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Impact of physico-chemical parameters on primary productivity of Lake Nainital

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Abstract
The present study was carried out to assess the occurrence and diversity of phytoplankton in relation to abiotic factors of Lake Nainital situated at Kumaon Himalayas of Uttarakhand State, India. The samples of phytoplankton and water were collected from three selected study sites S_1, S_2 and S_3 for a period of eight months from September, 2016 to April, 2017. The phytoplankton composition of Lake Nainital consisted of four groups namely Bacillariophyceae (20 genera), Chlorophyceae (16 genera), Cyanophyceae (3 genera) and Euglenophyceae (2 genera). Dominant phytoplankton species of Lake were *Fragilaria sp., Tabellaria sp., Gomphonema sp., Navicula sp., Amphora sp., Synedra sp.* and *Caloneis sp*. The density of phytoplankton shows peak in the months of January and April, dominated by green algae and diatoms.

Keywords: Lake Nainital, phytoplankton, diversity, density

1. Introduction
Lakes are discrete, largely isolated ecosystems in which the interplay between physical, biogeochemical and organismal processes can be studied, understood, and put to use in effective management [1]. Lakes in mountainous terrain are considered an extreme environment because they are small and sensitive ecosystems with rapid flushing rates [2]. Lake ecosystems are made up of the physical, chemical and biological properties contained within these water bodies and serve an important ecosystem for many organisms as they depend on freshwater for survival, and humans frequently depend on lakes for a great many 'goods and services' such as drinking water, waste removal, fisheries, agricultural irrigation, industrial activity and recreation [1]. Lake Nainital is a natural lake in the state of Uttarakhand, India, where the climate is subtropical. The catchment area around the lake has been rapidly urbanized in recent years and as a result, various environmental problems have been reported [3]. Illegal construction, litter, domestic discharge, and recreational use of lake water are major concerns for sedimentation and eutrophication of the lake water [4]. Hence there is need for determination of various physical and chemical parameters of lake waters, in order to evaluate water quality for determining the extent of pollution. Phytoplankton are vital and important organisms which act as producer to the primary food supply in any aquatic ecosystem. These are also widely used as bio indicators to monitor water quality, pollution and eutrophication [5]. The phytoplankton composition is affected by various environmental factors such as pH, temperature, salinity, turbidity, light and nutrients [6]. They are the initial biological components from which the energy is transferred to higher organisms through food chain [7]. Changes in physico-chemical parameters of ecosystems have a substantial impact on the species that live within them. The present study was carried in order to assess the occurrence and diversity of phytoplankton in relation to abiotic factors of Lake Nainital.

2. Materials and Methods
2.1 Study Site
The present study was conducted at Lake Nainital, which is a natural freshwater body, situated amidst the township of Nainital in Uttarakhand State of India. It is formed tectonically and is situated in the Kumaon Himalayas (between 29.24° N, 79.28° E and 29.4°N, 79.47°E) at an altitude of 1938 m above sea level. Lake Nainital is divided into two parts, southern side of the Lake is Tallital and Mallital, consists of the northern upper reaches. Nainital exhibits temperate climate in winter and subtropical climate in summer season. Morphological features

of Lake Nainital are presented in Table-1. Samples of water for analysis of physico-chemical parameters along with the phytoplankton samples were taken for a period of eight months from September, 2016 to April, 2017.

Table 1: Morphological features of Lake Nainital

S. No.	Features	Lake Nainital
1.	Formation	Tectonically formed
2.	Elevation	1938 m
3.	Latitude	29.24°N - 29.4°N
4.	Longitude	79.28°E - 79.47°E
5.	Maximum Length	1432 m
6.	Maximum Width	457 m
7.	Maximum Depth	27.3 m
8.	Surface Area	48.76 ha

2.2 Sampling Plan

Three sampling stations S_1, S_2 and S_3 were selected at different locations of lake depending on various anthropogenic influences. As depicted in Fig. 1, Site1 (S_1) was near aerator plant, which was operated to improve the dissolved oxygen content of the lake, Site 2 (S_2) was near Naina Devi Temple, where drainage of temple was flushed into the water and Site 3 (S_3) was near Boating site, where there was lot of human intervention by activities of tourists. Surface water sample for physico-chemical analysis was collected from the selected locations using sampling bottles (250ml), during morning hours of the day between 10:00 am to 11:00 am.

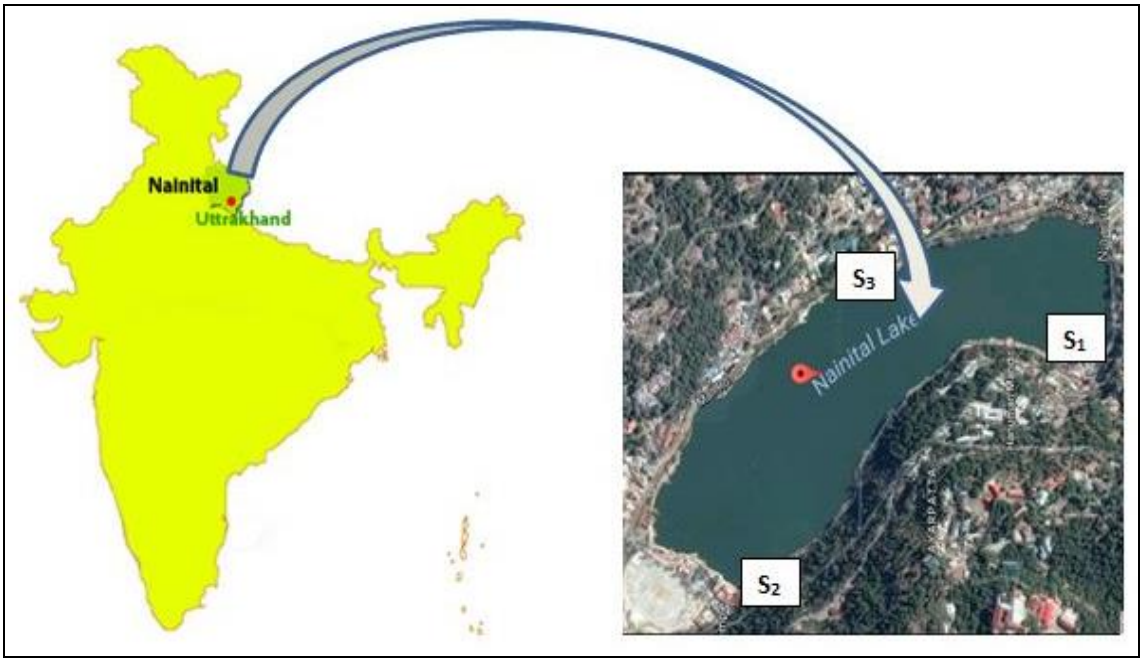

Fig 1: Location of sampling stations at Lake Nainital of India

2.3 Parameters and Analytical procedure

Fortnight sampling of lake water was done to examine-

- ✓ Physical parameters like transparency, temperature, electrical conductivity and total dissolved solids.
- ✓ Chemical parameters such as pH, dissolved oxygen, free carbon-dioxide, alkalinity and nitrate and phosphate concentration.
- ✓ Biological investigation includes qualitative and quantitative estimation of phytoplankton.

The air temperature, water temperature, transparency, conductivity, pH, total dissolved solids (TDS), dissolved oxygen (DO), free carbon-dioxide (CO_2) were analysed using standard methods at the site itself while alkalinity, nitrate and phosphate were analysed at the research laboratory of Department of Aquatic Environment Management, College of Fisheries, GBPUA&T, Pantnagar following APHA, 2012 [8]. On-site measurement of transparency and temperature was performed with the help of 25 cm diameter Secchi disk and mercury thermometer respectively. 100 litres of water was filtered from the surface with minimal disturbance using plankton net for collection of phytoplankton sample. Plankton samples were collected in specimen tubes and preserved in Lugol's iodine (0.3ml/ 100ml sample). Identification of phytoplankton was done using high power (40 X) of the compound microscope was done using reference books [9, 10, 11, 12].

2.4 Statistical Analysis

Monthly data of physico-chemical parameters as well as phytoplankton population was subjected to statistical analysis by using software SPSS version 16.0., MS Excel and correlation was used to examine seasonal changes in abiotic and biotic parameters and establishing relation between them.

3. Results and Discussion

The values of observed physico-chemical parameters during the study period are presented in the Table-2, while the per cent composition of different genera at selected sites S_1, S_2 and S_3 is presented in Fig 2, 3 and 4 respectively.

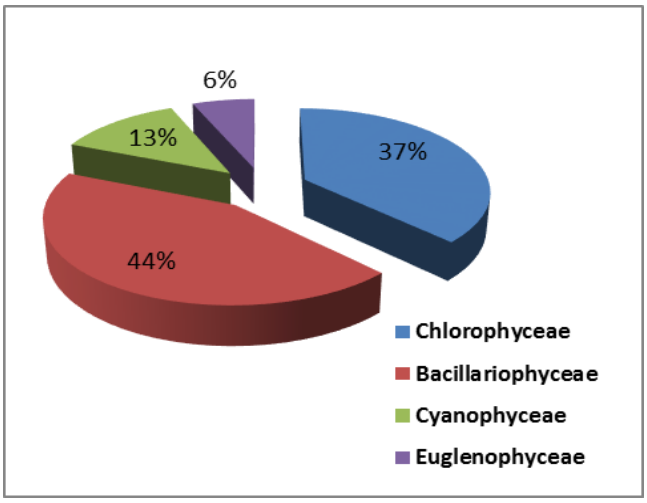

Fig 2: Per cent composition of various classes of phytoplankton at site S1

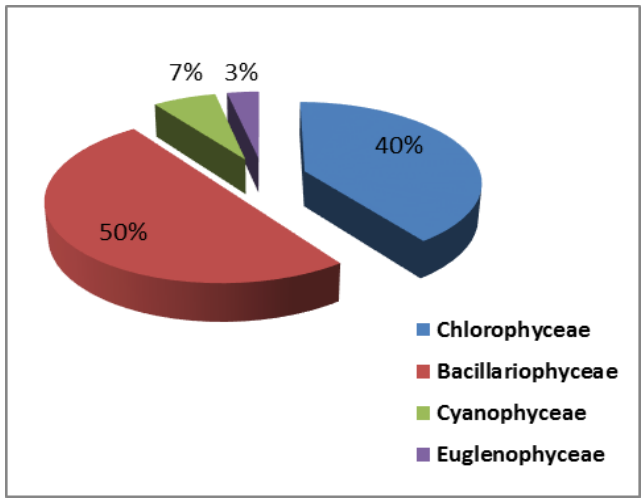

Fig 3: Per cent composition of various classes of phytoplankton at site S2

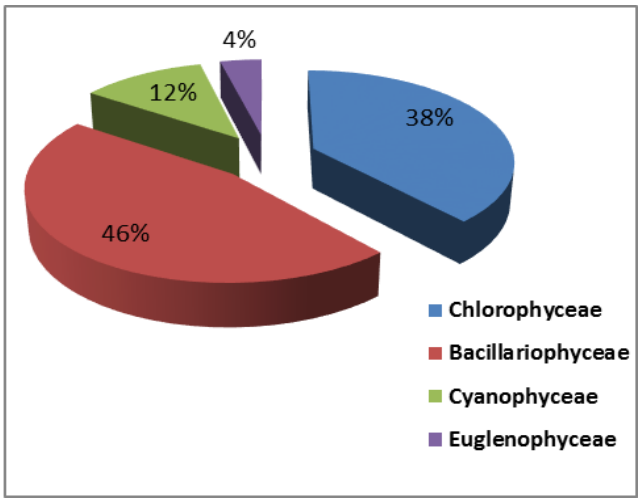

Fig 4: Per cent composition of various classes of phytoplankton at site S3

Table 2: Average mean and standard deviation of physicochemical parameters at selected sites S_1, S_2 and S_3.

Parameters	Site 1	Site 2	Site 3
Water Temperature (ºC)	17.89±3.26	18.66±3.04	18.7±3.26
Transparency (cm)	227.82±39.39	220.40±30.65	212±26.52
Electrical Conductivity (µScm^{-1})	169±12.36	172.46±15.46	175±14.28
TDS (mgL^{-1})	184.15±69	188.12±16.75	194.18±19.37
pH	7.76±0.28	7.78±0.31	7.85±0.27
Alkalinity (mgL^{-1})	192.25±21.90	190.81±25	190.68±17.63
Total Hardness (mgL^{-1})	167.5±32.09	176.87±34.73	182.18±37.25
Dissolved oxygen (mgL^{-1})	6.9±0.49	6.53±0.67	6.61±0.49
Free CO_2 (mgL^{-1})	5.18±0.72	5.96±0.93	6.375±1.01
Nitrate (mgL^{-1})	0.515±0.143	0.56±0.151	0.53±0.16
Phosphate (mgL^{-1})	0.53±0.028	0.083±0.069	0.066±0.051

As far as thermal profile of the lake is considered highest temperature (23.8 ^{0}C) was observed in the month of September at boating site (S_3) while lowest temperature (14.25 ^{0}C) was recorded at the aeration plant (S_1) in the month of December. The trend in variability of thermal regime indicated lowest temperature profile of site S_3 all over the period as the site has least anthropogenic activities and also the aeration plant, while Site S_3 showed maximum mean average temperature this may be due to maximum anthropogenic activities at this site.

In the present study maximum value of transparency was observed in winter season during the month of January. It may be due to low dissociation rate of organic matter and also sedimentation of suspended soil particles. It was found that transparency remained high during winter which is due to the lower rate of decomposition and less human activities during winter season in Wular Lake at Kashmir [13].

Electrical conductivity shows significant positive correlation with total dissolved solids and hardness of water body as mobility of calcium and magnesium ions of water body increases with increase in temperature. Among all the three sites maximum (175 ± 14.28 µScm^{-1}) and minimum conductivity (169.18 ± 12.36 µScm^{-1}) were recorded at boating site (S_3) and aeration plant (S_1) respectively. A similar trend of seasonal variation in conductivity was depicted at Oti river in Ghana in which variation was observed from a

minimum in December to a maximum in May [14].

Maximum and minimum monthly values of total dissolved solids were observed at site S_3 and site S_1 respectively during the study period. Highest value of total dissolved solids was 232.5 mgL^{-1}, recorded in the month of April at Site S_3 while minimum value of TDS was 163 mgL^{-1} in January at S_1. Higher TDS in summer season may be attributed to increased decomposition process during summers. Similar findings have been reported with regards to seasonal variations of TDS of Almatti Reservoir at Bijapur district of Karnataka and found that highest values of TDS were recorded in summer season and least during winter months [15].

Overall mean value of pH of all the three sites S_1, S_2 and S_3 during study period was 7.76, 7.78 and 7.85 respectively. pH of Lake Nainital shows positive correlation with temperature. Highest pH was observed in March while November shows lowest pH range. Similar results of low pH in winter and high pH in summer were also observed at Nigeria [16]. More pH in summers may be attributed to increased rate of decomposition of carbonate rocks at high temperature.

During the investigation period highest alkalinity was 220 mgL^{-1} which was recorded at S_1 in the month of January, while lowest value (163.5 mgL^{-1}) was recorded in the month of September at S_2. Same increasing pattern of alkalinity with decrease in temperature is followed at Anchar Lake of Kashmir Himalayas [17]. Similar range of alkalinity was observed in Morana Lake of Maharastra [18].

Highest value of hardness was 230 ± 11.45 mgL^{-1}, it was observed in April and was found to be positively correlated with temperature. The reason for higher hardness values during summer may be due to decrease in water volume and increase in rate of evaporation at higher temperature. Minimum value of hardness was recorded in January; it may be associated with low decomposition rate in winters due to low temperature. Hardness of water is due to cations of calcium, magnesium, manganese and iron. From fisheries point of view hard waters are more productive than soft waters [19].

Dissolved oxygen is very important parameter to estimate productivity of aquatic flora and fauna in aquatic ecosystem, so it serves as an indicator for determining conditions of lake. Highest content of dissolved oxygen throughout the experiment period was 7.43 mgL^{-1}, which was recorded in December due to low temperature, while lowest dissolved oxygen content was 5.98 mgL^{-1} in the month of September. Concentration of dissolved oxygen shows inverse relationship with thermal profile of lake [20]. Similar average dissolved oxygen content of 5.75 mgL^{-1} was reported at Lake Pichhola of Udaipur [21].

Mean average free carbon-dioxide content at site S_3 was maximum and at site S_1 it was minimum, with monthly average values of 6.375 ± 1.01 mgL^{-1} and 5.18 ± 0.72 mgL^{-1} respectively. Highest CO_2 load at boating site S_3 may be due to high pollutant load at the site, as there is continuous boating activities and discharge of drainage from nearby hotels. Variations in free CO_2 content of water body is influenced by human activities, runoff from catchment area, rate of photosynthesis, diffusion and decomposition [22].

Out of the three sites, highest monthly mean of total nitrate content (0.56 mgL^{-1} with a standard deviation of 0.151 mgL^{-1}) was recorded at site S_3, whereas site S_1 possessed minimum monthly mean nitrate content of 0.515 mgL^{-1}. Nitrate was present in higher concentration in the water due to the application of NPK fertilizers in farms and its entry through water run-offs into the Kudiddiffi stream at Nigeria [23].

The mean monthly phosphate content of site S_1 (0.053 ± 0.028 mgL^{-1}) was minimum, while at site S_2 it was maximum (0.083 ± 0.069 mgL^{-1}) among all the three sites. Highest value of phosphate content was 0.25 mgL^{-1}, which was recorded at site S_2 in December; this may be due to nutrient inflow from catchment areas. Phosphorus content within a range of 0.015 to 0.0575 mg L^{-1} was also reported in various seasons at lower Manair reservoir of Karimnagar district, Andhra Pradesh [24]. Phosphate concentration shows positive correlation with nitrate content in water, this positive relation was also reported at Bellandur Lake, Varthur Lake and TG Halli of Greater Bangalore [25].

During the course of the study a total of 41 genera of phytoplankton belonging to different groups were recorded. Out of the total 41 genera, 16 genera of Chlorophyceae, 20 genera of Bacillariophyceae, 2 genera of Euglenophyceae and 3 genera of Cyanophyceae was observed. Bacillariophyceae was recorded as dominant group. This finding is similar in which a total of 25 genera of phytoplankton, belonging to three classes Bacillariophyceae (13 genera), Chlorophyceae (8 genera) and Cyanophyceae (4 genera) at Nainital Lake was recorded from 2007 to 2009 [26]. Study of phytoplankton community structure and species diversity of Nangal wetland, Punjab, India shows that in fresh water ecosystems Bacillariophyceae, Chlorophyceae and Cyanophyceae make up the three major groups of algae [5]. During the present study two peaks of phytoplankton density was observed, summer peak was in April and winter peak in January dominated by green algae and diatoms. It was found that number of genera and species of different algal groups were maximum during summer, declined during monsoon and again increased during winter [27].

Correlation coefficients calculated between various physico-chemical attributes and density of phytoplankton dwelling in Lake Nainital has been presented in Table-3. Density of phytoplankton was positively correlated to conductivity, TDS, hardness, transparency, pH, alkalinity and nitrate content while it was negatively correlated to temperature, dissolved oxygen, free carbon-dioxide and phosphate content of water. The study on Tighra reservoir of Gwalior, Madhya Pradesh also revealed that phytoplankton density had positive relationship with pH, alkalinity, hardness and negative correlation with dissolved oxygen [28]. The penetration of light, temperature, pH, hardness, phosphate and nitrate are important factors for growth and density of phytoplankton in aquatic habitat [29].

Table 3: Correlation coefficient between various physico-chemical parameters and phytoplankton

	Temperature	Transparency	Conductivity	TDS	Hardness	pH	Alkalinity	DO	CO2	Nitrate	Phosphate	Phytoplankton
Temperature	1											
Transparency	-.701*	1										
Conductivity	.777*	-.433	1									
TDS	.761*	-.824**	.618	1								
Hardness	.635*	-.538	.632*	.800**	1							
pH	.412	-.245	.748*	.523	.700*	1						
Alkalinity	-.695*	.752*	-.312	-.734*	-.298	.093	1					
DO	-.786*	.497	-.705*	-.756*	-.874**	-.732*	.301	1				
CO2	.884**	-.696*	.581	.749*	.810**	.359	-.588	-.815**	1			
Nitrate	-.666*	.872**	-.316	-.815**	-.429	.008	.961**	.344	-.639*	1		
Phosphate	-.421	.066	-.327	-.270	-.564	-.531	.017	.612	-.563	.003	1	
Phytoplankton	-.334	.115	.097	.127	.436	.433	.365	-.055	-.111	.179	-.017	1

*. Correlation is significant at the 0.05 level (1-tailed)

**. Correlation is significant at the 0.01 level (1-tailed).

4. Conclusion

Assessment of existing physico-chemical parameters and phytoplankton community of Lake Nainital indicates that maximum density of phytoplankton was present in the month of April due to cumulative effect of favorable physico-chemical parameters. Out of the three sites S_1, S_2 and S_3 maximum and minimum mean densities of phytoplankton were recorded at sites S_2 and S_3, respectively. Site S_1 provides optimum conditions for propagation of maximum floristic diversity of Lake while due to more human interaction and polluted water quality Site S_3 exhibits least diversity. It was concluded from the study that physico-chemical parameters play major role in determining the density, diversity and occurrence of phytoplankton. Per cent composition of various groups of phytoplankton was 44 for Bacillariophyceae, 37 for Chlorophyceae, 13 for Cyanophyceae and 6 for Euglenophyceae at Site S_1, while at Site S_2 it was 50 for Bacillariophyceae, 40 for Chlorophyceae, 7 for Cyanophyceae and 3 for Eugenophyceae. Site S_3 exhibits 46, 38, 12 and 4 per cent of Bacillariophyceae, Chlorophyceae, Cyanophyceae and Euglenophyceae respectively of the total phytoplankton population. Bacillariophyceae forms most dominant group followed by Chlorophyceae, Cyanophyceae and Euglenophyceae. The complete evaluation of phytoplankton and physico-chemical aspects of the lake indicates that lake water is still optimum for aquatic flora and fauna but it is quickly shifting towards eutrophication. So, it can be suggested that by reducing the amount of pollution load, the rate of deterioration of water quality can be lowered.

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