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VARIATION IN SHORELINE MACROPHYTES AND WATER QUALITY OF BEESHAZARI LAKE, CENTRAL NEPAL

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Abstract.

The purpose of the study was to assess seasonal variation of the macrophytes diversity in response to physicochemical parameters of lakeshore water which determine the ecological status of the Lake. Field data were collected in two seasons (monsoon and winter) from 42 plots with 1 m x 1 m quadrat size, laid down at the shoreline of the Beeshazari Lake (a Ramsar site), each plot being 30 m apart from the adjacent plot along the lake perimeter for the quantitative analysis of the macrophytes. A total of 42 macrophytes (40 in monsoon and 31 in winter) were recorded during the sampling seasons. Poaceae was dominant during both seasons, followed by Asteraceae and Euphorbiaceae families during monsoon, whereas Asteraceae and Polygonaceae were found to be dominant during winter seasons. Based on growth form, emergent macrophytes were dominant during both seasons. The Shannon-Weiner Diversity Index (SWI) value of macrophytes was higher during the winter (H = 0.98 ± 0.04) than monsoon (H = 0.97 ± 0.04). Lemna perpusilla *(Importance Value Index, IVI = 22.8) was the dominant species during the monsoon and* Azolla pinnata *(IVI = 38.2) during the winter. Macrophytes species richness was positively correlated with temperature, pH, DO, and conductivity whereas negatively correlated with TDS during the monsoon season. Further, the richness was positively correlated with pH, DO, TDS, and electric conductivity in the winter season, whereas negatively correlated with temperature.*

Key words: Azolla pinnata*; Correlation; Importance Value Index;* Lemna perpusilla*; Physicochemical parameters; Shannon-Weiner Diversity Index; Species richness*

1. Introduction

The study expected to trace the composition, distribution, and dominancy of macrophytes with reference to the water quality of the lake. Comparative study of these aspects during the monsoon and winter seasons will be beneficial while making plans and policies for conservation and sustainable management of the lake. Macrophyte effects on water quality have been widely studied in temperate lakes (Moss et al. 1996), are well-known ecosystem engineers that improve water quality and stabilize the clear-water state, although these effects have mainly been associated with temperate shallow lakes, and are believed to be weaker in the (sub) tropics (Song et al. 2018).

In tropical lakes or small stagnant temperate waters, aquatic plants may represent an alternative stable state. Temperate shallow lakes may dominated alternatively by submerged angiosperms, charophytes, , green algae, or cyanobacteria. Variation in the lake communities along a gradient of eutrophication may therefore be seen as a continuum in which gradual species replacements are interrupted at critical points by more dramatic shifts to a contrasting alternative regime dominated by different species. Widespread problems resulting from the eutrophication of shallow lakes in populated areas invoked numerous restoration projects in the last decades of the 20th century (Scheffer & Nes 2007).

The ecological ecology of the land-lake shoreline is diverse and changing, and it serves as an essential water purification area and pollution buffer zone, with microorganisms playing a key role in the material cycle, nutrition transmission, and element transformation (Huang et al. 2016).The transition zone between diverse natural systems (ecosystems, landscapes), natural and artificial systems, media (water-land), and biomes is the shoreline (Ivanova & Soukhovolsky 2016).

Macrophytes differ in terms of biomass production, the ability to recycle nutrients, the release of oxygen and organic carbon into the rhizosphere, and the potential to operate as a methane pipeline. Wetland macrophyte species diversity often falls as eutrophication increases, and species communities are replaced by monoculture-forming strong competitors (Rejmankova 2011).

Macrophytes influence nutrient cycling by transferring chemical elements from sediment to water via active and passive processes (Camargo et al. 2003).They also influence creatures like invertebrates, fish, and water fowl by providing physical structure, enhancing habitat complexity and variability, and providing physical structure to aquatic populations through a range of mechanisms involving the availability of shelter and feeding locations that are linked to habitat complexity, macrophytes influence animal assemblages and promote biodiversity. Invasive macrophyte species may change habitat structure, affecting the organisms that dwell there. They are appropriate as the primary focus of management techniques aimed at biodiversity restoration and conservation in this regard (Thomaz & Cunha 2010).

Habitat destruction and degradation, loss of ecological integrity, and depletion of species abundance and variety were identified to be the most susceptible and threatened in Nepal's wetlands, particularly in the Terai region. Research had been conducted to study the ecology of Beeshazari Lake, but seasonal information on the physicochemical parameters and macrophytes diversity is still in shade. The site is being degraded as a result of both anthropogenic and natural disturbances, such as invasive species spread, increased pollution (e.g., pesticides used by local farmers to kill birds to protect their crops), declining water levels, and encroachment (Burlakoti & Karmacharya 2004). Seasonal detection of physicochemical parameters of lake water is the best way to evaluate water quality and whether it is suitable for macrophytes or not. The research hypothesis is that macrophytic diversity at the freshwater lake system's shoreline varies with the seasons. In this context, this study aims to seek the relationship between macrophytes diversity in two different seasons and the physicochemical parameters at the shoreline of the Beeshazari Lake system located in the tropical region.

2. Materials and Methods

2.1 Study area

This research took place on the shores of Beeshazari Lake (27°37'05" N, 84°26'11" E) in central Nepal (Fig. 1), which is one of the Ramsar sites of international significance.The research area has a sub-tropical climate with three distinct seasons: summer, monsoon, and winter, with the monsoon season lasting from mid-June to late September and being marked by torrential downpours and a hot and humid atmosphere. The average temperature of the area is 34°C. The lake has a surface area of 3,200 hectares and is located at an altitude of 286 m above sea level. Within the buffer zone of the Chitwan National Park, a World Heritage site, it creates a large characteristic oxbow lake system of the tropical inner Terai. The main source of water throughout the year is the Khageri canal and during the monsoon, precipitation increases the water level. The overall catchment area of the lake helps in groundwater recharge. The mean annual rainfall is recorded as 2,150 mm (Lamichhane et al. 2017).

2.2. Water analysis

The quadrat approach was employed for the quantitative analysis. As a plot, a 1 m × 1 m wooden frame quadrat was built out along the lake's shoreline. Each sampling plot was around 25 to 30 meters apart from the one next to it. Data was collected from 42 plots from the same locations in each season (monsoon and winter).

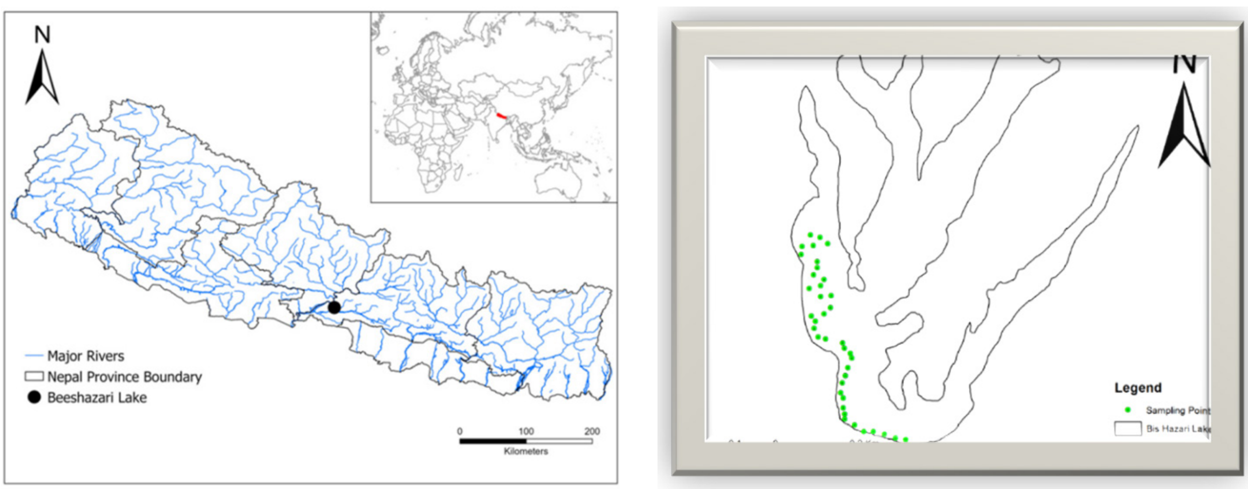

Figure 1. Beeshazari Lake in the map of Nepal showing sampling points.

In each season, physicochemical properties of shoreline water were measured in the field using various electric devices and a multi-parameter probe. Temperature, pH, total dissolved solute (TDS), and conductivity were recorded in each of 42 sampling plots using an electric kit multi-parameter probe (HANNA port), while dissolved oxygen (DO) was assessed using an Ecosense DO 200A DO meter.

2.3. Macrophytes analysis

The quadrat sampling method was used for collecting the quantitative data on the macrophytes. A wooden-framed quadrat sized 1 m x 1 m was laid down along the shoreline of the lake. Each quadrat plot was located at around 25 to 30 m distance along the lake boundary. A total of 42 quadrats were laid to collect data in each season (monsoon and winter). All the aquatic, semi-aquatic, and terrestrial macrophytes present in each quadrat were documented as per their presence or absence and their total number, except tree saplings.

Aquatic, semi-aquatic, and terrestrial species collected from the shoreline of the lake were identified by comparing with relevant literature (Malla et al. 1986; Siwakoti & Varma 1999; Press et al. 2000). Cross-validation of the prepared herbarium specimens was performed with a comparison of the herbarium specimens in Tribhuvan University - Central Herbarium (TUCH). The recorded plant species were categorized into different groups based on their growth forms and taxonomic group (family). Macrophytes species diversity index was calculated by using Shannon-Weiner Diversity Index (SWDI) which is a commonly used method for calculating the biotic diversity in the aquatic system (Ghosh & Biswas 2015).

2.4 Statistical analysis

The Spearman correlation coefficient was obtained using statistical analysis software SPSS to analyze the correlations between physicochemical properties of water and macrophytes (version 23.0). The relationships were assessed for significance at 0.05 and 0.01 levels. R was used to perform redundancy analysis (RDA).

3. Introduction

3.1. Water quality.

The highest mean value for temperature was found during the monsoon season (31 ± 0.3ºC) while the lowest was in winter (17 ± 0.2ºC) (Table 1). The highest mean value for conductivity was recorded in the winter season (83.95 ± 0.59 µS/cm) and the lowest during monsoon (74 ± 1.0 µS/cm). The highest mean value for TDS was found during the winter season (46 ± 0.3 mg/l) and the lowest during monsoon (37 ± 0.5 mg/l). (Table 1). The highest mean value for DO was observed during the winter season (10.7 ± 0.26 mg/l) and the lowest during monsoon (3.3± 0.1 mg/l). The highest mean value for pH was recorded during the winter season and the lowest (7.5 ± 0.1) during the monsoon. (Table 1).

The temperature had shown a strong positive correlation with pH during monsoon season and a weak negative correlation with conductivity. DO has shown a weak negative correlation with conductivity in comparison to TDS and a strong positive correlation with pH in comparison to temperature during monsoon season. DO has shown a weak negative correlation with conductivity in comparison to TDS and a weak positive correlation with temperature in comparison to pH during the winter season (Table 1-3, Fig. 2-3). pH had shown a weak negative correlation with conductivity in comparison to TDS and a strong positive correlation with DO in comparison to temperature during monsoon season. pH had shown a weak positive correlation with TDS in comparison to conductivity, DO, and temperature during the winter season. During the winter season, conductivity displayed a modest negative association with DO when compared to temperature and a high positive correlation with TDS when compared to pH. (Table 2- 3, Fig. 2-3). Conductivity had shown a weak negative correlation with temperature in comparison to DO and a strong positive correlation with TDS in comparison to pH during monsoon season.

During the monsoon season, TDS displayed a modest negative correlation with temperature compared to DO and pH, and a large positive correlation with conductivity. When compared to DO, TDS displayed a high negative correlation with conductivity and a slight positive link with pH when compared to temperature (during the winter season).

3.2. Macrophytes composition

A total of 42 vascular plant species were recorded belonging to 24 families during August (monsoon season) and January (winter season). Poaceae was the dominant family followed by Asteraceae during both seasons followed by Euphorbiaceae during monsoon and followed by Polygonaceae during win-

Table 1. Physicochemical parameters of water in different seasons

Physicochemical parameters	Seasons	Mean ± SE
Temperature (ºC)	M	31.0± 0.3
	W	17.1± 0.2
Dissolved Oxygen (mg/L)	M	3.3± 0.1
	W	10.7± 0. 3
pH	M	7.9± 0.1
	W	7.9± 0.1
Conductivity (µS/cm)	M	74.3± 1
	W	83.9± 0.6
Total Dissolved solute (mg/L)	M	36.9± 0.5
	W	45.9± 0.3

(M= monsoon, W= winter)

Table 2. Correlation coefficient (*r*) between water parameters during monsoon season

Spearman correlation coefficient (r)					
	Temperature	pH	DO	TDS	Conductivity
Temperature	1				-0.3
pH	0.5**	1			-0.1
DO	0. 5**	0.6**	1		-0.1
TDS	-0. 3	-0. 1	-0. 1	1	0.8**

**. Correlation is significant at the 0.01 level (2-tailed).

Table 3. Correlation coefficient between water parameters during winter season

Spearman correlation coefficient (r)					
	Temperature	pH	DO	TDS	Conductivity
Temperature	1				-0. 1
pH	0.0	1			0.4**
DO	0.3*	0.2	1	-0.3*	-0.3
TDS	0.0	0.4**	-0.3*	1	0.9**

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level

ter. Shannon-Weiner diversity value of macrophytes was higher during winter H = 0.98 ± 0.04 than during the monsoon (H = 0.97 ± 0.04) season (Table 4). Macrophytes plant species were more evenly distributed during winter (H = 0.29 ± 0.08) than during monsoon (H = 0.26 ± 0.07) season. *Lemna perpusilla* (IVI = 22.81), *Eichhornia crassipes* (IVI = 20.08), *Saccharum spontaneum* (IVI = 19.45) and *Trapa qaudrispinosa* (IVI = 15.40) were the most dominant macrophytes species during monsoon season (Table 5) while *Azolla pinnata* (IVI = 38.20), *Najas minor* (IVI = 35.17), *Hydrilla verticillata* (IVI = 28.46), *Themeda arundinacea* (IVI = 25.39), *Lemna perpusilla* (IVI = 23.48), *Trapa qaudrispinosa* (IVI = 21.69), *Eichhornia crassipes* (IVI = 16.68) and *Ipomoea carnea* ssp. *Fistulosa* (IVI = 15.83) were the most dominant macrophytes species during the winter season (Table 5).

Table 4. Variation in diversity indices value and richness of macrophytes

S.N.	Seasons	Shannon-Weiner Index (H)	Species richness	Evenness (E)
1	Monsoon	0.97± 0.04	40	0.26± 0.07
2	Winter	0.98 ± 0.04	31	0.28±0.07

Table 5. Importance Value Index (IVI) of macrophytes during monsoon and winter season at shoreline of Beeshazari Lake

S.N.	Name of species	RF		RD		RC		IVI	
		W	M	W	M	W	M	W	M
1	*Ageratum conyzoides*	0.4	5.1	0.1	4.7	0.1	2.7	0.7	12.5
2	*Ageratum haustonianum*	0.8	0.8	0.2	0.3	0.3	0.3	1.3	1.3
3	*Alternanthera sessilis*	1.3	3.5	0.2	2.3	0.4	1.6	1.9	7.4
4	*Azolla pinnata*	9.7	3.8	20.8	8.6	7.7	2.6	38.2	14.9
5	*Carex* sp.		0.3		0.1		0.1		0.4
6	*Cassia occidentalis*		0.8		0.4		0.7		1.9
7	*Centella asiatica*		0.5		0.5		0.2		1.2
8	*Ceratophyllum demersum*	0.8	0.3	0.4	0.1	0.9	0.1	2.2	0.5
9	*Colacasia esculenta*	2.9	4.0	1.1	1.7	0.9	4.9	4.9	10.5
10	*Commelina benghalensis*	2.1	1.1	1.1	1.4	0.7	1.3	3.8	3.8
11	*Cynodon dactylon*	2.1	1.3	3.0	1.5	1.3	0.5	6.4	3.3
12	*Cyperus exaltatus*	2.5	1.9	1.4	3.4	1.5	3.7	5.4	8.9
13	*Digitaria ciliaris*		0.3		0.4		0.5		1.2
14	*Eichhornia crassipes*	5.9	5.1	2.3	2.8	8.5	12.2	16.7	20.1
15	*Euphorbia hirta*		3.5		4.5		1.6		9.6
16	*Hemarthria compressa*	0.4	1.9	0.2	3.6	0.1	2.8	0.7	8.2
17	*Hydrilla verticillata*	5.0	4.6	12.1	6.8	11.3	6.4	28.5	17.8
18	*Hygrorhyza aristata*	2.9		1.4		0.9		5.3	
19	*Hyptis suaveolens*		0.3		0.0		0.1		0.4
20	*Ipomoea carnea* ssp. *fistulosa*	4.2	2.4	3.8	1.1	7.8	2.2	15.8	5.6
21	*Lemna perpusilla*	4.6	5.6	13.4	11.4	5.5	5.7	23.5	22.8
22	*Ludwingia adscendens*	4.2	1.1	1.6	0.3	2.0	0.4	7.7	1.8
23	*Mikenia micrantha*	4.2	5.9	1.4	1.8	1.3	6.3	6.9	14.0
24	*Najas minor*	7.1	3.8	11.2	4.1	16.9	6.1	35.2	14.0

25	*Panicum psilopodium*		1.6		2.0		1.8		5.4
26	*Panicum* sp.		0.3		0.3		0.1		0.6
27	*Paspalum dilatatum*		3.0		3.6		3.2		9.7
28	*Paspalum distichum*	3.8	2.2	1.8	3.2	1.9	3.3	7.5	8.6
29	*Paspalum scrobiculatum*		0.3		0.4		0.1		0.7
30	*Persicaria glabra*	0.4		0.1		0.1		0.7	
31	*Persicaria hydropiper*	3.4	4.8	1.1	3.5	1.1	3.3	5.5	11.6
32	*Persicaria lapathifolia*	1.7	1.3	0.8	1.3	0.4	1.4	2.8	4.0
33	*Phyllanthus urinary*	0.4	2.4	0.2	1.6	0.1	1.3	0.7	5.3
34	*Pistia stratoites*	0.8		0.4		1.6		2.9	
35	*Pogostemon benghalensis*	0.4	0.5	0.1	0.1	0.1	0.6	0.6	1.3
36	*Saccharum spontaneum*	1.7	3.5	5.1	9.1	1.9	6.9	8.7	19.5
37	*Setaria parviflora*		1.1		1.4		0.8		3.3
38	*Solanum* sp.		0.3		0.0		0.1		0.4
39	*Spermacoce alata*		0.5		0.1		0.2		0.9
40	*Synedrella nodiflora*	0.8	2.7	0.2	0.9	0.3	1.8	1.3	5.4
41	*Thelypteris prolifera*	2.5	2.4	0.8	0.8	0.8	0.8	4.1	4.0
42	*Themeda arundinacea*	8.4	2.7	8.0	3.3	9.0	4.9	25.4	10.8
43	*Trapa quadrispinosa*	10.1	7.2	3.9	4.1	7.7	4.1	21.7	15.4
44	*Utricularia aurea*	2.5		1.9		2.9		7.4	

[W = winter, M = monsoon, RF = Relative Frequency, RD = Relative Density, RC = Relative Coverage]

During monsoon season, pH (r^2= 0.064) had shown higher positive strength towards macrophytes species richness than temperature (r^2= 0.055), DO (r^2= 0.007) and conductivity (r^2= 0.002) whereas TDS (r^2= 0.001) had negative strength towards macrophytes species richness (Fig. 2). Similarly, during winter season, TDS (r^2= 0.066) had higher negative strength towards macrophytes species richness than pH (r^2= 0.0003) whereas DO (r^2= 0.038) had shown high positive strength towards macrophytes species richness than conductivity (r^2= 0.0004) and temperature (r^2= 0.0002) respectively (Fig. 3).

During monsoon season, *Eichhornia crassipes*, *Cyperus exaltatus*, *Panicum psilopodium*, *Euphorbia hirta,* and *Spermacoce alata* showed high abundance with conductivity and TDS while these species showed negative abundance with DO. *Cassia occidentalis*, *Saccharum spontaneum*, *Ageratum houstonianum,* and *Lemna perpusilla* showed high abundance with pH. *Ludwigia adscendens*, *Colocasia esculenta*, *Hyptis suaveolens,* and *Digitaria ciliaris* were more concentrated towards high DO while these species showed low abundance with conductivity and TDS (Fig. 3).

During the winter season, *Pistia stratoites, Ageratum conyzoides*, *Alternanthera sessilis* and *Persicaria glabra* showed high abundance with pH, conductivity and TDS. *Colacasia esculenta*, *Eichhornia crassipes*, *Mikenia micrantha*, *Ipomoea carnea* ssp. *Fistulosa*, *Pogostemon benghalensis*, *Hygrorhyza aristata*, *Hemarthria compressa,* and *Thelypteris prolifera* showed strong negative abundance with temperature and DO (Fig. 4).

3.3 Relationship between macrophytes and influence of water characteristics

Poaceae was recorded as a dominant family during both seasons at the shoreline of the lake system. The second dominant family was Asteraceae during both seasons. The highest mean value for macrophytes species richness was observed during the monsoon season and the lowest during winter season. Shannon-Weiner diversity value (H) of macrophytes was higher during winter than during the monsoon season.

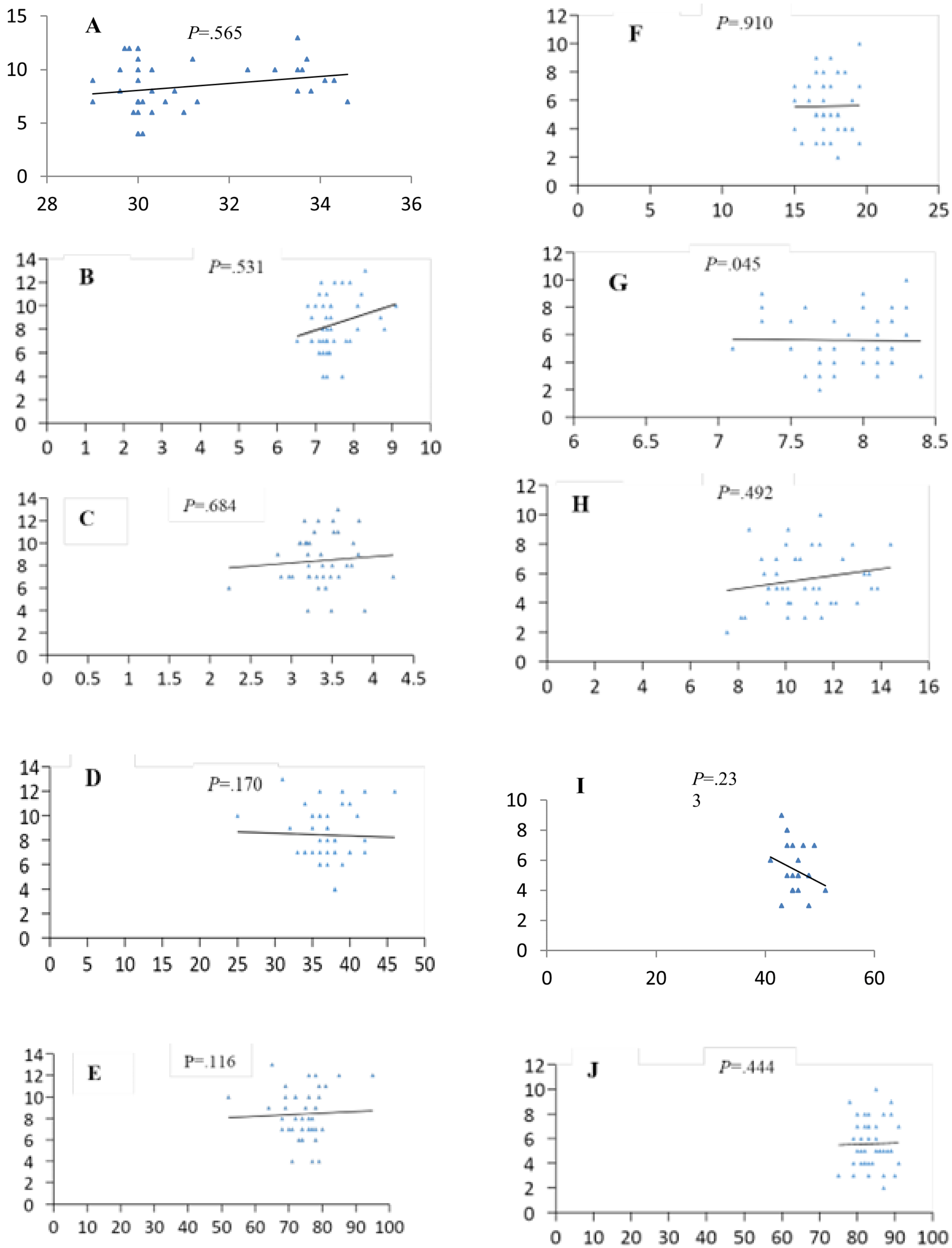

Figure 2. Graphs showing the relation between macrophytes species richness and water parameters; **A** temperature vs macrophyte species during monsoon, **B:** pH vs macrophyte species richness during monsoon, **C:** DO vs macrophyte species richness during monsoon, **D:** TDS vs macrophyte species richness during monsoon, and **E:** conductivity vs macrophyte species richness during monsoon season respectively. **F:** temperature vs macrophyte species richness during winter, **G:** pH vs macrophyte species richness during winter, **H:** DO vs macrophyte species richness during winter, **I:** TDS vs macrophyte species richness during winter, and **J:** conductivity vs macrophyte species richness during winter season respectively.

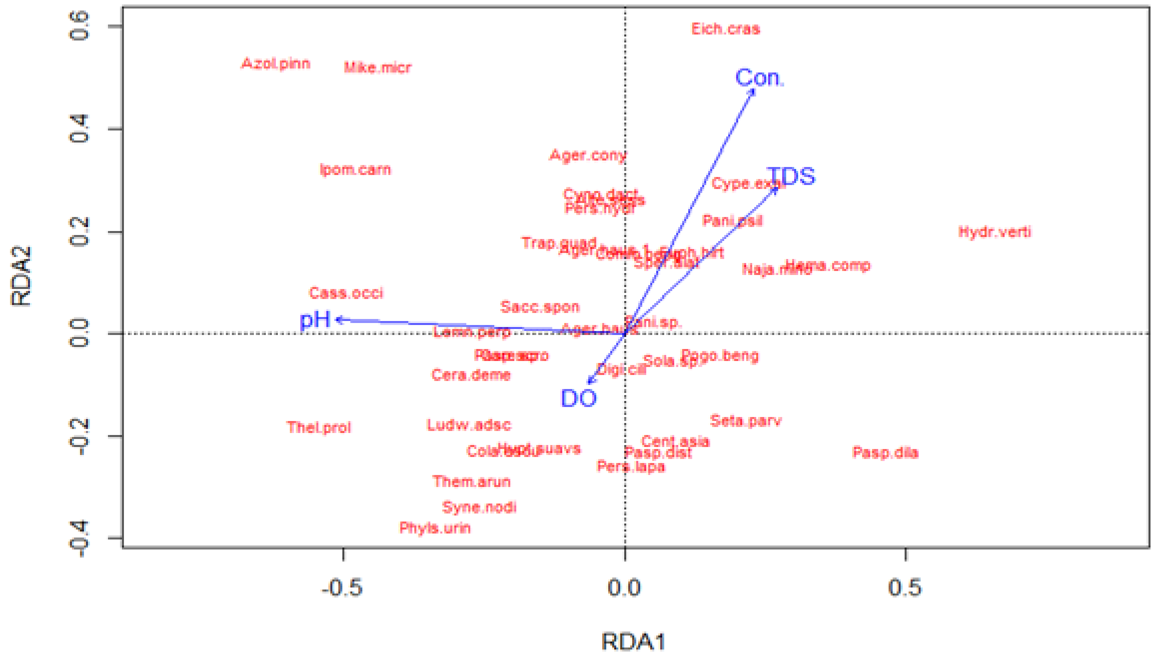

Figure 3. RDA biplot for macrophytes species along with environmental variables during monsoon season

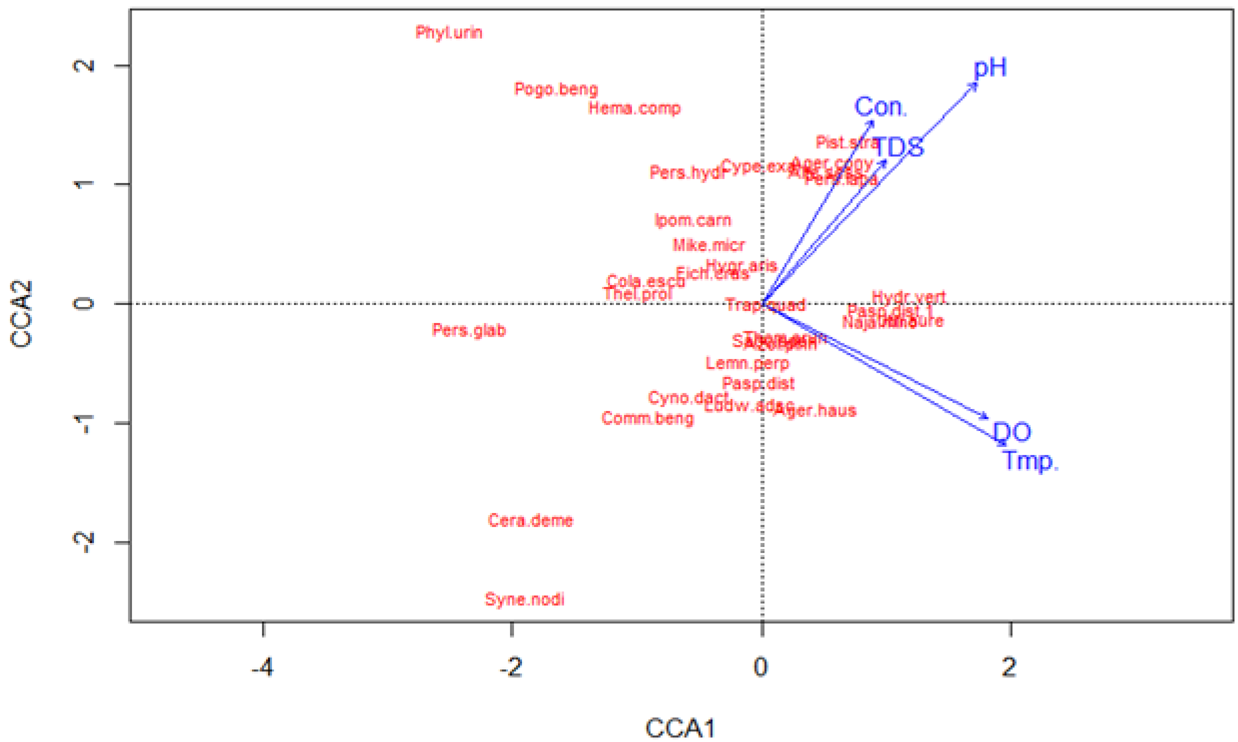

Figure 4. CCA biplot for macrophytes species along with environmental variables during the winter season

4. Discussion

The invasive ability of some species in water bodies is being success due to their mode of propagation and dominant nature (Halder & Venu 2012). Due to the physical presence of *Eichhornia crassipes* which greatly blocks sunlight and oxygen exchange by preventing the growth of emerged and submerged plant species hence promotes its own growth towards invasion (Brendonck et al. 2003). The dominancy of this species during monsoon might be due to the mixing of irrigation to the lake through Khageri Canal during monsoon. Similarly, *Saccharum spontaneum*, *Hydrilla verticillata*, and *Trapa qaudrispinosa* showed high IVI values during monsoon might be due to the active vegetative propagation and presence effective light source. *Panicum* sp., *Hyptis suaveolens*, *Solanum* sp., and *Spermacoce alata* showed lowest IVI values. These species were accidentally there might be due to anthropogenic regulation for recreational purposes.

Azolla pinnata is a free-floating plant growing in high nutrient leveled water. The lake was rich in nitrate content which is luxuriant for the growth of *Azolla pinnata* as well as *Eichhornia crassipes* (Niraula 2012) and *Ipomoea carnea* ssp. *fistulosa*. Likewise, *Najas minor*, *Hydrilla verticillata*, *Themeda arundinacea*, *Lemna perpusilla*, and *Trapa qaudrispinosa* dominancy during winter might be due to the presence of inorganic matters. The availability of light and temperature appears to be the most important factors in determining the macrophyte distribution (Dar et al. 2014). The temperature at the thermal tolerance promotes growth and reproduction in aquatic plants but decreasing in water temperature is responsible for depth-related reductions in the growth of macrophytes (Barko et al. 1991).

The effect of atmospheric temperature and the influence of the season might be the factor to bring fluctuation in surface water temperature. Water temperature becomes high during monsoon than during the winter season might be due to the high temperature of a clear atmosphere (Manjare et al. 2010).

The water pH plays a vital role in the biochemical and chemical reactions of any aquatic ecosystem. The increasing rate of photosynthetic activities reduces the production of carbon dioxide and bicarbonates which are ultimately responsible for increasing pH value (Manjare et al. 2010). The pH of the lake water was low in the monsoon season due to heavy rainfall and due to the in-flow of water from the nearest Khgeri cannel (Sharma & Kannaujia 2013). The high pH during winter might be associated with dense phytoplankton growth. Algal bloom in fish ponds showed a synergistic effect in changing water character with the season where pH became more basic during winter (Mandal et al. 2016). High pH might be due to low photosynthesis resulting in the less formation of carbonic acid (Thapa & Saund 2012). Extreme low values in pH are stressful to aquatic organisms and even deadly.

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. Low DO in monsoon might be the function of higher water temperature and vigorous decomposition of organic matter brought in by nearest in-flowing Khageri cannel with warm temperature (Badge & Verma 1985). The higher value of DO during winter than during monsoon might be due to sufficient temperature and duration of intense sunlight during winter than during monsoon which influences the percentage of soluble gases (oxygen and carbon dioxide). Winter sunlight was better for photosynthesis by aquatic plants than monsoon sunlight, which used carbon dioxide and released oxygen (Manjare et al. 2010). DO was reduced during the monsoon season as compared to winter due to higher temperature and seasonal variation (Matta et al. 2015). The value of DO rises in the winter season due to the circulation of cold water and the high solubility of oxygen at low temperatures (Suthar et al. 2005). As solar energy increased gradually from February, photosynthesis and decomposition rates increased as well, resulting in an increase in DO from February to June (Sharma & Kannaujia 2013).

During the monsoon, high rainfall and large inflow by the Khageri cannel into the lake may lower TDS more than during the winter season, when rainfall is low. The total dissolved solute in water may rise as anthropogenic activity accumulates (Senthilkumar & Sivakumar 2008). Because of the diluting of water during rainfall, conductivity is highest in winter and lowest in monsoon (Singh et al. 2010). The highest conductivity in winter and lowest in monsoon might be due to the dilution of water during the rainfall (Singh et al. 2010). Conductivity is also affected by temperature, as warmer the water, lower the conductivity, so conductivity was negatively correlated to temperature.

A high value of pH favored the better growth of macrophytes such as *Cassia occidentalis*, *Saccha-*

rum spontaneum, *Ageratum houstonianum,* and *Lemna perpusilla* during monsoon whereas *Pistia stratoites, Ageratum conyzoides*, *Alternanthera sessilis,* and *Persicaria glabra* during winter showed high abundance with pH. The high value of pH supported better growth of macrophytes with higher species diversity index during monsoon season (Chaudahary & Devkota 2018) rather than the low value of pH supporting poor growth of macrophytes with lower species diversity index during monsoon season.

Poaceae was recorded as a dominant family during both seasons at the shoreline of the lake system. The dominance of this family might be due to the presence of different physical and physicological nature of the plant species belonging to this family such as the ability of efficient long-distance dispersal, effective establishment biology, ecological flexibility, high resilience power, and capacity to modify environments by changing the nature of fire and mammalian herbivores. The C3 and C4 photosynthesis phenomena existing within the plant species of this family survive the harsh environmental conditions such as drought (Linder et al. 2018).

The second dominant family was Asteraceae during both seasons. This might be due to the reason that plant species under this family produce a huge number of seeds that are light in weight accelerating in seed dispersal mechanism. Most of the plant species under this family are invasive in nature mostly the herbs rather than shrubs and trees (Rastogi et al. 2015).

The highest mean value for macrophytes species richness was observed during the monsoon season and the lowest during winter corresponding to the finding of Niroula and Singh (2010). Shannon-Weiner diversity value (H) of macrophytes was higher during winter than during the monsoon season. Macrophytes were more evenly distributed during winter than during the monsoon season similar to Bhattapokhari (Niroula & Singh 2010). High values of H would represent a more diverse community. A community with single species results an H value of 0. If the species are evenly distributed, then the H value becomes higher. Therefore, the H value confirms how the abundance of a species is distributed among all of the species in a community.

5. Conclusion

Based on growth morphology, emergent macrophytes were prevalent during both seasons. During monsoon, the Poaceae family was dominating, followed by the Asteraceae and Euphorbiaceae families, whereas during winter, the Asteraceae and Polygonaceae families were dominant. During the monsoon season, macrophyte species richness was positively correlated with temperature, pH, DO, and conductivity, but negatively correlated with TDS, while in the winter season, it was positively correlated with pH, DO, TDS, and electric conductivity, but negatively correlated with temperature.

The findings of this study contribute to a better understanding of macrophyte effects on lake water quality, as well as how physicochemical factors influence these effects, with an increased focus on lake eutrophication and aquatic macrophytes, which will aid in the conservation of the overall lake ecosystem.

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