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SEASONAL VARIATIONS OF ALGAL DIVERSITY IN RESPONSE TO WATER QUALITY AT BEESHAZARI LAKE, TROPICAL LOWLAND, NEPAL

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Abstract

The algal diversity of an ecotone between land and water is majorly determined by the quality of water. Seasonal fluctuation in water quality due to natural and anthropogenic influence in tropical lowland lakes of Nepal brings variations in algal diversity. The purpose of the study was to assess seasonal variation of the algal diversity in response to physicochemical parameters of lakeshore water. Sampling was performed for algae during monsoon and winter season in the year 2018-2019. The value of pH, dissolved oxygen (DO), total dissolved solute (TDS) and conductivity were recorded highest during winter while highest temperature was recorded during monsoon season. Chlorophyceae was found to be dominant during both seasons. Shannon-Weiner Index was higher during monsoon with more evenly distributed algae species. *Closterium* sp. and *Glaucocystis* sp. were more frequent while *Gomphonema* sp. was highly abundant during monsoon. *Dictyosphaerium* sp., *Anabaena* sp., *Pinnularia* sp. and *Closterium* sp. showed high abundance with high conductivity during winter but *Cymbella* sp., *Ulnaria* sp. and *Pleurotaenium* sp. seemed concentrated towards high DO during winter.

Key words: Density (D), Evenness (E), Frequency (F), Species richness, Statistical analysis.

Introduction

Lakeshores are ecotones constituting of transitional habitat for both terrestrial and aquatic organisms. Due to the variation in physicochemical conditions, diverse assemblage of algae colonizes these zones (Zohary & Ostrovsky, 2011). Hence, are considered as rich source of biodiversity of the world and refer as supermarket of biodiversity (Shine & De Klemm, 1999). Algae as bio-indicators show early sign of water quality change (Parmar *et al.*, 2016). In Nepal, the wetlands occupy approximately 5% of the total area of the country and nearly one fourth of Nepal's biodiversity is wetland/lake dependent (Bhandari, 1992). Nepal's wetlands are being threatened and are vulnerable to habitat destruction and degradation, loss of ecosystem integrity, depletion of species abundance, rapid increase in invasive species cover and anthropogenic pollution (Kafle & Savillo, 2009). Seasonal monitoring of water quality and algal diversity might be helpful to evaluate biological as well as physicochemical status of lake. The maximum number of phytoplankton taxa was recorded during pre-monsoon season, decreased during the monsoon season and thereafter increased during the post-monsoon season (Ghosh *et al.*, 2012). During pre-monsoon, monsoon and post-monsoon season the distribution of algae under different groups were in order of: chlorophyceae > bacillariophyceae > cyanophyceae > eulenophyceae (Kaparapu & Geddada, 2013). Algal species richness was higher during winter season than during monsoon (Yuan *et al.*, 2014). Phytoplankton population was in the order of diatoms > green algae > blue-green algae during winter and monsoon season (Matta *et al.*, 2015). The major objective of this study was to understand the relationship between physico-chemical characteristics of lake water and algal diversity at the lakeshore located in the tropical region.

Materials and Methods

Study area: The geographic focus of the research was the lakeshore of Beeshazari Lake (Fig. 1). It is located at coordinates: 27037'05"N and 84026'11"E at an altitude of 286 m with surface area of 3,200 hectares and forms an extensive typical oxbow lake system of the tropical inner Terai within the buffer zone of the Chitwan National Park, a World Heritage site. It was designated as Ramsar site on 8th August, 2003. The main source of water throughout the year is Khageri canal and during monsoon season precipitation increases the water level. The mean annual rainfall is recorded 2150 mm (Lamichhane *et al.*, 2017).

Algae and water quality analysis: A wooden framed quadrat (size 1m x 1m) was laid down at shore of the lake as a plot. Each sampling plot was about 25 to 30 m apart from adjacent sampling plot. Total of 42 plots were studied in each season (monsoon and winter) at similar co-ordinates. The algal samples were collected directly in polythene sampling bottles (1 L capacity) from the depth of about 10 cm below the surface of water from the center of quadrat and as well by squishing the roots of floating aquatic macrophytes within the quadrat. Each collected sample was added with 4% formaldehyde as preservative immediately after collection. Algae were identified with the help of literature (Desikachary, 1959; Scott & Prescott, 1961; Lange-Bertalot & Metzeltin, 1996; Komárek & Anagnostidis, 2005) and were classified as per Fritsch (1959). The qualitative and quantitative assessment of each individual species in each plot was done with the help of Sedgewick-Rafter cell (S50code 02 C00415). Species presence or absence and total counting of present species in ten random squares at the base of Sedgewick-Rafter cell were considered as representatives of each plot for the quantitative analysis of algae. Quantitative characteristics of algae were calculated as per Zobel *et al.*, (1987). Physicochemical parameters viz., temperature, pH, total dissolved solute (TDS) and conductivity were measured with the help of electric kit multi-parameter probe (HANNA, HI9812-5) whereas dissolved oxygen (DO) was measured by using DO meter (Ecosense DO 200A).

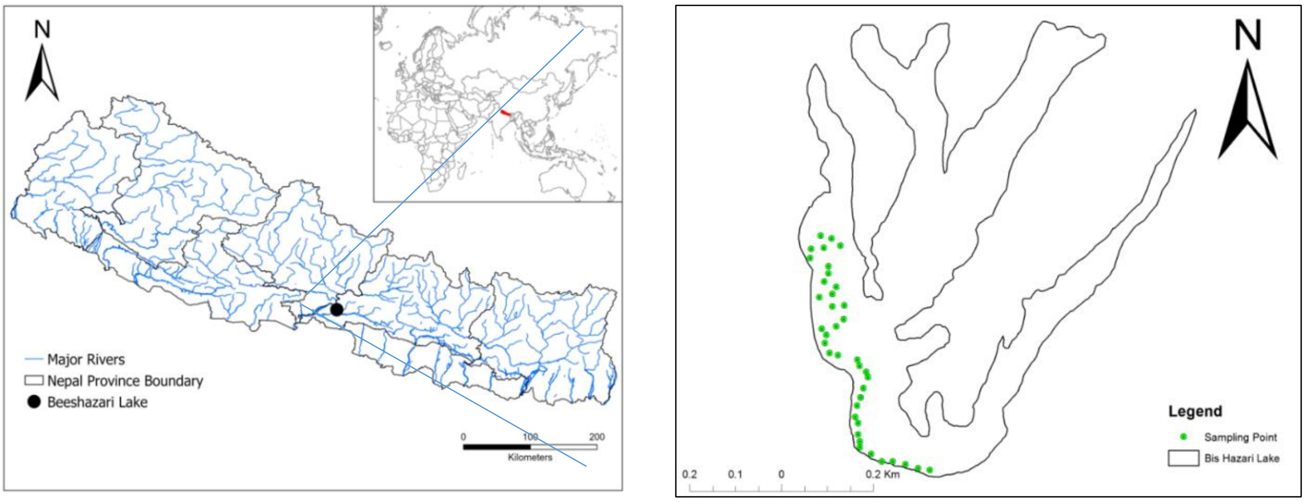

Fig. 1. Location of study area (Beeshazari Lake).

Statistical analysis

Spearman correlation coefficient was calculated to evaluate the relationships between the abiotic (i.e., physicochemical parameters of water) and biotic factor (i.e., algae) by statistical analysis software SPSS (version 23.0). All the tests were two tailed and the correlations were tested at 0.05 and 0.01 level of significance. Whereas Redundancy analysis (RDA) was performed by softwareR.

Results

Physicochemical parameters of water: The highest mean value for temperature was observed during monsoon season (31.01 ± 0.26ºC) and lowest during winter (17.35 ± 0.18ºC). Temperature showed strong positive correlation with pH (r = 0.52) in comparison to DO (r = 0.47) during monsoon season and week positive correlation with DO (r = 0.31) compared to TDS (r = 0.03) and pH (r = 0.02) during winter season (Tables 1-3).

For pH, the highest mean value was recorded during winter season (7.92 ± 0.05) and lowest during monsoon (7.48 ± 0.08). Water pH had shown strong positive correlation with DO (r = 0.60) in comparison to temperature (r = 0.52) during monsoon season. Water pH showed week positive correlation with TDS (r = 0.44) compared to conductivity (r = 0.43), DO (r = 0.24) and temperature (r = 0.02 during winter season (Tables 1-3).

Similarly, the highest mean value for DO was observed during winter season (10.72 ± 0.26 mg/l) and lowest during monsoon (3.34 ± 0.05 mg/l). DO showed strong positive correlation with pH (r = 0.60) in comparison to temperature (r = 0.47) during monsoon season. DO had shown week positive correlation with temperature (r = 0.31) in comparison to pH (r= 0.24) during winter season (Tables 1-3).

For TDS, the highest mean value was observed during winter season (45.98 ± 0.34 mg/l) and lowest during monsoon (36.98 ± 0.53 mg/l). TDS had shown strong positive correlation with conductivity (r = 0.80) during monsoon season. TDS had shown weak positive correlation with temperature (r = 0.03) in comparison to pH (r = 0.44) during winter season (Tables 1-3).

In the same way, the highest mean value for conductivity was observed during winter season (83.95 ± 0.59 µS/cm) and lowest during monsoon (74.33 ± 1.00 µS/cm). Conductivity showed strong positive correlation with TDS (r = 0.89) in comparison to pH (r = 0.01) during monsoon season. Conductivity had shown strong positive correlation with TDS (r = 0.92) in comparison to pH (r = 0.44) during winter season (Tables 1-3).

Algal diversity: A total of 45 genera of algae belonging to five classes were recorded in the month of August (monsoon season) and January (winter season) during 2018-2019. Chlorophyceae was the dominant class followed by bacillariophyceae and myxophyceae during monsoon season while in the winter chlorophyceae was the dominant class followed by bacillariophyceae, myxophyceae, euglenophyceae, chrysophyceae, respectively (Table 4).

Shannon-Weiner diversity value of algae was slightly higher during monsoon (H = 2.78 ± 0.02) than during winter (H = 2.74 ± 0.02) season. Algal species were more evenly distributed during monsoon (E = 0.75 ± 0.01) than during winter (E = 0.07 ± 0.01) season (Table 5).

Gomphonema sp. (F = 100) showed maximum frequency followed by *Closterium* sp. and *Glaucocystis* sp. (both F = 88.10) values while *Mougeotia* sp. and *Chaetophora* sp. showed minimum frequency (both F = 2.38) values, whereas *Gomphonema* sp. showed maximum density (D = 11.67) followed by *Cosmarium* sp. (D = 4.62), *Glaucocystis* sp. (D = 3.67) however *Mougeotia* sp. and *Chaetophora* sp. (D = 0.02) showed minimum density during monsoon season. Similarly, *Gomphonema* sp. (F = 95.24) was the algal species showing high frequency value followed by *Cosmarium* sp. (F = 85.71) and minimum value of frequency was shown by *Dinobryon* sp., *Euglena* sp., *Netrium* sp., *Gyrosigma* sp. and *Oedogonium* sp. (F = 2.38) while the maximum density was shown by *Euastrum* sp. (D = 24) followed by *Gomphonema* sp. (D = 15.86) and *Cosmarium* sp. (D = 10.52) while minimum value of density was shown by *Netrium* sp., *Dinobryon* sp. and *Gyrosigma* sp. (D = 0.02) during winter season (Table 6).

Table 1. Physico-chemical parameters of water in monsoon and winter season during 2018-2019.

Physico-chemical parameters	Seasons	Mean value	Standard deviation (±)
Temperature (°C)	Monsoon	31.01	0.26
	Winter	17.35	0.18
pH	Monsoon	7.48	0.08
	Winter	7.92	0.05
Dissolved Oxygen (mg/L)	Monsoon	3.34	0.05
	Winter	10.72	0.26
Total Dissolved Solute (mg/L)	Monsoon	36.98	0.53
	Winter	45.98	0.34
Conductivity (µS/cm)	Monsoon	74.33	1.00
	Winter	83.95	0.59

Table 2. Spearman correlation coefficient (r) of temperature, pH, dissolved oxygen (DO), total dissolved solids (TDS) in monsoon season during 2018-2019.

	Temperature	pH	DO	TDS	Conductivity
Temperature	1				-0.30
pH	0.52[a]	1			-0.12
DO	0.47[a]	0.60[a]	1		-0.10
TDS	-0.28	-0.05	-0.07	1	0.80[b]

[a] = Correlation is significant at the 0.01 level (2-tailed)
[b] = Correlation is significant at the 0.05 level (2-tailed)

Table 3. Spearman correlation coefficient (r) of temperature, pH, dissolved oxygen (DO), total dissolved solids (TDS) in winter season during 2018-2019.

	Temperature	pH	DO	TDS	Conductivity
Temperature	1				-0.08
pH	0.02	1			0.43[a]
DO	0.31[b]	0.24	1	-0.32[b]	-0.34
TDS	0.03	0.44[a]	-0.32[b]	1	0.93[a]

[a] = Correlation is significant at the 0.01 level (2-tailed)
[b] = Correlation is significant at the 0.05 level (2-tailed)

Table 4. Total number of algae genera belonging to five classes in monsoon and winter season during 2018-2019.

S.No.	Classes	Total no. of genera	
		Monsoon	Winter
1.	Chlorophyceae	25	27
2.	Chrysophyceae	0	1
3.	Bacillariophyceae	8	8
4.	Euglenophyceae	2	2
5.	Myxophyceae	6	2
Total number of species		41	40

Relationship between algal species richness and water parameters of two different seasons: In monsoon, temperature (Fig. 2a) showed higher positive strength than conductivity (Fig. 2e) whereas DO (Fig. 2c) showed higher negative strength than pH (Fig. 2b) and TDS (Fig. 2d) towards algal species richness. Similarly, during winter season, DO (Fig. 2h) showed higher positive strength than temperature (Fig. 2f) whereas TDS (Fig. 2i) showed higher negative strength than conductivity (Fig. 2j) and pH (Fig. 2g) towards algal species richness.

During monsoon season, *Dictyosphaerium* sp., *Anabaena* sp., *Pinnularia* sp. and *Closterium* sp. showed high affinity with conductivity and TDS while these species showed low affinity with temperature. *Sphaerocystis* sp., *Glaucocystis* sp., *Coelastrum* sp. and *Micrasterias* sp. showed high abundance with high temperature while these species showed low abundance with conductivity and TDS. *Cosmarium* sp. showed high abundance with high pH and DO (Fig. 3). *Oedogonium* sp., *Nitzschia* sp., *Arthrodesmus* sp. and *Fragilaria* sp. were negatively correlated with pH and DO (Fig. 4).

During winter season, *Spirogyra* sp. and *Trachelomonas* sp. abundance was higher towards high pH, TDS and conductivity. *Nitzschia* sp., *Ankistrodesmus* sp. and *Fragilaria* sp. seemed to be more concentrated towards high temperature. Similarly, *Cymbella* sp., *Ulnaria* sp. and *Pleurotaenium* sp. seemed to be more concentrated towards high DO. *Lyngbya* sp. showed negative correlation with DO. *Kirchneriella* sp., *Teilingia* sp., *Pediastrum* sp., *Euglena* sp., *Mougeotia* sp., *Dictyosphaerium* sp. and *Staurastrum* sp. showed negative correlation with pH, TDS and conductivity (Fig. 4).

Table 5. Shannon-Weiner Index (H), Species richness and Evenness (E) of algae genera in monsoon and winter season during 2018-2019.

S.No.	Season	Shannon-Weiner Index (H)	Species richness	Evenness (E)
1.	Monsoon	2.78 ± 0.02	41	0.75 ± 0.01
2.	Winter	2.74 ± 0.02	40	0.07 ± 0.01

Table 6. Frequency, Relative Frequency, Density and Relative Density of algae genera in monsoon (M) and Winter (W) season during 2018-2019.

S.No.	Name of genera	Frequency		Relative frequency		Density		Relative density		Abbre viation
		M	W	M	W	M	W	M	W	
	Class: Chlorophyceae									
1.	*Ankistrodesmus* sp.	50.00	11.91	4.23	0.93	1.33	0.14	0.03	0	Anki.sp
2.	*Arthrodesmus* sp.	26.19	64.29	2.21	5.00	0.31	1.6	0.01	0.02	Arth.sp
3.	*Botrycoccus* sp.	-	4.76	-	0.37	-	0.14	-	0	Botr.sp
4.	*Chaetophora* sp.	2.38	-	0.2	-	0.02	-	0.01	-	Chae.sp
5.	*Closterium* sp.	88.10	73.81	7.45	5.74	3.19	5.05	0.08	0.07	Clos.sp
6.	*Coelastrum* sp.	16.67	14.29	1.41	1.11	0.31	0.76	0.01	0.01	Cole.sp
7.	*Cosmarium* sp.	80.95	85.71	6.84	6.67	4.62	10.52	0.11	0.15	Cosm.sp
8.	*Dictyosphaerium* sp.	28.57	9.52	2.41	0.74	0.48	0.31	0.01	0	Dict.sp
9.	*Euastrum* sp.	33.33	14.29	2.82	1.11	0.62	24	0.02	0	Euas.sp
10.	*Glaucocystis* sp.	88.10	59.52	7.45	4.63	3.67	2.29	0.90	0.03	Glau.sp
11.	*Gonatozygon* sp.	16.67	66.67	1.41	5.19	0.19	3.12	0.01	0.05	Gona.sp
12.	*Hyalotheca* sp.	-	14.29	-	1.11	-	1.02	-	0.02	Hyal.sp
13.	*Hydrodictyon* sp.	9.52	4.76	0.81	0.37	0.17	0.05	0.01	0	Hydr.sp
14.	*Kirchneriella* sp.	35.71	45.24	3.02	3.52	0.57	1.29	0.01	0.02	Kirc.sp
15.	*Micrasterias* sp.	52.8	38.1	4.43	2.96	1.31	0.69	0.03	0.01	Micr.sp
16.	*Mougeotia* sp.	2.38	76.19	0.2	5.93	0.02	3.98	0.01	0.06	Moug.sp
17.	*Netrium* sp.	-	2.38	-	0.185	-	0.02	-	0	Netr.sp
18.	*Oedogonium* sp.	9.52	2.38	0.81	0.19	0.1	0.05	0.01	0	Oedo.sp
19.	*Oocystis* sp.	28.57	11.91	2.41	0.93	0.55	0.33	0.01	0.01	Oocy.sp
20.	*Pediastrum* sp.	7.14	11.91	0.6	0.93	0.07	0.12	0.01	0	Pedi.sp
21.	*Pleurotaenium* sp.	21.43	45.24	1.81	3.52	0.31	0.76	0.01	0.01	Pleu.sp
22.	*Scenedesmus* sp.	19.05	23.81	1.61	1.85	0.26	0.36	0.01	0.01	Scen.sp
23.	*Sphaerocystis* sp.	50.00	47.62	4.23	3.7	1.05	1.24	0.03	0.02	Spha.sp
24.	*Spirogyra* sp.	7.14	7.14	0.60	0.56	0.10	0.07	0.01	0	Spir.sp
25.	*Spondylosium* sp.	11.91	35.71	1.01	2.78	0.21	0.98	0.01	0.01	Spon.sp
26.	*Staurastrum* sp.	19.05	52.38	1.61	4.07	0.21	1.6	0.01	0.02	Stau.sp
27.	*Teilingia* sp.	19.05	45.24	1.61	3.52	0.31	1.00	0.01	0.01	Teli.sp
28.	*Xanthidium* sp.	28.57	45.24	2.41	3.519	0.43	1.17	0.01	0.02	Xant.sp
	Class: Chrysophyceae									
29.	*Dinobryon* sp.	-	2.38	-	0.19	-	0.02	-	0	Dino.sp
	Class: Bacillariophyceae									
30.	*Cymbella* sp.	4.76	16.67	0.4	1.3	0.1	0.52	0.01	0.01	Cymb.sp
31.	*Fragilaria* sp.	11.91	33.33	1.01	2.59	0.14	0.55	0.01	0.01	Flag.sp
32.	*Gomphonema* sp.	100.0	95.24	8.45	7.41	11.67	15.86	0.28	0.23	Gomp.sp.
33.	*Gyrosigma* sp.	61.91	2.38	5.23	0.19	1.60	0.02	0.04	0	Gyro.sp
34.	*Navicula* sp.	38.10	19.05	3.22	1.48	0.93	0.57	0.02	0.01	Navi.sp
35.	*Nitzschia* sp.	9.52	52.38	0.81	4.07	0.24	8.02	0.01	0.12	Nitz.sp
36.	*Pinnularia* sp.	38.10	23.81	3.22	1.85	1.50	0.67	0.04	0.01	Pinn.sp
37.	*Ulnaria* sp.	45.24	76.19	3.82	5.93	0.81	2.93	0.02	0.04	Ulna.sp
	Class: Euglenophyceae									
38.	*Trachelomonas* sp.	50.00	16.67	4.23	1.30	1.07	0.24	0.03	0	Trac.sp
39.	*Euglena* sp.	28.57	2.38	2.41	0.19	0.45	0.1	0.01	0	Eugl.sp
	Class: Myxophyceae									
40.	*Anabaena* sp.	9.52	19.05	0.81	1.48	0.17	0.62	0.01	0.01	Anab.sp
41.	*Chrococcus* sp.	4.76	-	0.4	-	0.04	-	0.01	-	Chro.sp
42.	*Cylindrospermum* sp.	4.76	-	0.4	-	2.38	-	0.06	-	Cyli.sp
43.	*Lyngbya* sp.	7.14	11.91	0.6	0.93	0.14	0.12	0.01	0	Lyng.sp
44.	*Oscillatoria* sp.	11.91	-	1.01	-	0.14	-	0.01	-	Osci.sp
45.	*Scytonema* sp.	4.76	-	0.4	-	0.12	-	0.01	-	Scyt.sp

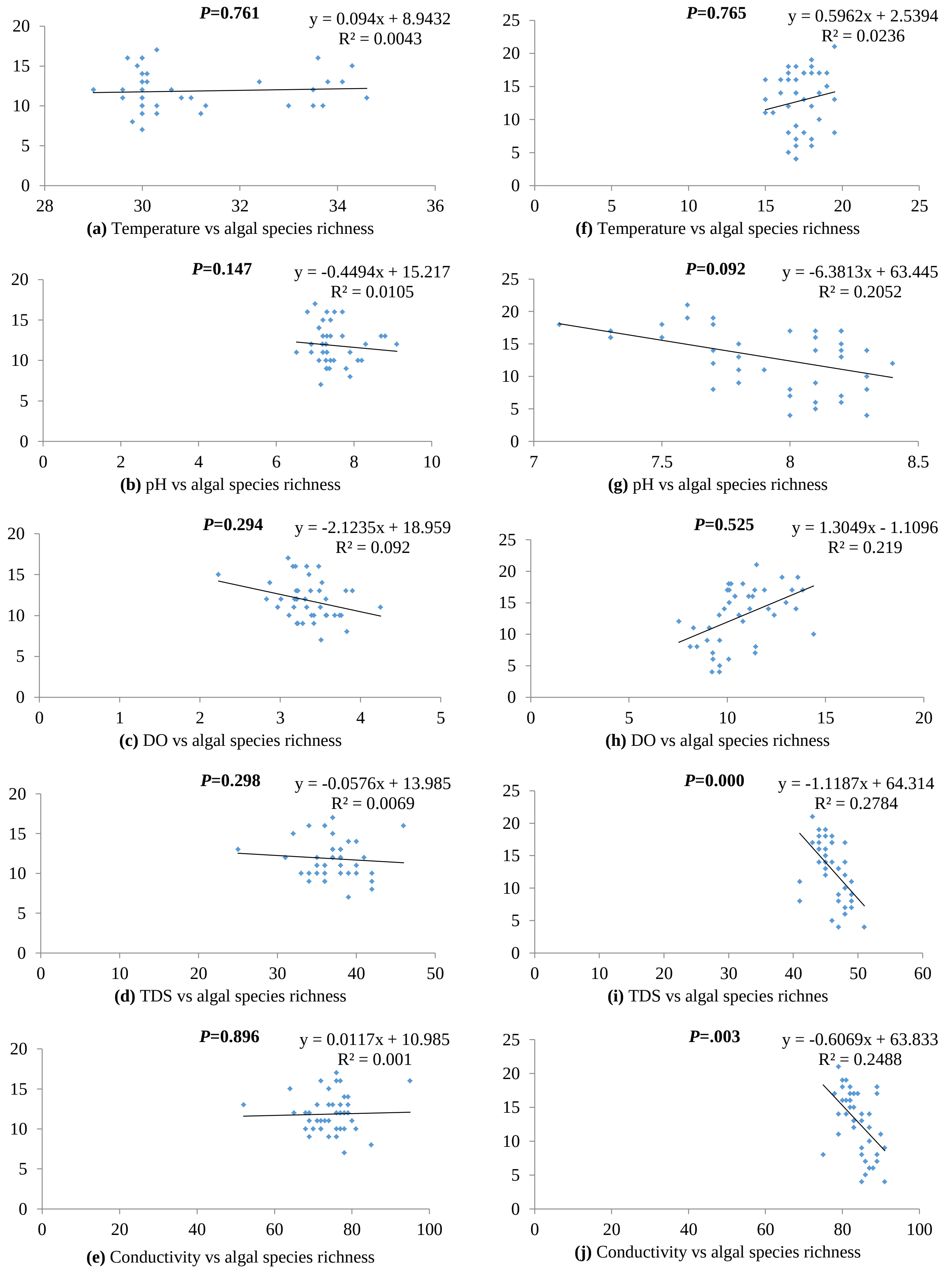

Fig. 2. Regression graph of water parameters in x-axis and algal species richness in y-axis at 0.05 level of significance (a-e) of monsoon season, (f-j) of winter season; (a) temperature vs. algal species richness, (b) pH vs. algal species richness, (c) DO vs. algal species richness, (d) TDS vs. algal species richness, (e) conductivity vs. algal species richness, (f) temperature vs. algal species richness, (g) water pH vs. algal species richness, (h) DO vs. algal species richness, (i) TDS vs. algal species richness and (j) conductivity vs. algal species richness.

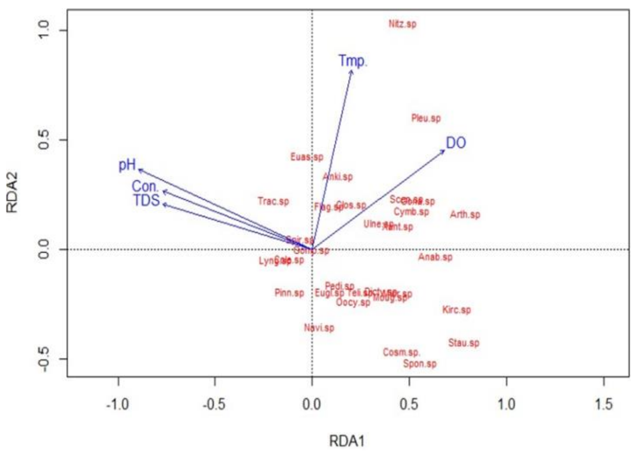

Fig. 3. Redundancy analysis (RDA) biplot for algae genera along with environmental variables such as temperature (Temp.), pH, dissolved oxygen (DO), total dissolved solids (TDS) and conductivity (Con.) of monsoon season during 2018-2019 (Abbreviation of algae genera as per the table 6).

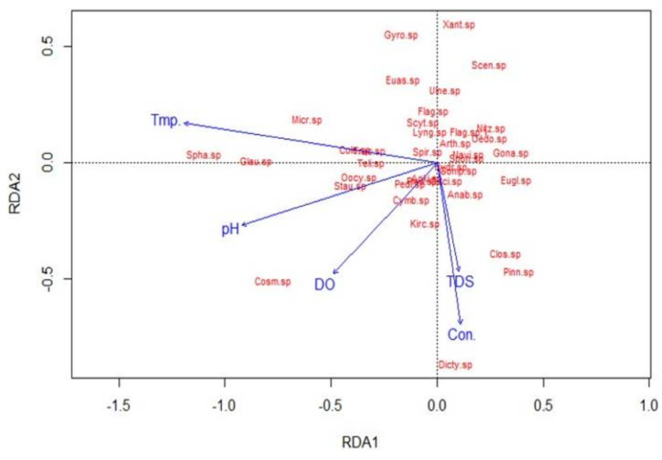

Fig. 4. Redundancy analysis (RDA) biplot for algae genera along with environmental variables such as temperature (Temp.), pH, dissolved oxygen (DO), total dissolved solids (TDS) and conductivity (Con.) of winter season during 2018-2019 (Abbreviation of algae genera as per the table 6).

Discussion

Seasonal fluctuations in physico-chemical parameters of lake shore water: Several studies have advanced our understanding that physico-chemical conditions play a significant role as driving force of any ecosystem. The effect of atmospheric temperature, clear atmosphere and influence of the season might be the factors that bring fluctuation in surface water temperature (Manjare *et al*., 2010). The pH of the lake water was low in monsoon season due to heavy rainfall (Sharma & Kannaujia, 2013) and an in-flow of water from nearest Khgeri cannel. The high pH during winter might be associated with dense algal growth increasing the rate of photosynthetic activities, reducing the production of carbon dioxide and bicarbonates which were ultimately responsible for increasing in pH value (Manjare *et al*., 2010).

The total amount of DO in water gives the sense of biological activity taking place within it and helps in the determination of the biological changes which are brought about by aerobic or anaerobic organisms as well as the higher values recorded for dissolved oxygen during winter can be attributed to lower rate of decomposition, low respiratory demand and the capacity of water to hold high oxygen concentration at low temperature (Ganai & Parveen, 2014). During the study period, DO was reduced during the monsoon season as compared to winter due to higher temperature and seasonal variation (Matta *et al.*, 2015). Low DO in monsoon season might be the function of higher water temperature and strong decomposition of organic matter (Badge & Verma, 1985) brought in by nearest in-flowing Khageri cannel. In winter season, due to the circulation of cold water as well as high solubility of oxygen at low temperature, the value of DO increases (Suthar *et al*., 2005). The sunlight during winter was supportive for photosynthesis by algae than during monsoon utilizing carbon-dioxide and giving off oxygen (Manjare *et al*., 2010). From February as the solar radiation slowly increased, the photosynthesis rate and decomposition rate also increased and for that DO also increased up to the month of June from February (Sharma & Kannaujia, 2013). Total dissolved solute in water might be increase and may be the cause of high anthropogenic activity (Senthilkumar & Sivakumar, 2008). High rainfall and heavy in-flow by Khageri cannel in the lake may reduce the TDS during monsoon than during winter season with low rainfall.

Highest conductivity was observed in winter and lowest in might may occur due to the dilution of water during the rainfall (Singh *et al*., 2010). It may be deduced that conductivity was also affected by temperature, as warmer the water, lower was the conductivity hence conductivity was negatively correlated to temperature.

Seasonal variation, algal diversity and influence of water characteristics: In the present study, chlorophyceae was recorded as dominant class during both the seasons. Due to the eutrophic nature of the lake system, chlorophyceae showed dominancy over other groups of algae (Bhat *et al*., 2012). The mode of reproduction plays a vital role in existence of any species in a community along with the ambient environmental circumstances. The common ways of reproduction in chlorophyceae are vegetative, asexual and sexual but also gives out several penetrating bodies which can increase individual species number even in adverse environmental conditions. Similarly, bacillariophyceae showed two distinct but interconnected phases, i.e., vegetative phase and a sexual phase. To avoid death and reduction in number of new individual cells, sexual phase is the only way in class bacillariophyceae (Mann, 1993). In cyanophyceae, only vegetative and asexual type of reproduction is present. In euglenophyceae, sexual reproduction is absent but asexual reproduction occurs (Sahoo & Seckbach, 2015) which resulted in different frequency and density of different class of algae in two different seasons of a year.

Shannon-Weiner diversity value indicates the abundance of a species within the abundance of all species in a community. Hence, the algal species during monsoon are more evenly abundant than during winter season (Table 5).

Gomphonema sp., *Closterium* sp. and *Glaucocystis* sp. showed maximum frequency during monsoon. As winters are favorable for the chlorophyceae and bacillariophyceae (Tiwari & Chauhan, 2006), *Gomphonema* sp. followed by *Cosmarium* sp. showed maximum frequency during winter. *Maugeotia* sp. and *Chaetophora* sp. during monsoon and *Dinobryon* sp., *Euglena* sp., *Netrium* sp., *Gyrosigma* sp. and *Oedogonium* sp. during winter showed minimum value of frequency that might be due to the unsuitable environmental condition for reproduction to form new individuals to show their presence in each seasons of a year. Maximum density of *Euastrum* sp., followed by *Gomphonema* sp. and *Cosmarium* sp. during winter season might provide the evidence of their ability of resilience and tolerance to both harsh and suitable environments for their growth and reproduction. Minimum density of *Chaetophora* sp. during monsoon and *Netrium* sp., *Dinobryon* sp., *Nitzschia* sp. and *Gyrosigma* sp. during winter might be due to their poor ability in maintaining growth and reproduction as per the changing environmental condition within a year (Tables 6-7).

Chaetophora sp., *Oscillatoria* sp., *Scytonema* sp., *Cylindrospermum* sp. and *Chrococcus* sp. were observed only during monsoon might be due to their physiological adaptation to high temperature and low pH, DO, TDS and conductivity values. *Dinobryon* sp., *Hyalotheca* sp., *Botrycoccus* sp. and *Netrium* sp. were observed only during winter might be due to their physiological adaptation to low temperature and high pH, DO, TDS and conductivity value of lake water.

High TDS supports high frequency for bacillariophyceae (Sahoo & Seckbach, 2015) hence, high TDS during winter accumulated higher frequency of occurrence of bacillariophytes than low TDS during monsoon. Inflow of water from nearby Khageri Canal is low or none during winter season which might have made the lake polluted and promoted the growth of euglenophytes during winter season (Rai & Rai, 2007). Therefore, seasonal variation of algal diversity might be associated with the seasonal fluctuation in physico-chemical parameters of water due to climatic changes.

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