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Spatial and seasonal variations of phytoplankton dynamics with special reference to physico-chemical variables in Lower Lake of Bhopal, India

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Abstract
Phytoplankton is almost universal in distribution but fluctuation in abundance depends on the surrounding environment, their consumer's abundance influence with change in the environment. They are very sensitive to their environment, any change in their habitat may lead to the change in the planktonic communities in terms of tolerance, abundance, diversity and dominance in the habitat. Moreover, the physico-chemical properties and nutrient status of the water plays an important role in production of plankton, which is essential in maintaining healthy and productive aquatic organisms. The purpose of this study was to look into the seasonal variations in the species dynamics, diversity and abundance of phytoplankton in relation to some physico-chemical variables in Lower Lake of Bhopal. A total of 36 species of phytoplankton were documented of which 17 belongs to the group Chlorophyceae, 8 species represented by Cyanophyceae, 7 species belongs to Bacillariophyceae, Euglenophyceae (3 species) and only 1 species represents the whole group of phylum Pyrophyceae. Chlorophyceae recorded with highest number of species with a contribution of (47%), followed by Cyanophyceae recorded (22%), whereas (20%) of total phytoplankton was contributed by Bacillariophyceae which in turn followed by Euglenophyceae (8%) and (3%) Pyrophyceae. The present study revealed that cumulative seasonal diversity ranged from 22 to 33. The annual average ratio of Chlorophyceae, Cyanophyceae, Bacillariophyceae, Euglenophyceae and Pyrophyceae phytoplankton abundance in total was 37%, 21%, 13%, 22% and 7%, respectively. The average Chlorophyceae, Cyanophyceae, Bacillariophyceae, Euglenophyceae and Pyrophyceae abundance was 24227 units/l, 13583 units/l, 8701 units/l, 14165 units/l and 4341 units/l respectively.

Keywords: lake, physico-chemical variables, phytoplankton, dynamics, density

Introduction

Whole aquatic life relies on phytoplankton population as they constitute the primary producers of most water bodies. They form the basic link in the food chain of all aquatic animals (Misra *et al.*, 2001) [20] and are important food source for higher organisms. The water quality especially the nutrients, influence their population (Rajesh *et al.*, 2002; Ananthan *et al.*, 2004; Tiwari and Chauhan, 2006; Tas and Gonulal, 2007; Saravanakumar *et al.*, 2008) [25, 4, 34, 33, 27] and are important indicators of the productivity of aquatic environments. Their productivity and composition are influenced by the spatial and temporal dynamics of environmental factors such as nutrients, underwater light climate, temperature, pH, water clarity, dissolved oxygen, biological components and wind-induced mixing, that bring about the dynamics of phytoplankton (Jones, 1977; Reynolds, 1984) [14]. They are almost universal in distribution but fluctuation in abundance depends on the surrounding environment, their consumer's abundance influence with change in the environment. Moreover, the physico-chemical properties and nutrient status of the water plays an important role in production of plankton, which is essential in maintaining healthy and productive aquatic organisms (Rahman and Hussain, 2008) [24]. The phytoplankton biomass and hydrogeochemical characteristics of water bodies do not remain same but they fluctuate with variations of seasons as well due to degree of pollution (Prasad, 2006) [23]. Their communities have been extensively used as biological monitors from various parts of the world (Atazadeh *et al*, 2007) [5]. The quality and quantity of phytoplankton and their seasonal patterns have been successfully utilized to assess the quality of water and its capacity to sustain heterotrophic communities (Hulyal and Kaliwal, 2009) [13]. Therefore, population of plankton observation can be used as a reliable tool to assess the pollution status of waters (Basu, *et al*, 2010; Prabhahar, 2011) [6, 22]. Therefore, phytoplankton survey indicates the trophic status and the presence of population in the ecosystem

Study Area

The Lower Lake (Chhota Talab) was built in 1794 to enhance the beauty of Bhopal city. The construction was commissioned by Chote Khan, a minister of Nawab Hayat Muhammad Khan Bahadur. The lake is situated in thickly populated area of Bhopal between 23^0 16` N latitude and $75^0$ 25` E longitude and 505 meters above sea level. The Lower Lake is located to the east of the Upper Lake and is separated by earthen dam from Upper Lake. The two lakes are built in a terraced manner the lowest level of the Upper Lake is just below the highest level of the Lower Lake. The Lower Lake has an area (water spread) of 1.29 km^2 and its catchment area is 9.6 km^2. The lake receives subsurface seepage from the Upper Lake. It is an artificial lake and is situated towards the east end of the Upper Lake and is an integral part of the Upper Lake (Verma *et al.*, 2006) [36]. The Lower Lake does not have any fresh water source as it receives seepage water from the Upper Lake and drainage from 28 sewage-filled nallahs. It drains into the Patra rivulet, which ultimately culminates into Halali River, a small tributary of the Betwa River. The lake has a great significance for the people of Bhopal and is being used for various needs. Three stations were selected for the study based on anthropogenic pressure, pollution load and surrounding environment (Fig. 1).

Station L1 (Neelam Park)
This station is situated near Jehangirabad. The raw sewage from Jehangirabad, Police Headquaters, residential colonies and other surrounding densely populated areas make its way to this water body. It has moderate macrophytic population due to shallow area, sandy bottom.

Station L2 (Kali Mandir)
This sampling station is situated near Kali Mandir. At this station lake has maximum depth of near about 10-11 meter. The main source of pollution for this station is sewage and solid waste from surrounding area.

Station L3 (P.H.Q.)
This station is near the bathing ghat adjacent to Kathalapura temple. The sewage from police Headquaters enters in the lake from this point.

In order to have an insight into the ecological changes the water body is experiencing, detailed limnological investigations has to be carried out. The aim of this study was to contribute to the knowledge of the phytoplankton dynamics and spatial and temporal distribution pattern in Lower Lake considering physical and chemical factors along the study period.

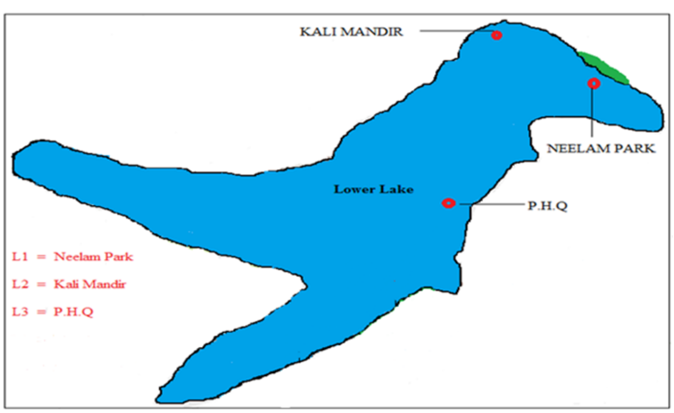

Fig 1: Map of Lower Lake showing selected sampling stations

Materials and Methods

The study was carried out during Jan. 2016 to Dec. 2016. Water samples were collected in 1-liter plastic cane with the help of Ruttner (Hydrobios, Germany). Temperature, pH, and total dissolved solids (TDS), Electrical Conductivity were measured using mercury thermometer, digital pH meter, portable TDS meter and digital portable conductivity meter respectively. Analysis of these parameters along with Free carbon dioxide, Transparency, fixing of sample for dissolved oxygen, Alkalinity, Total hardness was carried out immediately. For estimation of dissolved oxygen, samples were fixed at the sampling site in accordance with modified Wrinkler method. The analysis of water samples was done by adopting standard methods of (Adoni, 1985) [3] and (APHA, 1998) [1]. Sample aliquots of 100 ml were preserved by adding 5ml of 4% formalin simultaneously for analyses of phytoplankton, which were examined after 24 hours of undisturbance so that plankton settled down. For the quantitative estimation of phytoplankton drop count method is preferred using a standard calibrated dropper following the method given in Adoni (1985) [3]. Phytoplankton species were identified based on the morphology with the help of standard taxonomic literatures Needham and Needham (1962) [21], Adoni (1985) [3], Sinha and Naik (1997) [32] and APHA (1998) [1].

Results and Discussion

Physicochemical Variables

The diverse use of freshwater is based on its unique physico-chemical properties that render it either fit or unfit for one or the other purposes. The (Fig. 2a-e) represents seasonal variation of physicochemical variables in Lower Lake. The average air temperature varied significantly with season (ranged from 22.2 °C in winter to 39.54 °C in summer). Spatial fluctuations in air temperature experienced during a particular season might be due to the timing of collection and the influence of weather, which quite fluctuate diurnally and seasonally in the Lakes (Welch, 1952). Water temperature also shows seasonal fluctuations as it ranges from minimum (18.4 °C) to maximum (28.57 °C). Water temperature has been noted to increase correspondingly with the increasing atmospheric temperature. The rising of water temperature particularly in summer in the present study can be attributed to overall increasing trend in atmospheric temperature in addition to exothermic chemical process of the human activities prevail all along the lake. Khan *et al.*, (2016) [16] studied water quality of Lower Lake and found temperature between 21.6 to 32.4 °C. Transparency values were ranged between 14.6 to 25.14 cm during monsoon and summer respectively. The minimum value of transparency recorded during monsoon may be due to influx of rain water from catchments area, cloudiness, less penetration of light and high turbidity due to suspended inert particulate matter. Shinde *et al.*, (2010) [31], Saxena (1998) [28] recorded low values of transparency during monsoon as compared to summer and winter. However, high values of transparency in summer may be due to clear atmosphere and high light penetration. pH of the water fluctuated between 7.7 and 7.9. Similar range of pH in Lower Lake was reported by (Bhargava *et al.*, 2013) [8]. Alkaline pH has been reported to be mainly a characteristic feature of eutrophic and mesotrophic lakes (Whitemore *et al.*, 2006) [38]. WHO has recommended maximum permissible limit of pH from 6.5 to 9.2 (De, 2002).

Total dissolved solids varied from the average of 140mg/ l in post-monsoon to 167.2 mg/l in summer. In summer, most of the vegetation were decaying so a rise in the amount of dissolved solids was natural, and as the products of decaying matter were returned to the water (Khan *et al.*, 2015) [17]. The average electric conductivity ranged between 292.76 to 314 µS/cm. Free Carbon dioxide content of freshwater varies like that of other parameters. The Lake exhibited maximum carbon dioxide as 4.6 mg/l during summer and minimum of 2.06 mg/l in winter. Water rich in free CO_2 is comparatively less alkaline and vice versa as stated by (Begum, 2016) [7]. Dissolved oxygen concentration varied from average value of 5.4 to 6.3 mg/l with higher concentration in winter and lower in monsoon. Total alkalinity ranges from 82.2 to 90.46 mg/l, the maximum value (90.46 mg/l) was noted in the winter and minimum value (82.2 mg/l^{l}) during monsoon season. As per the Bureau of Indian standards the desirable level of total alkalinity for drinking water is below 200 mg^{-l} and permissible level in the absence of alternate source is 600 mg^{-l} (BIS, 1992). Total hardness ranged from 89.6 mg/l to 109.7 mg/l. High concentration of total hardness recorded during monsoon may be attributed to the decline and decomposition in submerged macrophytes. Similar results were also reported by (Dubey, 2013; Khan *et al.*, 2015) [12, 18].

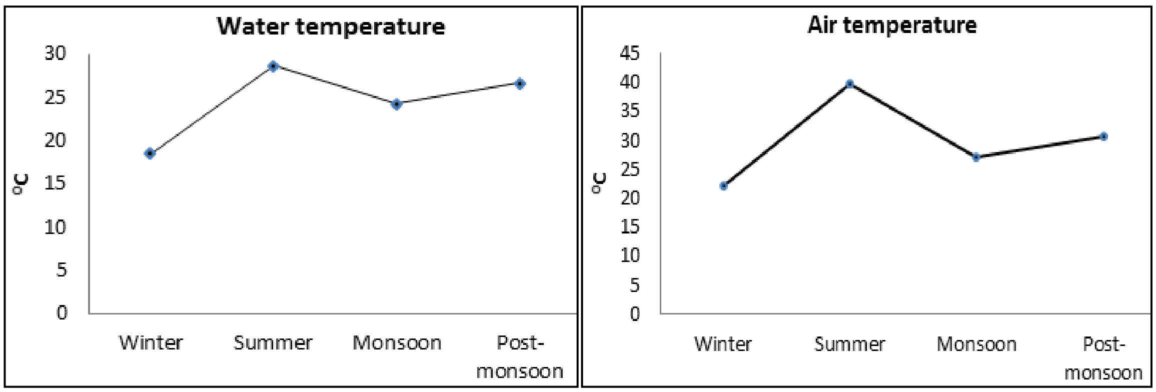

Fig 2a: Seasonal variation of water and air temperature in Lower Lake (*dots* represent average of three sampling stations)

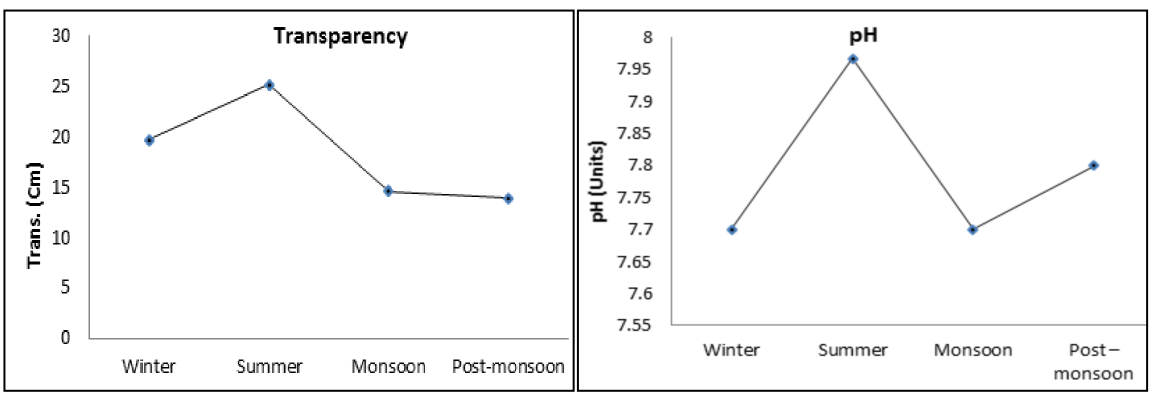

Fig 2b: Seasonal variation of transparency and pH in Lower Lake (*dots* represent average of three sampling stations)

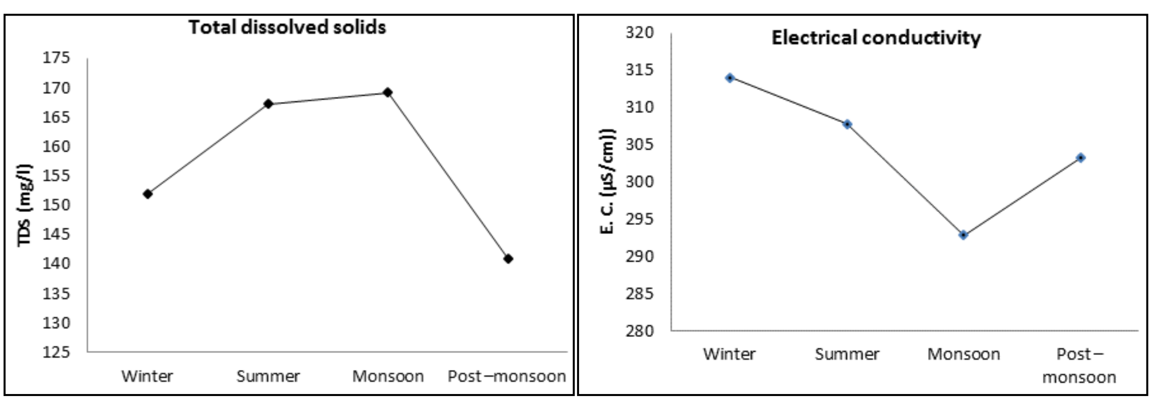

Fig 2c: Seasonal variation of total dissolved solids and electrical conductivity in Lower Lake (*dots* represent average of three sampling stations)

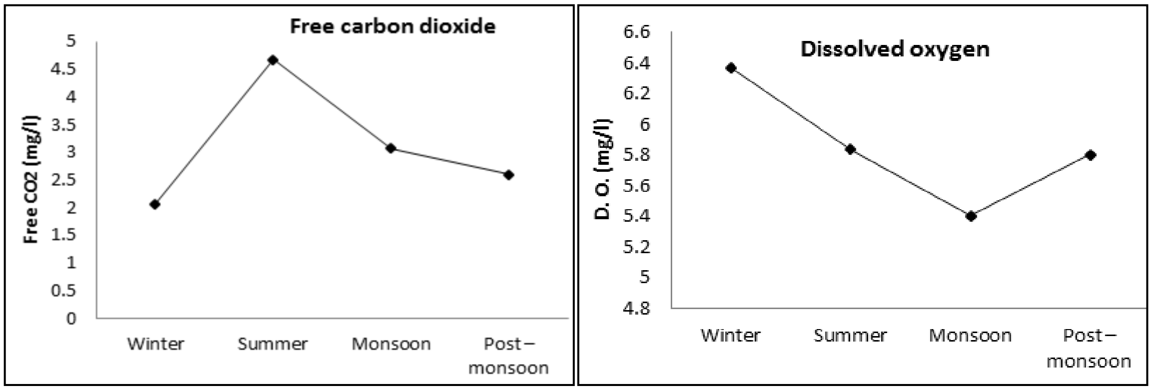

Fig 2d: Seasonal variation of free carbon dioxide and dissolved oxygen in Lower Lake (*dots* represent average of three sampling stations)

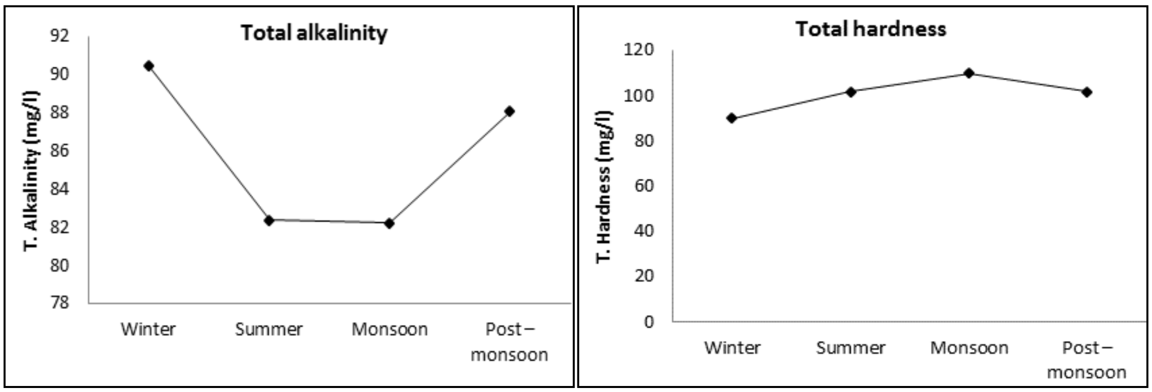

Fig 2e: Seasonal variation of total alkalinity and total hardness in Lower Lake (*dots* represent average of three sampling stations)

Composition of Phytoplankton

A total of 36 species of phytoplankton were documented (Table 1), of which 17 belongs to the group Chlorophyceae, 8 species represented by Cyanophyceae, 7 species belongs to Bacillariophyceae, Euglenophyceae (3 species) and only 1 species represents the whole group of phylum Pyrophyceae. Chlorophyceae recorded with highest number of species with a contribution of (47%), followed by Cyanophyceae recorded (22%), whereas (20%) of total phytoplankton was contributed by Bacillariophyceae which in turn followed by Euglenophyceae (8%) and (3%) Pyrophyceae (Fig. 2). The present study revealed that cumulative seasonal diversity ranged from 22 to 33. Maximum diversity of 14 Chlorophyceae species was noted in summer and minimum (9) species were observed in post-monsoon season, while maximum diversity of 7 species of Cyanophyceae was also recorded in summer and a minimum diversity of 4 species were noted in winter. The maximum diversity of 7 species of Bacillariophyceae was observed in summer and minimum of 5 each were observed in winter, monsoon and post-monsoon, while as maximum diversity of 3 species each of Euglenophyceae was documented in winter, summer and monsoon and minimum diversity 2 species was documented in post-monsoon season. The Pyrophyceae showed a meager occurrence with diversity of 1 species during all seasons. The above results showed that Chlorophyceae and Cyanophyceae was found to be dominant over all other groups in Lower Lake.

The order of dominance of phytoplankton groups in terms of diversity is as under:

Chlorophyceae > Cyanophyceae > Bacillariophyceae > Euglenophyceae > Pyrophyc

Table 1: List of phytoplankton species identified in Lower Lake, Bhopal

Chlorophyceae	1. *Actinastrum* sp.	10. *Kirchneriella* sp
	2. *Chlamydomonas* sp.	11. *Micractinium* sp.
	3. *Chlorella* sp.	12.*Oedogonium* sp.
	4. *Chlorococcus* sp.	13. *Pediastrum* sp.
	5. *Closterium* sp.	14. *Pediastrum simplex*
	6. *Cosmarium* sp.	15. *Scenedesmus* sp.
	7. *Crucigenia* sp.	16. *Ulothrix* sp.
	8. *Dimorphococcus* sp.	17. *Volvox* sp.
	9. *Gonatozygon* sp.	
Cyanophyceae	18. *Anabaena* sp.	22. *Nostoc* sp.
	19. *Anacystis* sp.	23. *Oscillatoria* sp.
	20. *Aphanizomenon* sp.	24. *Rivularia* sp.
	21. *Microcystis aeruginosa*	25. *Spirulina* sp

Bacillariophyceae	26. *Amphora* sp.	30. *Navicula* sp
	27. *Cymbella* sp	31. *Nitzschia* sp.
	28. *Fragilaria* sp.	32. *Syndra* sp
	29. *Melosira* sp.	
Euglenophyceae	33. *Euglena acutissima*	35. *Phacus* sp.
	34. *Euglena* sp	
Pyrophyceae	36. *Peridinium* sp.	

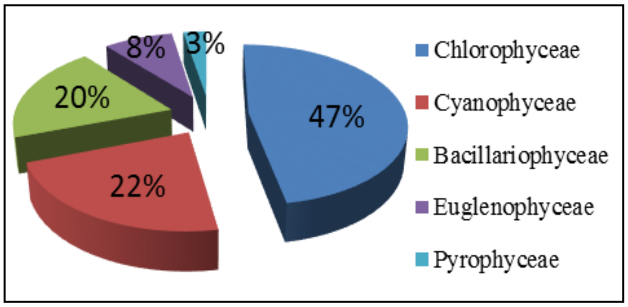

Fig 2: Percentage contribution (species) of different phytoplankton groups

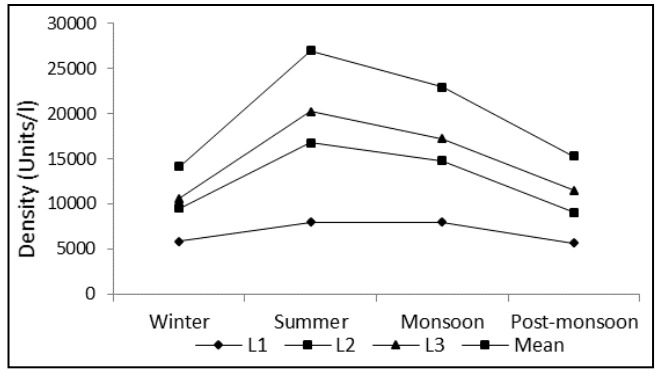

Fig 4: Seasonal variation of phytoplankton density at three sampling stations

Phytoplankton Density

The total phytoplankton population density recorded in the Lower different seasons is provided in Fig. 3. Highest density (20245 units/l) was observed during summer and lowest total density of 10601units l^{-1} was recorded during winter. There was considerable fluctuation in the population density of phytoplankton in the different stations of the lake. Station L1 showed maximum density of 7982 units/l during monsoon season against the minimum (5656 units/l) during post-monsoon. In station L2, the maximum (8839 units/l) and minimum (3425 units l^{-1}) densities were recorded during summer and post-monsoon respectively. The maximum density of 3441 units/l during summer and minimum of 1116 units/l was registered at station L3 in winter. (Fig. 4). Highest average phytoplankton density was observed at station L2 and lowest recorded at station L3. The maximum abundance of phytoplankton appeared at station L1 (Neelam Park) can be attributed to the human activities leading to the nutrient input at and around the sites and minimum abundance at station L3. Wu and Chou (1998) [39] related variation in phytoplankton with various environmental factors. Shams *et al.*, (2012a, b) [29, 30] also related the variation of phytoplankton density to the trophic conditions of the system. The present study suggests that temperature, nitrate, and total dissolved solids were the most important variables affecting the dynamics of phytoplankton variation.

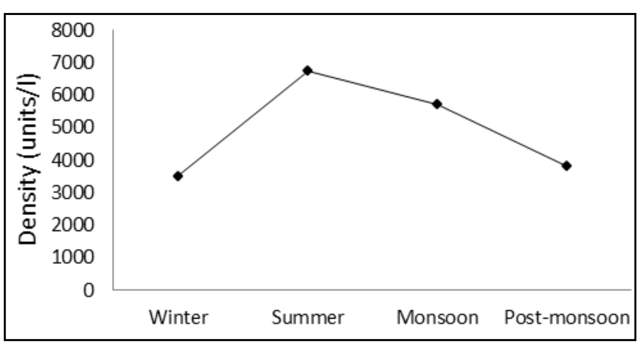

Fig 3: Seasonal and spatial variation of phytoplankton density

The maximum abundance of phytoplankton abundance during summer was dominated by group Chlorophyceae (Fig. 5). Chlorophyceae dominance has been attributed to eutrophic nature of the lake. The maximum population recorded in summer season may be due to low dissolved oxygen and adequate temperature. Increased temperature and long photoperiod may also explain high Chlorophycean diversity during summer months. Chlorophycean bloom in summer could be attributed to high water temperature and resultant dilution of water (Valecha and Bhatnagar, 1988) [35]. Increase in chlorophyceae in response to high temperature is in conformity with the findings of (Kant and Kachroo, 1977; Zutshi and Vyas, 1982) [15, 40] from lakes of Kashmir. The highest density in summer and lowest in winter months shows distinct temporal difference of phytoplankton abundance. This statement is in accordance with the work of (Wang *et al.*, 2002) [37]. The annual average ratio of Chlorophyceae, Cyanophyceae, Bacillariophyceae, Euglenophyceae and Pyrophyceae phytoplankton abundance in total was 37%, 21%, 13%, 22% and 7%, respectively. The average Chlorophyceae, Cyanophyceae, Bacillariophyceae, Euglenophyceae and Pyrophyceae abundance was 24227 units/l, 13583 units/l, 8701 units/l, 14165 units/l and 4341 units/l respectively. The Chlorophyceae was found to be dominant over all other groups in Lower Lake of Bhopal (Fig. 6). The present results indicate that high frequency of some species like *Nitzschia* sp., *Chlorella* sp., *Ulothrix* sp., *Microcystis aeroginosa* and *perinidium* species in Lower Lake indicates eutrophication, which was in relevance to findings of (Acharya *et al.*, 2015) [2]. *Microcystis sp.* and *Chlorella* species abundance are indicators of water pollution. The abundance of Euglenophyceae members in a water body can be attributed to the entry of nutrients through the influx of domestic sewage which is an indication of organic pollution (Laskar and Gupta, 2009) [19]. Dinoflagellate community appeared relatively less in abundance in both the Lakes throughout the study period as compared to the diatoms and other groups. This might be due to the preferential oligotrophic nature of dinoflagellate and their competition with diatoms (Cushing, 1989) [10].

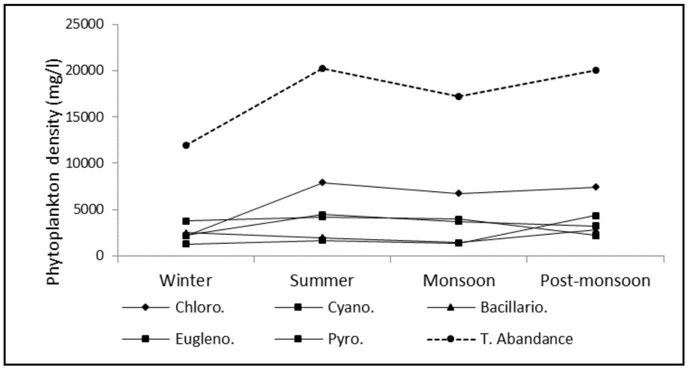

Fig 5: Seasonal phytoplankton variations in different classes and total abundance

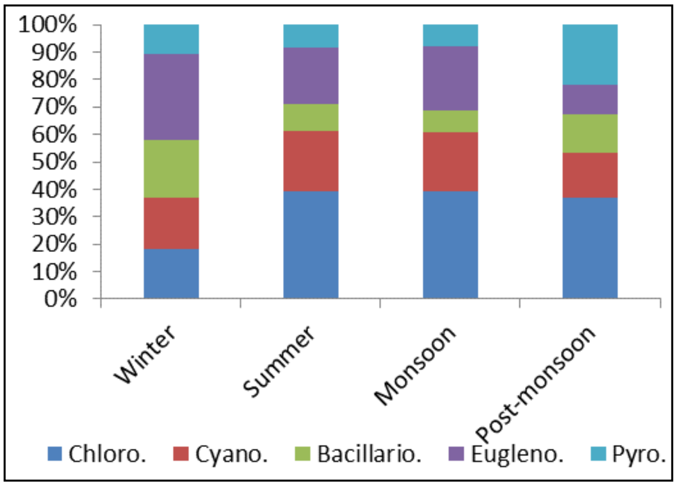

Fig 6: Community succession of phytoplankton in Lower Lake

Conclusion

The present study ensures that variation in the abundance and diversity of phytoplankton can be best explained when environmental factors jointly influence. Phytoplankton shows great variations in diversity as well as density during different seasons. The temperate pattern of succession involves a winter minimum of phytoplankton adapted to low temperature and a summer burst of Chlorophyceae forms followed by other phytoplankton groups. Thus it may be concluded that the density of phytoplankton is dependent on different abiotic factors, which are disturbed and results in ecological imbalance with drastic results, should be addressed by doing the irreversible damage. The physicochemical variables such as temperature, pH and nutrients influence the biological systems to varying degrees, these sources should be treated properly before entering into lake. The lake has been going through successive changes in terms of biological and physical condition. The present study shows that there is successive shifting within the community of phytoplankton and can extend to the higher trophic levels as well.

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