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Comparative analysis of phytoplankton dynamics and water quality assessment in selected lentic water bodies of Haryana, India

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ABSTRACT

The study was designed to assess the water quality based on physico-chemical parameters and phytoplankton communities of eight lentic water bodies of Haryana which are famous for mass bathing and religious rituals taking place here. To evaluate comparative analysis of composition, diversity and distribution of Phytoplankton and physico-chemical factors, water samples were collected seasonally viz., summer, monsoon, post monsoon and in winters from all the eight sites in triplicate. Total 118 phytoplankton taxa were observed at all sites. Among these cyanophyceae group was found most dominant at sites 1, 2, 4, 5, 7, 8 whereas cholorophyceae at site 6, bacillariophyceae at site 1,3,4,7 whereas xanthophyceae was in abundance at site 5. Population density (nos. L^{-1}) wise phytoplankton trend was Cyanophyceae > Chlorophyceae > Bacillariophyceae >Desmidiaceae and Species diversity wise phytoplankton trend observed was Chlorophyceae > Bacillariophyceae > Cyanophyceae >Desmidiaceae. Correlation of different phytoplankton groups with physicochemical factors revealed a significant negative correlation of Cyanophyceae with pH, whereas a significant positive correlation of ortho-phosphate with Desmids and bacillariophyceae wheareas CO_2 showed a positive correlation with Xanthophyceae. Appearance of pollution tolerant taxa of phytoplankton *Microcystis aeruginosa*, *Phormidium* sp., *Scenedesmus* spp., *Pediastrum* spp., *Mougeotia* sp., *Synedra* sp., *Pediastrum* spp. at most of the sites indicated the sign of the more organic pollution and degradation in the water quality of the selected sites due to religious immersion, mass bathing and by other anthropogenic activities. Suitable remedial actions should be adopted by regulatory bodies and policy makers to maintain the water quality of these aquatic systems.

Introduction

Assessment of quality of water of any aquatic ecosystem is mainly assessed by its physicochemical and biological characteristics which usually fluctuate with season and degree of pollution. Any variation in physicochemical factors of waters directly or indirectly affects its aquatic organisms. Among aquatic organisms phytoplankton have proved to be good bioindicators of water quality (Meng et al. 2017; Nguyen and Nhien 2020). They are the primary producers that biosynthesize organic material for most of the aquatic lives like zooplankton, larvae, crustaceans, fish and indirectly also for human beings functioning as a basic link in aquatic food web structure (Van de Waal and Litchman, 2020). The Phytoplankton abundance, their composition and growth are mainly affected by the physical and chemical variables of the water bodies in which they are located (Vajravelu *et al.*, 2018). Phytoplankton respond very quickly to the surrounding environment so acts as crucial biomarkers and are sensitive indicator for determining water quality status (Li *et al.*, 2019, Akhter and Brraich 2020). So, distribution patterns of phytoplankton are strongly correlated with environmental factors (Lepisto *et al.*, 2004) and

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gives insight view on interactions between biotic and abiotic factors (Kumari *et al.*, 2018). Several studies were conducted on physico-chemical parameters and phytoplankton community of water bodies such as on stream of Garhwal Himalayas (Sharma *et al*., 2016), Sulur lake of Coimbatore, South India (Manickam *et al*., 2017), water bodies of Vinh Long province, Vietnam (Trang *et al*., 2019), Coastal Water of Kudat, Sabah, Malaysia (Romin *et al*., 2021), Warna and Pengilon Lakes, Dieng, Central Java (Soeprobowati *et al*., 2021).
The knowledge of phytoplankton diversity, community structure, distribution is essential for assessing the health of any aquatic ecosystem as they are the primary biotic community that indicates changes in ecological water quality due to their sensitivity and dynamic responses to the surrounding environment (Suseela, 2009). However, no such study has been conducted so far on the selected lentic water bodies of Haryana, which are under the influence of anthropogenic activities like mass bathing and other religious rituals activities, which increases organic matter load in the waters and might be responsible for eutrophication and further algal blooms. Therefore, the present study was aimed to investigate the ecological status of the eight water bodies of Haryana on the basis of their phytoplankton composition, diversity, distribution in different seasons *viz.*, Summer, Monsoon, Post monsoon and Winter and their interrelationship with physico-chemical variables for deep understanding of water quality status of the aqua systems over time to time, this study might provide a valuable baseline data for ecological management strategies for preservation of these fragile habitat.

Material and Methods

Study area: The research area selected for study was eight lentic water bodies of Haryana State (India) situated in four districts of Haryana i.e. Yamunanagar, Kurukshetra, Kaithal and Jind shown in Table 1and Figure 1.

Sample Collection: For the collection of surface water samples, three stations were selected at each of the eight sites and samples were collected seasonally during Summer, Monsoon, Post monsoon and Winter season. 50 L water was filtered through mesh size 50 µm in collecting tube and made up to a standard volume of 40 ml, preserved for analysis of plankton. The physico-chemical characteristics were analyzed according to standard procedures of APHA (2005).

Table 1: Details of sites selected

	Name of water body	District	Latitude, Longitude
1.	Site 1(Kapalmochan)	Yamunanagar	30^0 326' N, 77^0 317' E
2.	Site 2 (Kulotarantirth)	Kurukshetra	29^0 922' N, 76^0 806' E
3.	Site 3(Bangangatirth)	Kurukshetra	29^0 937' N, 76^0 813' E
4.	Site 4 (Brahmsarovar)	Kurukshetra	29^0 961'N, 76^0 827' E
5.	Site 5 (Jyotisar)	Kurukshetra	29^0 956' N, 76^0 778' E
6.	Site 6 (Saraswati tirth)	Pehowa, Kurukshetra	29^0 978' N, 76^0 596' E
7.	Site 7 (Phalgu tirth)	Kaithal	29^0 835' N, 76^0 587' E
8.	Site 8 (Pindara tirth)	Jind	29^0 309' N, 76^0 322' E

Plankton Identification and quantification

The number of plankton to genus level was studied and identified, using the keys from Needham and Needham (1975); Tonapi (1980) and APHA (2005). Plankton abundance was expressed as plankton per liter (nos. L^{-1}) using formula:-

$$L^{-1} = \frac{(P \times C \times 100)}{L}$$

P = Number of plankton counted in ten fields, C = Volume of final concentrate of sample (i.e. 40 ml) and L = Volume of water sample filtered

Statistical analysis of data of phytoplankton composition and physicochemical parameters were analyzed and significant differences between were calculated using T test while season wise and site wise comparison of data was done using Duncan's Multiple Range test (Duncan, 1955).

Results and Discussion

Physico-chemical characteristics (Table 2): Mean Water temperature ranged from 22.75^{0}C to 25.82^{0}C that is favorable for the optimum growth of phytoplankton (Dao & Bui, 2016). pH ranged from 7.01 to 7.48 and according to Lantang and Pakidi (2015) the ideal pH for the growth of phytoplankton in the waters is 6.5 – 8.0 so it indicates good water quality of all the sites.

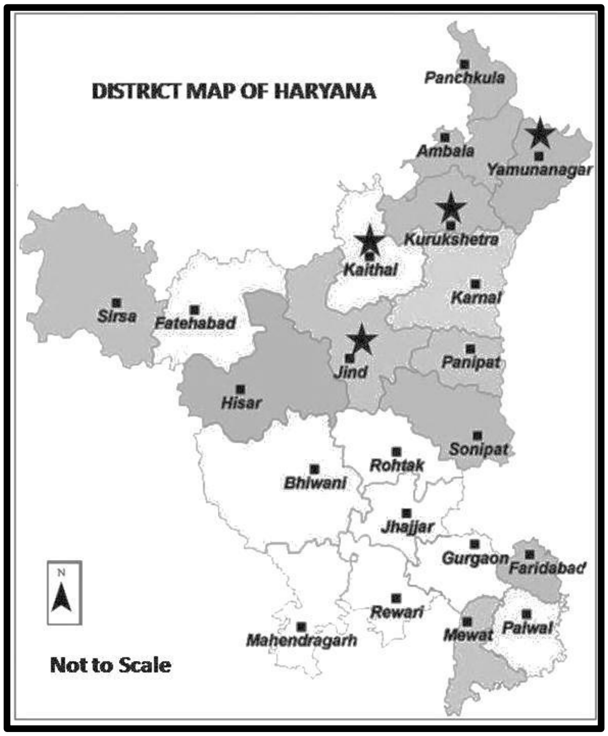

Figure 1: Map of Haryana showing the districts (✶) covered under study

Conductivity ranged from 157.23 to 924.74 µ mhos cm^{-1}. The conductivity was below 500 µ mhos cm^{-1} at sites 1, 3, 4, 5 and 8 whereas at sites 2, 6 and 7 values were above 500, values above 500 µ mhos cm^{-1} indicate water was not suitable for fish and other macro-invertebtares (Mondal *et al.* 2012). Total Dissolved Solids (TDS) at sites 4, 5 and 8 have concentration less than 500 mg/Lwhile others were having the values beyond 500 mg/L. High total solids decrease the light penetration so may affect water quality indirectly and cause imbalance in aquatic life (Pawale, 2014). High turbidity and TDS might favour the growth of Cyanophyceae (Harsha and Malammanavar, 2004). Turbidity ranged from 5.14 to 43.09 NTU. According to World Health Organization (2003) the highest desirable limit is 5.0 NTU and maximum permissible limit 25.0 NTU. All the values of turbidity were within the maximum permissible limits except at sites 2. The free CO_2 which comes from microbial decomposition and by respiration activity of organisms is a vital factor for algal growth, as it is required for the process of photosynthesis. Free CO_2 ranged from 1.34 to 37.04 mg/L. High value of the free carbon dioxide content i.e. 37.04 mg/L at site 2 and 30.0 mg/L at site 8 is an indication of high degree of pollution. Dissolved Oxygen (DO) ranged from 7.14 to 10.48 mg/L. High photosynthetic rate of phytoplankton may results in higher values of dissolved oxygen (Ravindra *et al*., 2003). The obtained DO concentration satisfied the minimum recommended standard (5 ppm) set by EPA Redbook and others (USEPA 2008, Yajurvedi, 2008). As all the sites were having DO values more than 5 mg/L were found suitable for fishing and growth of planktons and was a good indication of a highly productive nature of water body (Das, 2000). Alkaline water promotes high primary productivity (Jana *et al*., 2006, Kumar and Prabhahar, 2012). Jhingram, (1982) stated that high productive water body has alkalinity over 100 mg/L and according to Yulfiperinus (2004) good alkalinity value for living organisms ranges from 100-150 ppm. During the present research most of the sites were having alkalinity more than 100 mg/L indicating their productive status and were good for the growth of phytoplankton except at site 4 and 8 where the mean values were reported lower may be due to change of water every year in December on the eve of "Geeta Jayanti". Chloride concentration fluctuated between 6.63 to 97.7 mg/L. High chloride at site 2 indicated the presence of high organic matter, hence degree of pollution of animal origin. Total hardness was between 73.34 to 266.67 mg/L. The total hardness values were observed more than the prescribed standard (100 mg/L) of World Health Organization (WHO) except at site 4. It may be attributed to the increased mobilization of hardness causing elements like Calcium and Magnesium to be released from the subsurface ground waters having higher hardness (Badrakh *et al*., 2008). Ortho-Phosphate (o-PO_4) is the most significant nutrient responsible for eutrophication of waters. In present study, o-Phosphate varied from 0.25 to 2.85 mg/L. The higher values may be due to throwing of ashes, bathing and washing activities using soaps and detergents by the pilgrims. Davies *et al*. (2009), Sharma and Walia

Table 2: Mean (± Standard error) values of physico-chemical characteristics of waters at all the selected sites
All values are Mean ± S.E of mean

S N	Parameter	(Site 1)	(Site 2)	(Site 3)	(Site 4)	(Site 5)	(Site 6)	(Site 7)	(Site 8)
1	Temperature (^{0}C)	22.75±5.36 ^{A}	25.82±4.72 ^{A}	23.90±4.21 ^{A}	23.84±4.23 ^{A}	23.88±4.14 ^{A}	25.82±4.72 ^{A}	25.58±4.07	22.79±3.09
2	pH	7.15±0.10 ^{A}	7.21±0.12 ^{A}	7.17±0.12 ^{A}	7.10±0.18 ^{A}	7.48±0.31 ^{A}	7.01±0.16 ^{A}	7.01±0.14 ^{A}	7.03±0.13 ^{A}
3	Conductivity (µ mhos/cm)	413.50±54.18^{DE}	924.74±119.07^{A}	496.50±24.83^{CD}	157.23±4.74^{F}	284.31±36.02^{EF}	656.24±28.46^{B}	620.67±19.66^{BC}	345.42±81.32^{DE}
4	TDS (mg L^{-1})	585.59±34.15^{C}	1207.85±167.76^{A}	602.57±25.86^{C}	200.59±4.28^{D}	368.21±43.91^{D}	850.97±39.97^{B}	802.39±36.29^{B}	376.20±82.64^{D}
5	Turbidity (NTU)	10.50±4.01^{B}	43.09±16.10^{A}	7.55±2.42 ^{B}	6.58±2.43 ^{B}	5.14±1.88 ^{B}	9.63±2.49 ^{B}	20.43±8.51 ^{B}	9.14±2.14 ^{B}
6	Free CO_2 (mg/L)	8.22±4.63 ^{BC}	37.04±18.58 ^{A}	10.67±2.84 ^{BC}	1.34±0.55 ^{C}	6.83±3.98 ^{BC}	29.72±5.42 ^{AB}	4.00±2.40 ^{C}	30.00±13.40 ^{AB}
7	DO mg/L)	9.07±0.74^{A}	7.14±0.50^{A}	10.18±1.58^{A}	8.14±0.38^{A}	9.17±0.71^{A}	8.18±1.75^{A}	10.48±1.51^{A}	8.24±0.41^{A}
8	T. alkalinity (mg/L)	165.78±6.89 ^{C}	264.52±29.36 ^{A}	178.06±3.52 ^{BC}	34.73±1.21 ^{E}	100.28±11.00 ^{D}	179.39±7.80 ^{BC}	204.67±2.83 ^{B}	79.39±8.74 ^{D}
9	Chloride mg/L)	31.40±1.38 ^{CD}	97.70±14.47 ^{A}	37.36±2.19 ^{CD}	6.63±0.57 ^{F}	10.16±0.42 ^{EF}	74.99±5.88 ^{B}	42.27±3.38 ^{C}	24.47±8.14 ^{DE}
10	Hardness (mg/L)	190.89±21.88 ^{B}	140.59±40.05 ^{BC}	180.31±14.29 ^{B}	73.34±4.99 ^{C}	127.33±16.90 ^{BC}	266.67±17.52 ^{A}	185.22±38.98 ^{B}	100.78±8.62 ^{C}
11	o^- Phosphate (mg/L)	0.25±0.09 ^{B}	2.85±1.12 ^{A}	0.35±0.05 ^{B}	0.40±0.10 ^{B}	0.25±0.11 ^{B}	0.79±0.12 ^{B}	1.20±0.39 ^{B}	0.61±0.12 ^{B}
12	Ammonia (mg/L)	0.69±0.15 ^{AB}	1.14±0.37 ^{AB}	0.82±0.29 ^{AB}	0.31±0.13 ^{B}	1.19±0.85 ^{AB}	0.81±0.13 ^{AB}	1.89±0.83 ^{A}	0.44±0.05 ^{AB}

Means with different capital letters in the same row are significantly ($p<0.05$) different (Duncan's Multiple Range test). The capital letter is denoting the site wise comparison of all sites.

Table 3: Season wise distribution of total phytoplankton population (nos. L^{-1}) at all the selected sites

Site	Summer	Monsoon	Post Monsoon	Winter
Site 1 (Kapalmochan)	10480± 160Cb	9360± 160Ac	10720± 80EFb	11600±80Ea
Site 2 (Kulotarantirth)	7360±800DEa	4760± 120Db	8880± 480Fa	
Site 3 (Bangangatirth)	6280± 40Eb	6200± 120Cb	28080± 80Ca	27760± 240Ba
Site 4 (Brahmsarovar)	6600 ± 200Ec	5840±160Cc	25560± 440Da	17680± 160Db
Site 5 (Jyotisar)	37480± 40Aa	7560±280Bc	23880±120Bb	10920±200Ec
Site 6 (Saraswati tirth)	10920± 200Cb	2640± 400Ec	12680± 440Eb	36160± 1120Aa
Site 7 (Phalgu tirth)	7920± 400Dc	7400± 520Bc	42200± 1720Aa	19960± 1000Cb
Site 8 (Pandu-Pindara tirth)	23960±120Ba	9440±240Ab	10000± 80Fb	9640±200Eb

Table 4: Coefficient of Correlation between Phytoplanktons and Physico-chemical variables

SN	Phyoplankton	Abiotic factor	r value variable
1	Xanthophyceae	CO_2	0.427(*)
2	Desmidiaceae	Ortho-phosphate	0.568(**)
3	Cyanophyceae	pH	-0.424(*)
5	Desmidiaceae	Bacillariophyceae	0.505(**)
6	Total Plankton	Total Phytoplankton	0.844(**)

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

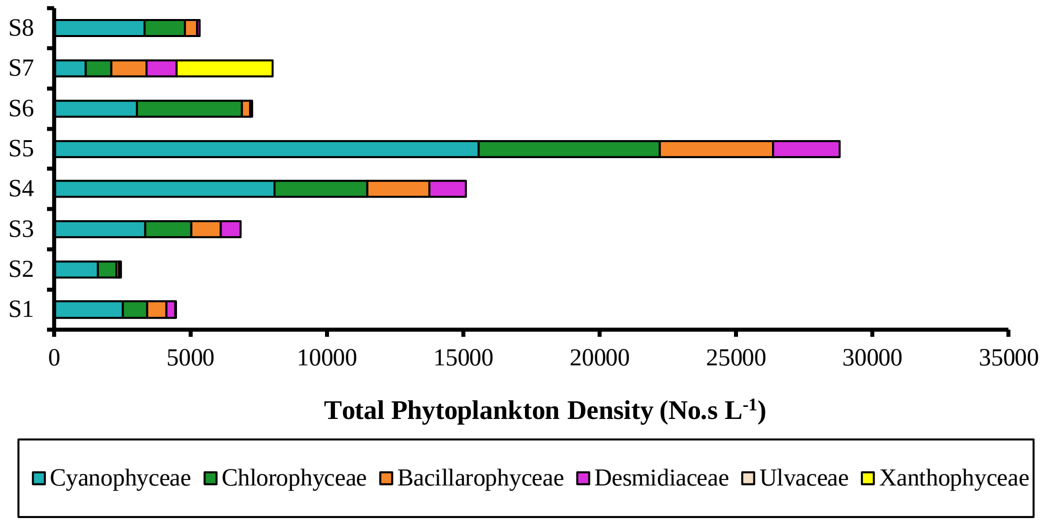

Figure 2: Total Population Density of different Phytoplankton groups at all the investigated sites

(2017) also reported increase in values of o-Phosphate due to fertilizers, soaps, detergents, and domestic sewage. However, according to Jhingram (1982) o-Phosphate content of more than 0.2 mg/L indicate productive nature of water and in the present studies it was higher than 0.2 mg/L indicating eutrophic nature of the sites. However, according to Permatasari (2016) the optimal value of orthophosphate for phytoplankton growth ranges from 0.09 to 1.80 mg/l. Ammonia ranged from 0.31 to 1.89 mg/L. Ammonia levels greater than approximately 0.1 mg/L usually indicates polluted waters and during present study mean values of ammonia were found higher than 0.1 mg/L at all the sites indicating that these sites need attention for the improvement of the water quality. Dumping of domestic and organic waste and the activities like bathing, adding ashes may be responsible for this increased ammonia concentration.The phytoplankton population ranged from 2640 to 42200 nos. L^{-1} and were found abundant at sites 2, 3, 4 and 7 during the post monsoon season, at site 5 and 8 during summer season whereas at sites 1 and 6 phytoplankton were in abundance during the winter season (Table 3). Abundance of phytoplankton during winter season is consistent with the findings of Sharma *et al.* (2016). Phytoplankton abundance during winter may be due to low water velocity, high dissolved oxygen and utilization of nutrients. A total of 118 phytoplankton species were recorded from all the eight sites and. Of these, 26 taxa belonged to Cyanophyceae, 42 taxa to Chlorophyceae, 33 taxa to Bacillarophyceae, 14 taxa to Desmidiaceae and one taxa to Xanthophyceae, Rhodophyceae, and Dinophyceae each. Amongst these, Cyanophyceae was the dominant group followed by Chlorophyceae, Bacillarophyceae and Desmidiaceae at sites 1, 2, 3, 4, 5 and site 8 that confirms the findings of Ansari *et al.* (2008) and Trang *et al.* (2019) whereas, the trend at site 6 was Chlorophyceae >Cyanohyceae>Baccilarophyceae (Figure 2). Cyanophyceae was observed in abundance at site 1, 2, 5 and 8 during summer season (Figure 4) similar to the findings of Tiwari and Chauhan (2006), Dembowska (2021) and Zhu *et al.* (2021). High temperature, extremely low water flow and high rate of evaporation might favour the growth of Cyanobacteria during summer season. Cyanophyceae was recorded maximum (65%) at site 2, followed by at site 4, 8 (62%) then at site 1 (57%), at site 5 (52%) and least was observed at site 6 (i.e. 42%) (Figure 3). Abundance of cyanophyceae at sites 6 and 7 during monsoon season consistent with the findings of Tran *et al.* (2022) (Figure 4). Cyanophyceae abundance at most of the sites indicates high pollution load and nutrient rich condition of the selected sites (Muhammad *et al*., 2005; Tas and Gonulol, 2007). Cyanophyceae revealed a significant negative correlation with pH ($r= -0.424$, $p < 0.05$) (Table 4). *Phormidium*, *Coccochloris* sp. (at site 1), *Rivularia* sp. (at site 5), *Aphanocapsa* sp. (at site 8) were abundant during the summer season (Table 5).

Table 5: Seasonal dominance of different phytoplankton taxa at all the selected sites

	Summer	Monsoon	Post Monsoon	Winter
(Site 1)	*Mougeotia, Oscillatoria*	*Mougeotia, Desmids, Diatoms*	*Mougeotia*	*Bacillarophyceae Phormidium*
(Site 2)	*Phormidium*	*Euglena, Oscillatoria*	*Microcystis, Characium, Oscillatoria, Melosira*	-
(Site 3)	*Oscillatoria, Nannochloris*	*Microcystis, Botryococcus, Oscillatoria*	*Docidium (Desmid), Oscillatoria, Ulva* sp.*, Microcystis*	*Bacillarophyceae Oscillatoria, Ulothrix*
(Site 4)	*Spirogyra, Zygnema*	*Mougeotia*	*Microcystis*	*Characium Bacillarophyceae bloom*
(Site 5)	*Rivularia, Zygnema, Mougeotia, Rhoplalodia, Syneccococcus*	*Cymbella, Microspora, Phormidium*	*Microcystis, Stichococcus, Coelastrum, Phormidium, Oscillatoria*	*Zygnema, Synedra*
(Site 6)	*Oscillatoria, Pediastrum, Nannochloris*	*Oscillatoria*	*Oscillatoria, Nannochloris, Microcystis*	*Cladophora, Phormidium*
(Site 7)	*Microcystis aeruginosa*	*Microcystis*	*Pediastrum, Tribonema*	*Closterium juncidum*
(Site 8)	*Oscillatoria, Microcystis, Aphanocapsa, Enteromorpha*	*Microcystis, Pediastrum duplex*	*Mougeotia , Microcystis, Cladophora, Draparnaldia*	*Oscillatoria, Bacillarophyceae*

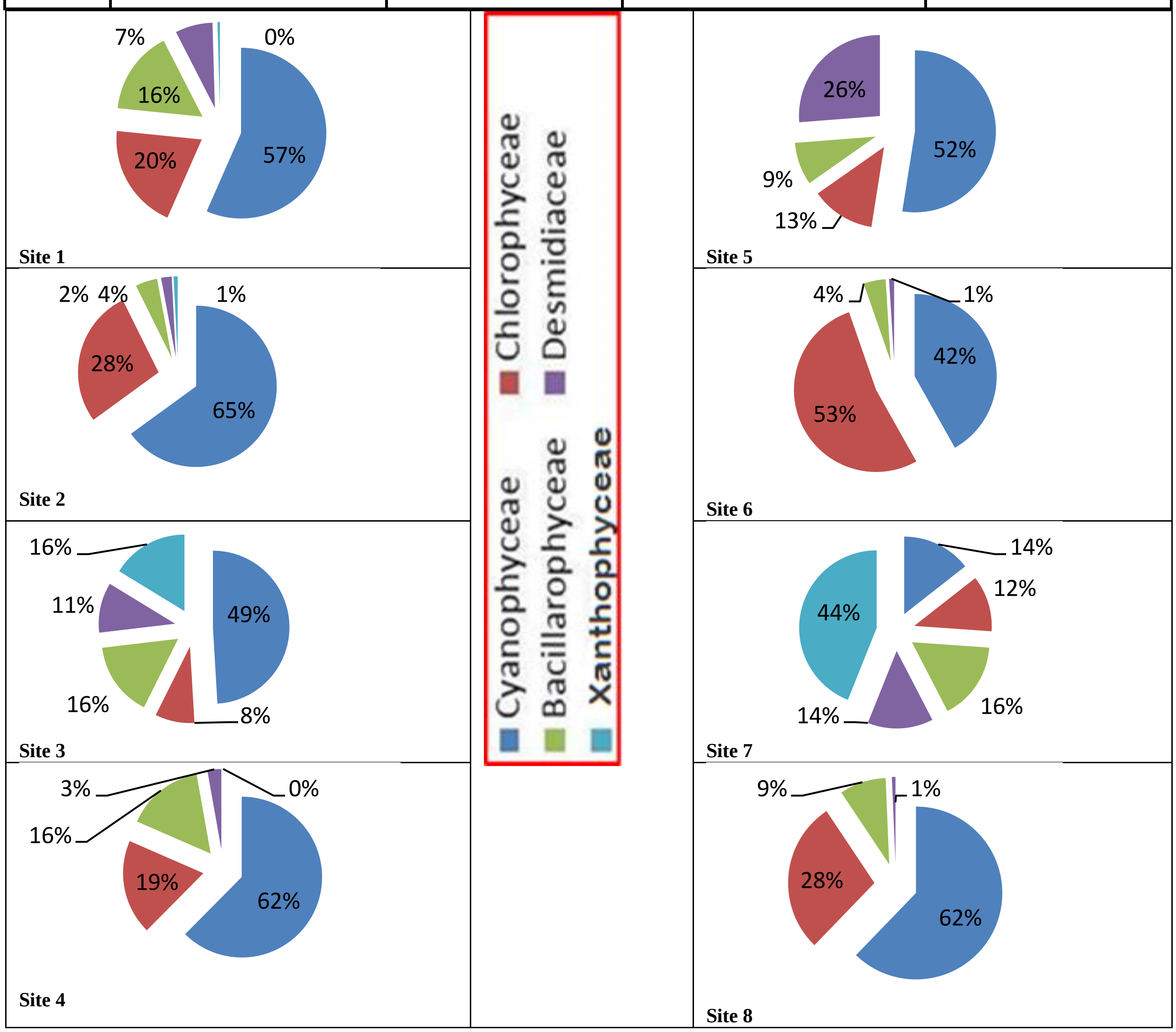

Figure 3: Per cent distribution of different groups of phytoplankton at all the sites (1-8).

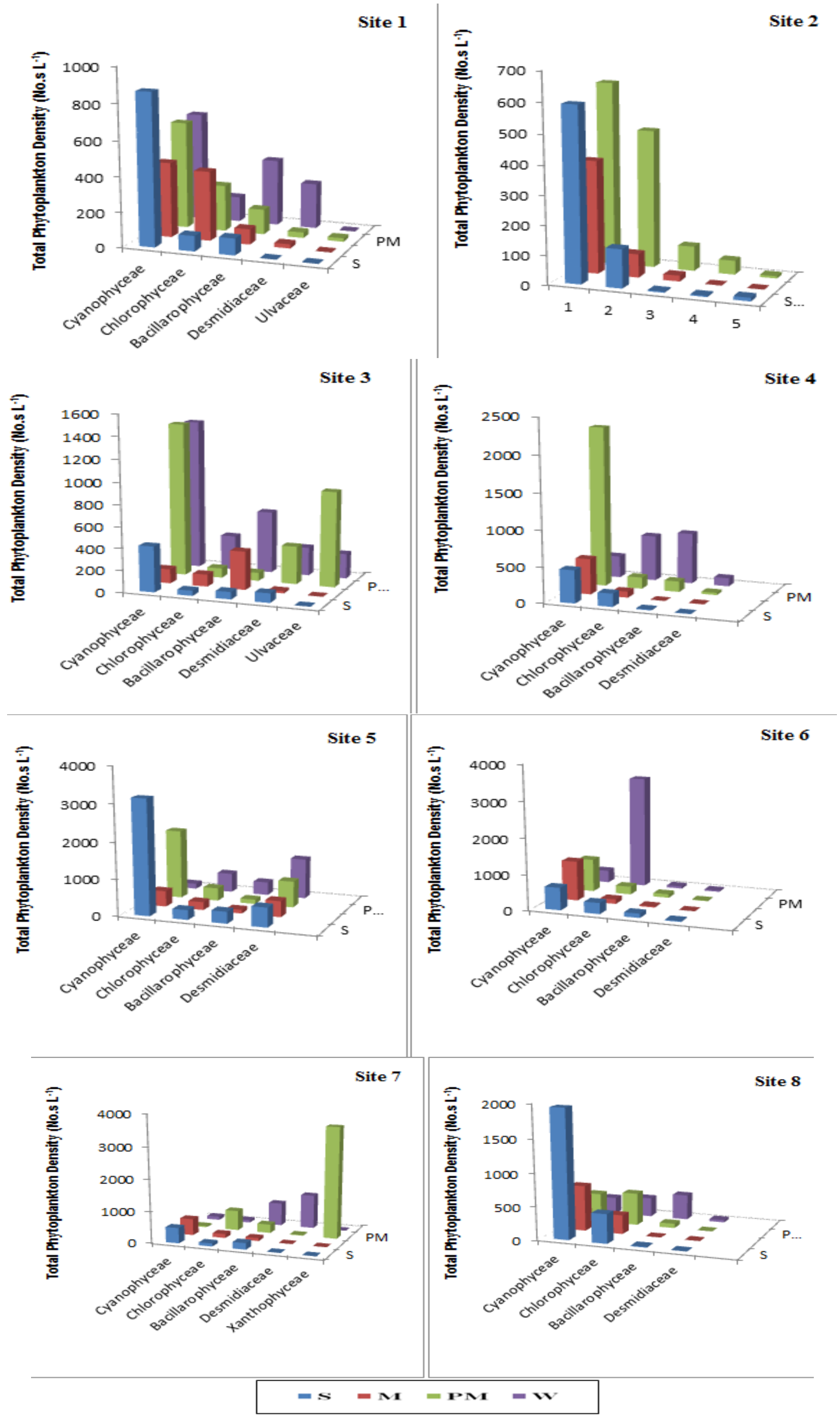

Figure 4: Seasonal distribution of different groups of phytoplankton at all the sites (1-8)

Microcystis aeruginosa was recorded in abundance at all the sites in all the seasons and forms blooms mainly in the post monsoon season except at site 1 (Table 5) indicates the eutrophic status of waterways and best indicator of pollution in water bodies (Nandan and Aher, 2005). Presence of *Rivularia* sp. (Hulyal and Kaliwal, 2009), *Oscillatoria* (Ansari *et al.*, 2008, Kumari *et al*., 2008, Rishi and Awasthi, 2012) indicates eutrophication of lake and can be regarded as 'Marker species' or indicator of water pollution. The study revealed that Cyanophyceae prefer to grow at slightly alkaline conditions that is similar to the findings of Kadhim (2014).Chlorophyceae was the dominant group at site 6 (Figure 2) i.e. 53% and least was recorded at site 3 (8%) (Figure 3). A total of 42 species were recorded from Chlorophyceae. Chlorophyceae are found in abundance in lakes having sufficient light intensity (Dembowska *et al*., 2018) and High N and P content also favors chlorophyceae (Deyab, 2002). It was found in abundance at site 3, 4, 5 and 6 during winters (Figure 4). At site 6 it was mainly represented by the *Cladophora* sp. in winter and *Nannochloris* sp. in post monsoon season (Table 5). *Scenedesmus* spp., *Pediastrum* spp. and *Mougeotia* sp. were reported at all the sites. Scenedesmus spp., *Pediastrum* spp., *Cosmarium, Ulva* sp. abundance may indicates eutrophic waters and also indicates that sewage pollution of waters reservoirs (Rogers, 2003, Kumari *et al*., 2008). Sewage wastes may be added in the waters by the village people around the site. *Pediastrum duplex, Ulothrix* sp., *Cladophora* sp., *Coelastrum* sp. and *Ulva* sp. were regarded as pollution tolerant taxa in present study. Abundance of *Ulothrix sp*. in winters at site 3 and abundance of *Coelastrum* and *Zygnema* sp. at site 5 during post monsoon period and winter period respectively (Table 5) indicates pollution of water at these sites is consistent with the findings of Rai *et al*. (2008) and Hulyal and Kaliwal (2009).Diatoms are regarded as the best indicators of quality and tropic status of the water body (Callieri, 2008). Bacillariophyceae can be used as bio-indicators for water quality evaluation due to their short regeneration time and sensitive behaviour towards ecological characteristics (Goma *et al.*, 2005). Overall population density wise it was in abundance at site 5 and least at site 2 (Figure 2). Percent wise distribution revealed that it was maximum (i.e. 16%) at sites 1, 3, 4 and 7 and least (i.e. 4 %) was recorded at sites 2 and 6 (Figure 2). Members of Bacillarophyceae were in abundance during the winter season at almost all the sites (Figure 4). This dominance is similar to the findings of Tiwari and Chauhan (2006), Negi *et al.* (2012) and Sharma *et al.* (2016). Nautiyal *et al.* (2012) and Tarar and Bodhke (2002) stated that winter months were more favourable for the multiplication of diatoms. In the present results, Bacillarophyceae was represented by 33 genera. The dominant taxa observed were *Navicula* spp., *Synedra* spp.*, Nitzschia* spp. that was recorded from almost all the sites. *Nitzschia, Pinnularia* regarded as indicators of organic pollution (Rai *et al.*, 2008, George *et al.*, 2012, Bhat *et al.*, 2015). *Cyclotella* sp. and *Navicula* sp. also indicated the eutrophic and polluted nature of aquatic system (Kumari *et al.*, 2008 and Shruthi *et al*., 2011). In Desmidiaceae group a total of 14 taxa were observed at sites 1-8. Population density of desmids (No.s L^{-1}) and Per cent wise distribution was found maximum at site 5 (i.e. 26%) followed by at site 7 (14%) then at site 3 (11%) (Figure 2, Figure 3). *Docidium sp.* was recorded in abundance during post monsoon period at site 1 and Site 3 whereas *Closterium juncidum* was recorded as dominant sp. during winter period and was in abundance at site 7 (Table 5). Presence of *Closterium* sp. indicated the polluted nature of the water body (Hulyal and Kaliwal, 2009). Hence site 7 can be considered as polluted in winter season. *Closterium* sp. and *Cosmarium* sp. indicated the pollution and eutrophic status of the sites 3, 7. Bacillariophyceae and Desmids were found to be positively correlated ($r= 0.505, p<0.01$) with each other (Table 4).Xanthophyceae was found to be dominant (44%) among phytoplankton at site 7 in post monsoon period followed by at site 3 (16%) (Figure 3 & Figure 4). It was mainly represented by mainly one genera i.e. *Tribonema* sp. Xanthophyceae ($r= 0.427, p<0.05$) and CO_2 also showed a positive correlation (Table 4).Season wise distribution showed that *Phormidium, Coccochloris, Syneccococcus, Rhopalodiagibba, Aphanocapsa, Nannochloris, Microcystis aeruginosa*, *Synedra* sp, *Aphanocapsa, Enteromorpha* taxa were common during summer season. The abundance of phytoplankton during summer may be attributed to faster microbial decomposition action making nutrient rich water with abundant food present in form of photosynthesis (Hassan *et al.*, 2010). Overall *Phormidium* sp., *Microcystis* sp., *Synedra* sp., *Spirogyra* sp., *Mougeotia*, *Scenedesmus* sp., *Pediastrum* sp., *Navicula* spp., *Nitzschia* sp. were common to all the stations and can be regarded as good indicators of water pollution. Presence of *Microcystis aeruginosa*, *Phormidium* sp., *Oscillatoria* sp., *Closterium* sp., *Synedra* sp., *Spirogyra* sp., *Ulothrix* sp., *Pediastrum* spp., *Cladophora* sp., *Synedra* spp., clearly indicated that water is polluted. Similar observation has been made by (Chandrashekar *et al.*, 2003 and by Tiwari and Chauhan, 2006).

Conclusion

Physicochemical factors analysis depicted that the sites 2, 6 and 7 were more polluted as comparison to the other sites and site 4 was found least polluted. The study of physicochemical parameters and phytoplankton were found correlated with each other as both were showing the productive and eutrophic nature of the sites. Presence of *Microcystis aeruginosa*, *Oscillatoria* sp., *Rivularia* sp., *Pediastrum* sp., *Scenedesmus*, *Spirogyra* sp., *Synedra* sp., *Navicula* spp., *Nitzschia* sp. can be used as pollution indicators species to know the ecological status of waters to meet the needs for particular assessment of water protection programs. Suitable remedial measures and social awareness campaigns should be adopted to control pollution of these aquatic systems arising from the various anthropogenic activities and mass bathing at these sites for maintaining the water quality of these ponds. Detail knowledge of identification, reproductive period, life cycle, ecological niche of phytoplankton also required for detail analysis of their response to the environment variables and effects like eutrophication, acidification, salinity, warming. Besides that, regular quantitatively and qualitatively monitoring of other water quality like nutrient and hydrodynamics profiling is indispensable to realize better management of healthy ecosystem.

Conflict of interest

The authors declare that they have no conflict of interest.

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