogen defence, nitrogen metabolism, synthesis of some enzymes, scavenging of reactive oxygen species (ROS), and hormone signaling (Alejandro et al., 2020; Patterson and Gardner, 2021). Also, it can be related to anthropogenic influences like effluent discharge from sewage treatment plants, sewage sludge, atmospheric fallout, etc., (Jaques, 1987; Moore, 1991). The concentrations of arsenic (As) at all the study sites were below the detection limit (BDL) of the atomic absorption spectrophotometer (AAS).

Correlation of physicochemical parameters

For the average mean of both seasons combined for each location/study site, the correlation of the water quality parameters is shown in Table 4. From Table 4, most of the parameters were found to have an insignificant negative correlation with pH, and a few like PO_4^{3-}, Mg^{2+}, and total hardness had an insignificant positive correlation with pH. Only DO was found to have a significantly strong positive correlation with pH. This shows that a decrease/increase in pH will cause a corresponding decrease/increase in DO. This is due to the fact that when pH decreases (increase in H^+ concentration), hydrogen ions and oxygen react (in a

Table 3. Heavy metals concentration (ppm) on a seasonal basis at all the study sites.

Heavy metals	Copper (Cu)		Zinc (Zn)		Iron (Fe)		Manganese (Mn)		Cadmium (Cd)		Lead (Pb)		Arsenic (As)	
Sampling sites	Summer	Autumn	Summer	Autumn	Summer	Autumn	Summer	Autumn	Summer	Autumn	Summer	Autumn	Summer	Autumn
Botkoul	0.000	0.047	0.011	0.974	3.500	0.000	0.345	0.400	0.000	0.000	0.170	0.090		
Telbal Nallah	0.000	0.172	0.000	0.754	3.400	0.000	0.341	0.400	0.000	0.000	0.200	0.120		
Pishpav Nallah	0.000	0.136	0.088	0.216	3.800	0.000	0.221	0.400	0.000	0.000	0.160	0.150		
Nallah Meerek Shah	0.000	0.172	0.000	0.754	3.200	0.000	0.721	0.400	0.000	0.379	0.200	0.100		
Char Chineri	0.000	0.154	0.000	0.240	3.400	0.000	0.345	0.400	0.000	0.529	0.170	0.050		
Nehru Park	0.000	0.154	0.000	0.853	3.500	0.000	0.521	0.400	0.000	0.000	0.170	0.110	BDL	
SKICC-Southeast	0.000	0.190	0.000	0.778	0.000	0.000	0.342	0.400	0.000	0.000	0.100	0.060		
SKICC-Northeast	0.000	0.047	0.030	0.803	0.000	0.000	0.345	0.400	0.000	0.000	0.110	0.080		
Near Karpora Lam	0.000	0.154	0.000	0.853	3.500	0.000	0.421	0.320	0.000	0.000	0.150	0.070		
Dal Lock Gate	0.000	0.047	0.030	0.998	3.500	0.000	0.781	0.400	0.000	0.214	0.220	0.140		
Nallah Amir Khan	0.000	0.047	0.011	0.876	3.500	0.000	1.594	0.400	0.000	0.000	0.190	0.050		
Mean (S)	0.000	0.120	0.015	0.736	2.845	0.000	0.543	0.393	0.000	0.102	0.167	0.093		

BDL: Below Detection Limit.
Source: Authors Reserach Data, 2020

redox reaction) to form water molecules thereby decreasing dissolved oxygen. Also, it could be related to the consumption of CO_2 by algae during photosynthesis causing an increase in pH and a corresponding increase in DO; where the oxygen produced during photosynthesis is higher than that consumed by aquatic organisms during respiration (Zang et al., 2011). A significant strong positive correlation between pH and DO has been found in many other studies (Luo, 2002; Zhang, 2009; Luis et al., 2010). On the other hand, temperature had a significantly strong positive correlation with NO_3^{-}-N, Na^+, K^+, COD, BOD, oil and grease, and SO_4^{2-}, and a significantly strong negative correlation with only DO. This shows how lake water quality strongly depends on temperature, which means, the increase in temperature had a significant impact on the increase of the aforementioned parameters and the decrease of dissolved oxygen. Also, TDS and EC which had a significant positive correlation with each other show a significantly strong positive correlation with NO_3^{-}-N, NH_3^{-}N, Na^+, K^+, BOD, oil and grease, and SO_4^{2-}, and a significantly strong negative correlation with DO. This shows that TDS and EC increase with these parameters, but decreases with increasing dissolved oxygen. Also, the data shows that even though COD had an impact on the decrease/increase of DO, it was statistically insignificant. Meaning there were other factors like temperature, TDS, EC, NO_3^-, NH_3, Na^+, K^+, BOD, and SO_4^{2-} which significantly influenced the fluctuation of DO. Conversely, BOD had a significantly strong negative correlation with DO and a significantly strong positive correlation with COD. This means that BOD increases with a corresponding decrease of DO, but it increases/decreases with COD.

Conclusion

The study was carried out to assess the seasonal/ temporal variation of the water quality of Dal Lake and its tributaries based on some physicochemical water quality parameters. From the data obtained, it was observed that the inlets recorded higher concentrations of most of the parameters analysed. This might be due to the discharge of effluents from the sewage treatment plants around them, the runoff of agricultural chemicals from agricultural fields, and the illegal dumping of wastes into these inlet tributaries. Dal Lake and its

Table 4. Pearson correlation matrix of physicochemical parameters.

Correlation	pH	Temp	TDS	EC	NO_3^-	NH_3	TP	PO_4^{3-}	Na^+	K^+	COD	DO	BOD	O&G	Ca^{2+}	Mg^{2+}	TH	SO_4^{2-}
pH																		
Temp	-0.194^{NS}																	
TDS	-0.295^{NS}	0.587^{NS}																
EC	-0.306^{NS}	0.583^{NS}	0.999**															
NO_3^-	-0.195^{NS}	0.720*	0.897**	0.893**														
NH_3	-0.189^{NS}	0.547^{NS}	0.890**	0.901**	0.762**													
TP	-0.059^{NS}	-0.155^{NS}	0.304^{NS}	0.313^{NS}	0.077^{NS}	0.384^{NS}												
PO_4^{3-}	0.037^{NS}	0.180^{NS}	0.407^{NS}	0.425^{NS}	0.338^{NS}	0.598^{NS}	0.653*											
Na^+	-0.390^{NS}	0.766**	0.730*	0.723*	0.630*	0.697*	0.203^{NS}	0.379^{NS}										
K^+	-0.094^{NS}	0.755**	0.803**	0.806**	0.783**	0.862**	0.389^{NS}	0.596^{NS}	0.794**									
COD	-0.208^{NS}	0.643*	0.329^{NS}	0.318^{NS}	0.468^{NS}	0.168^{NS}	0.018^{NS}	0.325^{NS}	0.589^{NS}	0.383^{NS}								
DO	0.603*	-0.604*	-0.850**	-0.850**	-0.775**	-0.680*	-0.144^{NS}	-0.066^{NS}	-0.650*	-0.605*	-0.257^{NS}							
BOD	-0.368^{NS}	0.793**	0.839**	0.826**	0.827**	0.628*	0.175^{NS}	0.213^{NS}	0.855**	0.742**	0.660*	-0.832**						
O&G	-0.166^{NS}	0.900**	0.630*	0.637*	0.706*	0.681*	0.057^{NS}	0.475^{NS}	0.720*	0.820**	0.648*	-0.502^{NS}	0.689*					
Ca^{2+}	-0.078^{NS}	0.153^{NS}	0.426^{NS}	0.422^{NS}	0.320^{NS}	0.246^{NS}	0.726*	0.445^{NS}	0.346^{NS}	0.492^{NS}	0.345^{NS}	-0.289^{NS}	0.490^{NS}	0.247^{NS}				
Mg^{2+}	0.066^{NS}	0.117^{NS}	-0.180^{NS}	-0.181^{NS}	-0.109^{NS}	-0.170^{NS}	0.028^{NS}	0.241^{NS}	0.169^{NS}	0.121^{NS}	0.124^{NS}	0.156^{NS}	0.011^{NS}	-0.032^{NS}	0.219^{NS}			
TH	0.007^{NS}	0.167^{NS}	0.092^{NS}	0.088^{NS}	0.088^{NS}	0.004^{NS}	0.404^{NS}	0.414^{NS}	0.308^{NS}	0.350^{NS}	0.274^{NS}	-0.037^{NS}	0.267^{NS}	0.107^{NS}	0.690*	0.857**		
SO_4^{2-}	-0.191^{NS}	0.641*	0.842**	0.824**	0.883**	0.581^{NS}	0.044^{NS}	0.021^{NS}	0.642*	0.667*	0.383^{NS}	-0.802**	0.885**	0.491^{NS}	0.420^{NS}	-0.080^{NS}	0.163^{NS}	

*Significant at $p \leq 0.05$; **Significant at $p \leq 0.01$.
Source: Authors Reserach Data, 2020

outlet's tributaries do not have much variation with regards to the concentration of nutrients in both seasons, respectively. The fact that lakes have the potential of diluting and mixing pollutants and discharging them in diluted form into their outlets might have caused less variation of nutrients concentration in Dal Lake and its outlets.

The summer season recorded higher temperatures, lower pH, and DO levels than the autumn season at most of the study sites, respectively. From the correlation analysis, temperature had a significant negative correlation with both pH and DO. This tells us that the natural increase in temperature during the summer decreases both pH and DO levels. As temperature increases, water molecules vibrate and dissociate thus increasing hydrogen ion (lowering pH) and decreasing DO by the redox reaction of hydrogen ion with oxygen to form water molecules. Also, due to the higher temperatures in the summer, increase in microbial degradation of organic matter, increase in dissolved atmospheric CO_2 causing a decrease in pH and a corresponding decrease in DO might have led to the high level of TP, PO_4^{3-}, COD, and BOD in the summer. The autumn season observed higher concentrations of TDS, EC, NO_3^--N, NH_3-N, SO_4^{2-}, oil and grease, Ca^{2+}, Mg^{2+}, and total hardness at all/most of the study sites, respectively. During the autumn season, the decrease in temperature might have led to reduced microbial degradation of organic matter and plant's photosynthetic processes thereby causing the ineffective use of nutrients. Also, the death of some micro- and macro-phytes and their subsequent release of nutrients in the autumn season might have enhanced the concentration of these parameters at most of the study sites.

Fe, Mn, and Pb were higher during the summer season, whereas Cu, Zn, and Cd were higher during the autumn season. The high concentration of Fe, Mn, and Pb in the summer could be related to higher water temperatures, low pH, low dissolved oxygen, and reducing conditions in the catchment area of the study sites. Increasing dissolved organic matter might also be another cause for their higher concentrations in the summer. The high concentration of Cu, Zn, and Cd in the autumn could be attributed to natural load from rocks in the watersheds, refuse dumps, sewage sludges, and their release by dead aquatic plants. Most of the parameters were negatively correlated with pH and DO, but positively correlated with temperature, COD, and BOD, respectively. The microbial degradation and chemical oxidation of organic matter at increasing temperatures thus decrease pH and DO and increase COD and BOD.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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