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Studies on Limnological Parameters and their Impact on the Distribution and Diversity of Zooplankton in Anchar Lake, Kashmir

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Abstract

The transfer of energy from producers to consumers, such as fish, fish larvae, and invertebrates, is facilitated by zooplankton. Consequently, zooplankton play a crucial part in the productivity and functioning of aquatic ecosystems, and they are also involved in the application of several emerging environmental management concepts, such as Environmental Impact Assessment (EIA), bioindication of pollution, and biomonitoring. To analyse the present condition of the Anchar Lake, this research was conducted to investigate the zooplankton association, their abundance, richness, diversity (Cladocera and Rotifera), and their seasonal fluctuations in connection to limnological factors. Four sampling sites were used to examine thirteen physicochemical parameters along with the abundance of zooplankton from January 2019 to December 2020. During the present investigation, significant variation ($p < 0.05$) was observed in transparency (trans), dissolved oxygen (DO), pH, electrical conductivity (EC), total alkalinity (TA), nitrate-nitrogen (NO_3-N), total hardness (TH), and total phosphorus (TP) between the different sites of Anchar Lake, whereas non-significant variation was observed in air temperature (AT), water temperature (WT), free carbon dioxide (FCO_2), chloride (Cl-), and nitrite-nitrogen (NO_2-N). The results further revealed a total of 44 zooplankton species, belonging to two: Rotifera (27 species) and Cladocera (17 species). The zooplankton diversity was found to vary on spatiotemporal scales showing maximum values for the Shannon diversity index in the case of Cladocera during spring

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(2.63±0.25) and for Rotifera during summer (2.53±0.25) whereas, minimum diversity values were recorded during winter for both Cladocera and Rotifera (1.54±0.44 & 1.47±0.54 respectively). On the spatial scale, site-A2 showed maximum diversity of Cladocera (2.3±0.21), while site-A4 showed maximum diversity of Rotifera (1.99±0.03). The influence of physicochemical parameters on zooplankton distribution and diversity provides a detailed picture of the impact of pollution load in Anchar Lake.

Introduction

Water is an essential and basic aspect that is necessary for the growth and existence of every living being on earth and covers nearly 71% of its surface in the form of fresh and marine waters.[1] The freshwater available on the earth provides services in many sectors like industries, agriculture, fisheries, and domestic activities.[2] Over the past two decades, the deterioration of freshwater quality is speeding up due to various natural and anthropogenic activities, which pose a major global challenge.[3] Some of the principal causes of water quality degradation and detrimental threats to freshwater ecosystems include the discharge of chemicals from industries, fertilizers from agricultural activities, and sewage from domestic activities. Freshwater bodies have become a limited resource due to excessive pollution, over-exploitation of water resources, and other domestic activities.[4-7] Lentic ecosystems such as wetlands, ponds, and lakes sustain a variety of biological communities like phytoplankton, zooplankton, zoobenthos, macrophytes, fishes, and aquatic birds. These communities are crucial to the aquatic food web, nutrient cycling, ecosystem flexibility, and ecological balance. In a lake ecosystem, communities like zooplankton and macrophytes act as potential bioindicators of pollution and are also primary food sources for fish. However, in the last few decades, the distribution, abundance, and richness of macrophytes and zooplankton communities have been influenced due to various anthropogenic activities which have caused serious threats to the ecology of lakes. Moreover, the physicochemical parameters have been adversely changed from their optimum ranges in the eutrophic lakes. One of the vital bioindicators of the aquatic environment is the zooplankton community. Zooplankton are crucial for maintaining the health of our ecosystem as they play specific roles like nutrient recycling, providing food for other biotic communities, and maintaining soil fertility[8,9] and being at the core of the chain of aquatic food webs which serve as a substantial source of nutrition directly or indirectly for nearly all freshwater fishes.[10] The biotic and abiotic aspects of aquatic ecosystems can be reflected by zooplankton diversity patterns and community structure, which can help in tracking ecological changes.[11,12] Local and regional environmental factors that alter the variety, abundance, and composition of zooplankton populations cause changes in their spatial patterns.[13] Furthermore, zooplankton populations are vulnerable to anthropogenic influences, and the communities are very sensitive to environmental changes. While assessing them through various techniques may help in predicting the long-term changes in lake ecosystem.[14-17] According to Manickam *et al*. (2018),[18] zooplankton can act as an indicator for changes in trophic dynamics and the ecological health of lakes caused by variations in nutrient loading and climatic conditions. Changes in zooplankton diversity, abundance, and community structure can all act as indicators of environmental change or stress.[16,19] Since changes in physicochemical conditions of aquatic systems result in corresponding changes in the richness, abundance, and distribution of zooplankton which have been regarded as ecologically significant organisms.[20,21] The implementation of any management methods requires knowledge of the aspects of water quality and the survey on the pollution status of water bodies.

At present Anchar Lake is under heavy stress due to significant ecological changes brought about by heavy urbanization around the lake. Pollution of this lake is a major problem since it is a breeding ground for many aquatic birds, fishes and food supply for animals. The influx of inorganic nutrients through surface run-off from surrounding agricultural land, sewage from domestic activities, and illegal disposal of garbage into the Anchar Lake are the main detrimental hazards to the ecosystem of the lake[22]

Additionally, the lake's water quality has been severely diminished by the discharge and unintentional release of hazardous chemicals from the neighbouring Sher-e-Kashmir Institute of Medical Sciences (SKIMS) hospital.[23] To deal with the threats and harmful impacts on the lake ecosystem, it is necessary to study the current status of the lake by analyzing its biotic communities and physicochemical parameters. In this respect, the current study has been conducted to examine the physicochemical characteristics of Anchar Lake as well as the distribution, density, and variety of zooplankton groups.

Materials and Methods

Study Area

The Anchar Lake is located between the geographic coordinates 34° 20´ to 34° 26´ N latitude and 74° 82´ to 74° 85´ E longitude and at 1583 m a.s.l., towards the Northwestern side of Srinagar city J&K, India (Fig. 1). The lake receives water from two sources wherein, it is fed by the Sindh River at the northern end and Khushal Sar Lake at its southern end. While on the other hand, it recharges the adjoining Shalbugh wetland through minor outlet channels. A survey conducted by ESRO (2007)[24] reported that in the previous two decades, the lake has been illegally encroached on and reduced from an area of 19.54 km^2 to 5.8 km^2. The lake has been degraded by effluents from the Sindh (Jhelum river tributary), agricultural wastes, and untreated sewage from the surrounding area (particularly the 66 km^2 watershed). In addition, the lake is polluted by the disposal of unethical biomedical wastes from SKIMS hospital. As a result of these unplanned and illegal activities, the water quality of Anchar Lake has worsened and is currently under heavy degradation. Based on the pollution status, vegetation, and land use around the catchment area, four sites have been selected from the lake (Fig. 2).

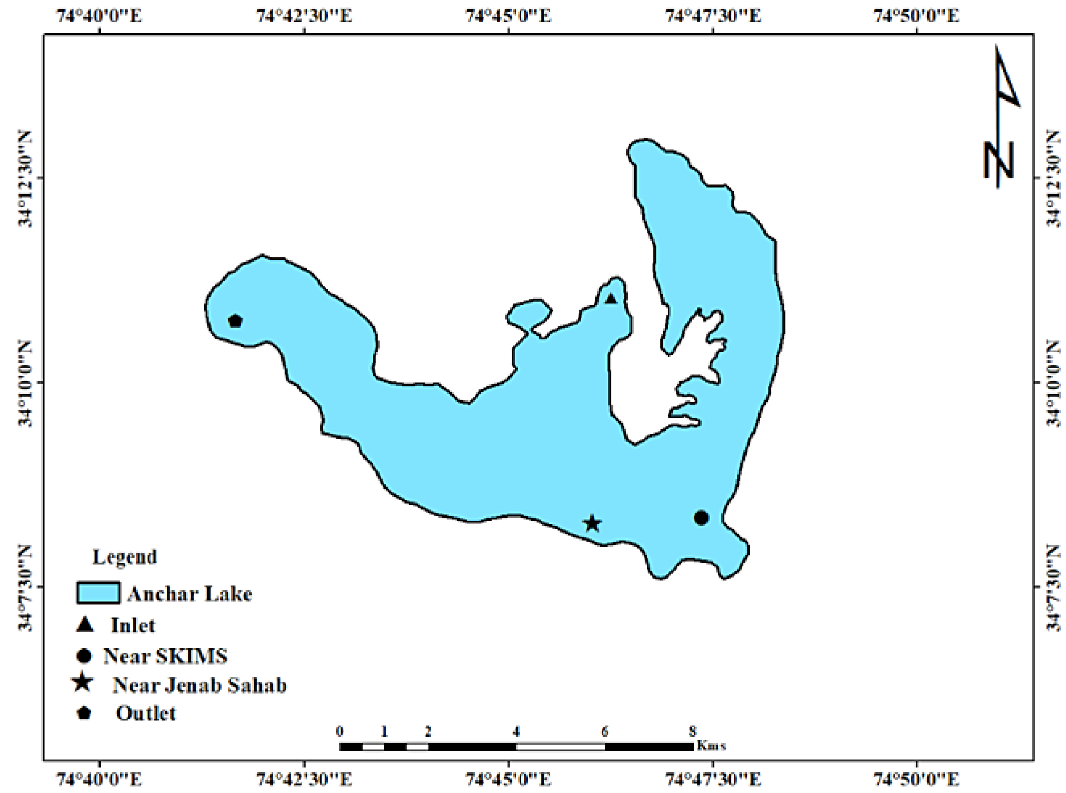

Fig. 1: Map of Anchar Lake depicting the location of study sites

Fig. 2: Ecology of different sites of Anchar Lake

The selected sampling sites for the present study as shown in Fig. 1 are as under.

(1) Site-A1 is located between coordinates 34°08′13″ N and 74°46′50″ E, where the Sind River joins northern side of the lake by network of canals.

(2) Site-A2 is located between coordinates 34°08′30″ N and 74°46′42″ E towards the southeast of the lake adjacent to SKIMS hospital with marshy land. It receives biomedical wastes and sewage from the SKIMS hospital drainage system.

(3) Site-A3 is located between coordinates 34°10′38″ N and 74°47′57″ E towards the northeast of the lake. This location is covered by thickly by trees, particularly Poplar and Willow trees. The wastewater from nearby household toilets and kitchen trash from residences is dumped directly into the lake.

(4) Site-A4 is situated at the exit of the lake on the southern side between coordinates 34°09′41″N and 74°47′30″E. This site receives slow-moving waters from the middle of the lake. It is distinguished by macrophytes and extensive growth of trees along its banks.

Analysis of Physicochemical Parameters

From January 2019 to December 2020, water sampling was carried out at four distinct sites of the lake, below the water's surface (almost 10 to 15 cm). During the present study, the physicochemical parameters like water temperature (WT), transparency, pH, and electrical conductivity (EC) were noted on the spot while the remaining samples underwent laboratory analysis. A mercury thermometer was used to record the temperature, while a 20 cm-diameter standard Secchi disc was used to gauge transparency. The pH and electrical conductivity were monitored through a hand-held digital pH meter (Systronics-MKVI) and conductivity meters (Systronics-DB-104). The parameters like dissolved oxygen (DO), free carbon dioxide (FCO_2), total alkalinity (TA), total hardness (TH), chloride (Cl-), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), and total phosphorus (TP) were detected through standard methods APHA (2017).[25]

Table 1: Overall mean and standard deviation of physicochemical parameters of Anchar Lake

Season	Sites	AT (°C)	WT (°C)	Trans (m)	pH	EC (µS/cm)	DO (mg/l)	FCO_2 (mg/l)	TA (mg/l)	TH (mg/l)	Cl- (mg/l)	NO_3-N (µ g/l)	NO_2-N (µ g/l)	TP (µg/l)
Spring	A1	19.1±4.9	16.9±4.7	0.48±0.13	8.36±0.20	356.6±31.1	5.4±0.23	8.0±3.5	183.8±13.18	195.3±3.46	37±8.94	31.6±7.09	238±32.1	416.0±20.2
	A2	19.8±5.2	17.5±4.86	0.66±0.05	8.23±0.23	385.3±21.4	3.6 ±0.15	3.5±2.6	290.0±38.6	160.0±5.0	32.8±6.01	24.6±4.16	372±43.0	422.0±28.3
	A3	19.2±5.3	17.3±4.93	0.43±0.12	7.98±0.27	398.0±29.3	3.2 ±0.36	8.3±2.0	256.6±21.07	142.3±16.1	36±13.3	29.6±4.72	342.6±29.0	359.3±5.29
	A4	18.9±5.07	17.1±4.79	0.45±0.07	8.05±0.29	392.8±26.6	5.7 ±0.98	10.6±0.52	259.16±30.6	196.6±4.0	30.3±10.4	29.0±4.58	298.3±30.1	298.0±45.0
Summer	A1	32.5±1.78	28.5±1.09	0.6±0.187	8.76±0.17	313.6±25.2	5.5 ±1.02	7.6 ±2.6	178.0±14.0	246±10.01	22±3.21	27.3±2.63	221.3±15.6	230.0±22.0
	A2	32.6±2.64	28.8±1.36	0.67±0.02	8.41±0.28	378.6±39.8	3.0 ±0.7	4.6 ±5.4	220.0±10.4	238±10.06	23.6±2.64	25.3±5.03	342±20.1	344.0±46.0
	A3	32.3±1.89	28.6±1.76	0.59±0.14	8.55±0.33	374.6±34.3	1.4 ±0.11	6.6 ±8.0	221.8±6.46	200±14.4	22±3.05	24.0±3.05	362.3±58.7	276.6±50.3
	A4	31.8±1.87	28.2±1.46	0.65±0.014	8.2±0.17	367.6±23.02	3.4 ±0.7	9.0 ±2.3	203±19.3	245.6±19.7	21.3±4.72	23.3±3.46	312.0±23.5	240.6±37.6
Autumn	A1	21.7±5.40	19.6±6.26	0.37±0.074	8.25±0.10	406.3±49.5	6.0 ±0.95	23.1 ±0.89	224±31.1	202±21.3	36.3±4.72	30.6±5.68	310.0±29.4	406.6±77.1
	A2	21.6±5.65	20.0±6.04	0.52±0.03	8.13±0.24	548.3±64.8	2.6±0.1	29.0 ±4.4	388.5±48.1	207.3±27.0	30.3±2.30	36.3±6.02	472.0±34.0	447.3±74.2
	A3	21.9±5.22	20.0±6.16	0.31±0.09	8.25±0.16	482.3±52.5	1.8 ±0.41	22.1±0.72	382.8±36.3	148.6±23.0	34±4.72	34.6±5.56	450.3±80.6	381.3±34.0
	A4	21.1±5.14	19.51±6.44	0.38±0.026	8.33±0.17	458.5±40.8	3.7 ±0.26	22.1±3.8	297.6±46.6	194±23.0	33±7.02	30.6±2.64	375.0±21.3	298.6±59.4
Winter	A1	7.55±2.42	5.41±2.50	0.52±0.09	8.43±0.13	388.8±14.2	7.0 ±0.30	21.8±1.15	208.5±15.6	243±18.0	43.6±5.03	38.0±4.58	306.0±34.0	502.6±41.0

A2	7.71±2.19	5.58±2.25	0.56±0.024	8.26±0.19	449±24.4	4.6 ±0.88	25.3±2.8	328.6±30.5	234.6±9.16	40±6.11	47.0±3.0	441.3±16.6	532.0±21.5
A3	7.53±2.15	5.73±2.05	0.49±0.03	7.55±0.24	438.6±19.2	3.5 ±1.15	19.2±5.6	353.8±26.2	180.0±10.0	36.6±9.45	45.3±5.6	426.0±4.75	419.3±33.5
A4	7.21±2.20	4.44±1.38	0.54±0.02	8.35±0.10	402.6±27.8	6.0 ±0.87	20.3±2.3	267.8±17.09	234.3±20.8	37.3±6.86	36.6±7.5	368.6±15.5	413.3±25.7

Mean±Standard Deviation represents 24 observations

Qualitative and Quantitative Analysis of Zooplankton Species

The samples used in the current investigation were taken from Anchar Lake with the help of a standard plankton net of bolting silk having a mesh size of 150 µm. The collected samples were kept in 50 ml vials and were fixed in 4% formaldehyde solution. Zooplankton samples were counted using the Sedgwick rafter cell. The systematic identification of zooplankton species was done through a binocular microscope (MLX-16B1296) with the help of standard taxonomic works.[26,27]

Plankton samples were collected for quantitative enumeration by filtering 10 litres of water retrieved independently from various depths using Rutner's sampler (2000 ml) and stored in 4% formalin. The conserved sample was shaken before 1 ml was removed with a wide-mouthed glass pipette into the Sedgwick rafter cell and examined under a binocular microscope at the time of counting. For accuracy, the subsamples were counted three times, and the mean value was selected to calculate the number of individuals per litre (ind./l) of water using Welch's[28] formula.

$$n=(a\times c)/l$$

n: number of individuals per cubic meter of water, a: individuals per 1 ml of concentrated sample, c: volume of concentrated sample; l: volume of water usually sieved (10 liters).

Diversity Indices

Various indices were used to calculate the diversity based on species richness, abundance, and evenness.

Shannon-Wiener index ‘H’’ (Shannon and Weaver 1963)[29]
Simpson index ‘1-D’ (Simpson 1949)[30]
Margalef”s index ‘MD’ (Clifford and Stephen son 1975)[31]
The evenness index (J) was calculated by using the formula of Pielou[32]

Statistical Analytical

SPSS (ver. 20.0) was used to carry out statistical analysis wherein the significant variation was determined through one-way ANOVA using Tukey’s test. The ecological correlations between physicochemical parameters and zooplankton were estimated by using a two-tailed Pearson's correlation. The population density was calculated as ind./l in MS Excel software. The diversity indices and cluster analysis were performed in Past software.

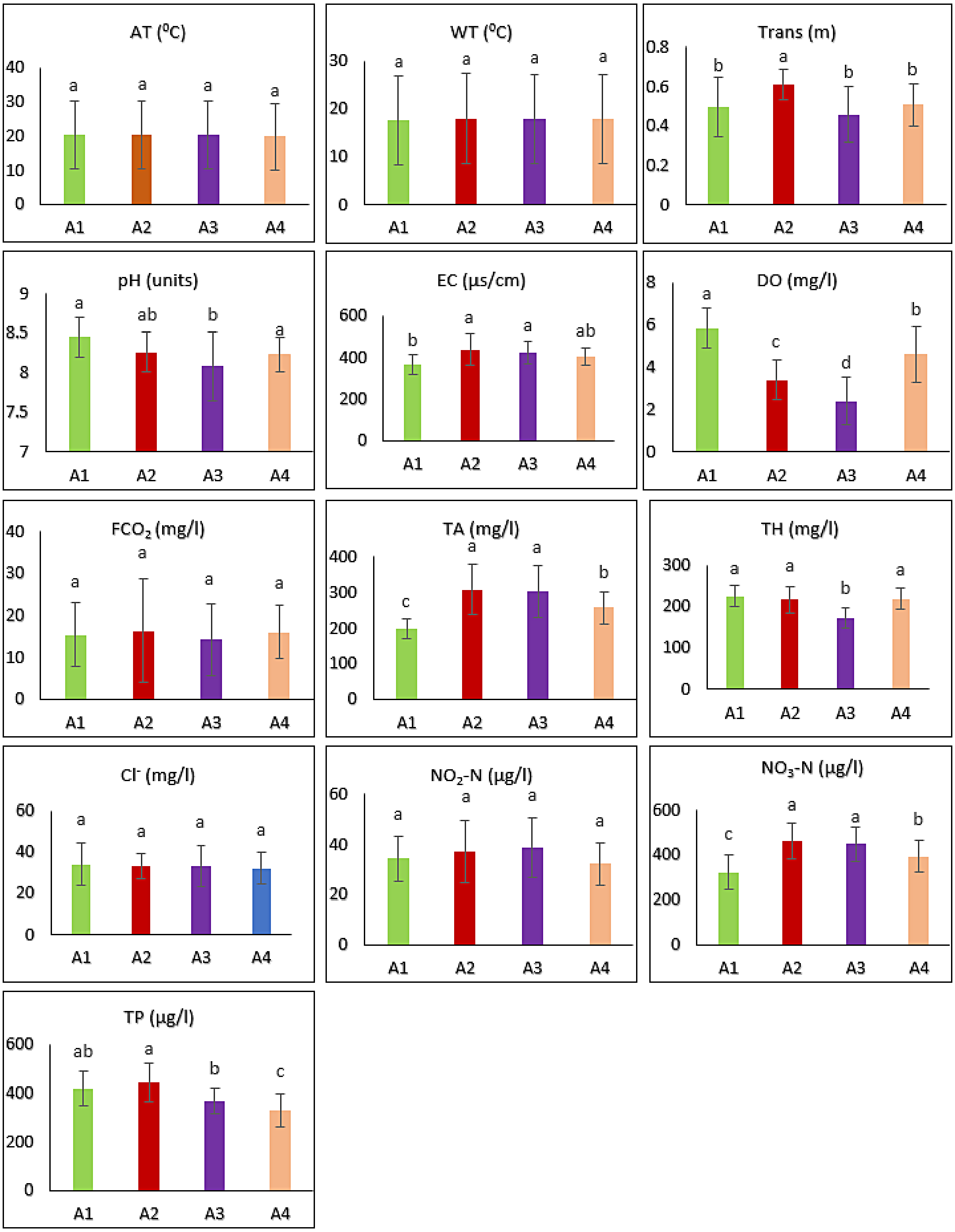

Fig. 3: Spatial variations in the physicochemical parameters of Anchar Lake

Mean±SD represents the 24 observations. Parameters sharing the different small case letters between the sites are significant ($p<0.05$); Tukey's HSD test

Results and Discussion

Physicochemical Parameters

The descriptive summary regarding the general variation on site-season scales in the physicochemical parameters of the Anchar Lake is depicted in Table 1 while the significant variations are depicted in Fig. 3.

During the current study, a significant variation ($p < 0.05$) was observed in transparency, dissolved oxygen, pH, electrical conductivity, total alkalinity, nitrate-nitrogen, total hardness, and total phosphorus between the different sites of Anchar Lake, whereas non-significant variation was observed in air temperature, water temperature, free carbon dioxide, chloride, and nitrite-nitrogen (Fig. 2).

During the research period, air temperature (AT) did not fluctuate between the different sites. The winter was bitterly cold with a minimum mean value of 7.21±2.2 °C at site-A4. The highest annual mean value of air temperature of the lake was found to be 32.6±2.64 °C in summer at site-A2. Water temperature (WT) was recorded as lowest at 4.44±1.38 °C during winter at site-A4, while highest at 28.8±1.36 °C in summer at site-A2. The increase in the WT during the summer season may be due to the maximum sunlight falling on the water surface of the lake which is also confirmed by the strong correlation between AT and WT. Similar findings regarding the fluctuation in the temperature were also reported by Chowdhury and Mazumder (1981)[33] while studying the limnology of Lake Kaptai.

The lake water was found to be murky throughout the research period, resulting in decreased transparency value of 0.31±0.09 m in the autumn at site-A3 and high transparency value of 0.67±0.02 m in the summer at site-A2. Overall higher values for transparency were observed during the summer period and low during the winter and autumn seasons in Anchar Lake which has been related to different factors, viz., planktonic population,[34,35] glacial silt,[35] suspension of phytoplankton in water[36] the volume of water body[37] and addition of sewage.[38]

The pH was recorded as a minimum of 7.55±0.24 in the winter at site-A3 and a maximum of 8.76±0.17 in the summer at site-A1. The lower pH during the winter season may be due to low photosynthetic activity and freezing of the surface water layer which increases the respiratory carbon dioxide level and organic acids in the lake.[39-42] While the rise in pH during summer appears to be linked to increased photosynthetic activity, a faster temperature rise, and a longer photoperiod.[43,44]

Electrical conductivity (EC) is used to assess the aqueous solution's capability to conduct an electric current. During the current investigation, EC was recorded to be maximum (548.3±64.8 µs/cm) in the autumn at site-A2 and a minimum of 313.6±25.2 in the summer season at site-A1. The lower conductivity throughout the summer may be attributed to the utilization of ions by macrophytes. EC was higher as compared to earlier studies wherein values of EC in the lake were recorded as 95 to 490 µs/cm.[45] The higher values at site A2 in the Anchar Lake might be due to the increased pollution and higher trophic status.[46]

The outcomes are in line with the findings of Freimuth (1994),[47] wherein, he found an increase in EC throughout the autumn and linked it to an increase in organic material.

The alkalinity ranged from 178.0±14.0 mg/l in the summer at site A1 to 388.5±48.1 mg/l in the autumn at site-A2. The difference between summer and autumn alkalinity in epilimnetic waters determines a higher level of eutrophication in Lake.[48] The alkalinity level in the lake might rise due to the accumulation of the ions of bicarbonate as the pace of their absorption decreases over the winter and autumn months. The lower alkalinity in the summer is due to a decrease in bicarbonate ions which might be utilized through phytoplankton development. The greater alkalinity at site-A2 involved the combined effect of detergent, chloride, and other pollution loadings.[49]

Dissolved oxygen (DO) is one of the most crucial factors in water quality analysis. In the present study, DO was recorded at a maximum of 7.0±0.30 mg/l in winter while a minimum of 1.4±0.11 mg/l in summer. The increased level of DO during the winter may be due to the fact that cold water has a higher oxygen content than warm water, which creates an inverse connection between dissolved oxygen and water temperature.[50] Moreover, the greater rate of decomposition of organic matter influenced by the higher temperature and microbial activity in the summer season decreases the level of DO[9,49,51,52] According to Dokulil *et al*. (2006),[53] biological activities and eutrophication in the lake cause a decrease in the DO levels of water. While the high DO during the winter season indicates low biological activity in Lake.[54]

Free carbon dioxide (FCO_2) involves the release of carbon dioxide by the respiration activity of living organisms in aquatic ecosystems. In the current study, FCO_2 was observed to be lowest (3.5±2.6 mg/l) in spring at site-A2 while the highest value of 29.0±4.4 mg/l was reported in the autumn season at site-A2. The maximum FCO_2 noticed in the autumn may be attributed to the breakdown of organic materials. The higher FCO_2 levels in the autumn season may be because of microbial decomposition and metabolic activities which release a huge amount of CO_2. Similar results regarding the seasonal trend of FCO_2 in Anchar Lake were also observed by various other workers.[55,56,57]

The chloride ion (Cl^-) is found in most natural waters. According to Dokulil *et al*. (2006),[53] excessive Cl- concentration in freshwater is considered a sign of contamination. In the present study, the minimum Cl^- concentration of 21.3±4.72 mg/l was reported in summer at site-A4 while the maximum of 43.6±5.03 mg/l in winter at site-A1. The outcomes are in accordance with the findings of Salim *et al*. (2015).[58] The maximum Cl- concentration at site-A1 appears due to chloride-containing wastes like domestic sewage and disposal of municipal garbage, flowing from the catchment region, while the low concentration in summer reflects the diluting effect of contaminants by surface runoff, reducing the chloride content of the lake.

The quantity of carbonates and bicarbonates due to calcium and magnesium salts determines the total hardness (TH) of water. In the existing study, a maximum value of 246±10.01 mg/l of TH was detected in the summer at site-A1 while a minimum value of 142.3±16.1 mg/l was in the spring at site-A3. According to Sawyer (1960),[59] three categories of TH have been created: mild (0-75 mg/l), moderately harsh (75-150 mg/l), and hard (151-300 mg/l). The higher TH of the Anchar Lake might be due to the presence of vast amounts of sewage, detergents, and other human activities. Moreover, eutrophication is also an indication of the higher hardness of the aquatic habitat.[60]

The nitrite-nitrogen (NO_2-N) was found to be highest (472.0±34.0 µg/l) in autumn at site-A2 and the lowest (221.3±15.6 µg/l) in summer at site-A1. Because nitrite is an unstable product originating from the nitrification of ammonia or denitrification of nitrates, it is usually considered that nitrite concentrations in freshwaters are insignificant.[61,62] The increasing NO_2-N at site-A2 in Anchar Lake is likely due to increased sewage pollution and fertilizer use in the catchment region.

The nitrate-nitrogen (NO_3-N) concentration was reported to be maximum (47.0±3.0 µg/l) in winter at site-A2 and minimum (23.3±3.46 µg/l) in the summer at site-A4. The high values in the lake during the winter season are a result of the decomposition of autochthonous and allochthonous elements. The increase in NO_3-N concentration during winter may also be attributed to the fact that under high oxygen concentration, the nitrate-rich sediments add increasing quantity of NO^3-N to water.[63,64] The reduced concentration of nitrates in the summer might be related to the absorption of these nutrients by autotrophs during their growth and development.[65]

Phosphorus is a critical limiting nutrient that causes eutrophication in freshwater systems.[66] The highest concentration of 532.0±21.5 µg/l of phosphorus in the current investigation was found during winter at site-A2 and the lowest concentration of 230.0±22.0 µg/l was found during summer at site-A1. The primary sources of phosphorus are household waste, detergents, fertilizers from agricultural fields, and wastewater. Higher phosphorus levels in the lake have been linked to pollution from the discharge of sewage, agricultural wastes, and surface runoff from the catchment area.[67] The presence of a high level of phosphorus also indicates eutrophic conditions, which can give rise to algal blooms in the lake. While low phosphorus concentrations in summer may be attributable to phytoplankton's utilization of nutrients, other factors may also contribute to this phenomenon.[68] Moreover, the high anthropogenic pressure at inlet locations from sewage and other pollution effluents results in high phosphorus concentration in the lake.[69]

Correlation

The descriptive analysis of the correlation between the physicochemical parameters of Anchar Lake is presented in Table 2. Wherein, significantly positive and strong correlations were observed for AT with WT, pH with AT; Cl- with EC and TA; DO with Cl- and TH; FCO_2 with EC, TA, Cl-; NO_2-N with EC, TA, Cl- and FCO_2; NO_3-N with EC, TA, DO, FCO_2, and NO_2-N; TP with EC, TA, Cl-, DO, FCO_2, NO_2-N, and NO_3-N whereas significantly negative and strong correlations were observed for both AT and WT with Cond., TA, Cl-, DO, FCO_2, NO_2-N and TP; Trans with EC, TA, and FCO_2; TA with pH, TH and DO.

Table 2: Correlation coefficients between various physicochemical parameters of water and zooplanktons in Anchar Lake

	AT	WT	Trans	EC	TA	pH	Cl	TH	DO	FCO_2	NO_2-N	NO_3-N	TP
AT	1												
WT	.987**	1											
Trans	.243*	.215*	1										
EC	-.317**	-.288**	-.326**	1									
TA	-.407**	-.378**	-.330**	.791**	1								
pH	.273**	.249*	.191	-.254*	-.353**	1							
Cl-	-.742**	-.758**	-.243*	.263**	.290**	-.288**	1						
TH	-.002	-.035	.340**	-.249*	-.362**	.363**	-.090	1					
DO	-.508**	-.507**	-.040	-.259*	-.362**	.123	.370**	.433**	1				
FCO2	-.528**	-.514**	-.427**	.667**	.608**	-.112	.380**	.086	.139	1			
NO2-N	-.720**	-.705**	-.233*	.467**	.517**	-.189	.551**	.089	.197	.605**	1		
NO3-N	-.214*	-.209*	-.161	.634**	.662**	-.242*	.218*	-.110	-.407**	.461**	.548**	1	
TP	-.676**	-.684**	-.025	.362**	.366**	-.044	.545**	.115	.350**	.530**	.641**	.279**	1

*Correlation is significant at the 0.05 level (2-tailed)- reflects the confidence level is 95%
**Correlation is significant at the 0.01 level (2-tailed)-reflects the confidence level is 99%

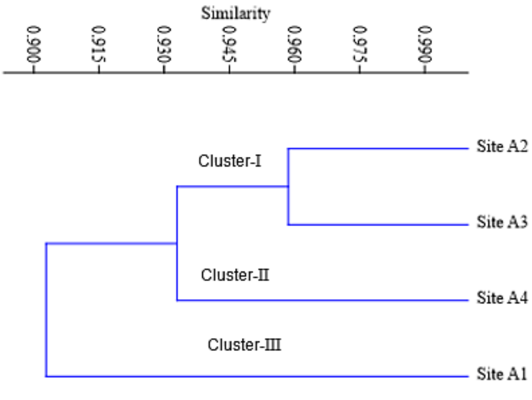

Fig. 4: Hierarchical cluster results of dendrogram of selected sampling sites of Anchar Lake

Cluster Analysis

By using cluster analysis, the degree of resemblance between sites in terms of physicochemical parameters was determined. During the present study, the cluster analysis on the dataset of Anchar Lake revealed three well-defined clusters in the form of a dendrogram (Fig. 4). The cluster-I represent site-A2 and site-A3 with 0.96% similarity, cluster-II represents site-A4, and cluster-III represent site-A1. On clustering different sites of Anchar Lake, Site- A2, and A3 showed maximum similarity during the study period. Site-A1 recorded the least similarity with other sites.

Zooplankton Densities

Zooplankton is the most significant biotic community in an aquatic ecosystem and plays a function in the food web, energy transfer, and nutrient cycling.[70-72] They also serve as potential bioindicators and are a well-suited way of understanding the pollution load of lentic ecosystems.[73] This plankton community is considered to be a good source of knowledge while studying environmental events and disturbances like climate change and trophic shifts in Lake.[74] In this investigation, a total of 44 species of zooplankton were found in Anchar Lake which belonged to two major taxonomic groups viz., Rotifera and Cladocera, wherein 27 species were identified from Rotifera while 17 species were identified from Cladocera (Table 3).

Table 3: Distribution pattern of zooplankton at four sites in Anchar Lake

Zooplankton	Site-A1	Site-A2	Site-A3	Site-A4
Cladocera				
Family: Chydoridae				
Alona affinis	-	+	+	+
Alona costata	-	-	+	-
Alona monocanthus	+	+	+	+
Acropus harpae	+	+	+	+
Camptocercus rectirostris	+	+	-	+
Chydorus sphaericus	+	+	-	+
Pleuroxus denticulatus	+	+	-	-
Family: Daphnidae				
Ceriodaphnia quadrangula	+	+	+	-
Daphnia pulex	+	+	+	+
Daphnia rosea	-	-	+	-
Daphnia magna	+	+	+	+
Simocephalus vetulus	-	+	+	-
Family: Moinidae				
Moina micrura	+	+	+	+
Family: Bosminidae				
Bosmina coregoni	+	+	+	+
Bosmina longirostris	+	+	+	+
Family: Sididae				
Diaphanosoma brachyurum	+	+	+	+
Family: Macrothricidae				
Macrothrix rosea	-	+	+	-
Total	**12**	**15**	**14**	**11**
Rotifera				
Family: Brachionidae				
Brachionus angularis	+	+	+	+
Brachionus quadridentata	+	+	+	+
Brachionus bidentate	-	-	+	-
Keratella cochlearis	+	+	+	+
Keratella hiemalis	-	+	-	+
Keratella quadrata	+	+	+	+
Notholca acuminate	-	+	-	+
Mytilina ventralis	+	+	+	+
Mytilina mucronata	-	-	+	+
Platyias quadricornis	+	-	-	+
Platyias patulus	-	+	-	+

Family: Trichocercidae				
Trichocerca cylindrical	-	-	+	-
Trichocerca longiseta	-	-	+	+
Family: Lepadellidae				
Lepadella ovalis	+	+	+	+
Lepadella patella	-	-	+	+
Family: Lecanidae				
Monostyla quadridentata	-	-	+	+
Monostyla bulla	+	+	+	-
Monostyla lunaris	-	+	-	-
Family:Notommatidae				
Cephalodella auriculata	+	-	-	+
Cephalodella gibba	+	-	-	+
Family: Synchaetidae				
Polyarthra vulgaris	+	-	+	+
Family: Gastropidae				
Gastropus stylifer	+	-	-	+
Family: Filinidae				
Filinia longiseta	+	+	-	+
Filinia terminalis	-	-	+	-
Family: Philodinidae				
Philodina roseola	-	+	+	-
Family: Testudinellidae				
Testudinella sp.	+	+	-	+
Family: Asplanchnidae				
Asplanchna priodonta	-	+	-	-
Total	**14**	**15**	**16**	**20**

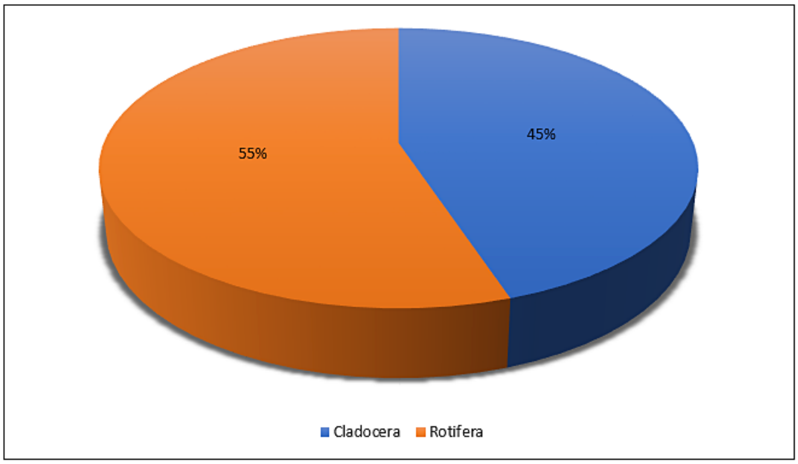

Fig. 5: Overall percent contribution of Cladocera and Rotifera in Anchar Lake

In the present study, the maximum percentage contribution was recorded from class Rotifera (55%) followed by Cladocera (45%) inhabiting the Anchar Lake (Fig. 5), Throughout the study period, the highest Cladocera density was recorded at site-A2. (15.8±28.39 ind./l) and minimum density at site-A4 (11.38±10.4 1ind./l) whereas the maximum density of Rotifera (7.29±5.26 ind./l) at the site-A4 and minimum density (5.04±5.11 ind./l) at site-A2 (Tables 4 & 5).

Table 4: Spatial variation in population density (ind./l) of Cladocera species in Anchar Lake

Species	A1	A2	A3	A4
Alona affinis	0	7.791±13.44	24.75±17.95	10.41±10.34
Alona costata	0	0	27.62±8.54	-
Alona monocanthus	11±12.09	11.79±12.28	11.46±12.84	9.0±9.63
Acropus harpae	26.42±13.84	23.95±10.86	22.08±15.28	20.87±12.46
Camptocercus rectirostris	22.42±15.46	13.54±12.19	0	13.91±12.46
Chydorus sphaericus	32.21±14.90	32.5±9.88	0	30.83±11.84
Pleuroxus denticulatus	21.16±13.24	18.37±15.59	0	0
Ceriodaphnia quadrangula	16.3±15.43	17.92±16.93	19.45±16.26	0
Daphnia pulex	24.79±15.65	19.66±15.73	21.29±13.79	24.33±11.06
Daphnia rosea	0	0	17.37±12.22	0
Daphnia magna	28.66±13.84	22.79±16.26	25.25±16.63	25.46±14.006
Simocephalus vetulus	0	13.16±11.89	10.58±11.52	0
Bosmina coregoni	21.33±9.29	18.66±12.11	21.42±8.107	18.2±11.13
Bosmina longirostris	20.04±14.89	20.83±16.38	24.08±15.32	13.5±9.26
Moina micrura	7.5±9.41	8.58±8.77	8.04±9.16	8.12±9.46
Diaphanosoma brachyurum	19.5±12.96	19.79±15.79	20.37±13.80	18.83±17.55
Macrothrix rosea	0	19.71±14.76	12.08±13.31	0
Mean ± SD	**14.78±11.41**	**15.8±28.39**	**15.63±9.30**	**11.38±10.4**

Table 5: Spatial variation in population density (ind./l) of Rotifera species in Anchar Lake

Species	A1	A2	A3	A4
Brachionus angularis	7.58±10.66	5.83±9.56	5.33±9.11	5.583±9.09
Brachionus quadridentata	14.04±11.82	7.83±11.33	13.25±14.62	11.92±16.38
Brachionus bidentate	0	0	5.75±9.57	0
Keratella cochlearis	9.21±10.65	12.04±13.05	12.5±14.54	4.79±9.60
Keratella hiemalis	0	7.25±10.91	0	12.33±13.78
Keratella quadrata	16.08±14.89	11.08±13.14	10.5±15.49	16.83±17.58
Notholca acuminate	0	5.58±9.956	0	7.292±11.14
Mytilina ventralis	11.75±13.92	11.67±13.0	13.08±17.76	10±13.09
Mytilina mucronata	0	0	13.5±18.3	7.5±11.69
Platiyas quadricornis	13.54±14.22	0	0	12.33±14.37
Platiyas patulus	0	12.79±13.0	0	13.04±13.35
Trichocerca cylindrical	0	0	13.37±12.66	0
Trichocerca longiseta	0	0	17±17.34	14.83±15.23
Lepadella ovalis	8.5±12.62	6.37±9.13	7.25±13.3	5.83±9.76
Lepadella patella	0	0	6.21±10.08	6.83±9.47
Monostyla quadridentata	0	0	13.33±17.12	6.42±12.88
Monostyla bulla	7.0±8.0	5.25±8.32	6.42±9.51	0
Monostyla lunaris	0	14.17±16.50	0	0
Cephalodella auriculata	14.62±16.92	0	0	14.04±17.08
Cephalodella gibba	7.08±8.55	0	0	10.41±10.63
Polyarthra vulgaris	12.08±14.58	0	3.75±7.16	11.08±13.13
Gastropus stylifer	13.12±17.26	0	0	7.92±13.74

Filinia longiseta	11.5±16.68	12.75±16.53	0	9.583±15.41
Filinia terminalis	0	0	15.08±13.78	0
Philodina roseola	0	7.83±12.54	10±12.58	0
Testudinella sp	10.75±15.25	9.25±15.72	0	8.42±15.36
Asplanchna priodonta	0	6.58±9.48	0	0
Mean ±SD	**5.81±6.07**	**5.04±5.11**	**6.15±6.04**	**7.29±5.26**

On a seasonal scale, the maximum values of densities in the summer season for Cladocera were recorded as 18.9±11.36 ind./l, while for Rotifera as 7.6±5.15 ind./l (Tables 6 & 7) which may be due to favorable climatic conditions.[75] The maximum temperature during the summer season indicates a higher rate of degradation of organic matter,[76] an upsurge in phytoplankton productivity, and growth of macrophytes which in turn increases the obtainability of food material and shelter for zooplankton in the lake.[19,77,78] Winter's low zooplankton concentration can be related to a lack of sustenance and low temperatures, which inhibit zooplankton growth.[77] Rotifers in eutrophic lakes have been documented with high density[80] and are considered bioindicators of water quality.[81,82] The number of zooplankton species in Anchar Lake showed clear seasonal fluctuations with a rise during the summer and a decrease in the winter and monsoon seasons. Different environmental elements such as water temperature, nutrient content, and other factors appeared to have a significant impact on varied zooplankton distribution during different seasons.[83]

Table 6: Seasonal variation in population density (ind./l) of Cladocera species in Anchar Lake

Species	Winter	Spring	Summer	Autumn
Alona affinis	0	8.58±11.18	21.08±14.25	13.29±19.30
Alona costata	6.71±12.19	8.5±15.48	7.71±14.12	4.71±8.57
Alona monocanthus	2.16±3.94	15.66±8.49	19.79±14.67	5.62±6.46
Acropus harpae	17.58±10.48	25.71±7.91	32.25±11.33	17.79±16.15
Camptocercus rectirostris	0±0	11.29±9.55	23.16±14.58	15.4±14.69
Chydorus sphaericus	18.6±16.64	26.16±18.38	26.79±17.83	23.9±16.73
Pleuroxus denticulatus	8.04±8.77	16.62±18.38	13.46±15.86	1.42±4.94
Ceriodaphnia quadrangula	0	15.87±11.88	29.46±18.20	8.37±9.15
Daphnia pulex	6.66±8.78	37.46±7.454	28.04±7.63	17.92±9.18
Daphnia rosea	4.17±8.67	7±14.10	4.291±8.75	1.92±4.64
Daphnia magna	8.37±6.51	35.21±10.49	38.66±7.91	19.92±10.68
Simocephalus vetulus	8.21±10.68	5.92±10.55	7.21±10.59	2.42±8.19
Bosmina coregoni	19.87±6.52	27.46±6.92	10.0±9.64	22.29±8.98
Bosmina longirostris	29.37±10.69	25.33±9.98	1.75±4.09	22±13.01
Moina micrura	4.62±4.28	10.62±9.64	17±7.61	0
Diaphanosoma brachyurum	1.71±3.51	22.75±12.11	33.33±9.96	20.71±10.8
Macrothrix rosea	10.08±18.03	7.958±9.88	7.67±13.03	6.08±9.37
Mean ± SD	**8.6±8.28**	**18.12±10.07**	**18.9±11.36**	**11.9±8.51**

In the present investigation, most of the rotifer species like *Brachionus quadridentata, Mytilina mucronata, Platiyas quadricornis, Platiyas patulus, Cephalodella auriculata, Monostylla quadridentata, Monostylla bulla, Monostylla lunaris, Filinia longiseta, Filinia terminalis* and *Philodina roseola* attained peak population density in summer while *Polyarthra vulgaris* and *Notholca acuminata* attained peak value in the winter season (Table 6). This could be explained by the fact that most of the rotifers depend upon phytoplankton for their food, which flourishes mostly in summer. Therefore, they could maintain their stable population in summer. Also, the population density of some rotifer species did not decline drastically in winter which means being eurythermal, they can survive in the cold waters of winter easily. Similarly, the Cladoceran species like *Alona affinis, Alona monocanthus, Camptocercus rectrirostris, Chydorus sphaericus, Daphnia magna, Moina micrura, Diaphanosoma brachyurum, Daphnia magna, Ceriodaphnia quadricangula* and *Acropus harpae* attained peak population density in summer while *Bosmina longirostris*, *Simocephalus vetulus* and *Macrothrix rosea* showed peak population in winter (Table 6). Temperature and nutrition are the key elements that determine the distribution and density of zooplankton populations.

Table 7: Seasonal variation in population density (ind./l) of Rotifera species in Anchar Lake

Species	Winter	Spring	Summer	Autumn
Brachionus angularis	0	14.25±10.10	0	10.08±10.42
Brachionus quadridentata	10.2±10.27	7.5±12.65	15.66±15.89	13.6±14.65
Brachionus bidentate	0	1.83±5.104	1.83±6.21	2.08±7.06
Keratella cochlearis	8.33±10.82	6.54±10.18	11.21±14.12	12.45±13.55
Keratella hiemalis	2.33±5.49	6.16±11.58	0.25±1.22	10.8±13.75
Keratella quadrata	6.25±10.01	11±14.34	17±18.05	20.25±14.97
Notholca acuminate	7.33±11.8	2.66±7.358	0	2.875±6.71
Mytilina ventralis	11.92±12.44	15±16.22	13.33±16.50	6.25±10.89
Mytilina mucronata	1.66±3.94	3.25±9.04	12.92±17.36	3.16±11.12
Platiyas quadricornis	7.66±12.57	4.66±12.63	10.54±12.71	3.0±8.382
Platiyas patulus	4.12±7.92	4.58±9.07	10.71±15.49	6.42±13.02
Trichocerca cylindrical	0	5.5±11.30	4.96±10.406	2.92±6.70
Trichocerca longiseta	1.92±6.55	5.58±11.46	9.33±16.104	15±16.37
Lepadella ovalis	0	10.75±12.7	7.33±13.91	9.87±9.47
Lepadella patella	2.79±7.56	2.5±6.93	3.04±7.58	4.71±8.37
Monostyla quadridentata	2.5±8.79	4.33±9.18	8.58±15.98	4.33±12.15
Monostyla bulla	3.16±6.18	6.16±10.09	8.92±8.298	0.41±2.041
Monostyla lunaris	2.5±8.49	3.16±9.00	5.25±13.09	3.25±10.02
Cephalodella auriculata	3±8.145	8±14.16	10.5±15.02	7.17±16.41
Cephalodella gibba	2.83±7.34	7.16±11.25	5.08±6.56	2.42±5.74
Polyarthra vulgaris	9.08±13.23	2.08±5.82	7.66±11.09	8.08±13.39
Gastropus stylifer	2.25±4.76	9.33±16.69	6.0±14.60	3.46±8.438
Filinia longiseta	3.0±6.80	8±16.14	18.5±17.55	4.33±11.16
Filinia terminalis	2.92±6.56	2.25±7.628	7.08±13.09	2.83±8.92
Philodina roseola	4.58±9.24	3.83±11.15	5.25±10.53	4.17±8.88
Testudinella sp	3.25±9.19	14.33±19.30	6.08±12.86	4.75±9.46
Asplanchna priodonta	1.25±4.33	2.33±6.69	0	3.0±7.413
Mean± SD	**3.88±3.24**	**6.39±3.90**	**7.6±5.15**	**6.36±4.73**

Zooplankton Diversity

Anchar Lake's zooplankton community structure was estimated using Shannon-Wiener diversity (H), Simpson's index (1-D), Margalef's richness (MD), and Pielou's evenness index (J), among others. The Shannon-Weiner index is most widely used in ecology and is expected to measure species abundance and evenness,[84-86] In the present study, the results revealed some variations in the diversity indices between the different sites and seasons (Figs. 6 & 7). The Simpson index values of Cladocera were found highest at site-A2 (0.884±0.027) and for Rotifera, the highest value was observed at site-A4 (0.84±0.04). The higher value of the Shannon-Wiener index for Cladocera was recorded at site-A2 (2.3±0.21) and for Rotifera, it was recorded at site-A4 (1.99±0.03). The Pielou's evenness index values of Cladocera were found highest at site-A1 (0.93±0.03) and for Rotifera, the highest value was observed at site-A2 (0.93±0.05). The higher value of the Margalef's index for Cladocera was recorded at site-A3 (1.74±0.26) and for Rotifera, it was recorded at site-A4 (1.37±0.37). There was no significant difference in diversity between the sites in Anchar Lake. However, the distribution of zooplankton species was unequal in different sites due to the effect of dominating species. The seasonal distribution and diversity of the zooplankton community are presented in Figs. 8 & 9, wherein, the higher value of the Shannon diversity index for Cladocera was recorded in spring as 2.63±0.2 and the highest value for Rotifera was recorded in summer (2.54±0.28), whereas the lowest for Cladocera and Rotifera was recorded in winter 1.55±0.45 and 1.47±0.54 respectively. A higher diversity value in spring and summer indicates the power of resilience and ecosystem stability in the lake due to the behavior of zooplankton living in adjacent colonies. In the winter season, the zooplankton community was more uneven as compared to other seasons which means that the community is not stable. Additionally, changes in physicochemical characteristics, especially in water temperature may have an impact on the population structure of these organisms by altering biological processes including survival, growth, and reproduction rates. Imoobe and Adeyinka (2009)[87] have found higher richness and abundance of zooplankton at vegetative sites and related it to greater availability of detritus as well as protection from predation. In water quality research, diversity indices are employed to know the effect of pollution on species abundance, and diversity.[88]

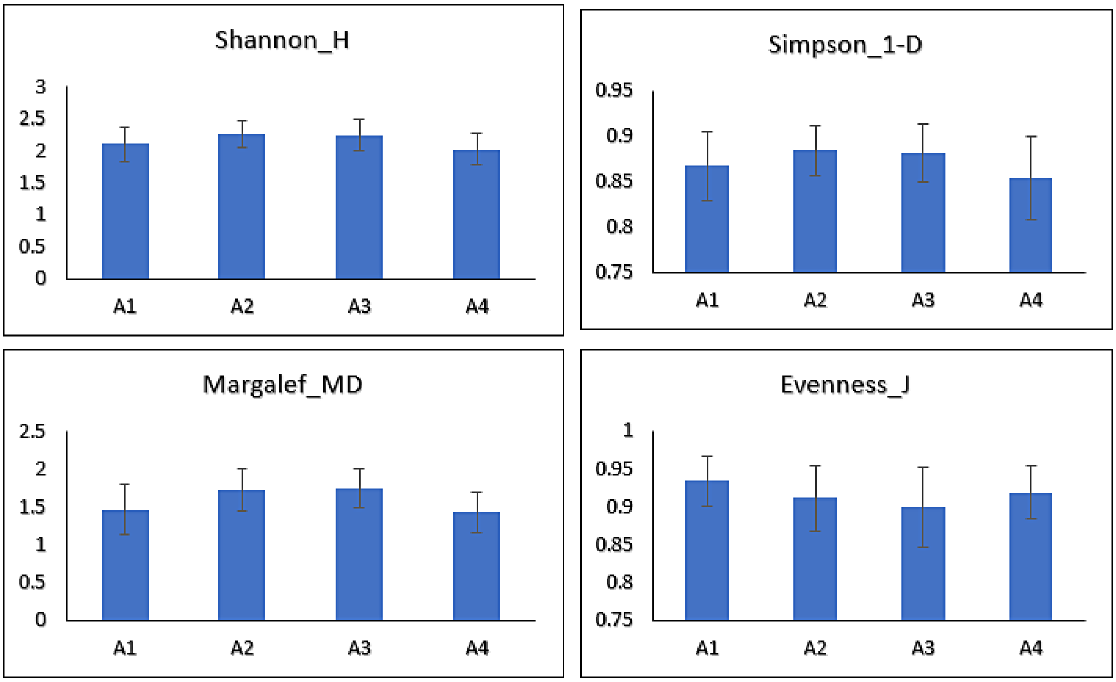

Fig 6: Spatial variation in diversity indices of Cladocera in Anchar Lake

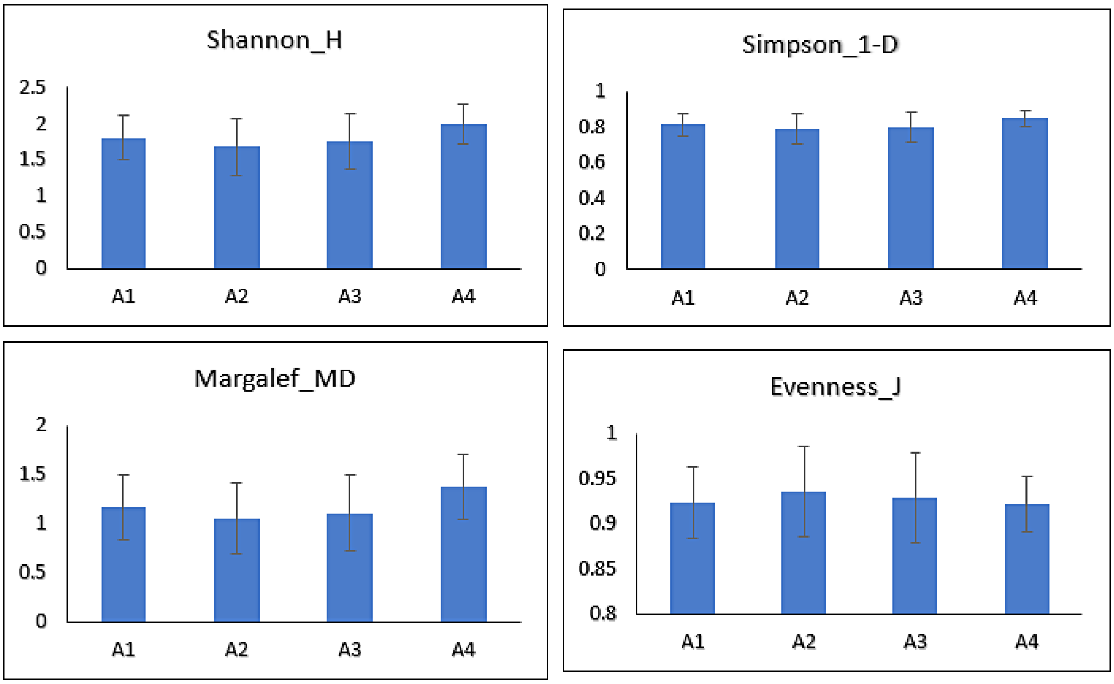

Fig 7: Spatial variation in diversity indices of Rotifera in Anchar Lake

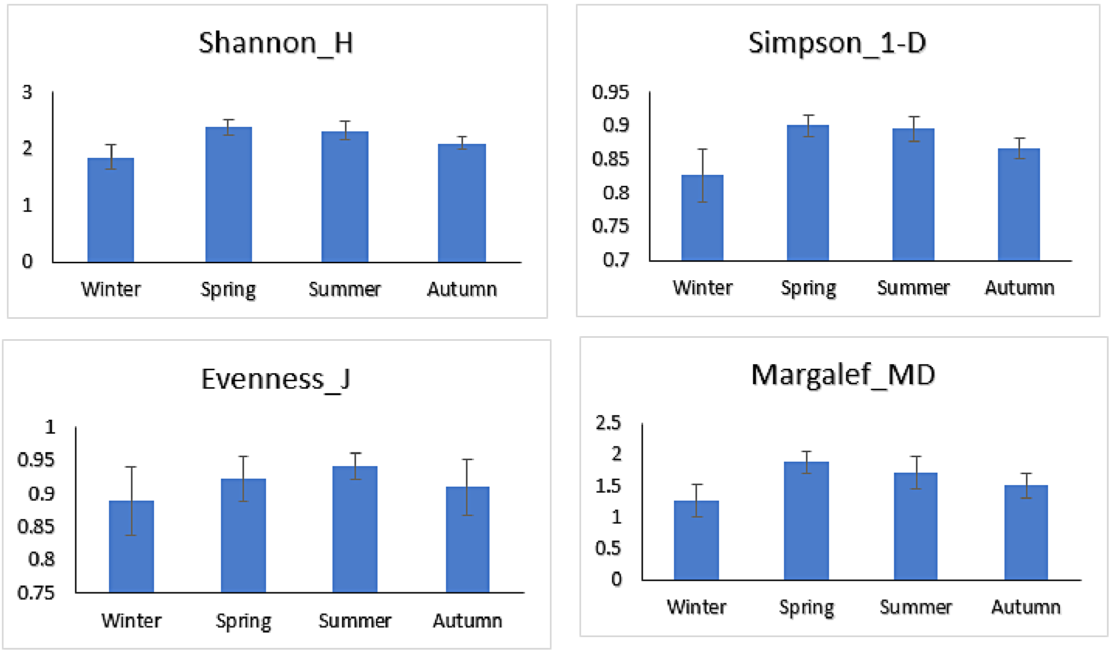

Fig. 8: Seasonal variation in diversity indices of Cladocera in Anchar Lake

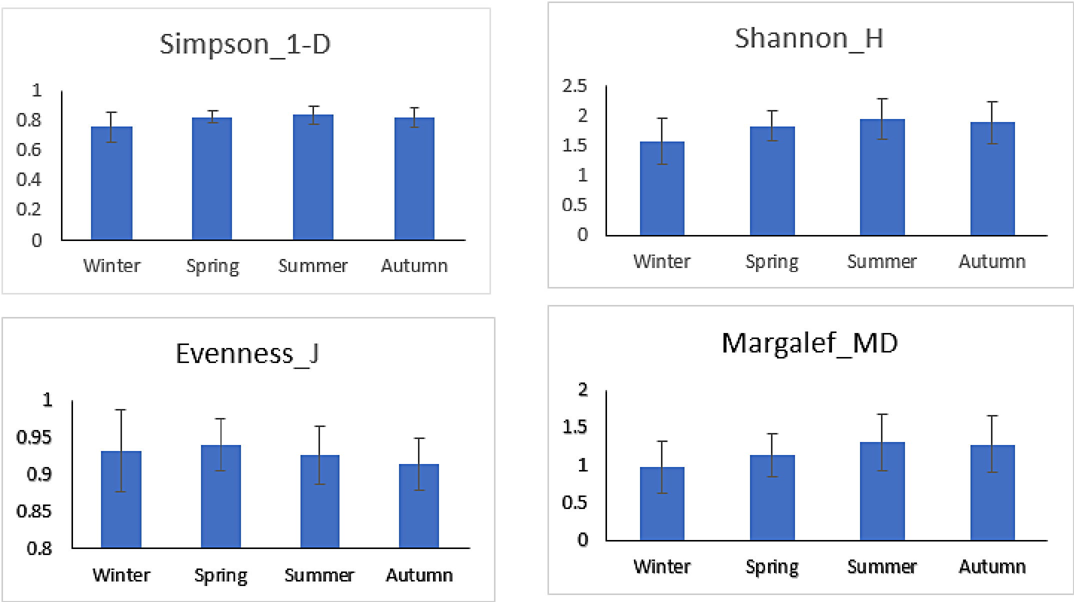

Fig 9: Seasonal variation in diversity indices of Rotifera in Anchar Lake

Table 8: Correlation coefficient (r) between the zooplankton groups and physicochemical parameters in Anchar Lake

Parameters	Zooplankton taxonomic groups	
	Cladocera	Rotifera
Air Temperature (°C)	.826**	.573**
Water Temperature (°C)	.802**	.591**
Transparency (m)	.385**	0.007
Conductivity (μs/cm)	-.267**	-0.1
Total Alkalinity (mg/l)	-.401**	-0.162
pH value (units)	.312**	0.178
Chloride (mg/l)	-.689**	-.541**
Total Hardness (mg/l)	0.014	0.043
Dissolved Oxygen (mg/l)	-.491**	-.252*
Free CO_2 (mg/l)	-.524**	-.254*
Nitrite–Nitrogen (μg/l)	-.542**	-.369**
Nitrate–Nitrogen (μg/l)	-0.184	-0.177
Total Phosphorus (μg/l)	-.358**	-.525**

*Correlation is significant at the 0.05 level (2-tailed)- reflects the confidence level is 95%
**Correlation is significant at the 0.01 level (2-tailed)-reflects the confidence level is 99%

Correlation between Physicochemical Parameters and Zooplankton

Zooplanktons are an essential component, and their study in conjunction with other biotic components is an essential method for determining the lake's trophic status. The overall descriptive analysis of the correlation between the zooplankton and physicochemical parameters is presented in

Table 8, wherein, both Cladocera and Rotifera showed a significant positive correlation ($p < 0.01$; $r > 0.5$) with AT, WT whereas they revealed a significant negative correlation ($p < 0.01$; $r > 0.5$) with Cl-, NO_2-N and TP. Individually, Cladocera showed a significant negative correlation ($p < 0.01$; $r > 0.5$) with EC, TA, Cl-, D.O, FCO_2, NO_2-N, and TP while the Rotifera showed a significant negative correlation ($p < 0.01$; $r > 0.5$) with Cl-, NO_2-N and TP. Temperature appears to be the single most critical physicochemical parameter that affects zooplankton populations.[89,90] Many researchers also found a positive correlation between temperature and rotifers.[91-93] Wheel animalcules and water fleas had a negative connection with dissolved oxygen in the current research. According to Rutner-Kolisko (1974),[94] the majority of rotifers are detritus feeders and can survive in low-oxygen environments. Chittapun *et al*.(2007)[95] observed that rotifers had a negative connection with dissolved oxygen and total hardness, which is in line with the present results. The present study supports the claims made by Saler and Sen (2002),[96] which suggest that cladocerans can tolerate low dissolved oxygen concentrations. Additionally, the zooplankton population continued to exhibit a negative connection between total alkalinity and free carbon dioxide.[97,98] The above statements are in concordance with our findings regarding the correlation between zooplankton and physicochemical parameters.

Conclusion

The current investigation revealed that Anchar Lake has deteriorated significantly over time, resulting in a deterioration of its water quality.

In addition to the distribution and diversity of zooplankton species, physicochemical parameters show a significant influence on the water quality of Anchar Lake. Temperature, nutrients, chloride, and free carbon dioxide have a major impact on the composition, distribution, abundance, and richness of zooplankton species. Furthermore, the maximum abundance of Rotifera at all sites is suggestive of a eutrophic state of the Anchar Lake. The maximum Shannon-Wiener diversity index was observed for Cladocera at site-A2 & for Rotifera at site-A4 throughout the spring and summer seasons respectively indicating the existence of abundant food material such as algae and macrophytes in the lake. Moreover, the presence of high content of nutrients in the lake has adversely prompted the process of eutrophication through excessive growth of macrophytes and unchecked disposal of garbage and medical wastes have degraded the ecology of the lake. Despite many treatment plans made to limit pollution by the concerned authorities J and K Lake Conservation and Management Authority (LCMA), no efforts have been taken to safeguard the lake. The current study provides information about the detrimental threats to the water quality and the productivity of Anchar Lake. The current status of the lake focuses on the requirement of management aspects and the need of national importance for protection under strict guidelines from concerned government agencies.

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No

Conflict of interest

The authors have no conflict of interest.

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