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Understanding water dynamics in Dal Lake: a comprehensive analysis of physiological parameters and seasonal variations

Seerat Sultan[a], Shruti Singh[a,*], Rajesh Kumar[b], Showkat A. Malik[c], Javaid Hassan Sheikh[d] and Amrit Sudershan[e]

[a] Department of Environmental Sciences, SBSR, Sharda University, Greater Noida, U.P. 201306, India
[b] Department of Environmental Science, School of Earth Sciences, Central University of Rajasthan (CURAJ), N.H.8, Bandar Sindri, Ajmer, Rajasthan 305 817, India
[c] Department of Zoology, Government Degree College Kupwara, Kupwara, Jammu and Kashmir-193222, India
[d] PG Department of Zoology, Hydrobiology Research Laboratory S.P. College, Cluster University Srinagar, Gogji Bagh, Srinagar, Jammu and Kashmir-190001, India
[e] Department of Human Genetics, S.P. College, Cluster University Srinagar, Gogji Bagh, Srinagar, Jammu and Kashmir-190001, India
*Corresponding author. E-mail: shruti.singh1@sharda.ac.in

ABSTRACT

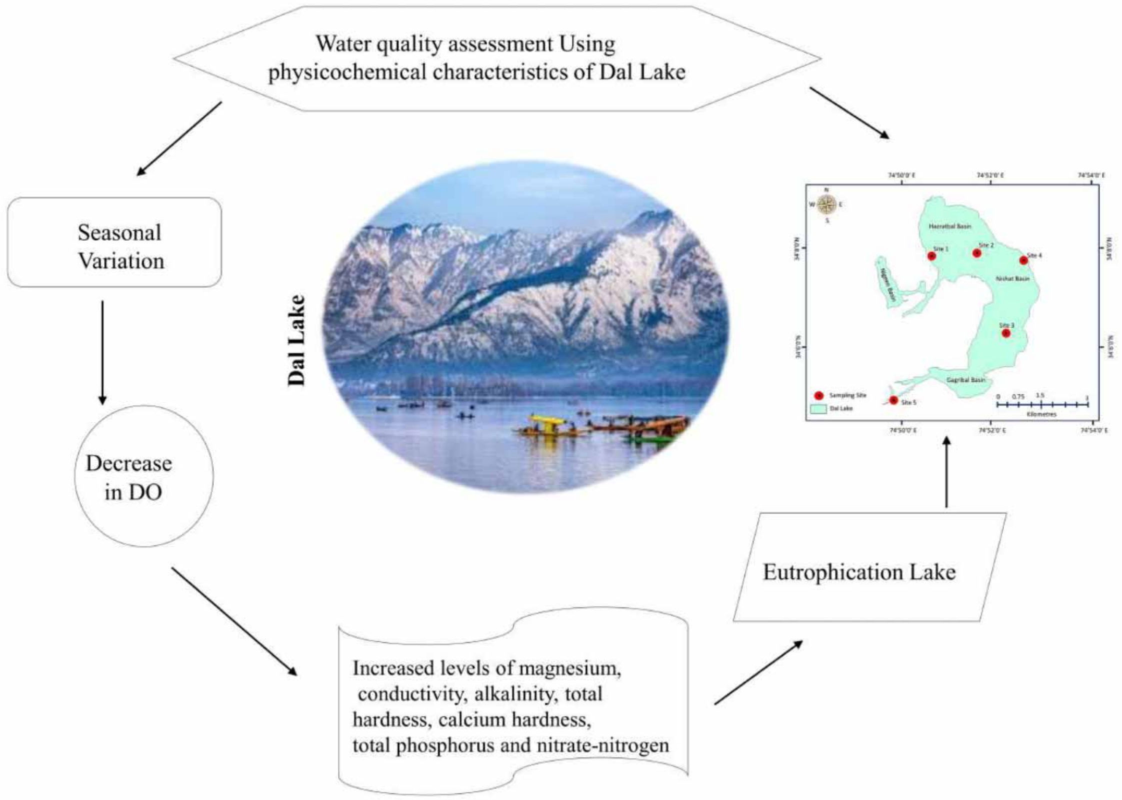
Maintaining the standard of water quality in an aquatic habitat necessitates continual assessment of its physicochemical properties. The purpose of this study was to evaluate physicochemical properties and to discuss the causes of spatiotemporal variability in key physicochemical parameters at five different locations of Dal Lake. Water samples were collected in four seasons for 3 years (i.e., January 2019–December 2021) to evaluate various physicochemical properties using standard methods. The analysis shows that the macrophytic development has increased due to organic and inorganic load, leading to the Lake's deterioration. The analysis indicates positive and negative correlations among various parameters across five sampling sites. Principal component analysis shows that two components (PC1 and PC2) explain 47.35, 47.54, and 48.11% of the variability in the years 2019, 2020, and 2021, respectively. From 2019 to 2021, the continuous decrease in dissolved oxygen and increased levels of magnesium, conductivity, alkalinity, total hardness, calcium hardness, total phosphorus, and nitrate-nitrogen suggest a trend toward eutrophication in the lake.

Key words: Dal Lake, physicochemical characteristics, seasonal variation, water pollution

HIGHLIGHTS

- Water quality assessment of Dal Lake.
- Multivariate analysis of various physiochemical properties of Dal Lake.
- Seasonal variation in various physiochemical attributes for a period of 3 years.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Water is essential for numerous formative activities and a major resource for life's endurance (Kumar *et al.* 2022). Due to its indispensability, there is a worldwide demand for its ease of accessibility, availability, purity, safety, and reasonable price (Pantha *et al.* 2022). Approximately 70% of the surface of the world is covered by water, 97% of which is in the ocean, 2% of which is frozen in polar ice caps and glaciers, and 1% of which is present as fresh water in rivers, lakes, streams, reservoirs, and groundwater. Due to its high salt, ocean water is typically unsuited for human consumption and other applications. Only fresh water is acceptable for human consumption and other uses, but it is not abundantly available. Freshwater bodies are essential for various domestic activities, including drinking, fishing, irrigation, navigation, and recreation. In addition to this, they are essential to the industries, irrigation, and hydropower sectors of the economy of countries (Duan & Bastiaanssen 2015; Saleem & Jeelani 2016; Vasistha & Ganguly 2020a). This may be a critical factor in maintaining fresh water that is uncontaminated and suitable for human consumption.

Lakes are one of the most significant freshwater ecosystems, important for human health, and a major source of food. There are 304 million lakes worldwide, covering 4.2 million km^2 and accounting for around 4% of the planet's land area (Downing *et al.* 2006). Additionally, lakes are essential components of the atmosphere's structure because they facilitate the flow of radiation, energy, water vapor, and gases between the surface of the Earth and the atmosphere above it (Wang *et al.* 2019). Since lakes are still bodies of water and are more susceptible to pollution than rivers, they are sensitive ecosystems. According to Akabugwo *et al.* (2007), the self-purification processes in lakes are poorer and typically collect more pollutants (Shahid *et al.* 2019). In addition to losing surface area due to human activity, the lake water quality is also declining, impacting the flora, fauna, and public health (Pant *et al.* 1985; Ravikumar *et al.* 2013). An aquatic ecosystem's ability to function properly and support a variety of life forms depends on our ability to analyze the water quality, which provides up-to-date information about the concentration of different solutes at a specific location and time (Kuklina *et al.* 2013).

The chemical composition of lake water is the primary determinant of its quality. According to limnologists and hydrologists, the dissolved oxygen (DO) concentration is the main indicator. Well-oxygenated water is thought to be of good quality.

Lower levels of DO cause the release of poisonous hydrogen sulfide into the water, which inhibits biological functions. The concern is also expressed about the fundamental nutrients cycling throughout the lake system, notably carbon, nitrogen, phosphorous, and sulfate. When too many of those nutrients enter the lake, like in the case of the latter in runoffs, the concentration of hydrogen ions in the water may rise. The biological processes in the Lake are undermined and impacted by this acid, which has a low pH value. Since aluminum compounds are still soluble in water at low pH levels, fish may end up dying as a result of the reaction this causes in their gills. The distribution of organisms in various freshwater habitats according to their adaption is caused by variability in physicochemical factors (Kuklina *et al.* 2013). Given that water is essential to all living things, including humans, animals, and plants, it is more crucial to evaluate its quality and provide recommendations for its sustainable use, or to take corrective action to ensure its quality (Adedeji *et al.* 2022). Thus, for various reasons, it is crucial to continuously monitor the quality of the water.

The water quality parameters show the water body's current condition and hydrological changes (Vasistha & Ganguly 2020a). To research the relationships between different water quality indicators, lakes are thought to offer a unique environment (Vasistha & Ganguly 2020b). Large-scale evaluations of the water quality of lakes have been conducted throughout the past 20 years. Overall, research has shown that industrialized areas' lakes are rapidly losing their natural qualities due to various anthropogenic activities, such as the misuse of dirty water and its direct discharge into water bodies (Jeelani *et al.* 2014). Additionally, saltation, the release of domestic sewage, and other similar activities are also responsible for the degradation of lakes. The wastewater coming from inflow is not the only cause of lake corruption (Sonal & Kataria 2012). In the same vein, research on Dal Lake's water quality shows that over the course of a decade, its natural water quality has deteriorated (Jeelani & Shah 2006; Qadri & Yousuf 2008). As a result of the ongoing process of water quality variation, assessment requires up-to-date water quality data. This study is being done to assess several physicochemical aspects of Dal Lake's water quality. When examining additional Dal Lake changes brought on by natural or anthropogenic factors, the data collected could serve as a baseline and point of comparison.

2. MATERIALS AND METHODS

2.1. Site description

Sampling operations were carried out at Dal Lake, situated in northern India within the Jammu and Kashmir union territory, framed by the imposing Himalayan Mountains. The Kashmir valley is renowned for its breathtaking landscapes, and Dal Lake holds a prominent status as the 'Jewel in the crown of Kashmir'. Positioned between coordinates 34.05′–34.06′ N and 74.08′–74.09′ E, at an elevation of 1,584 meters above sea level, Dal Lake comprises five basins: Hazratbal, Nagin, Nishat, Nehru Park, and Brari. This urban Lake, with a shallow depth of around 6 m, currently covers an estimated area of 16 km^2, although it has previously extended over approximately 22 km^2. It is conveniently accessible via a well-established road network, and a nearby airport in Budgam is just 7 km away, enhancing its accessibility for tourists and visitors. While Dal Lake supports certain commercial activities like weed harvesting for compost and fishing, its primary allure lies in its recreational and tourism hotspot role. The Lake boasts a multitude of houseboats moored along its shores, contributing to its charm and appeal.

The Lake has been shaped due to the fluviatile action of waterway Jhelum (Rather *et al.* 2016) and is taken care of by the Dagwan stream (Sabha *et al.* 2019). It has reduced from ~32 km^2 in 1859 to 24 km^2 in 2020 because of the development of settlements (Rashid *et al.* 2017). The five sampling sites in and around Dal Lake are five bowls viz., Hazratbal, Bod dal, Nishat, Lakut dal, and Dal gate bowl (Figure 1). Each sampling site is situated in the Srinagar area. Hazratbal Bowl is located a way off by 9.1 km on the western side of Dal Lake. Bod dal begins with Kotarkhana and Rupa Slender, and a little island is situated on it. Nishat Bowl is located a way off of 13 km from the Srinagar downtown area on the eastern side of Dal Lake, and Chashmashahi Bagh lies on its eastern side with a profundity of 4 m. Lakut dal has a normal profundity of 3 m. Dal Gate Bowl is situated away 3 km from Srinagar's downtown area on the southern flank, as shown in Figure 1. The general geographical features of five sampling sites in Dal Lake have been detailed in Supplementary file 1.

2.2. Water sample collection, processing, and analysis

Over 3 years spanning 2019 to 2021, water samples were collected from five distinct sites in Dal Lake to assess its physicochemical characteristics. A total of 120 samples, 40 from each year, were obtained. The sampling locations were selected based on factors such as elevation, geology, the confluence of main streams in the watershed, and geographical considerations. Each sample bottle underwent a thorough cleaning process with nitric acid and was rinsed with distilled water

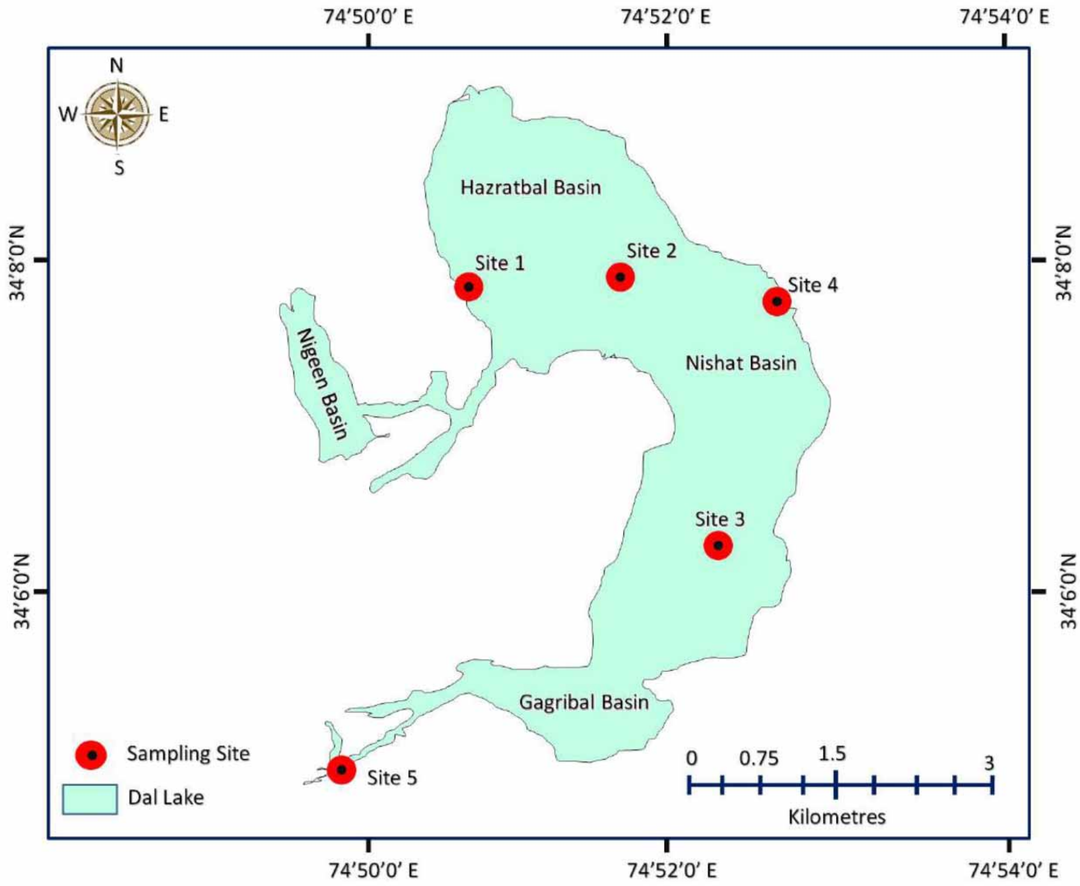


Figure 1 | Map showing sampling sites in Dal Lake (*Source*: Google Maps, 2019).

before sample collection. Samples were retrieved from a depth of 10 to 15 cm beneath the water's surface to ensure representative sampling. Additionally, samples were taken from slightly below the surface, approximately 15 cm deep to achieve a well-mixed concentration. Sampling occurred twice daily, in the morning and evening, using 250 mL polyethylene bottles previously rinsed with lake water. Water samples were filtered using Whatman 0.45 μm filter papers to remove impurities. To prevent contamination, an alkaline potassium iodide solution was added to the samples post-collection. After proper labeling, the sample bottles were transported to the laboratory in airtight containers and stored refrigerated for analysis. Standard procedures and analytical techniques outlined in literature references, such as APHA (2005), were followed for water sample testing. On-site measurements of parameters, including pH, water temperature, air temperature (AT), and conductivity, were conducted using a portable multi-parameter device (HANNA, model no. HI9829). DO levels were stabilized using sodium thiosulfate, alkali iodide azide, and sulfuric acid before transport to the laboratory. Prior to laboratory analyses, all collected samples were maintained at a refrigerated temperature of 4 °C.

Winkler's technique was used to test the D.O., and an argentometric titration was used to measure the chloride content (APHA 2005). Total hardness, calcium, and magnesium were assessed using the ethylenediamine tetraacetic acid (EDTA) titration method (APHA 2005). Nitrogen is produced from nitrates and ammonia using the phenate and salicylate methods, respectively (APHA 2005). To quantify total phosphorus (TPh) and sulfate, stannous chloride and turbid metric techniques were utilized concurrently (Golterman 1969). The mean value was used for the analysis after three iterations of each analysis.

2.3. Statistical analysis

To investigate temporal changes in physicochemical parameters, various statistical methods were employed. Pearson's correlation matrix was initially generated with a significance level of $p < 0.05$ to analyze the relationships between variables. Subsequently, principal component analysis (PCA), a multivariate analysis technique, was conducted using Origin Pro

(2019) statistical software. PCA aimed to reduce the dimensionality of the dataset and identify variables explaining a significant portion of the overall variance in physicochemical parameters.

3. RESULTS

3.1. Physiochemical properties of water

Various physicochemical parameters like AT, water temperature, chloride content, total alkalinity, etc., have been recorded at five different sites for different seasons during the years 2019–2021, and the values are presented in Tables 1–3 and supplementary files 2, 3, and 4. For analysis, the data have been divided into four seasons, i.e., spring (March to April), summer (May–August), autumn (October to November), and winter (December to February).

3.1.1. Air and water temperature

The AT data for the sampling years 2019–2021 at five different sites of Dal Lake are presented in Table 2, respectively. During the sampling year 2019, the seasonal mean AT at five different sites of Dal Lake ranged from 6.57 to 28.93 °C (Table 1). In the sampling years 2020 and 2021, it ranged from 5.63 to 28.58 °C (Table 2) and 5.70 to 28.75 °C (Table 3), respectively. Notably, the maximum (recorded during summer) and minimum (recorded during winter) temperatures for all 3 years were observed at the Dal Gate site, denoted as site 5. Water temperature, a critical factor governing chemical reactions and the well-being of aquatic organisms, varies between 4.77 and 26.03 °C (Table 1), 4.57 °C to 27.35 °C (Table 2), and 4.10 °C to 25.93 °C (Table 3) across the sampling years of 2019, 2020, and 2021, respectively.

3.1.2. Depth

The depth of water at a particular site in a water body is one of the major physical factors that control the water quality. In 2019, depth measurements ranged from a maximum of 4.05 m at site 3 during summer to a minimum of 1 m at site 1 in autumn (Table 1). Similarly, in 2020, depths varied from a minimum of 1.10 m at site 1 in autumn to a maximum of 4.01 m at site 3 in summer (Table 2). Finally, in 2021, depths ranged from a minimum of 1.37 m at site 1 in winter to a maximum of 3.15 m at site 2 in spring (Table 3). The computed annual average depth values for 2019, 2020, and 2021 were 2.57, 2.29, and 2.34 m, respectively.

3.1.3. Transparency

The transparency of water fluctuated both spatially and temporally. Water transparency changes over time and space due to the various particles present in water bodies. For this study, transparency values in 2019 varied from 0.73 m at site 1 in the fall to 3.30 m at site 2 in the summer (Table 1). In 2020, site 1′s transparency ranged from 1.07 m in the autumn to a maximum of 3.18 at site 2 in the summer (Table 2). The transparency measured in the sampling year of 2021 varied from 1.37 m at site 1 in winter to 2.80 m at site 2 in autumn (Table 3). Transparency values averaged 2.00 m in 2019, 2.12 m in 2020, and 2.21 m in 2021 during the full study period.

3.1.4. pH

The pH of water plays a pivotal role in determining its suitability for various applications. During the current investigation, the pH values observed at different sites and seasons indicate a neutral to alkaline nature of the water in Dal Lake. In 2019, pH values ranged from 7.10 to 8.14 in autumn and spring at sites 4 and 3, respectively (Table 1). In 2020, pH varied from 7.26 at sites 4 and 5 in the summer to 8.50 at site 2 in the spring (Table 2). Similarly, in 2021, pH ranged from 7.20 at site 2 in autumn to 8.04 at site 3 in winter (Table 3). The average pH readings for each year were 7.63 in 2019, 7.68 in 2020, and 5.3 in 2021, indicating an alkaline water composition.

3.1.5. Conductivity

The conductivity of Dal Lake's water, influenced by the region's topography, was examined across the sampling years. In 2019, conductivity ranged from 128.33 to 323 $\mu S\ cm^{-1}$, with the lowest value recorded at site 4 in winter and the highest at site 3 in spring (Table 1). In 2020, conductivity varied from 141 $\mu S\ cm^{-1}$ in winter at site 4 to 375 $\mu S\ cm^{-1}$ in spring at site 2 (Table 2). For 2021, conductivity ranged from a minimum of 156.25 $\mu S\ cm^{-1}$ at site 3 in summer to a maximum of 331 $\mu S\ cm^{-1}$ in spring, also at site 3 (Table 3). Annual average conductivity values showed slight fluctuations, with 216.76 $\mu S\ cm^{-1}$ in 2019, 220.18 $\mu S\ cm^{-1}$ in 2020, and 230.76 $\mu S\ cm^{-1}$ in 2021.

Table 1 | Physicochemical properties (temperature, depth, transparency, pH, conductivity, dissolved oxygen, and chloride) of Dal Lake water in four distinct seasons recorded at five different locations during the year 2019

Site	Season	Air temp. (°C)	Water temp. (°C)	Depth (m)	Transparency (m)	pH	Conductivity (μs/cm)	Dissolved oxygen (mg L^{-1})	Chloride (mg/L)
Site 1	Spring	15.75 ± 0.64	13.30 ± 0.99	1.35 ± 0.21	1.45 ± 0.21	7.80 ± 0.57	300.00 ± 42.43	3.00 ± 0.28	24.50 ± 0.71
	Summer	27.08 ± 1.64	24.58 ± 2.43	1.33 ± 0.19	1.03 ± 0.05	7.78 ± 0.24	200.25 ± 0.50	3.38 ± 0.75	15.00 ± 2.16
	Autumn	20.13 ± 11.05	17.70 ± 12.73	1.00 ± 0.01	0.73 ± 0.25	7.40 ± 0.17	207.67 ± 11. 59	4.37 ± 1.39	12.67 ± 0.58
	Winter	7.17 ± 0.90	5.70 ± 3.52	1.13 ± 0.15	1.10 ± 0.52	7.70 ± 0.52	204.67 ± 35.53	5.50 ± 2.18	12.33 ± 2.08
Site 2	Spring	17.00 ± 0.01	13.80 ± 0.99	2.75 ± 0.49	2.80 ± 0.57	7.75 ± 0.64	215.00 ± 65.21	6.00 ± 0.01	18.00 ± 0.01
	Summer	28.50 ± 2.08	25.40 ± 2.49	3.93 ± 0.29	3.30 ± 0.68	7.53 ± 0.15	242.50 ± 60.76	4.30 ± 1.30	18.25 ± 5.62
	Autumn	19.53 ± 10.44	18.47 ± 13.22	2.60 ± 0.10	2.70 ± 0.26	7.40 ± 0.17	200.33 ± 0.58	4.30 ± 1.47	18.33 ± 3.06
	Winter	7.07 ± 0.06	4.77 ± 2.41	3.17 ± 0.15	2.67 ± 0.58	7.80 ± 0.56	185.67 ± 30.99	4.67 ± 1.26	11.33 ± 0.58
Site 3	Spring	20.60 ± 0.85	15.00 ± 1.41	2.75 ± 0.35	2.55 ± 0.64	8.14 ± 0.14	323.00 ± 31.11	4.50 ± 1.37	17.50 ± 2.12
	Summer	28.15 ± 1.63	24.83 ± 2.47	4.05 ± 0.42	2.75 ± 0.06	7.58 ± 0.36	144.00 ± 42.20	4.03 ± 0.58	18.00 ± 5.35
	Autumn	19.80 ± 10.88	20.00 ± 13.08	2.80 ± 0.20	1.60 ± 0.66	7.41 ± 0.25	209.67 ± 19.50	4.00 ± 0.87	17.67 ± 2.52
	Winter	7.20 ± 0.10	5.00 ± 2.70	3.17 ± 0.06	2.23 ± 1.07	7.97 ± 0.15	188.00 ± 53.36	4.90 ± 1.04	14.00 ± 2.00
Site 4	Spring	19.10 ± 0.14	14.40 ± 2.69	2.40 ± 0.14	1.80 ± 0.28	7.80 ± 0.28	260.00 ± 55.33	4.50 ± 1.03	23.00 ± 8.49
	Summer	28.75 ± 1.71	24.60 ± 3.04	2.80 ± 0.29	2.43 ± 0.81	7.53 ± 0.33	170.25 ± 67.21	3.23 ± 0.43	18.00 ± 4.55
	Autumn	19.87 ± 11.59	19.33 ± 10.97	2.83 ± 0.67	1.63 ± 0.67	7.10 ± 0.36	233.67 ± 35.44	3.13 ± 0.37	15.33 ± 5.13
	Winter	7.20 ± 0.36	5.70 ± 2.17	2.27 ± 0.25	2.03 ± 0.06	7.70 ± 0.44	128.33 ± 47.33	4.67 ± 1.22	13.67 ± 1.15
Site 5	Spring	15.65 ± 0.78	14.00 ± 1.41	2.30 ± 0.01	1.50 ± 0.14	7.50 ± 0.01	305.00 ± 37.11	5.15 ± 1.34	21.50 ± 4.95
	Summer	28.93 ± 0.83	26.03 ± 2.70	3.58 ± 0.61	1.63 ± 0.25	7.43 ± 0.26	264.25 ± 15.22	4.78 ± 0.89	16.50 ± 4.04
	Autumn	19.27 ± 11.08	18.07 ± 12.05	2.80 ± 0.26	2.00 ± 0.01	7.40 ± 0.10	223.67 ± 26.22	3.83 ± 0.23	17.00 ± 5.57
	Winter	6.57 ± 1.01	4.77 ± 3.53	2.43 ± 0.49	1.97 ± 0.90	7.63 ± 0.35	129.33 ± 28.71	4.67 ± 0.67	8.67 ± 6.11
Mean 2019		**18.17**	**15.77**	**2.57**	**2.00**	**7.63**	**216.76**	**4.35**	**16.56**

Data are presented as mean ($n = 3$) and standard error.

Table 2 | Physicochemical properties (temperature, depth, transparency, pH, conductivity, dissolved oxygen, and chloride) of Dal Lake water in four distinct seasons recorded at five different locations during the year 2020

Site	Season	Air temp. (°C)	Water temp. (°C)	Depth (m)	Transparency (m)	pH	Conductivity (μs/cm)	Dissolved oxygen (mg L^{-1})	Chloride (mg L^{-1})
Site 1	Spring	15.55 ± 0.64	13.85 ± 1.63	1.25 ± 0.21	1.30 ± 0.28	7.95 ± 0.49	307.50 ± 60.10	3.50 ± 0.85	23.50 ± 0.71
	Summer	26.88 ± 1.25	24.95 ± 2.80	1.25 ± 0.24	1.10 ± 0.12	7.58 ± 0.10	201.00 ± 1.41	3.50 ± 0.52	15.50 ± 1.91
	Autumn	20.47 ± 9.64	17.30 ± 12.48	1.10 ± 0.10	1.07 ± 0.12	7.40 ± 0.26	193.00 ± 11.27	3.80 ± 0.53	12.33 ± 1.15
	Winter	7.13 ± 0.85	6.30 ± 4.56	1.17 ± 0.15	1.20 ± 0.17	8.17 ± 0.06	207.00 ± 32.05	4.47 ± 1.75	11.33 ± 2.08
Site 2	Spring	17.05 ± 1.48	13.80 ± 1.13	2.75 ± 0.35	2.80 ± 0.42	7.90 ± 0.42	222.50 ± 97.8	7.15 ± 1.48	17.00 ± 0.01
	Summer	28.50 ± 1.91	26.30 ± 2.73	3.00 ± 0.08	3.18 ± 0.26	7.53 ± 0.26	243.25 ± 60.32	5.03 ± 0.82	18.25 ± 3.43
	Autumn	19.80 ± 10.57	19.03 ± 13.63	2.83 ± 0.29	2.90 ± 0.44	7.37 ± 0.25	196.00 ± 7.81	4.70 ± 0.61	18.00 ± 3.46
	Winter	6.93 ± 0.12	5.73 ± 2.35	3.03 ± 0.21	2.97 ± 0.06	7.83 ± 0.70	196.33 ± 14.84	5.06 ± 0.15	11.00 ± 1.00
Site 3	Spring	20.60 ± 0.85	15.10 ± 1.41	2.80 ± 0.28	2.05 ± 0.07	8.50 ± 0.07	375.00 ± 21.21	5.45 ± 1.63	18.00 ± 0.01
	Summer	27.73 ± 2.48	27.05 ± 3.67	4.01 ± 0.87	2.88 ± 0.26	7.65 ± 0.24	142.00 ± 41.06	3.65 ± 0.37	18.75 ± 4.11
	Autumn	20.13 ± 11.22	19.67 ± 12.74	3.20 ± 0.26	2.47 ± 0.50	7.41 ± 0.28	213.00 ± 16.09	3.87 ± 1.21	18.33 ± 1.15
	Winter	7.33 ± 0.12	5.33 ± 2.86	3.10 ± 0.10	2.73 ± 0.21	7.91 ± 0.18	171.00 ± 40.45	6.33 ± 1.99	13.67 ± 0.58
Site 4	Spring	18.65 ± 0.92	14.75 ± 2.33	2.05 ± 0.07	1.75 ± 0.35	8.00 ± 0.14	253.50 ± 105.4	5.70 ± 2.26	23.00 ± 4.56
	Summer	27.80 ± 2.07	24.98 ± 3.79	1.98 ± 0.05	2.40 ± 0.26	7.26 ± 0.16	169.25 ± 80.65	3.53 ± 0.49	16.75 ± 4.11
	Autumn	19.50 ± 11.65	19.97 ± 11.51	1.80 ± 0.10	2.57 ± 0.15	7.30 ± 0.36	224.00 ± 25.51	2.77 ± 0.67	14.67 ± 3.22
	Winter	7.33 ± 0.86	5.00 ± 3.72	2.03 ± 0.35	2.03 ± 0.15	7.80 ± 0.36	141.00 ± 42.00	4.07 ± 0.06	12.33 ± 0.58
Site 5	Spring	15.75 ± 0.78	14.55 ± 0.78	2.05 ± 0.07	1.40 ± 0.14	8.00 ± 0.01	314.50 ± 41.72	6.15 ± 0.78	20.50 ± 4.95
	Summer	28.58 ± 1.79	27.35 ± 2.51	2.30 ± 0.47	1.95 ± 0.33	7.26 ± 0.23	266.75 ± 48.33	4.13 ± 1.14	16.75 ± 4.11
	Autumn	19.20 ± 10.92	18.37 ± 12.37	2.30 ± 0.61	1.90 ± 0.10	7.30 ± 0.20	224.33 ± 22.05	2.80 ± 0.26	16.00 ± 4.58
	Winter	5.63 ± 0.85	4.57 ± 2.90	1.90 ± 0.17	1.70 ± 0.52	7.87 ± 0.21	142.67 ± 48.29	5.00 ± 1.56	10.67 ± 1.53
Mean 2020		**18.03**	**16.20**	**2.25**	**2.12**	**7.68**	**220.18**	**4.53**	**16.32**

Data are presented as mean ($n = 3$) and standard error.

Table 3 | Physicochemical properties (temperature, depth, transparency, pH, conductivity, dissolved oxygen, and chloride) of Dal Lake water in four distinct seasons recorded at five locations during the year 2021

Site	Season	Air temp. (°C)	Water temp. (°C)	Depth (m)	Transparency (m)	pH	Conductivity (μs/cm)	Dissolved oxygen (mg L^{-1})	Chloride (mg L^{-1})
Site 1	Spring	16.50 ± 3.54	12.85 ± 0.21	2.55 ± 1.48	2.40 ± 0.57	7.65 ± 1.06	319.50 ± 34.65	4.80 ± 1.84	19.50 ± 2.12
	Summer	28.00 ± 2.31	23.88 ± 3.75	2.05 ± 0.44	2.28 ± 0.67	7.35 ± 0.47	235.00 ± 52.15	4.48 ± 0.77	16.50 ± 1.29
	Autumn	20.83 ± 8.55	18.23 ± 2.04	2.10 ± 1.01	2.23 ± 1.07	7.03 ± 0.06	195.67 ± 10.07	3.77 ± 0.51	14.00 ± 1.00
	Winter	6.90 ± 1.25	5.37 ± 4.10	1.37 ± 0.29	1.37 ± 0.55	7.73 ± 0.64	191.00 ± 17.44	4.87 ± 1.01	10.67 ± 1.53
Site 2	Spring	18.50 ± 2.12	13.45 ± 0.21	3.15 ± 0.49	1.65 ± 0.92	7.80 ± 0.42	267.50 ± 60.10	5.15 ± 1.34	20.00 ± 3.22
	Summer	28.68 ± 1.71	24.63 ± 3.74	2.23 ± 0.59	2.10 ± 1.07	7.30 ± 0.41	232.50 ± 54.85	4.45 ± 1.10	18.75 ± 2.92
	Autumn	21.00 ± 7.94	18.77 ± 7.12	2.30 ± 0.95	2.80 ± 0.69	7.20 ± 0.10	204.67 ± 17.67	4.73 ± 1.12	13.00 ± 2.22
	Winter	6.77 ± 0.42	4.80 ± 2.77	2.43 ± 1.07	2.30 ± 0.26	7.63 ± 0.86	187.33 ± 1.53	5.93 ± 0.31	10.00 ± 1.73
Site 3	Spring	20.00 ± 2.83	13.40 ± 3.39	2.85 ± 0.07	2.40 ± 0.71	7.55 ± 0.49	331.00 ± 50.91	5.90 ± 2.26	18.00 ± 1.41
	Summer	26.83 ± 1.93	25.00 ± 2.74	2.20 ± 0.45	2.33 ± 0.89	7.40 ± 0.32	156.25 ± 55.13	3.75 ± 0.75	18.00 ± 2.67
	Autumn	20.47 ± 8.75	18.63 ± 6.91	2.20 ± 0.35	2.67 ± 0.29	7.37 ± 0.31	204.33 ± 15.01	3.53 ± 1.10	17.00 ± 1.00
	Winter	7.03 ± 0.12	4.87 ± 2.90	2.77 ± 0.40	2.00 ± 0.10	8.04 ± 0.46	186.33 ± 9.02	5.83 ± 0.76	12.67 ± 2.12
Site 4	Spring	19.50 ± 4.95	15.10 ± 1.56	2.05 ± 0.07	2.20 ± 1.27	7.65 ± 0.49	308.50 ± 40.31	5.95 ± 0.21	24.00 ± 1.41
	Summer	28.10 ± 3.71	25.80 ± 3.41	2.58 ± 1.34	2.18 ± 0.81	7.40 ± 0.52	198.00 ± 71.71	3.90 ± 0.62	16.50 ± 2.20
	Autumn	21.37 ± 8.82	17.97 ± 8.75	2.70 ± 0.79	2.70 ± 0.95	7.33 ± 0.35	223.33 ± 18.79	3.50 ± 0.10	14.67 ± 3.22
	Winter	7.50 ± 0.10	4.67 ± 3.65	2.23 ± 0.32	1.83 ± 0.58	7.63 ± 0.67	193.67 ± 13.65	4.67 ± 0.58	11.00 ± 1.00
Site 5	Spring	20.25 ± 3.18	13.70 ± 2.83	2.10 ± 0.28	2.10 ± 0.14	7.75 ± 0.35	307.00 ± 38.18	4.95 ± 1.88	18.50 ± 0.71
	Summer	28.75 ± 2.49	25.93 ± 3.30	2.40 ± 1.04	2.23 ± 1.02	7.63 ± 0.26	266.25 ± 30.48	4.53 ± 0.51	16.75 ± 3.33
	Autumn	20.80 ± 8.51	18.97 ± 7.70	2.10 ± 0.53	2.57 ± 0.55	7.40 ± 0.53	212.33 ± 24.01	2.60 ± 0.26	15.67 ± 3.51
	Winter	5.70 ± 1.49	4.10 ± 2.79	2.47 ± 0.84	1.93 ± 0.67	7.93 ± 0.06	195.00 ± 7.00	4.70 ± 1.57	11.33 ± 0.58
Mean 2021		**18.67**	**15.59**	**2.32**	**2.21**	**7.53**	**230.76**	**4.53**	**15.83**

Data are presented as mean ($n = 3$) and standard error.

3.1.6. Dissolved oxygen

The main factors that regulate the DO concentration in water are atmospheric pressure and temperature. In this study, the DO showed a clear seasonal trend, with the maximum values of 6.00 mg L^{-1} at site 2 during the spring and the lowest values of 3.00 mg L^{-1} during the same season at a different site 1, in the year 2019 (Table 1). In 2020, D.O. levels varied from 2.77 mg L^{-1} in the autumn at site 4 to 7.15 mg L^{-1} in the spring at site 2 (Table 2). Similarly, from 2.60 mg L^{-1} at site 5 to 5.95 mg L^{-1} in the spring of 2021 (Table 3). In 2019, 2020, and 2021, the average DO was measured as 4.35, 4.53, and 4.60 mg L^{-1}, respectively.

3.1.7. Chloride content

During this investigation, there were fewer changes in chloride content. In 2019, the peak concentration was 24.50 mg L^{-1} at site 1 during the spring season, while the lowest concentration was 8.0 mg L^{-1} during the winter season at site 5 (Table 1). During the spring of 2020, site 1 recorded the highest chloride value of 23.50 mg L^{-1}, whereas, during the winter, site 5 recorded the lowest value of 10.67 mg L^{-1} (Table 2). The highest value was recorded at site 4 in the spring of 2021 (24 mg L^{-1}), whereas at site 2 in the winter, the lowest value was 10 mg L^{-1} (Table 3). Chloride levels in the research period averaged 16.56 mg L^{-1} in 2019, 16.32 mg L^{-1} in 2020, and 15.82 mg L^{-1} in 2021.

3.1.8. Total alkalinity

Alkalinity is a critical measure of water's ability to neutralize acidity, serving as a natural buffer to maintain pH levels. During the sampling year 2019, total alkalinity exhibited variability, ranging from the highest value of 321 mg L^{-1} in spring at site 1 to the lowest value of 47.50 mg L^{-1} in summer at site 2 (Supplementary file 2). In 2020, total alkalinity measurements ranged from a minimum of 47.25 mg L^{-1} in summer at site 2 to a maximum of 316 mg L^{-1} in spring at site 1 (Supplementary file 3). Similarly, in 2021, readings ranged from a low of 49.25 mg L^{-1} in the summer at site 2 to a high of 309 mg L^{-1} in the spring at site 1 (Supplementary file 4). The average values determined for the years 2019, 2020, and 2021 were 141.80, 138.19, and 142.25 mg L^{-1}, respectively.

3.1.9. Total hardness

Large cations, particularly calcium and magnesium, in a water body contribute to water hardness, resulting from hydrolysis and the natural conversion of bicarbonates and carbonates of these elements into cations. In 2019, total hardness ranged from 32.67 mg L^{-1} in autumn at site 5 to 405.75 mg L^{-1} in summer at site 1 (Supplementary file 2). Similarly, in 2020, measurements varied from 35.33 mg L^{-1} at site 5 in autumn to 407 mg L^{-1} at site 1 during summer (Supplementary file 3). In 2021, a maximum of 407 mg L^{-1} was recorded at site 1 in summer, while 37.67 mg L^{-1} was observed at site 5 in autumn (Supplementary file 4). On average, total hardness levels were 147.29 mg L^{-1} in 2019, 149.07 mg L^{-1} in 2020, and 148.92 mg L^{-1} in 2021.

3.1.10. Calcium content

The recorded calcium values in the sampling year 2019 were a minimum of 8.00 mg L^{-1} at site 5 in the spring season and a maximum of 73 mg L^{-1} at site 1 in the summer (Supplementary file 2). Throughout the spring season in 2020, the calcium concentration at site 5 was at a minimum of 7 mg L^{-1}, while during the summer, it was at a maximum of 74 mg L^{-1} (Supplementary file 3). In 2021, the calcium concentrations measured at sites 5 and 1 ranged from 7.50 mg L^{-1} at site 5 in the summer to 70.50 mg L^{-1} at site 1 in the spring (Supplementary file 4). The average calcium levels measured in 2019, 2020, and 2021 were 38.14, 38.07, and 38.28 mg L^{-1}, respectively.

3.1.11. Nitrogen content

At every sampling site, ammoniacal nitrogen (AN) fluctuated significantly during the year 2019. At site 3 in the spring, it was as low as 121.50 g L^{-1}, whereas at site 2 in the summer, it was as high as 361.50 g L^{-1} (Supplementary file 2). At site 3 in the summer of 2020 and spring, respectively, the highest ammoniacal nitrogen readings were 323.25 g L^{-1} and 120.00 g L^{-1} (Supplementary file 3). In the sample year 2021, the AN at site 3 fluctuated from a maximum of 323.25 g L^{-1} in the summer to a minimum of 126 g L^{-1} in the spring (Supplementary file 4). The computed annual mean concentrations of AN were 235.36 g L^{-1} in 2019, 248.58 g L^{-1} in 2020, and 250.59 g L^{-1} in 2021.

In the spring season of 2019, Dal Lake's nitrate-nitrogen concentration ranged from a low of 126.00 g L^{-1} at site 4 to a high of 633.00 g L^{-1} at site 1 (Supplementary file 2). In the spring of the 2020 sample year, nitrate-nitrogen levels were higher, reaching a maximum of 630.50 g L^{-1} at site 1 and a minimum of 125.50 g L^{-1} at site 4 (Supplementary file 3). Among different sites, there were noticeable differences in the nitrate-nitrogen and phosphate concentrations also, and this trend continued in 2021, with nitrate-nitrogen values ranging from a minimum of 128 g L^{-1} at site 4 in the spring season to a maximum of 640 g L^{-1} at site 5 in the same season (Supplementary file 4). The average annual nitrate-nitrogen concentrations recorded were 259.63 g L^{-1} in 2019, 320.20 g L^{-1} in 2020, and 358.65 g L^{-1} in 2021.

3.1.12. Phosphorus content

Regarding the total phosphorous in Dal Lake during the study period, the changes in both time and space were quite erratic. Summer time concentration levels were generally lower and wintertime levels were higher. In the 2019 sample year, the TPh concentration varied from a minimum of 141.50 g L^{-1} at site 2 in the summer to a maximum of 345 g L^{-1} at site 3 in the autumn (Supplementary file 2). In 2020, site 2 reported the lowest value at 143.50 g L^{-1} during the summer, and site 1 recorded the highest value at 298.33 g L^{-1} during the fall seasons (Supplementary file 3). In 2021, the readings varied from a summertime minimum of 144.00 g L^{-1} at site 2 to a wintertime maximum of 324.67 g L^{-1} at site 3 (Supplementary file 4). TPh levels averaged 227.97 g L^{-1} in 2019, 221.29 g L^{-1} in 2020, and 220.79 g L^{-1} in 2021, respectively.

3.1.13. Sulfate content

Throughout the investigation period, Dal Lake's sulfate content exhibited minor variations. In spring 2019, sulfate concentrations ranged from a minimum of 11.70 mg L^{-1} at site 2 to a maximum of 23.95 mg L^{-1} at site 4 (Supplementary file 2). Similarly, in 2020, sulfate levels varied from a low of 12.25 mg L^{-1} at site 5 in the spring to a high of 26.35 mg L^{-1} at site 2 in the summer (Supplementary file 3). In 2021, sulfate concentrations ranged from 12 mg L^{-1} at site 5 in the spring to 26 mg L^{-1} at site 2 in the summer (Supplementary file 4). The computed annual average sulfate concentrations were 17.13 mg L^{-1} in 2019, 18.75 mg L^{-1} in 2020, and 18.45 mg L^{-1} in 2021.

3.1.14. Magnesium content

During the present study, magnesium concentrations exhibited variability across the sampling years. In 2019, levels ranged from 4.67 mg L^{-1} at site 5 in autumn to 74.00 mg L^{-1} at site 1 in summer (Supplementary file 2). Similarly, in 2020, concentrations varied from 5 mg L^{-1} at site 2 in the spring to 73 mg L^{-1} at site 1 in the summer (Supplementary file 3). In 2021, magnesium content ranged from 5.75 mg L^{-1} at site 2 in the spring to 72.50 mg L^{-1} at site 1 in the summer (Supplementary file 4). The highest magnesium concentration recorded during the sampling period was 74.00 mg L^{-1} in summer, while the lowest was 4.67 mg L^{-1} in autumn. The computed annual average magnesium levels were 16.15 mg L^{-1} in 2019, 16.44 mg L^{-1} in 2020, and 16.73 mg L^{-1} in 2021.

3.2. Correlation analysis

The correlation analysis provides an overview of the water sample data from Dal Lake's five sampling locations for the 2019–2021 research period, as presented in Figure 2. These data include parameters for AT, water temperature (WT), Depth, transparency (Trs), pH, conductivity (Cond), dissolved oxygen (DO), chloride content (Cl), total alkalinity (TA), total hardness (TH), calcium content (Ca), AN, nitrate-nitrogen (NiN), phosphate (P), sulfur (S), and magnesium (Mg). When the correlation coefficient of the two parameters equals or approaches 1, it is considered positive; otherwise, it is considered negative. A positive relationship means increasing one parameter will increase the other, while a negative association means increasing one parameter will reduce the other.

AT showed a significantly positive correlation with water temperature and magnesium (Figure 2). A significant determinant of how lakes adapt to change is AT. The statistics show a linear 1:1 trend in air and water temperatures. Given that it is well known that rising air temperatures lead to increasing water temperatures, this equilibrium may be crucial in Dal Lake. Many aquatic habitats will suffer from increasing water temperatures and related water pollution issues. For the latter, a change in AT will likely result in a rise in magnesium concentration. Changes in AT also have an impact on another metric, chloride. AT and chloride were shown to be positively correlated (0.5). The chloride concentration in water will most likely rise when the AT rises, as shown in Figure 2.

A change in water temperature will likely impact these parameters through an increase, influencing the Dal Lake's biodiversity. Water temperature has a positive correlation with magnesium (0.5), chloride (0.5), and AN (0.5) (Figure 2). Total hardness showed a favorable correlation between calcium (0.9) and magnesium (0.9). The calcium carbonate concentration, the sum of the calcium and magnesium concentrations, determines water hardness. This was clear from the positive

	AT	WT	Depth	Trs	pH	Cond	DO	Cl	TA	TH	Ca	AN	NiN	P	S	Mg
AT	1	1	0.2	0.2	-0.5	0.2	-0.4	0.5	-0.5	0.4	0.3	0.4	-0	-0.3	0.2	0.4
WT	1	1	0.1	0.2	-0.6	0.1	-0.5	0.5	-0.5	0.4	0.3	0.5	0	-0.3	0.2	0.5
Depth	0.2	0.1	1	0.7	-0	-0	0.2	0.1	-0.4	-0.1	0.1	0.2	-0.3	0	-0.1	-0.2
Trs	0.2	0.2	0.7	1	-0.2	-0.1	0.1	0.1	-0.4	-0.1	0	0.1	-0	-0	0.1	-0.1
pH	-0.5	-0.6	-0	-0.2	1	0.2	0.5	0	0.3	0.1	0.2	-0.6	-0.1	-0	-0.3	-0.1
Cond	0.2	0.1	-0	-0.1	0.2	1	0.2	0.6	-0.1	-0.1	-0.2	-0.6	-0	-0.3	-0.2	-0.2
DO	-0.4	-0.5	0.2	0.1	0.5	0.2	1	-0	-0.1	-0.1	0	-0.5	-0.4	0.2	-0.3	-0.3
Cl	0.5	0.5	0.1	0.1	0	0.6	-0	1	-0.1	0	0.1	-0.4	-0.1	-0.2	-0.2	-0
TA	-0.5	-0.5	-0.4	-0.4	0.3	-0.1	-0.1	-0.1	1	0	0.2	-0.2	0.4	-0.1	-0.1	-0
TH	0.4	0.4	-0.1	-0.1	0.1	-0.1	-0.1	0	0	1	0.9	0.3	0	-0.3	0.3	0.9
Ca	0.3	0.3	0.1	0	0.2	-0.2	0	0.1	0.2	0.9	1	0.2	0.1	-0.4	0.2	0.7
AN	0.4	0.5	0.2	0.1	-0.6	-0.6	-0.5	-0.4	-0.2	0.3	0.2	1	0.1	-0.1	0.4	0.4
NiN	-0	0	-0.3	-0	-0.1	-0	-0.4	-0.1	0.4	0	0.1	0.1	1	-0.4	0.2	0.1
P	-0.3	-0.3	0	-0	-0	-0.3	0.2	-0.2	-0.1	-0.3	-0.4	-0.1	-0.4	1	-0.2	-0.2
S	0.2	0.2	-0.1	0.1	-0.3	-0.2	-0.3	-0.2	-0.1	0.3	0.2	0.4	0.2	-0.2	1	0.4
Mg	0.4	0.5	-0.2	-0.1	-0.1	-0.2	-0.3	-0	-0	0.9	0.7	0.4	0.1	-0.2	0.4	1

Figure 2 | Correlation matrix heat map of various physicochemical parameters collected during the period of 2019–2021 of five locations of Dal Lake; AT, air temperature; WT, water temperature; TP, transparency; Cond, conductivity; DO, dissolved oxygen; Cl, chloride; Alk, alkalinity; Hrd, hardness; Ca, calcium; AN, ammonical nitrogen; NiN, nitrate-nitrogen; TPh, total phosphorus; SLP, sulfate; Mg, magnesium.

correlation between calcium and magnesium (0.7), which controls the overall hardness of the water in Dal Lake. Furthermore, DO, pH (0.5), conductivity, and chloride showed positive associations (0.5). These settings will both increase when one is raised. The parameters, however, showed a negative correlation. Total alkalinity, pH, and AT negatively correlate (−0.5). Concerning total alkalinity (−0.5), DO (−0.5), and pH (−0.6), water temperature showed a negative association. DO (−0.5), conductivity (−0.6), and pH (−0.6) all had negative relationships with AN (−0.6). These negative characteristics are related, so a rise in one will probably result in a drop in the others (Figure 2).

3.3. Principal component analysis

PCA has also been used to closely explore the link between various factors at five separate sites of Dal Lake over a 3-year period. In PCA we would like to know which variables are influential, and also how the variables are correlated. Such knowledge is given by the principal component loadings called PC1 and PC2. Figures 3–5 display the relationships between all the 16 variables at the same time. Variables contributing similar information are grouped together, that is, they are correlated. When the numerical value of one variable increases or decreases, the numerical value of the other variable has a tendency to change in the same way. When variables are negatively correlated, they are positioned on opposite sides of the plot origin, in diagonally opposed quadrants. For instance, the variables DO and Ca are inversely correlated, meaning that when DO increases, Ca decreases, and vice versa. If two variables are positively correlated, when the numerical value of one variable increases or decreases, the numerical value of the other variable has a tendency to change in the same way. Moreover, the distance to the origin also conveys information. The further away from the plot origin a variable lies, the stronger the impact that variable has on the model.

In the present study, two principal components explain a total of 47.35% (Figure 3), 47.54% (Figure 4), and 48.11% (Figure 5) of observed data variability in the investigating years 2019, 2020, and 2021, respectively. In the sampling year

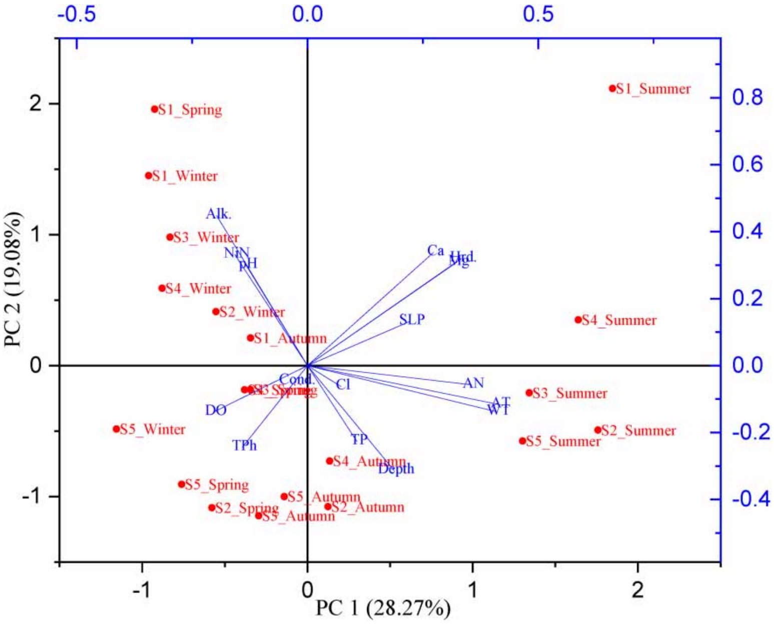


Figure 3 | Biplot of principal component analysis (PCA) showing the seasonal variation in various physiochemical properties of Dal Lake water at five different sites during the year 2019. AT, air temperature; WT, water temperature; TP, transparency; Cond, conductivity; DO, dissolved oxygen; Cl, chloride; Alk, alkalinity; Hrd, hardness; Ca, calcium; AN, ammonical nitrogen; NiN, nitrate-nitrogen; TPh, total phosphorus; SLP, sulfate; Mg, magnesium; S1, site 1; S2, site 2; S3, site 3; S4, site 4 and S5, site 5.

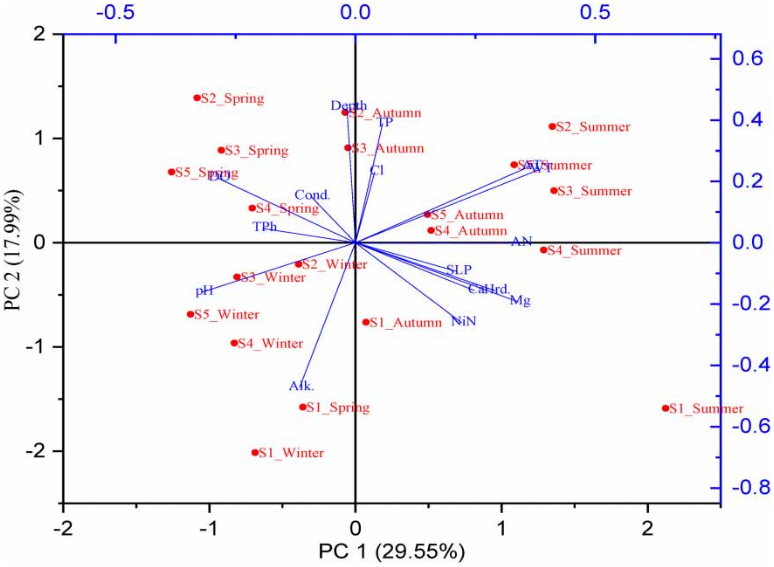


Figure 4 | Biplot of principal component analysis (PCA) showing the seasonal variation in various physiochemical properties of Dal Lake water at five different sites during the year 2020. AT, air temperature; WT, water temperature; TP, transparency; Cond, conductivity; DO, dissolved oxygen; Cl, chloride; Alk, alkalinity; Hrd, hardness; Ca, calcium; AN, ammonical nitrogen; NiN, nitrate-nitrogen; TPh, total phosphorus; SLP, sulfate; Mg, magnesium; S1, site 1; S2, site 2; S3, site 3; S4, site 4 and S5, site 5.

2019, the variables, water temperature, AT, depth, clarity, AN, hardness, total sulfate and calcium, all demonstrated high positive loadings, while D.O. and TPh, showed strong negative loadings on PC1. The variables total alkalinity, and pH showed positive loadings on PC2, in contrast to the strong negative loadings of nitrate-nitrogen, TPh, and D.O.

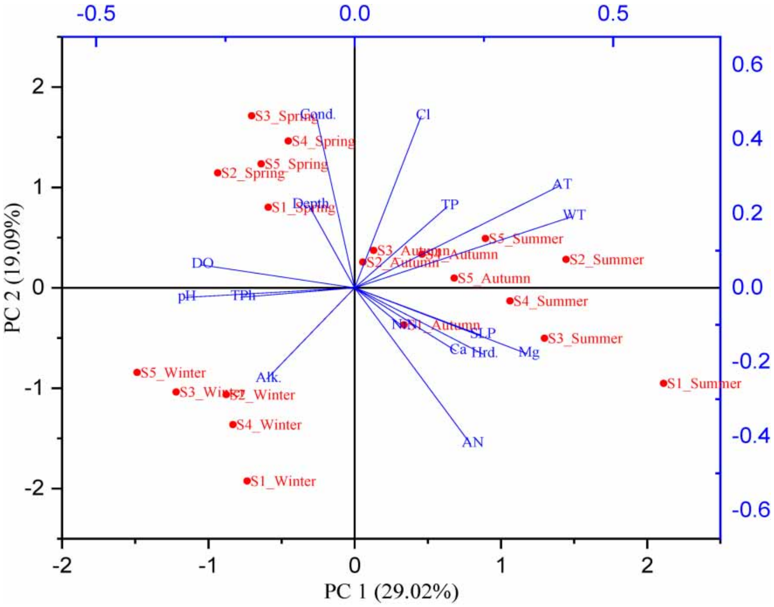


Figure 5 | Biplot of principal component analysis (PCA) showing the seasonal variation in various physiochemical properties of Dal Lake water at five different sites during the year 2021. AT, air temperature; WT, water temperature; T.P, transparency; Cond, conductivity; DO, dissolved oxygen; Cl, chloride; Alk, alkalinity; Hrd, hardness; Ca, calcium; AN, ammonical nitrogen; NiN, nitrate-nitrogen; TPh, total phosphorus; SLP, sulfate; Mg, magnesium; S1, site 1; S2, site 2; S3, site 3; S4, site 4 and S5, site 5.

The pH and alkalinity showed a significant negative loading on PC1 in 2020. In contrast, other factors like air and water temperatures, total hardness, sulfate, calcium, nitrate-nitrogen and magnesium showed a significant positive loading on PC1. Contrary to alkalinity and nitrate-nitrogen, which displayed negative loadings on PC2, water depth, transparency, DO, and chloride variables all displayed highly positive loadings. While the variables water temperature, AT, hardness, transparency, and alkalinity showed negative loadings on PC1. In the sampling year 2021, the variables pH, DO, transparency, alkalinity, hardness, AN, magnesium, TPh, sulfate, and calcium had positive loads during the sample on PC1. Alkalinity and AN showed similar negative loadings on PC2, as did conductivity, transparency, and water depth.

4. DISCUSSION

The physical and chemical properties of water from Dal Lake were examined at five distinct locations to assess variations. AT closely mirrored the temperature of the water's surface at each location, with variations observed during the study period conducive to the regular growth and survival of aquatic species (Rahman *et al.* 2021). The maximum (28.93 °C) and minimum (5.63 °C) AT recorded, particularly at site 5 during the analysis period, contribute to the highest and lowest AT, respectively. In the majority of lakes throughout the summer, a layer of warmer, lower-density water sits on top of colder water below. This upper layer starts to cool as air temperatures drop in the late summer. A study by Salve & Hiware (2006) and Jayabhaye *et al.* (2006) noted that in the summer, the water temperature was high due to the low water level and clear skies. Moreover, environmental factors such as impoundments, discharge of cooling water, urban stormwater, and groundwater inflows, along with human activities like vegetation removal from stream banks, influence both air and water temperature (Spellman & Drinan 2012).

Depth is a crucial physical variable influencing the quality of water in a given location within a water body (Basharat & Tariq 2013). During the current investigation, the Secchi disk transparency remained essentially low at each site throughout the duration, which might be a result of human intervention in Dal Lake, such as dredging, weeding, the influence of floating gardens, etc. The Lake's higher trophic status and shallow mean depth indicate evolutionary processes (Mushatq *et al.* 2013). Further, the maximum value of the depth of Dal Lake during the sampling years was 4.01 m, and this value is consistent with the average value of Crane Lake Minnesota, United States in 2019, indicating that the Lake has unusually clear water compared to most central and Albertan lakes.

Water transparency changes over time and space due to the various particles present in water bodies (Ma *et al.* 2021). Exceptionally clear lakes can be up to 30–40 m transparent. An extremely productive water body (i.e., one with a lot of tiny algae) would have a low value, less than 1 m. A high concentration of suspended solids might also contribute to a low value. With this in mind, it is possible to infer from the Dal Lake's transparency values during the sample years that either dissolved chemicals are present in the water or microscopic algae are growing there. The pH is a crucial parameter for assessing the acid–alkali balance and detecting water contamination. The alkaline pH measurements in this study suggest effective buffering in the lakes during the research period, with values falling within the productive range of 6.0–8.5 (Garg *et al.* 2010). Conductivity measures a solution's ability to conduct electrical current, indicating the quantity of electrolytes present, including dissolved and dissociated components. Conductivity in lakes and streams generally ranges between 0 and 200 s/cm, while in major rivers, conductivity may be as high as 1,000 scm^{-1}. Very high conductivity (1,000–10,000 s/cm) indicates saline (salty) conditions. During the current study, the average conductivity values of the Dal Lake were slightly above their normal range. Bhateria & Jain (2016) observed a positive correlation between electrical conductivity and factors such as temperature, pH, alkalinity, total hardness, and calcium concentration, highlighting the influence of dissolved salts on conductivity (Gupta *et al.* 2008).

There is more DO in the winter than in the summer because the water is cooler. The low concentrations of DO in the summer are a consequence of reduced solubility at high temperatures and consumption by decomposers in the water body. The DO in surface water is either produced by photosynthetically respiring plants and algae or is absorbed from the air. The DO concentrations at each site remain nearly low during the current experiment because of Dal Lake's high eutrophication. A decrease in DO in water is likely the most common result of several types of water pollution (Srivastava *et al.* 2009). Different human activities, such as the discharge of organic wastes from floating gardens that require oxygen to break down, may be to blame for the decreasing quantities of DO observed at various places. Aquatic bodies lose oxygen due to decomposing organic waste (Bhateria & Jain 2016).

Most rivers and lakes generally exhibit chloride concentrations of less than 50 mg L^{-1}. A significant increase beyond this threshold could indicate sewage pollution or, if the rise occurs seasonally, urban runoff linked to the application of rock salt on roadways. The present study discovered that the summer months had a higher chloride concentration than the winter ones. As temperatures rise and water evaporates, sewage may mingle with the air, contributing to the ' 'summer's rising chloride content (Corsi *et al.* 2015; Bhateria & Jain 2016). Similarly, alkalinity is a critical measure of water's ability to neutralize acidity, serving as a natural buffer to maintain pH levels. Significant compositional differences in total alkalinity were observed among the sampling locations, particularly noting that alkalinity in the floating garden area was solely attributable to bicarbonate ions rather than carbonate ions (Vasistha & Ganguly 2020a, 2020b).

The values for overall hardness exhibited substantial seasonal and site-specific variations throughout the investigation. The overall hardness ratings fluctuate from summer to fall, and they do the same thing in the winter, adhering to a similar pattern. Different places could have a higher concentration of hardness depending on where the sewage treatment facility discharges. Total hardness is usually classified (EPA 1986) as soft (0–60 mg L^{-1}), moderately hard (60–120 mg L^{-1}), hard (120–180 mg L^{-1}), and very hard (>180 mg L^{-1}). The average hardness measurements for Dal Lake are within the EPA 1986 range. Throughout the study period, magnesium and calcium were found in large quantities at almost every site. The primary sources of magnesium are carbonate rocks and rocks with ferromagnetism. Due to its high calcium and magnesium hardness, Dal Lake is considered calcium-rich (Mushatq *et al.* 2013; Vasistha & Ganguly 2020b). The Kashmir Valley's thick plankton population, particularly Cynophycean, has been linked to calcium and magnesium concentrations in freshwater bodies (Bhat & Pandit 2003; Vasistha & Ganguly 2020a).

All of the 'locations' AN levels fluctuated significantly throughout the year. Organically contaminated waters with high AN concentrations and easy availability as a fertilizer for plant uptake may lead to increased biological productivity (Sheela *et al.* 2011; Vasistha & Ganguly 2020b). The more significant amounts of this nutrient may be explained by the fact that fertilizers are utilized in floating gardens, which were shown to have high concentrations of nitrate-nitrogen. The nitrate-nitrogen and phosphate concentrations between sites also showed distinct variances. When phosphate enters lakes through domestic wastewater, rapid eutrophication results (Vyas *et al.* 2006). Higher levels of phosphate and nitrate-nitrogen increased lake formation (Vasistha & Ganguly 2020a; Hussain *et al.* 2021). The results show that the average sulfate content was 17.13 mg L^{-1} in 2019, 18.75 mg L^{-1} in 2020, and 18.45 mg L^{-1} in 2021. Sulfates are discharged into lakes by paper mills, textile mills, tanneries, and businesses that use goods containing sulfur, such as sulfuric acid sulfates, in mining and smelting operations. Overall, the, more significant concentrations of these nutrients as recorded in this investigation, produce eutrophication, which promotes the excessive development of algae and aquatic plants that clog streams and deplete oxygen supplies.

5. CONCLUSION

Analyzing the physicochemical characteristics of Dal Lake's water revealed some similarities and differences in the outcomes regarding time and space. Due to spatial and temporal variables, the AT of Dal Lake nearly corresponds to the water temperature. This suggests a healthy, productive aquatic ecosystem that supports a wide range of organisms and the existence of different nutrients and chemical ions necessary for these 'species' survival. The alkaline pH of Dal Lake showed high salt content and high concentration of minerals, particularly sodium and calcium. The dissolved salt content has an impact on the water's conductivity. The Dal Lake's measured average conductivity ranged from 216.76 scm^{-1} in 2019 to 220.18 scm^{-1} in 2020 to 230.76 scm^{-1} in 2021. Due to solubility at high temperatures and the use of oxygen by decomposers, the DO level is lower in the summer than it is in the winter. Eutrophication, however, is the leading cause of the reduced DO level. The lake is generally shallow, and no warm demarcation has yet been detected there. Dal Lake is becoming eutrophic, as indicated by the high magnesium values and low DO levels, total alkalinity, conductivity, calcium hardness, total hardness, nitrate-nitrogen, and TPh. In Dal Lake, eutrophication harms the fish and other aquatic life. In comparison to the winter, the summer had a greater chloride level. The mortality and reproduction of life in Dal Lake are impacted by acidification and other impacts that result from higher chloride content. Due to its substantial role as an acid rain buffer, Dal Lake is calcium-rich, which is a crucial nutrient for life in the lake. The AN, nitrate-nitrogen, and phosphate levels vary at all sites, which is also attributable to eutrophication in the lake.

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AUTHOR'S CONTRIBUTIONS

R.K. designed the experiments, S.S. conducted the experiments, S.S. and S.A.M. analyzed the data and wrote the manuscript, S.S. and R.K. edited the manuscript and supervised the overall work. J.H.S. and A.S. edited the manuscript

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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