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Phytoplankton Dynamics at Diverse Depths in the Nigeen Lake of Srinagar city, Kashmir Himalaya

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ABSTRACT

Phytoplankton community responds to various environmental stressors in aquatic ecosystems, but there is little information how they respond along the water column. In this context, present study was designed to see a distributional pattern of Phytoplankton and physico-chemical characteristics in the Nigeen Lake at various depths along the water column from November 2015 to April 2016. A perusal of the data obtained revealed the presence of 48 taxa, dominated by class Bacillariophyceae-22 taxa (75.49% relative density), and followed by Chlorophyceae- 20 taxa (20.22%), Cyanophyceae- 4 taxa (4.1%) and Euglenophyceae- 2 taxa (0.18%). Bacillariophyceae and Chlorophyceae were dominant numerically at all depths while Cyanophyceae was abundant at 1m and 1.5 m depths. On the other hand, Euglenophyceae represented by 2 taxa was restricted only at 1 m depth. Highest similarity coefficient of 82.67% was observed between 1.5m and 1m depth and lowest similarity coefficient of 32.65 % was found between 1m and 4m depth. Chemical Pollution Index (PB) was highest at 4m depth, while as community pollution value was highest at central site with 2m depth. Species pollution value was highest (5.51) for dominant species like *Cymbella* sp., *Navicula* sp., *Fragilaria* sp. and *Chlorella* sp. Application of various chemical, biotic indices and statistical analysis to data sets proved our hypothesis that the phytoplankton density and diversity decreases with increasing depth along the water column.

Key words: *Phytoplankton composition, Nigeen Lake, Cluster analysis, Vertical zonation, Community pollution index*

INTRODUCTION

Freshwater ecosystems render enormous goods and services for mankind, but off late anthropocene have witnessed the degradation in such services (Zhang *et al.,* 2007; Taranu *et al.*, 2015; Khanday *et al.,* 2018 and Allende *et al.*, 2019). As "lake is a reflection of its watershed," inferring that physico-chemical and biological setup of any lake ecosystem is directly interrelated with the characteristics and conditions of the lake's watershed. Urban sprawl has developed matter of apprehension in conservation ecology, primarily due to drastic modifications in habitat configuration and reduction in endangered species (Allende *et al.*, 2019). Phytoplankton being free-floating microscopic plants, primary producers fueling the aquatic food webs and are imperative constituents operated in monitoring, assessment, restoration and management of freshwater ecosystems (Cottingham and Carpenter,1998; Arhonditsis *et al.,* 2003, 2007 and 2005 and Qinghai *et al.,* 2010). The natural continuum of the lake ecosystem being multidimensional, and therefore Phytoplankton composition not merely respond to natural alteration but also characterize eccentricity as a consequence of human intervention degrading the lake ecosystem. Hydrology, seasonal alterations in temperature, light and nutrient accessibility are the most important variables which determine plankton abundance and composition (Cantonati *et al.,* 2010 and Vadebon coeur *et al.,* 2014). Lake morphometric features, in addition to nutrient contents and other factors play an important role in the distribution of phytoplankton populations (Agbeti and Smol, 1995 and Danilov and Ekelund, 1999, 2000, 2001). The ever increasing human population growth (Kunzig, 2011), land system changes (Roy *et al.,* 2015) and inadequate water treatment systems (Jamwal *et al.,* 2009) greatly influence the health of lake systems. Lakes in Kashmir are facing multiple pressures that include catchment scale land system changes (Rather *et al.,* 2016), urbanization (Amin *et al.,* 2014 and Rashid *et al.,* 2017), untreated sewage ingress (Parvez and Bhat, 2014), nutrient enrichment (Romshoo and Muslim, 2011 and Badar *et al.,* 2013) and sediment load (Rashid and Aneaus, 2019) that not only affect their water quality (Vass, 1980; Najar and Khan, 2012,Bhat and Pandit, 2014) but also aquatic biodiversity (Zutshi and Gopal, 2000; Khan *et al.,* 2004; and Bhat *et al.,* 2012)˙ Continuous sewage emancipation from houseboats and habitations is the main culprit for increasing organic pollution load and resulted in enhancement of eutrophic aquatic weeds in and around houseboats and habitational areas. Although some researchers have worked on various aspects of plankton ecology and water chemistry in freshwater habitats of Kashmir valley (Zutshi *et al.,* 1980; Kundangar *et al.,* 1995; Kundangar, 2002; Kundangar and Abubakr, 2004; Ganie *et al.,* 2010; Yaseen and Yousuf, 2013;Baba and Pandit, 2014; Ulfat *et al.,* 2015; Nissa and Bhat, 2016; Ahmad *et al.,* 2017; Maryam, 2017; Rashid *et al.,* 2017; Khanday *et al.,* 2018 and Abubakr *et al.,* 2018) yet little or no information and understanding available on vertical differences in terms of diversity and density of phytoplankton in lake ecosystems of Kashmir Valley including Nigeen lake. Lakes due to their intrinsic and extrinsic vulnerability are regarded as sentinels of environmental changes caused by various anthropogenic effects, thereby acting as one major threat to the ecological integrity of lentic systems (Hsieh *et al.,* 2011 and Sutton *et al.,* 2013). The ecological assessment of lake using water chemistry and phytoplankton attains an importance in this direction. Despite the role played by phytoplankton in primary production, very less number of studies is available regarding their distributional pattern in water column.

Keeping in view, the scenario of rapid urbanization and anthropogenic stresses in and around the Nigeen Lake, this study aimed at highlighting the vertical zonation of phytoplankton community dynamics and effect of environmental factors like nutrient dynamics, temperature, and transparency at varying depths in shaping their distribution along the water column.

MATERIAL AND METHODS

Study area and study sites

Nigeen lake “Jewel in a Ring”, an offshoot of Dal lake is situated 9 Km away from Srinagar towards North- East at the latitude of 34°7ˈ13''N and longitude of 74°49ˈ40''E with an elevation of 1584 m amsl (Rather *et al.,* 2013). Nigeen Lake in the North- East side is fed by Dal Lake via a narrow channel at Ashaibagh Bridge, while on its North-West side Nigeen Lake drains into Khushalsar Lake through Nallah Amir Khan. An elongated channel to the South-West of Nigeen Lake drains water directly to the river Jhelum. The lake is under anthropogenic stress which is evident from the lake area which has been reduced from 0.79 km^2 in 1971 to 0.65 km^2 in 2004 (Kundangar *et al.,* 1995; Jan *et al.,* 2015) while as settlement area has increased by 30.39% within lake from 2003-2016 (Dar *et al.,* 2020). The unabated encroachment by way of floating gardens, house boats, in-situ sewage entry has not only impacted most of the open water to narrow channels but has also lead to the deterioration of water quality. A total of four study sites (with different sampling depths), were chosen to study the vertical alteration in phytoplankton assemblages of Nigeen Lake (Table 1 and Fig. 1).

Table 1. Description of sampling points with varying depths in Nigeen Lake

Site Description	Average depth	Latitude	Longitude
Site I (Ashaibagh)	1.5 m	34˚06΄53.6״	74˚50΄06.2״
Site II (Khujyarbal)	1 m	34˚06΄39.2״	74˚49΄40.6״
Site III (Saderbal)	2 m	34˚07΄35.9״	74˚49΄40.6״
Site IV a (Centre)	2 m	34˚07΄29.0״	74˚49΄43.8״
Site IV b (Centre)	4 m	34˚07΄29.0״	74˚49΄43.8״

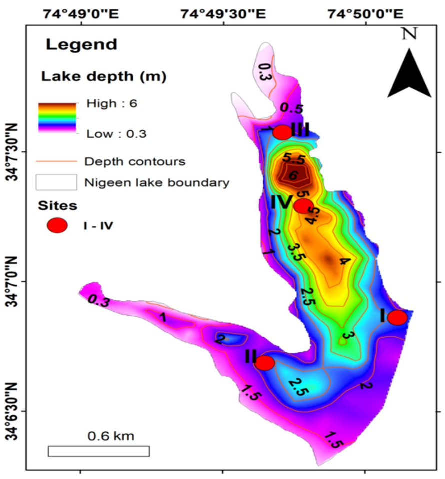

Fig. 1. Bathymetric map along with study sites of Nigeen Lake (Source: Esri,Digital Globe,CNES/Airbus Ds)

Phytoplankton composition collection, identification and enumeration

Phytoplankton samples for qualitative and quantitative analysis were collected from diverse depths of the lake using Ruttner sampler. Plankton net with mesh size 64 µm was employed for filtration and a volume of 50 liters of water was filtered in the vertical direction. The sampling was carried out from November 2015 to April 2016. Samples were preserved in 4% formalin and Phytoplanktonic identification and enumeration was carried out with the help of standard taxonomic works (Prescott, 1939; Edmondson, 1992; Cox, 1996; Jumppanen, 1996; Biggs and Kilroy,2000 and APHA, 2012). Identification of Phytoplankton community up to generic level was carried out under Binocular microscope (Magnus MLX-DX Olympus (India) pvt. ltd.). Community pollution value (CPV) was calculated at every sampling station which consisted mainly of PB and species pollution value (SPV) (Jiang and Shen, 2003; Jiang, 2006 and Guo *et al.,* 2010).

PB was calculated in accordance with the CPCB 2017 surface water standards (Dissolved oxygen, Nitrate nitrogen, Total phosphorus, pH, Conductivity and TDS).

PB = $\sum_{i=1}^{n} Pi$ *Pi* = $\frac{CS}{CU}$

Where

PB = Chemical pollution index

Pi= Comprehensive chemical pollution index for a single parameter

CS = Concentration of chemical parameter at particular sampling point

CU = Maximum permissible limit of chemical parameter according to CPCB standards

n=Total number of chemical parameters (here n= 6)

SPV was calculated as

$$SPV = \frac{\sum_{i=1}^{m} \ln\left(\frac{10PB}{n}\right) i}{N}$$

Where

SPV = Species pollution value

n = Total number of chemical parameters

N = total number of sampling stations

Biotic index or community pollution value was calculated as

$$CPV = \frac{\sum_{i=1}^{n} SPVi}{n}$$

Where n is number of species at particular sampling site

Physicochemical Parameters and bathymetric features

Water samples from selected depths were collected in one liter sampling bottles (Polyethylene) and were brought to the laboratory for analysis. In situ measurements of pH, Total Dissolved Solids (TDS) and conductivity were done with multi-parameter probe (Eutech PCSTEST35 -01x441506/ Oakton 35425-10). The remaining water quality parameters were determined in the laboratory following the standard protocols of APHA (2012). The random sampling method was followed for measuring depth of water column, depth was measured at

120 points in order to cover the whole Nigeen Lake. Depth was determined with graduated metallic rod. Nigeen Lake bathymetric surface map was created using natural neighbor interpolation in the Arc GIS 10.2 version. Transparency was estimated by Secchi disc (20cm diameter) attached to graduated non-stretchable rope.

Statistical analysis

Cluster analysis was applied for phytoplankton species composition matrices by using the Euclidean distance algorithm in computer package Minitab 18.0 (Danilov, 2000; Danilov and Ekelund, 1999, 2001 and Oliveira, 2020) and Multiple correlation matrices were calculated with the help of Microsoft excel 2013. Phytoplankton diversity indices were calculated using Paleontological statistics software (PAST software).

RESULTS AND DISCUSSION

The rapid growth of population, unplanned urban development and highly intensified agricultural practices in and around the vicinity of Nigeen Lake over a period of time, resulted in the establishment of a large quantity of waste material leading to the continued dilapidation of the lake ecosystem. Analysis of the data revealed 48 genera of planktonic algae throughout the course of study, wherein class Bacillariophyceae was dominant with 22 taxa followed by Chlorophyceae having 20 taxa, Cyanophyceae with 4 taxa and Euglenophyceae with 2 taxa (Fig. 2) (Table 2). Bacillariophyceae and Chlorophyceae species were dominant at all depths, highest diversity and density was found up to 2 m depths. Bacillariophyceae taxa like *Cymbella* sp., *Amphora* sp., *Tabellaria* sp., *Meridion* sp., *Navicula* sp., *Gomphonema* sp., *Synedra* sp., and *Fragillaria* sp. were present approximately at all depths while as species such as *Melosira* sp., *Pinnularia* sp., *Amphipleura* sp., *Asterionella* sp. and *Frustulia* sp. were present at 1-2m depths. The most abundant species among Chlorophyceae in terms of density and presence at varying depths were *Chlorella* sp., *Chlorococcum* sp., *Cosmarium* sp., *Scenedesmus* sp., *Pediastrum* sp., and *Selanastrum* sp. Species such as *Staurastrum* sp., *Hydrodictyon* sp., *Coelastrum* sp., *Closterium* sp., *Oedogonium* sp., and *Oocystis* sp. were least abundant. In accordance with studied depths, Cyanophyceae was abundant at 1m and 1.5m depth, the presence of Cyanophyceae can be related to higher nutrient enrichment as compared to other investigating depths (Nissa and Bhat, 2016). Euglenophyceae species like *Euglena* sp. and *Phacus* sp. were present only at 1m depth indicating considerable inputs of organic matter to lake ecosystem mainly due to entry of sewage and accumulation of feacal matter from house boats (Nissa and Bhat, 2016).

Vertical differences between phytoplankton communities of Bacillariophyceae, Chlorophyceae, Cyanophyceae and Euglenophyceae at different depths could be revealed at every investigated depth of the Nigeen Lake (Danilov and Ekelund 2001). The highest similarity coefficient 82.67% was documented between 1.5m and 1m depth and lowest similarity coefficient 32.65 % was accounted between1m and 4 m depth (Fig. 3). Highest similarity coefficient between 1 m and 1.5 m depth was due to presence of similar phytoplankton assemblages while as 4m depth was mainly represented by Bacillariophyceae and Chlorophycae. Presence of these groups at higher depths is due to the sinking velocities of Bacillariophyceae and remain suspended in the water column (Ptanick *et al.,* 2003; Rakocevic-Nedovic and Hollert, 2005 and Karpowicz and Ejsmont-Karabin, 2017). Bacillariophyceae symbolize an imperative assemblage of algae accounted to be prevailing amongst phytoplanktonic assemblages in lake and wetland ecosystems (Tian *et al.,* 2013; Mir and Kachroo, 1982; Zutshi *et al.,* 1980 and Rakocevic-Nedovic and Hollert, 2005).The prevalence of species like *Navicula, Pinnularia, Fragilaria*sp.*, Nitzschia* sp.*.,* *Cosmarium* sp., *Scenedesmus* sp., *Pediastrum* sp., *Coelastrum* sp., in the Nigeen Lake portray elevated trophic stage, as these diatom species develop copiously in waters loaded with organic pollution (Qadri and Yosuf, 1978; Wetzel, 1983; Hondzo and Stefan, 1993). *Anabaena* sp. and *Oscillatoria* sp. were found upto 2m depth while as *Nostoc* sp. and *Microsystis* sp. were present upto 1.5m depth. *Anabaena* sp. and *Oscillatoria* were dominant in the month of April. Our observations point out that Cyanophyceae prefers to dominate at high irradiance levels and high temperature as also reported else here by many investigators (Richardson, 1986; Ricahrd and Zohary, 1987; Tulonen *et al.,* 1994 and Savadova *et al.,* 2018). Phytoplankton species like *Anabaena* sp., *Oscillatoria* sp. and *Microcystis.* sp. are the charecteristics of eutrophic Lakes (Munawar, 1970; Holland and Beeton, 1972; Sommerfeld *et al.,* 1975; Wetzel, 1983 and Novais *et al.,* 2019).

Physicochemical water quality parameters are important for optimal growth of Lake biota as it helps in maintenance of various activities such as respiration, metabolism and reproduction (Sargaonkar and Deshpande, 2003), but the two most critical factors that have a profound influence on aquatic biodiversity are phosphorus and nitrogen (Ray *et al.,* 2020). Phosphorus concentrations less than 10 µg/l generally is considered oligotrophic, conversely concentration of 100 µg/l is used as threshold limit for hyper-eutrophication (Yang *et al.,* 2018; Cheng and Li, 2006; Likens *et al.,* 1977 and Richardson *et al.,* 2007). Dominant species like *Fragillaria* sp., *Cymbella* sp. and *Chlorella* sp. were positively correlated with total phosphorus (Table3). Higher concentrations of total phosphorus were observed throughout the water column, ranging from 283.5-799 µg/l (Table 4), clearly indicate that the lake is in hyper eutrophic state. The major sources of total phosphorus are domestic sewage, detergents, fertilizers and natural runoff while as increased concentrations of total phosphorus at increased depths could be attributed to release of phosphorus from sediments under anoxic conditions (Schernewski, 2003). Inorganic forms of nitrogen like nitrate nitrogen and ammoniacal nitrogen ranged from 500-1292 µg/l and 10.6-47.0 µg/l (Table 4). NO_3–N and NH_3–N levels were positively correlated with density of dominant species like *Amphora* sp. and *Navicula* sp. Ammoniacal nitrogen concentrations could be attributed to longer extend of sewage and fecal content in water body while as nitrate nitrogen concentrations may be due to biological oxidation of nitrogenous organic matter which includes domestic sewage and agricultural run-off (Vass and Zutshi, 1979 and Ray *et al.,* 2020). Water temperature fluctuated from 4˚C at 4m depth in February to 15˚C at 2m depth in April (Table 4). Water temperature was positively correlated with density pattern of *Amphora* sp., while as it was negatively correlated with species like *Gomphonema* sp., *Fragillaria* sp., *Navicula* sp. and *Tabellaria* sp. (Table3) (Qadri and Yosuf, 1978; Wetzel, 1983; Yousuf *et al.,* 1986; Hondzo and Stefan, 1993; Yeole and Patil,2005 and Ke *et al.,* 2008). A close relationship between water and air temperature in Nigeen Lake was recorded which is in conformity with the findings of other researchers (Qadri and Yosuf, 1978; Wetzel, 1983;Yousuf *et al.,* 1986 and Hondzo and Stefan, 1993). The depth of the Nigeen Lake fluctuated from 1.75m at site II to 6m at site IV (Fig.4a-4d). The depth of a lake is mainly associated with river and stream inflows, precipitation, snow melting (Tian *et al.,* 2013), augmentation in water flow, degree of dry period and sediment load. Transparency varied from 1.4m at site II to 2.7m at site IV (Table 4). The fluctuations in transparency can be ascribed to phytoplankton composition, suspension of phytoplankton species in water (Zutshi *et al.,* 1980; Mir and Kachroo, 1982; Ganai *et al.,* 2010;Tian *et al.,* 2013 and Oterler, 2018), volume of Lake (Sarwar and Zutshi, 1987), accumulation of sewage (Siraj *et al.,* 2010) and sedimentation rate (Donohue and Molinos, 2009).

Biotic diversity indices serve a vital tool, indicating water quality of fresh water ecosystems (Kutlu *et al.,* 2020). Oligotrophic freshwater ecosystems are characterized by rich diversity with low dominating species while polluted water ecosystems lack sensitive species while tolerant species become dominant (Kutlu *et al.,* 2020). Higher values of Shannon Weiner and Mergalef indices indicate oligotrophic state while lower values indicate higher pollution load (Fig 5a-5b) (Margalef, 1958 and Kutlu *et al.,* 2020). PB varied between 20.15 to 33.68 at 1m- 4m depth (Table 5), indicating increasing depths has higher concentrations of chemical parameters like Total phosphorus, nitrate nitrogen, conductivity and TDS. Lower values of the Shannon wiener index were observed at increasing depths. Species pollution value was calculated in the presence and absence of species at every sampling site which gives the tolerance capacity to water pollution and higher values of SPV depicts greater fitness of species under polluted conditions (Jiang and Shen, 2003; Jiang, 2006 and Guo *et al.,* 2010). Community pollution value is the summation of SPV of all species at particular sampling station, depicts the tolerance capacity of whole phytoplankton community and higher CPV values clearly indicate more dominant species. Community pollution index was also in accordance with the chemical pollution index as higher PB indicate higher CPV but lower CPV was calculated at 2m depth with least dominant species.

Cluster analysis clearly depicts that there is decrease in density and diversity with increase in depth. Cluster I consist two sites (1m and 2 m depth) and Cluster II consists of three sites within 2m-4m depth (Fig.6), these cluster are different from each other on the basis of Shannon Wiener index, Species pollution value and chemical pollution index. Authors are of the view that the present study was restricted to some months only and on shallow lake, it would be better to extend this line of research to other deep lakes with extensive sampling.

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Table 2. Percentage composition and species pollution value of phytoplankton taxa at different sites of varying depths in Nigeen lake ecosystem (Site I, 1.5m depth, Site II, 1m depth, Site III, 2m depth, Site IV a, 2m depth and Site IV b, 4m depth)

Species/Genus	November					January					February					April					SPV
	1.5 m	1m	2m	2m	4m	1.5 m	1m	2m	2m	4m	1.5 m	1m	2m	2m	4m	1.5 m	1m	2m	2m	4m	
Chlorophyceae																					
Closterium sp.	-	-	-	1.5	-	-	-	-	-	-	-	-	-	-	-	0.9	0.9	-	2.3	-	1.10
Chlorella sp.	4.1	3.3	6.1	6.2	16.7	3.0	2.5	2.8	4.8	11.1	2.2	1.9	2.5	4.2	16.7	5.7	3.6	4.5	6.8	27.3	5.51
Chlorococcum sp.	2.0	1.9	2.3	3.1	-	1.0	1.0	1.8	1.6	-	0.5	0.0	-	-	-	1.9	1.8	3.0	-	-	3.31
Cosmarium sp.	2.0	2.3	2.3	3.1	-	0.5	0.5	-	-	-	-	-	-	-	-	2.8	1.8	4.5	6.8	-	2.75
Hydrodictyon sp.	-	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.28
Klebsormidium sp.	1.6	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	3.8	2.7	-	-	-	1.38
Oedogonium sp.	-	0.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.28
Pediastrum sp.	0.8	-	3.0	3.1	-	-	-	1.8	1.6	-	-	-	1.3	0.0	-	1.9	3.6	4.5	4.5	-	2.75
Pandorina sp.	-	0.9	-	-	-	-	0.5	-	-	-	-	0.6	-	-	-	-	3.6	3.0	-	-	1.93
Rhizoclonium sp.	2.0	-	-	-	-	1.0	-	-	-	-	-	-	-	-	-	1.9	1.8	-	-	-	1.10
Scenedesmus sp.	2.9	2.3	4.5	4.6	5.6	1.5	1.0	2.8	3.2	-	1.1	1.2	2.5	4.2	-	3.8	4.5	4.5	6.8	-	4.41
Selenastrum sp.	2.0	2.3	-	4.6	-	1.5	1.5	-	1.6	-	0.5	0.6	-	2.1	-	-	2.7	-	4.5	-	3.03
Spirogyra sp.	1.2	1.4	3.0	-	-	1.0	1.0	1.8	-	-	1.1	1.2	1.3	-	-	2.8	2.7	-	-	-	3.03
Sphaerocystis sp.	-	1.4	-	4.6	11.1	-	1.0	-	3.2	5.6	-	1.2	-	4.2	-	-	2.7	-	6.8	18.2	3.03
Staurastum sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.9	-	-	-	-	0.28
Zygnema sp.	0.8	-	-	-	-	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.55
Mougeotia sp.	-	-	1.5	-	-	-	-	0.0	-	-	-	-	0.0	-	-	-	-	4.5	-	-	0.55
Oocystis sp.	-	-	-	3.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.5	-	0.55
Ulothrix sp.	-	-	2.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.28
Chorococcus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.7	5.4	-	-	-	0.55

Bacillariophyceae																					
Amphora sp.	6.1	4.7	10.6	6.2	11.1	7.0	6.4	13.8	9.7	16.7	8.2	7.4	15.0	12.5	16.7	3.8	3.6	6.0	6.8	-	5.23
Amphipleura sp.	1.6	2.3	-	-	-	1.5	2.0	-	-	-	1.6	1.9	-	-	-	1.9	1.8	-	-	-	2.20
Cocconeis sp.	2.4	2.3	-	-	-	1.5	2.0	-	-	-	1.6	1.9	-	-	-	-	2.7	3.0	-	-	2.20
Cyclotella sp.	2.0	0.5	-	1.5	-	2.0	1.0	-	3.2	-	0.5	-	-	-	-	3.8	1.8	4.5	4.5	-	3.03
Cymbella sp.	12.2	11.7	9.1	10.8	22.2	15.9	15.8	12.8	14.5	22.2	16.3	17.3	15.0	16.7	25.0	11.3	10.8	10.4	9.1	27.3	5.51
Diatoma sp.	1.2	0.9	-	-	-	1.0	1.5	-	-	-	1.6	2.5	-	-	-	5.7	1.8	-	-	-	2.20
Epithemia sp.	4.1	3.7	6.1	-	-	5.0	5.0	6.4	-	-	4.3	6.2	6.3	-	-	2.8	2.7	6.0	-	-	3.31
Fragillaria sp.	4.1	7.5	7.6	6.2	11.1	6.0	8.4	10.1	9.7	16.7	7.6	9.3	12.5	10.4	25.0	8.5	3.6	7.5	11.4	18.2	5.51
Frustulia sp.	-	0.9	2.3	-		-	0.5	1.8	-		-	-	2.5	-		-	-	-	-		1.10
Gomphonema sp.	6.1	5.6	-	3.1	5.6	8.0	5.0	-	6.5	11.1	6.5	4.9	-	8.3	0.0	2.8	2.7	6.0	4.5	0.0	4.13
Gomphoneis sp.	4.1	3.3	-	4.6	-	4.0	4.0	-	4.8	-	3.3	4.3	-	-	-	-	-	-	-	-	2.20
Meridion sp.	2.4	1.4	6.1	-	-	4.5	1.5	9.2	-	-	7.1	1.2	10.0	-	-	3.8	-	4.5	-	-	3.03
Melosira sp.	-	1.4	-	-	-	-	2.0	-	-	-	-	-	-	-	-	-	-	-	-	-	0.55
Navicula sp.	9.0	9.3	10.6	7.7	16.7	10.9	11.9	13.8	11.3	16.7	13.0	13.6	13.8	12.5	16.7	7.5	6.3	7.5	6.8	9.1	5.51
Nitzschia sp.	4.9	5.1	3.8	3.1	-	7.0	5.9	4.6	4.8	-	8.2	8.0	3.8	4.2	-	2.8	3.6	3.0	-	-	4.13
Pinnularia sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.6	-	-	-	0.28
Synedra sp.	4.5	4.2	3.8	7.7	-	4.0	4.0	2.8	4.8	-	5.4	3.7	2.5	4.2	-	3.8	2.7	6.0	4.5	-	4.41
Surirella sp.	2.4	-	-	-	-	1.5	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	0.83
Tabellaria sp.	4.9	7.0	8.3	7.7	-	6.0	7.9	8.3	9.7	-	5.4	7.4	8.8	12.5	-	2.8	4.5	4.5	4.5	-	4.41
Asterionella sp.	2.0	-	-	-	-	1.5	-	-	-	-	1.6	-	-	-	-	-	-	-	-	-	0.83
Diatomella sp.	-	-	3.0	-	-	-	-	2.8	-	-	-	-	-	-	-	-	-	-	-	-	0.55
Gomphosphaeria sp.	-	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.28

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Cyanophyceae																					
Anabaena sp.	1.6	1.9	1.5	3.1	-	1.0	1.5	-	-	-	1.1	1.2	-	-	-	3.8	2.7	-	-	-	2.75
Microcystis sp.	0.8	0.9	-	-	-	0.5	0.5	-	-	-	-	-	-	-	-	-	0.9	-	-	-	1.38
Nostoc sp.	2.0	0.9	-	-	-	-	0.5	-	-	-	-	0.6	-	-	-	-	0.9	-	-	-	1.38
Oscillatoria sp.	1.6	2.8	2.3	4.6	-	1.5	2.0	2.8	4.8	-	1.1	1.9	2.8	4.8	-	3.8	3.6	3.0	4.5	-	4.41
Euglenophyceae																					
Euglena sp.	-	0.9	-	-	-	-	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	0.55
Phacus sp.	-	0.5	-	-	-	-	0.5	-	-	-	-	-	-	-	-	-	-	-	-	-	0.83

Table 3. Pearson correlation coefficients(r) of dominant species with water quality parameters

Species	TP	DO	NO_3-N	Amm. N	Cond	TDS	pH	WT
Amphora sp.	-0.062	-0.388	**0.523***	**0.467***	**0.768****	**0.769****	0.182	**0.592****
Cymbella sp.	**0.513***	**-0.504***	0.359	0.334	0.415	0.413	-0.135	0.282
Gomphonema sp.	-0.521	-0.307	0.396	0.319	**0.761***	**.762***	0.322	**-0.709***
Fragillaria sp.	**0.585***	-0.412	0.239	0.302	0.408	0.405	-0.066	-0.199
Navicula sp.	0.017	**-0.496***	**0.609****	**0.545****	**0.755****	**0.754****	-0.259	**-0.694****
Nitzschia sp.	-0.724	-0.530	-0.179	.011	0.170	0.171	0.199	0.000
Tabellaria sp.	-0.426	-0.311	0.242	0.386	**0.784****	**0.787****	0.165	**-0.779****
Chlorella sp.	**0.868****	-0.164	-0.076	-0.246	-0.091	-0.094	-0.148	0.233

Values in bold are dissimilar from 0 with a significance level alpha=0.05 for "*" and 0.01 for "**"

Table 4. Monthly variations in physico-chemical parameters at various sites with different sampling depths (D) in NigeenLake.

Sites	Month	W Temp (˚C)	Trans (m)	Depth (m)	T P (µg/l)	Nitrate N (µg/l)	Amm. N (µg/l)	DO (mg/l)	Cond (µS/cm)	TDS (mg/l)	pH
I	Nov	8	1.7	2	413.9	739	10.58	9.6	313	220	6.81
I	Jan	6	1.6	1.75	283.5	1084	45	4.4	311	221	7.55
I	Feb	5	1.4	1.8	321.7	832	40	7.2	320	227	7.56
I	April	13	1.9	2	376	683	22	8	187	134	8.13
II	Nov	8.5	1.7	2	400.37	784	11.59	9.6	303	216	6.56
II	Jan	6	1.5	1.75	283.5	821	43	4.4	336	240	7.3
II	Feb	4.5	1.4	1.75	373.43	894	44	7.2	338	238	7.56
II	April	10.5	1.9	2	417	952	23	8	197	140	7.38
III	Nov	9.2	2.3	3.5	508.9	549	12.6	9.6	391	277	7.06
III	Jan	7	2	3.15	337.7	1292	47	4.4	357	253	7.65
III	Feb	5	1.8	3.15	343.4	948	38	7.2	396	281	7.55
III	April	15	2.5	3.5	446	733	23	8	298	212	7.5
Iva	Nov	9	2.5	6	463.7	500	16.58	7.2	385	274	6.92
Iva	Jan	7.8	2	5.75	427.5	998	42	2.93	396	281	7.11
Iva	Feb	4.5	2	5.75	352.1	918	34	7.2	375	267	7.56
Iva	April	15	2.7	6	515	700	23	7.2	258	182	8.08
Ivb	Nov	9	2.5	6	486.3	1024	16.58	6.4	397	282	6.91
IVb	Jan	7.6	2	5.75	630.3	1060	47	1.4	485	344	6.66
IVb	Feb	4	2	5.75	560.5	946	35	6	394	280	7.3
IVb	April	14	2.7	6	799	723	23	5.6	297	210	7.55

Table 5. Chemical parameters mg/l (µS/cm for conductivity), PB and community pollution value at varying depths in Nigeen Lake

Sites	TP ≤ 0.020	NO_3-N ≤ 20	DO ≥ 6	Cond ≤ 2250	TDS ≤ 500	pH ≥6.5≤ 8.5	**PB**	**CPV**
I	17.44	0.08	1.22	0.13	0.40	0.88	20.15	4.21
II	18.43	0.09	1.23	0.13	0.42	1.11	21.40	4.19
III	20.45	0.09	1.27	0.16	0.51	1.14	23.63	3.99
IV a	21.98	0.08	1.02	0.16	0.50	0.87	24.61	4.9
IV b	30.95	0.09	0.81	0.17	0.56	1.09	33.68	4.85

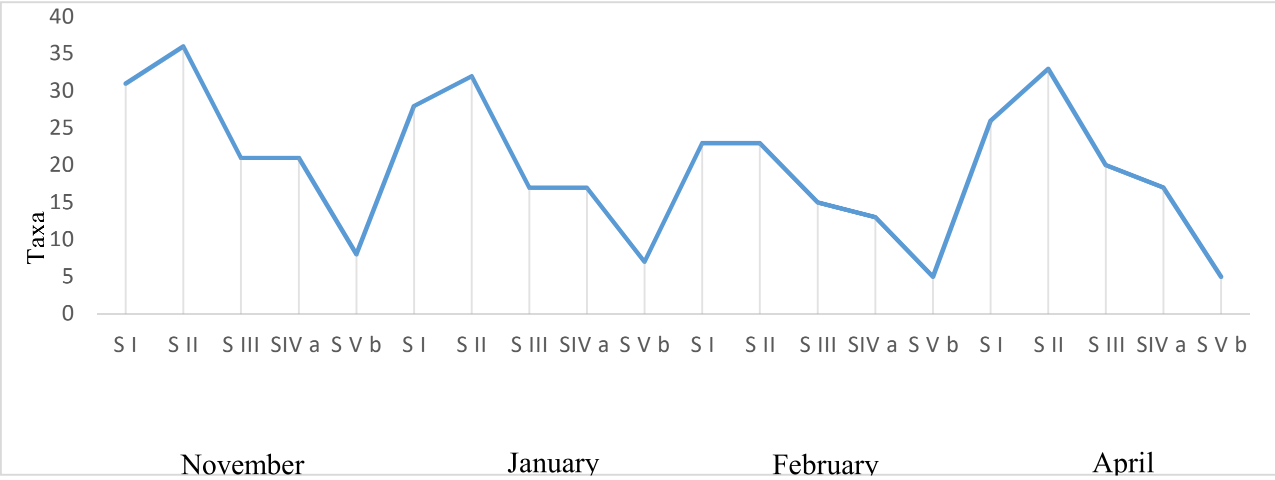

Fig. 2. Total no. taxa during study period at different sites of varying depths in Nigeen Lake

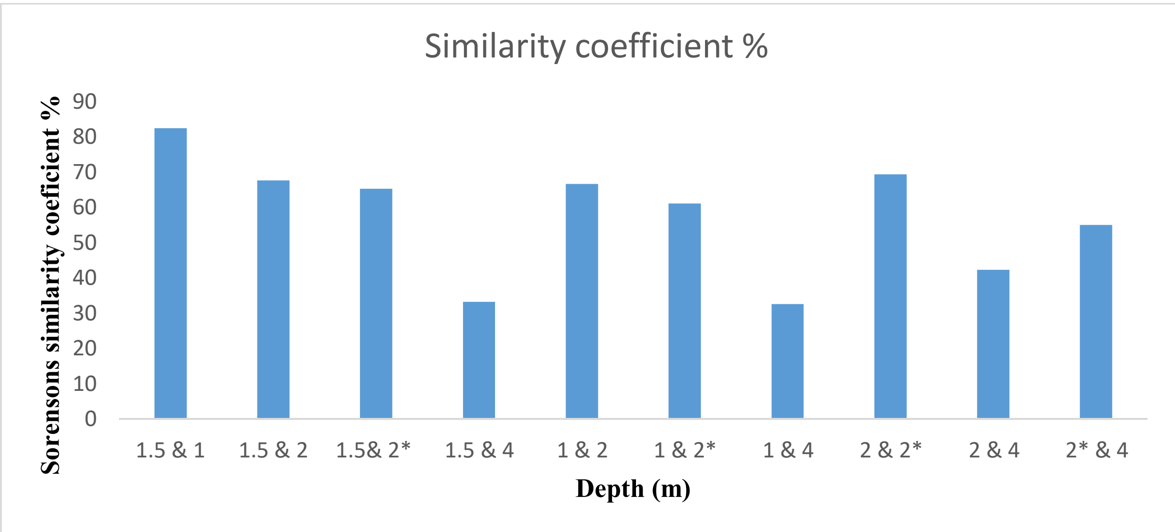

Fig. 3. Bar chart representing Sorenson's similarity coefficient between varying depths of the Nigeen Lake (2^*represents 2m depth at IVa site).

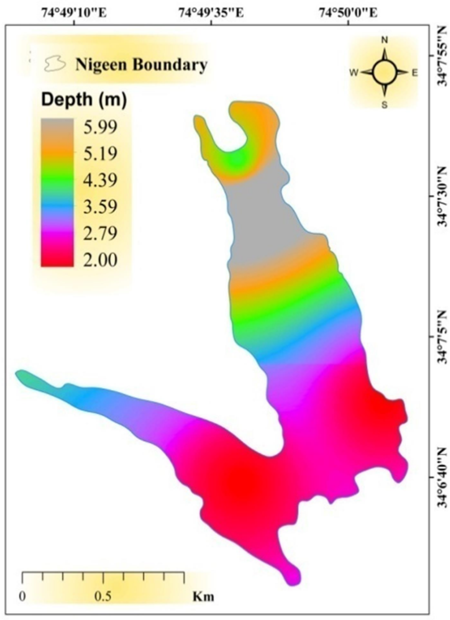

Fig. 4a

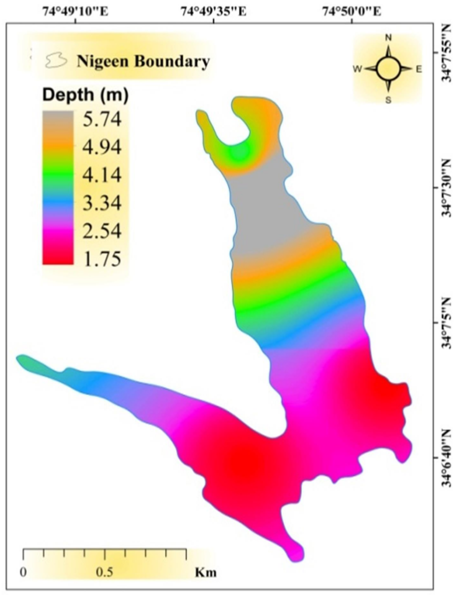

Fig. 4b

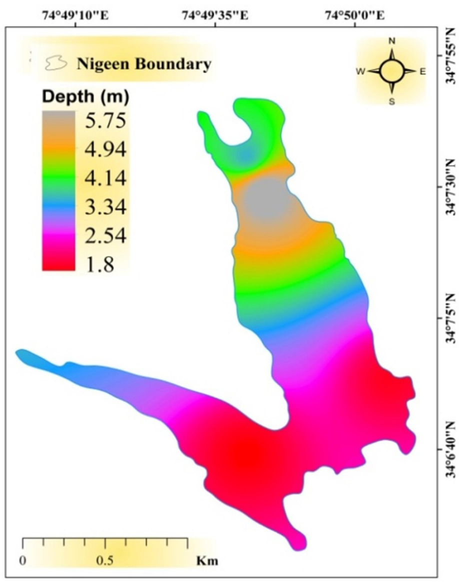

Fig.4c

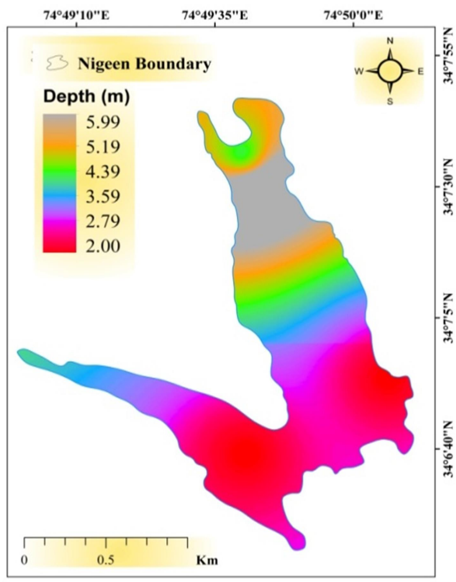

Fig. 4d

Fig. 4. (a=Nov, b= Jan, c= Feb and d= April) Depth variation during November to April at different sites of varying depths in Nigeen Lake

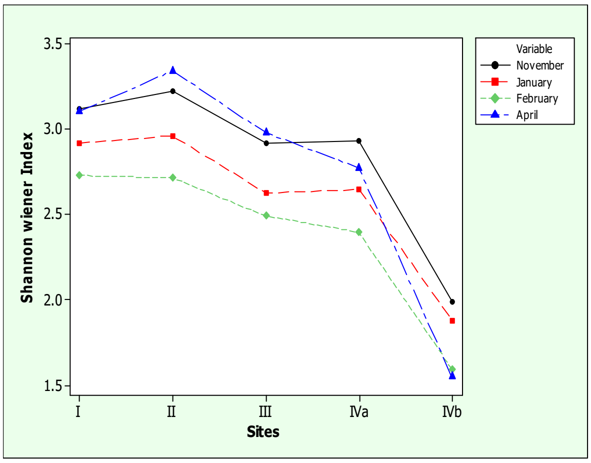

Fig. 5a

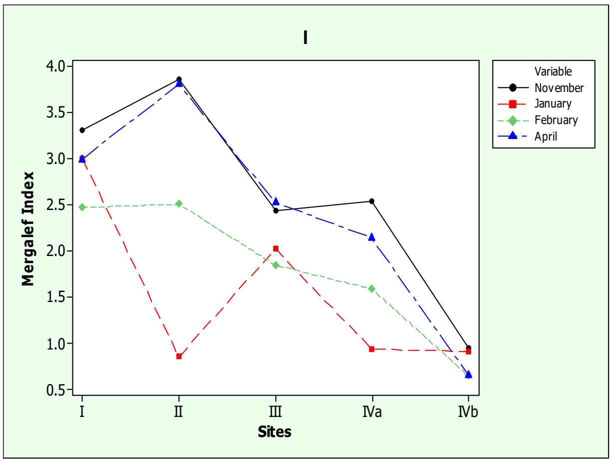

Fig. 5b

Fig.5 Shannon Weiner index (5a) and Mergalef index (5b) at all selected sites in Nigeen Lake

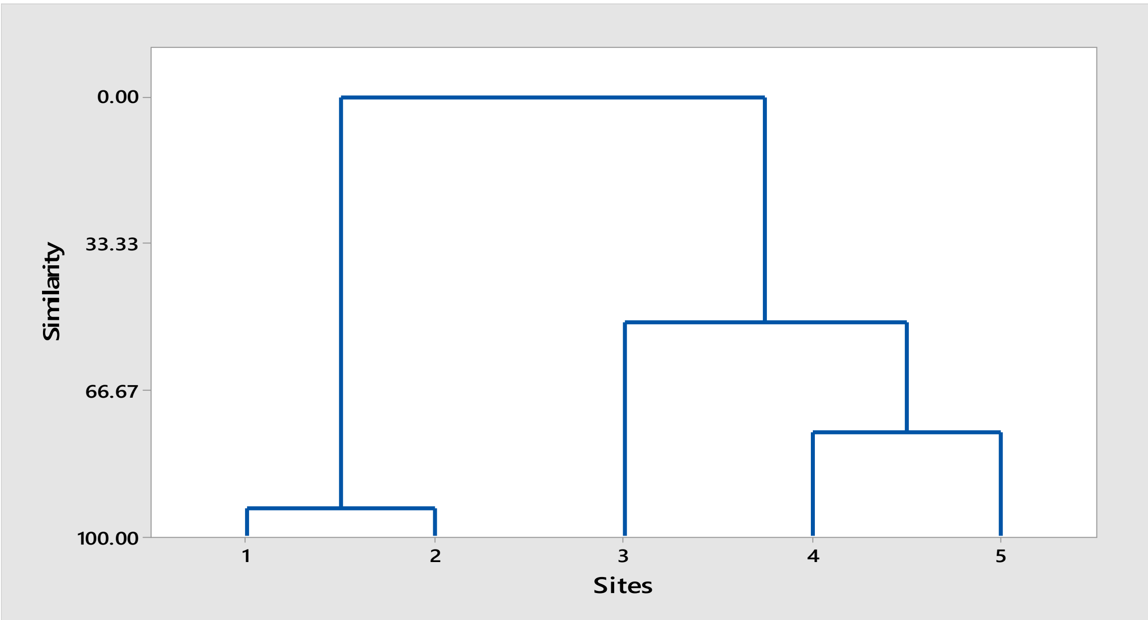

Fig. 6. Dendrogram highlighting Hierarchical Cluster Analysis of studied sites of varying depths in terms of phytoplankton composition

CONCLUSION

It is argued from the observations that depth had a profound impact on phytoplankton community dynamics in lake ecosystem. This study will help the researchers to uncover the critical areas of vertical dynamics and impact of environmental factors in relation to depth gradient on phytoplankton composition in lake ecosystems and to further this line of research. The relevance of the study can be a starter to evaluate the impact of stratification on plankton dynamics in high altitude and other urban Kashmir Himalayan lakes at a greater scale.

AUTHORS CONTRIBUTION

The first author has performed sampling and analysis portion of the study while second author contributed in statistical treatment of data and writing of manuscript. The study was being conducted under the supervision of third author from inception of idea, design of the study and manuscript writing in Aquatic Ecology Laboratory.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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REFERENCES

Abubakr, A., Balkhi, M.H. and Kumar, A. 2018. The hydrochemistry of a Himalayan Lake Nigeen. *Nature Environment and Pollution Technology*, **17** (2): 625-629.

Agbeti, M. D. and Smol, J. P. 1995. Winter limnology-a comparison of physical, chemical and biological character-istics in two temperate lakes during ice cover. *Hydrobiologia*, **304**: 221-234.

Ahmad, A., Qayoom, U., Sabha, I., Islam, S.T. and Bhat, S.U. 2017. An assessment of phytoplankton communities of various freshwater habitats of Gulmarg area in Kashmir valley. *Journal of Himalayan Ecology and Sustainable Development,* **12**: 89-99.

Allende, L., Fontanarrosa, M.S., Murno, A. and Sinistro, R. 2019. Phytoplankton functional group classifications as a tool for biomonitoring shallow lakes: a case study. *Knowl. Manag. Aquat. Ecosyst.*, **420**(5):1-14. http://hdl. handle.net/ 20.500.12110/ paper_19619502.

American Public Health Association (APHA) 2012. Standard Methods for the examination of water and wastewater. 22nd Ed. American Public Health Association, Washington, DC.

Amin, A., Fazal, S., Mujtaba, A. and Singh, S. K. 2014. Effects of land transformation on water quality of Dal Lake, Srinagar, India. *Journal of the Indian Society of Remote Sensing,* **42**(1): 119–128. https://doi.org/10.1007/s12524-013-0297-9.

Arhonditsis, G.B. and Brett, M.T. 2005. Eutrophication model for Lake Washington (USA). Part II. Model calibration and system dynamics analysis. *Ecol. Model.*, **187**:179–200.https://doi.:10.1016/j.ecolmodel.2005.01 .039.

Arhonditsis, G.B., Karydis, M. and Tsirtsis, G. 2003. Analysis of phytoplankton community structure using similarity indices: a new methodology for discriminating among eutrophication levels in coastalmarine ecosystems. *Environ. Manage.*, **31**: 619–632. https://doi.org/10.1007/s00267-002-2903-4.

Arhonditsis, G. B., Paerl, H. W., Valdes-Weaver, L. M., Stow, C. A., Steinberg, L.J. and Reckhow, K. H. 2007. Application of Bayesian structural equation modeling for examining phytoplankton dynamics in the Neuse River Estuary (North Carolina, USA*). Estuar. Coast. Shelf Sci.*, **57**:1–18. https://doi.:10.1016/j. ecss.2006.09.022.

Baba, A. I. and Pandit, A. K. 2014. Species Composition, Diversity and Population Dynamics of Phytoplankton at Saderkot in Walur lake, Kashmir. *Journal of Ecosystem and Ecography*, **4**(1):1-8. https://doi.: 10.4172/21577625.1000142.

Badar, B., Romshoo, S. A. and Khan, M. A. 2013. Modeling the catchment hydrological response in a Himalayan lake as a function of changing land system. *Earth System Science*, **112**(2):433–449.

Bhat, S. A., and Pandit, A.K. 2014. Surface water quality assessment of Wular Lake, a Ramsar site in Kashmir Himalaya, using discriminant analysis and WQI. *Journal of Ecosystems.* https://doi.org/10.1155/2014/724728.

Bhat, S. U., Dar, G.A., Sofi, A.H., Dar, N.A. and Pandit, A.K. 2012. Macroinvertebrate community associations on three different macrophytic species in Manasbal Lake. *Research Journal of Environmental Sciences,* **6**(2):62–76.

Biggs, B. J. F. and Kilroy, C. 2000. Stream Periphyton Monitoring Manual. The New Zealand Ministry for the Environment. NIWA, Christchurch.

Cantonati, M., Scola, S., Angeli, N., Guella, G. and Frassanito, R. 2009. Environmental controls of epilithic diatom depth-distribution in an oligotrophic lake characterized by marked water-level fluctuations. *Eur. J. Phycol*., **44**:15–29. https://doi.org/ 10.1080/09670260802079335.

Cheng, X.Y. and Li, S.J. 2006. An analysis on the evolvement processes of Lake Eutrophication and their characteristics of the typical lakes in the middle and lower reaches of Yangtze River. *Chinese Science Bulletin*, **51**(13): 1603-1613. https://doi:10.1007/s11434-0062005-4.

Cottingham, K.L. and Carpenter, S.R. 1998. Population, community, and ecosystem variates as ecological indicators phytoplankton responses to whole-lake enrichment. *Ecol. Appl*., **8**:508–530. https://doi.org/10. 1890/10510761(1998)008[0508:PCAEVA] 2.0.CO;2.

Cox, E. J. 1996. Identification of Freshwater Diatoms from Live Material.Ist Edition. Chapman and Hall, London, U.K.

Dar, S.A., Bhat, S.U., Sheikh, A. and Rashid, I. 2020. A geospatial approach for limnological characterization of Nigeen Lake, Kashmir Himalaya. *Environmental Monitoring and Assessmen*t, **192** (2): 1-18.

Danilov, R. A. and Ekelund, N. G. A. 1999. The efficiency of seven diversity and one similarity indices based on phytoplankton data for assessing the level of eutrophication in lakes in central Sweden. *Sci. Total Envir.,* **234**: 15-23.

Danilov, R. A., Ekelund, N. G. A. 2000. The use of epiphyton and epilithon data as a base for calculating ecological indices in monitoring of eutrophication in lakes in central Sweden. *Sci. Total Envir.,***248**: 63-70. DOI: 10.1016/s0048-9697(00)00363-6.

Danilov, R.A. and Ekelund, N.G.A. 2001. phytoplankton communities at different depths in two eutrophic and two oligotrophic temperate lakes at higher latitude during the period of ice cover. *Acta Protozool.,* **40**: 197 - 201.

Donohue, I., and Garcia Molinos, J. 2009. Impacts of increased sediment loads on the ecology of lakes. *Biological Reviews*, **84**(4): 517-531.

Edmondson, W. T. 1992. Ward and Whipple's Fresh Water Biology. 2nd ed. International Books and Periodicals Supply Service, New Delhi.

Ganai, A.H., Parveen, S., Khan, A.A. and Maryam, H. 2010. Phytoplankton diversity at Watlab Ghat in Wular Lake, Kashmir. *Journal of Ecology and the Natural Environment*, **2**(8): 140-146.

Ganie, S. U., Bhat,S. U., Shah, J. A. and Pandit, A. K.,2010. Phytoplankton studies of Hokarsar wetland, Kashmir *Journal of Himalayan Ecology and Sustainable Development,* **5**:157-167.

Guo, Q., Ma, K., Yang, L., Cai, Q. and He, K. 2010. A comparative study of the impact of species composition on a freshwater phytoplankton commun-ity using two contrasting biotic indices. *Ecological indicators,* **10**:296-302. DOI: 10.1016/ j.ecolind. 2009.06.002.

Holland, R.E. and Beeton, A.M. 1972. Significance of eutrophication of spatial difference in nutrients and diatoms in lake Michigan. Limnol. Oceanogr.*,* **17**:88-96. https:// doi.org/ 10.4319/lo.1972.17.1.0088.

Hondzo, M. and Stefan, H.G. 1993. Regional water temperature characteristics of lakes subjected to climate change: **24**: 187-211. https://doi:10.1007/BF01091829.

Hsieh, C.H., Sakai, Y., Ban, S., Ishikawa, K., Ishikawa T., Ichise, S., Yamamura, N. and Kumagai, M. 2011. Eutrophication and warming effects on long term variation of zoo plankton in Lake Biwa. *Biogeo sciences* **8**: 1383-1399. https://doi. org/10.5194/bg-8 13832011.

Jamwal, P., Mittal, A.K. and Mouchel, J.M. 2009. Efficiency evaluation of sewage treatment plants with different technologies in Delhi (India). *Environmental Monitoring and Assessment,* **153**:293–305. https:// doi.org/ 10.1007/s10661- 008-0356-9.

Jan, A., Pandit, A.K. and Shah, J.K. 2015. Diversity and abundance of zooplankton in Nigeen lake of Kashmir Himalaya. Egypt. *Acad. Biolog. Sci.,* **7**(2): 39-50.

Jiang, J.G. 2006. Development of new biotic index to assess freshwater pollution. *Environ. Pollut*., **139**: 306-317. DOI: 10.1016/ j.envpol.2005.05.006

Jiang, J.G. and Shen, Y.F. 2003. Appliocation and validation of a new biotic index using data from several water systems. *J. Environ. Monitor.* **5**: 871-875. DOI: 10.1039/b309536c.

Jumppanen, K. 1976. Effects of Waste Waters on a lake Ecosystem. *Ann. Zool. Fennici*., **13**:85-138. https://www.jstor.org/stable/23731769.

Karpowicz, M. and Ejsmont-Karabin, J. 2017. Effect of metalimnetic gradient on phytoplankton and zooplankton (rotifer and crustacea) communities in different trophic conditions. *Environ Monit Assess.,* **189**:367.https://doi..org/10.1007/s1066 1-017-6055-7.

Ke, Z.X., Xie, P. and Guo, L.G. 2008. Controlling factors of spring–summer phytoplankton succession in Lake Taihu (Meiliang Bay, China). *Hydrobiologia,***607**:41–49.https:// doi.10.1007/s10750-0089365-5.

Khan, M. A., Shah, M.A., Mir, S.S. and Bashir, S. 2004. The environmental status of a Kashmir Himalayan wetland game reserve: aquatic plant communities and eco-restoration measures. *Lakes & Reservoirs: Research & Management,* **9**(2):125–132. https:// doi.org/ 10.1111/ j.1440-1770.2004.00242.x.

Khanday, S.A., Romshoo, S.A., Jehangir, A., Sahay, A. and Chauhan, P. 2018. Environmetric and GIS techniques for hydrochemical characterization of the Dal lake, Kashmir Himalaya, India. *Stochastic Environmental Research and Risk Assessment.*

https://doi.org/10.1007/s00477-018-1581-6 01.

Kundangar, M.R.D. 2002. Pollution status of wetlands of Khushalsar and Gilsar, Srinagar, Kashmir-A report submitted to UEE Department, Govt. of J&K.

Kundangar, M.R.D. and Abubakr, A. 2004. Thirty years of ecological Research on Dal Lake Kashmir. *Journal of Resarch and Development.,* 4. Univ. of Kashmir. DOI:10.20546/ijcrar. 2017.503.007.

Kundangar, M.R.D., Sarwar, S.G. and Shah, M.A.1995. Hydrobiological features of Nigeen lake 1992-1993. Technical Report No. 3(B), Hydrobiology Res. Lab, S.P. College Srinagar.

Kunzig, R. 2011. Population 7 billion. National Geographic, **219**(1):32–63 Weblink.http://www.tamdistrict.org/cms/lib/CA01000875/Centricity/Domain/538/WIB_reading_NatGeo%20Population%207%20Billion%20Excerpt.doc.

Kutlu, B., Aydın, R., Danabas, D., and Serdar, O. 2020. Temporal and seasonal variations in phytoplankton community structure in Uzuncayir Dam Lake (Tunceli, Turkey). *Environmental Monitoring and Assessment*. **192**(2): 1-12.

Likens, G.E., Bormann, F.H., Pierce, R.S., Eaton, J.S and Johnson, N.M. 1977. Biogeochemistry of a Forested Ecosystem. Springer-Verlag, New York.

Margalef, R. 1958. Temporal succession and spatial heterogeneity in phytoplankton. In: Buzzati-Treverso AA (ed) Perspectives in Marine Biology, Berkeley. DOI: 10.3390/ije rph9103599.

Maryam, S. 2017. Assessment of Physico chemical changes in Nigeen lake. *Int. J. Adv. Res.* **5**(3): 225-236.

Mir, A.M. and Kachroo, P. 1982. Limnology of Kashmir lakes. VII: The ecology of Bacillariophyceae in two lakes of Srinagar. Proc. Indian Natl. Acad: 48: 378-390.

Munawar, M. 1970. Limnological studies on freshwater ponds of Hyderabad-11. *Hydrobiologia:* **36**: 105-128.https://doi.org/10.1007/BF00751286.

Najar, I. A., and Khan, B. 2012. Assessment of water quality and identification of pollution sources of three lakes in Kashmir, India, using multivariate analysis. *Environmental Earth Sciences,* **66**(8): 2367–2378. https:// doi.org/ 10.1007/ s12665-011-1458-1.

Nissa, M., and Bhat, S.U. 2016. Assessment of Phytoplankton in Nigeenlake of Kashmir. *Asian Journal of Biological Sciences* **9** (1-2): 27-40. https:// doi:10.3923/ ajbs. 2016.27.40

Novais, M.H., Penha, A.M., Morales, E.A., Potes, M., Salgado, R. and Morais, M. 2019. Vertical distribution of benthic diatoms in a large reservoir (Alqueva, Southern Portugal) during thermal stratification. *Science of the Total Environment*,**659**: 1242–1255.DOI: 10.1016/j.scitotenv.2018. 12.251.

Oliveira, B. M., Carneiro, C. D. C., Harari, J. and Belosevich, P. D. S. 2020. Coastal regionalization with self-organizing maps-Water quality variables applied to cluster formation. *International Journal of Advanced Engineering Research and Science (IJAERS).* https://dx.doi.org/ 10.22161/ijaers.79.2

Oterler, B. 2018. Daily vertical variation in phytoplankton composition of a drinking water reservoir (kadiköy reservoir-edirne) during summer stratification. Trakya University *Journal of Natural Sciences,***19**: 21-31.https://doi:10.23902/trkjnat. 356711.

Parvez, S., and Bhat, S.U. 2014. Searching for water quality improvement in Dal Lake, Srinagar, Kashmir. *Journal of Himalayan Ecology and Sustainable Development,* **9**: 51–64. Accessible from: http://envirsc.uok.edu.in/ Files/ ab1ac1f107e342a285bc83717ef39155/Journal/0f7e8ec339974af6b6f59cd55b18fd3b.pdf.

Prescott, G. W. 1939. How to know the fresh water Algae. Brown Co. Publishers. 450.

Ptanick, R., Diehl, S and Berger, S. 2003. Performance of sinking and non-sinking phytoplankton taxa in agradient of mixing depths. *Limnologia and oceanography*, **48** (5):19031912.DOI: 10.4319/lo. 2003. 48. 5. 1903.

Qadri, M.Y. and Yousuf, A.R. 1978. Influence of physico – chemical factors on the seasonality of Cladocera in lake Mansbal. *Geobios.,***7**: 273 – 276.

Qinghai, G., Keming, M., Liu, Y., Qinghua, C. and Kate, H. 2010. A comparative study of the impact of species composition on a freshwater phytoplankton community using two contrasting biotic indices. *Ecological Indicators,***10**:296–302. Doi 10. 1016/ j.ecolind.2009.06.002.

Rakocevic-Nedovic, J. and Hollert, H. 2005. Phytoplankton Community and Chlorophyll *a* as Trophic State Indices of Lake Skadar (Montenegro, Balkan). *ESPR – Environ Sci and Pollut Res*., **12**(3): 146-152.DOI: 10.1065/espr2005.04.241

Rashid, I., and Aneaus, S. 2019. High resolution earth observation data for assessing the impact of land system changes on wetland health in Kashmir Himalaya, India. *Arabian J. Geosci*.**12**:453.https://doi.10.1007/s12517-0194649-9.

Rashid, I., Romshoo, S.A., Amin, M., Khanday, S.A. and Chauhan, P. 2017. Linking human-biophysical interactions with the trophic status of Dal lake. *Limnol. Ecol. Manag. Inland Waters*, **62**:84–96. Doi10.1016/j.limno.2016.11.008

Rather, M. I., Rashid, I., Shahi, N., Murtaza, K. O., Hassan, K., Yousuf, A. R., Romshoo, S. A., and Shah, I. Y. 2016. Massive land system changes impact water quality of the Jhelum River in Kashmir Himalaya. *Environmental Monitoring and Assessment,* **188**(3):185. https://doi.org/10.1007/s10661-016-5190-x.

Rather, M.I., Yusuf, A.R., Shahi, N., Mehraj, M. and Khanday, S.A. 2013. Understanding the cause of fish kill in Nigeen Lake. *J. Res. Dev*, **13**: 20-32.

Ray, J.G., Santhakumaran, P. and Kookal, S. 2020. Phytoplankton communities of eutrophic freshwater bodies (Kerala, India) in relation to the physicochemical water quality parameters. *Environment, Development and Sustainability.* https://doi.org/10.1007/s10668-019-00579-y.

Richard, D. R. and Zohary, T. 1987. Temperature effects on photosynthetic capacity, respiration, and growth rates of bloom-forming cyanobacteria. New Zealand Journal of Marine and Freshwater Research, **21**(3):391-399. DOI: 10.1080/00288330.1987.9516235

Richardson, C.J., King, R.S., Qian, S.S., Vaithiyanathan, P., Qualls, R.G. and Stow, C.A. 2007. Estimating ecological thresholds for phosphorus in the Everglades. *Environmental Science and Technology*, **41**(23):80848091. https://doi.10.1021/es062624w

Richardson, J.L. 1986. Diatoms and Lake Topology in East and Central Africa*.* Int. Revue. *Ges.Hydrobiol. Hydrogr*, **53**:299-338. https://doi.org/10.1002/iroh.19680530204.

Romshoo, S. A., and Muslim, M. 2011. Geospatial modeling for assessing the nutrient load of a Himalayan lake. *Environmental Earth Sciences*, **64**(5):1269–1282. https://doi.org/ 10.1007/s12665-011-0944-9.

Roy, P. S., Roy, A., Joshi, P.P., Kale, M.P., Srivastava, V.K., Srivastava, S.K., Dwevidi, R.S., Joshi, C., Behera, M.D., Meiyappan, P., Sharma, J.A.K., Singh, J.S., Palchowdhuri, Y., Ramachandran, R.M., Pinjarla, B., Chakravarth, V., Babu, N., Gowsalya, M.S., Thiruvengadam, P., Kotteeswaran, M., Priya, V., Yelishetty, K.M.Y., Maithani, S., Talukdar, G., Mondal, I., Rajan, K.S., Narendra, P.S., Biswal, S., Chakraborty, A., Padalia, H., Chavan, M., Pardeshi, S.N., Chaudhari, S.A., Anand, A., Vyas, A., Reddy, M.K., Ramalingam, M., Manonmani, R., Behera, P., Das, P., Tripathi, P., Matin, S., Khan, M.L., Tripathi, O.P., Deka, J., Kumar, P. and Kushwaha, D. 2015. Development of decadal (1985–1995–2005) land use and land cover database for India. *Remote Sensing,* **7**(3):2401–2430. https:// doi.org/ 10.3390/rs70302401.

Sargaonkar, A. and Deshpande, V. 2003. Development of an Overall Water Quality Index (OWQI) for surface water in Indian context. *Environmental Monitoring and Assessment*, **89**:43–67. DOI: http:// dx.doi.org/10.12944/CWE.10.3.12.

Sarwar, S.G. and Zutshi, D. P. 1987. Primary productivity of periphyton. *Geobios.* **14**:127-129.

Savadova, K., Mazur-Marzec, H., Karosien, J., Kasperovi, K., Vitonyte, I., Anska-Sitarz, A. T., and Koreiviene, J. 2018. Effect of increased temperature on native and alien nuisance cyanobacteria from temperate lakes: An experimental approach. *Toxins*, **10**:1-15. http://dx.doi.org/10.3390/toxins1011044 5

Schernewski, G. 2003. Nutrient budgets, dynamics and storm effects in eutrophic, stratified Baltic lake. *Actahydrochim. Hydrobiol*, **31**(2): 152-161.DOI: 10.1002/ aheh.200300 479.

Siraj, S., Yousuf, A.R., Bhat, F.A., and Parveen, M. 2010. The ecology of macrozoobenthos in Shalbugwetland of Kashmir Himalaya India. *Journal of Ecology and natural Environ*., **2** (5) 84-91.

Sommerfeld, M.R., Cismeros, R.M. and Oisen, R.D. 1975. The phytoplankton of Canyon lake, Arizona. *South Western Naturalist*, **20**(1): 45-53.DOI: 10.2307/3670010.

Sutton, M.A., Howard, C.M., Bleeker, A. and Datta, A. 2013. The global nutrient challenge: from science to public engagement. *Environ. Dev. Sustain,* **6**:80–85. https://doi.org/ 10.1016/ j.envdev. 2013.03.003.

Taranu, Z.E., Gregory-Eaves, I., Leavitt, P.R., Bunting, L., Buchaca, T., Catalan, J., Domaizon, I., Guilizzoni, P., Lami, A., Mcgowan, S., Moorhouse, H., Morabito, G., Pick, F.R., Stevenson, M.A., Thompson, P.L. and Vinebrooke, R.D. 2015. Acceleration of cyanobacterial dominance in north temperate-subarctic lakes during the *Anthropocene. Ecol. Lett.,* **18**: 375–384.https://doi.org/10.1111/ele.12420.

Tian, C., Pei, H., Hu, W. and Xie, J. 2013. Phytoplankton variation and its relationship with the environmental factors in Nansi Lake, China. *Environ Monit Assess.,***185**:295–310. https:// doi.0.1007/s10661-012-2554-8

Tulonen T., Kankaala, P., Ojala, A. and Arvola, L. 1994. Factors controlling production of phytoplankton and bacteria under ice in a humic, boreal lake. *J. Plankton Res*., **16**:

1411-1432.https://doi.10.1093/plankt/16.10.1411

Ulfat, J., Sabha, I., Parvaiz, S. and Bhat, S.U. 2015. A preliminary study of Phytoplankton community of Dal lake. *Journal of Himalayan Ecology and Sustainable Development*,**10**: 15-25.

Vadeboncoeur, Y., Devlin, S.P., McIntyre, P.B. and Zanden, M.J.V. 2014. Is there light after depth? Distribution of periphyton chlorophyll and productivity in lake littoral zones. *Fresh. Sci*., **33**:524–536. https://doi.org/10.1086/676315.

Vass, K. K., 1980. On the trophic status and conservation of Kashmir lakes. *Hydrobiologia,* **68**(1):9–15. https://doi.org/ 10.1007/BF00009058.

Vass, K.K. and Zutshi, D.P. 1979. Limnological studies on Dal Lake. Morphometry and Physical features. *J. Ind. fish. Soc. India*., **11**: 12-20.

Wetzel, R.G. 1983. Limnology. 2nd Edition. Saunders College Publishing, Fort Worth, TX.

Yang, X., Xiang, W.U., Hu-lin, H.A.O. and Zhen-li. H.E. 2008. Mechanisms and assessment of water eutrophication. *J Zhejiang Univ. Sci. B.* **9(**3):197-209. doi: 10.1631/jzus.B0710626.

Yaseen, T., and Yousuf, A.R. 2013. Impact of thermal stratification on nutrient concentration in Manasbal lake Kashmir. Department of Environmental sciences, University of Kashmir.

Yeole, S.M. and Patil, G.P. 2005. Physico chemical status of Yedshilake in relation to water pollution .*J. Aquat. Biol.,* **20**: 41-44.

Yousuf,A.R., Balkhi, M.H. and Qadri, M.Y. 1986. Limnological features of forest lake of Kashmir. *J. Zoo. Soc. Ind*., **38**(1-2): 29-42.

Zhang, S.R., Lu, X.X., Higgitt, D.L., Chen, C.T.A., Sun, H.G. and Han, J.T. 2007. Water chemistry of the Zhujiang (Pearl River): natural processes and anthropogenic influences. *J. Geophys. Res*., **112**(F1):F01011.https://doi.org/10.1029/2006JF000493.

Zutshi, D. P., and Gopal, B. 2000. Himalayan lake ecosystems: current issues and threat perceptions. Internationale Vereinigung fürtheoretische und angewandte Limnologie: Verhandlungen, **27**(4): 2167–2170. https:// doi.org/ 10.1080/03680770.1998.11901622.

Zutshi, D.P., Subla, B.A., Khan, M.A. and Wanganeo, A. 1980. Comparative limnology of nine lakes of Jammu and Kashmir Himalayas. *Hydrobiologia*, **72**(1–2):101–112. https://doi.10.1007/BF00016238.