Lakes, reservoirs and ponds, vol. 7(2): 127-141, 2013

A REVIEW OF PHYTOPLANKTON ECOLOGY IN FRESHWATER LAKES OF INDIA

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Abstract

This is a comprehensive review of phytoplankton ecology in freshwater lakes of India. A review study was undertaken for the better understanding of the phytoplankton distribution. In broad terms, authors discussed the relations of phytoplankton with factors like lake temperature, sunlight exposure period, sunlight penetration, water pH, wind, transparency, seasonal variations, water characteristics, nutrient enrichment and prey-predator relation in the lakes of India. From the results, authors noticed that each lake habitat is different from other lake habitat. Finally, authors concluded that phytoplankton ecology is an indicator for the evaluation of impacts of influencing factors. These factors provide a suitable management plan for lakes. Phytoplankton ecology provides a ground for monitoring and assessing the strategies of the fresh water lake management.

Keywords: Phytoplankton ecology, Freshwater lakes, Seasonal fluctuation, Phytoplankton distribution, Freshwater lakes of India

1 INTRODUCTION

About four thousand million years ago, life initiated in an aquatic environment. Today, most of the taxonomic phyla dwell in an aquatic environment. In an aquatic environment, phytoplankton is most ubiquitous, unicellular and microscopic life form. Phytoplankton collectively accounted about half of the earth's primary producers. However, light penetration,

temperature, nutrient enrichment, toxic substances, mixing of water, parasites, herbivores and heterotrophic microorganism activities influenced the phytoplankton growth (Reynolds, 1987). In recent years, researchers have participated in the study of phytoplankton ecology of freshwater lakes in India. However, in early years, researchers reported many research studies on phytoplankton distribution and density in freshwater lakes of all over India (Ganapati, 1940; Mohan, 1987; Chaudhary & Pillai 2009; Singh & Balasingh 2011; Dakshini & Gupta 1979; Sarwar,1996, Tiwari & Chauhan 2006, Mukherjee et al., 2010; Jain et al., 1999; Chattopadhyay & Banerjee 2007; Ghosh et al., 2012; Jhingran, 1989; Somani et al., 2007; Maske et al., 2010). A report spanning a period of 50 years (1947-1998) emphasized factors influence on physical, chemical and biological conditions on the Indian freshwater lake ecology system (Sugunan, 2000; Gopal & Zutshi, 1998). Further, other studies reported the distribution pattern of phytoplankton with respect to the degree of water pollution, impact of aquaculture and climatic change (Chattopadhyay and Banerjee, 2007; Pradhan et al., 2008), role of macrophyte's root and shoot system (Sarwar, 1996; Raut & Pejaver, 2005) and harmful and toxic effects of cyanobacteria in Indian freshwater lakes (Chaudhary & Meena, 2007; Maske et al., 2010). In this review, we presented an elaborative literature synthesis on the phytoplankton ecology and various factors interacted in freshwater lakes of north, south, east and west regions of India. This review may provide a better understanding of phytoplankton ecology in Indian freshwater lake scenario. It should assess qualitatively for anthropogenic changes which resulted nutrient enrichment. It provides a ground for future studies on management of freshwater lakes with phytoplankton distribution.

2 PHYTOPLANKTON ECOLOGY IN INDIAN FRESHWATER LAKES

Indian researchers reported the several studies on the phytoplankton distribution with availability of light (Singh & Sharma, 2012), physical, chemical and biological qualities (Zafar, 1967; Munawar, 1974) in freshwater lakes. Today, Indian freshwater lakes are facing tremendous ecological stress due to raising of pollution from rapid industrialization. However, mainly seasonal changes regulated pattern of phytoplankton growth. Studies reported that the summer is the most suitable season for the growth of phytoplankton in freshwater lakes because of long duration of sunshine period, increased salinity, pH and trophotropic activities (Chaturvedi et al.,1999). Conversely, in late summer and monsoon season,

the production of phytoplankton reduced because of heavy rainfall, high turbidity, reduced salinity, temperature, pH, overcast skies and low nutrient concentration along with consumption of phytoplankton by zooplankton and fishes etc. (Saravanakumar et al., 2008). During monsoon, wave action of currents and influx of rain water acts as limiting factors for phytoplankton population. The water column of the lake was remarkably stratified to large extent in heavy rainfall with high turbidity in lake water, induced due to agricultural and surface runoff and soil erosion. Subsequently, the rate of phytoplankton gradually increased in post-monsoon to the late spring. Phytoplankton community progresses a serial successions to culminate in a peak sequences with low turbidity and low wind velocity in the lakes (Chaudhary & Pillai, 2009; Sugunan, 2000). In some cases, during post-monsoon and summer, permanent bloom of phytoplankton in lakes of the southern tip of Indian peninsula appeared due to shallow depth, nutrients enrichment and adequate sunlight (Sugunan, 2000). Generally, in Indian Lakes, phytoplankton density peaks found in post monsoon and summer (Gopal & Zutshi 1998). Factors influenced the phytoplankton distribution in Indian freshwater lakes, are shown in Figure 1 and Figure 2.

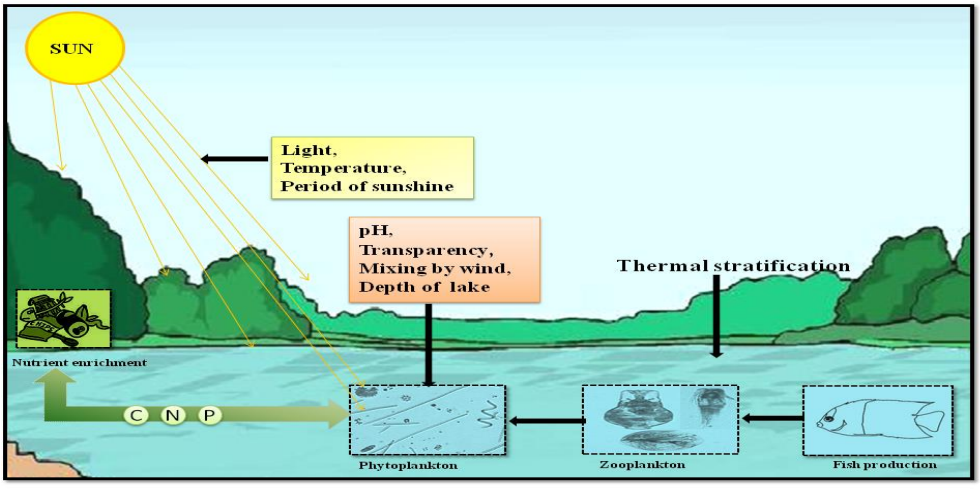


Figure 1. A sketch showing, factors influenced phytoplankton in freshwater lakes

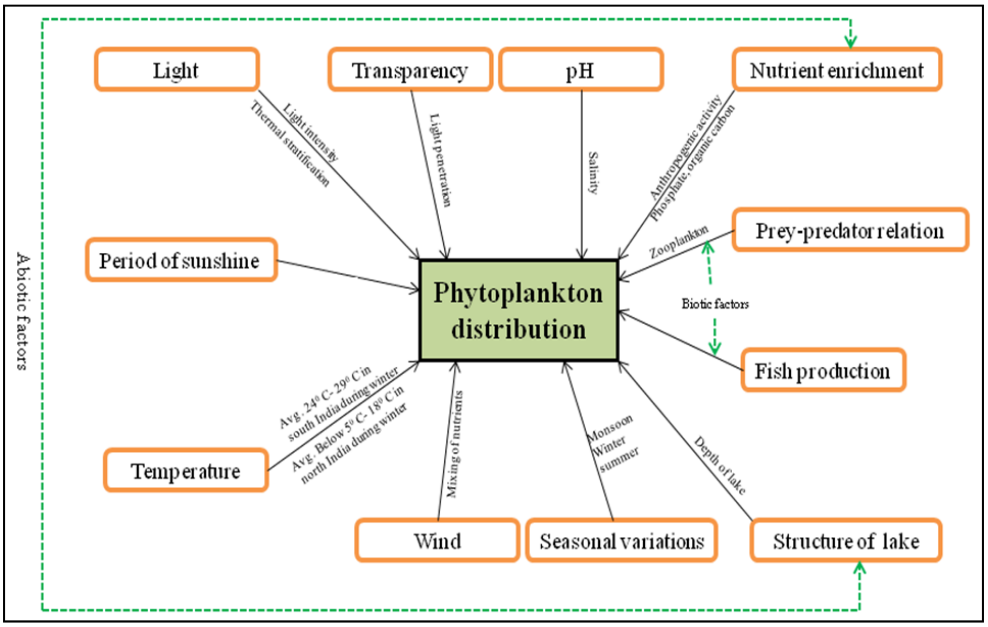


Figure 2. A flow diagram showing, factors influenced phytoplankton distribution in Indian freshwater lakes

3 HYDROGHAPHIC FACTORS OF INDIAN FRESHWATER LAKES

Indian lakes experience climatic changes because India has large size and variant terrain. In monsoon, Indian lakes experienced the marked variations in temperatures, reduced sunshine periods, flash floods and violent thunderstorms. In the higher Himalaya zone, temperature remains in sub-zero range for many months. Dal lake of north India showed 1 to 11°C average surface water temperature. The top crust of the lake was frozen in winter (Jain et al., 2007). Conversely, in southern India, winter season is negligible as the least temperature never drops below 16°C. Thus, it prevented thermal stratification in the water forms. With the arrival of summer, the top layer of water became warm and the wind induced turbulence which resulted nutrients mixing in lake water (Sreenivasan, 1964).

4 PHYTOPLANKTON ECOLOGY IN VICINITY

Researchers published some accounts on phytoplankton ecology in freshwater lakes around India. We present a comprehensive review of the

interaction between phytoplankton and factors of freshwater lakes of north, south, east and west regions of India. Authors discussed reports of phytoplankton distributions in lakes of northern India (Dakshini & Gupta 1979; Sarwar, 1996; Tiwari & Chauhan, 2006; Mukherjee et al., 2010), southern India (Ganapati, 1940; Sreenivasan, 1964; Sreenivasan et al., 1964; Abraham, 1980; Mohan, 1987; Chaudhary & Pillai, 2009; Singh & Balasingh 2011), eastern India (Sugunan & Yadava, 1991; Jain et al., 1999;Chattopadhyay & Banerjee, 2007; Ghosh et al., 2012) and western India (Jhingran, 1989; Trivedi, 1993; Somani et al., 2007; Maske et al.,2010). Authors formed these regions provisionally to consolidate the understanding of phytoplankton ecology. Details of lake studies (Table 1) and a summary on dominant groups of phytoplankton and factors influenced phytoplankton ecology of Indian fresh water lakes, discussed in this review study (Table 2) and depicted in map as distributed over four regions (Figure 3).

Table 1. Details of freshwater lakes in India referred in the review study

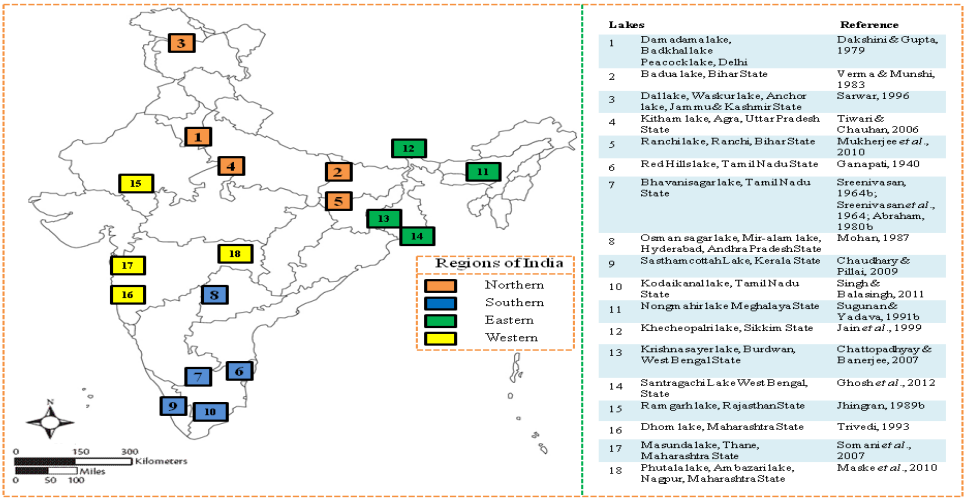
Lakes	Dominant groups of phytoplankton	Influencing factors	Reference
Damadama, Badkhal, Peacock lakes	Blue-green algae	Temperature with seasonality	Dakshini & Gupta, 1979
Badua lake	Blue-green algae, Diatoms	Seasonal variations	Verma & Munshi, 1983
Dal, Waskur lake, Anchor lakes	Diatoms, green algae	Hydrographic properties	Sarwar, 1996
Kitham lake	Green algae, Diatoms	Seasonal variations	Tiwari & Chauhan, 2006
Ranchi lake	Blue-green algae, diatoms	Organic matter	Mukherjee et al., 2010
Bhavanisagar lake	Blue-green algae	Seasonal variations	Sreenivasan, 1964; Sreenivasan et al., 1964
Red hills lake	Blue-green algae	Climatic factors	Ganapati, 1940
Osman sagar, Mir-alam lakes	Blue-green algae	Temperature, seasonality, water chemistry	Mohan, 1987
Sasthamcottah lake	Green algae	Water chemistry	Chaudhary & Pillai, 2009

Kodaikanal lake	Green algae	Temperature, pH, light, Seasonal variation.	Singh & Balasingh, 2011
Nongmahir lake	Green algae	Nutrient enrichment	Sugunan & Yadava, 1991
Khecheopalri lake	Green algae	Hydrology and nutrients	Jain et al., 1999
Krishnasayer lake	Diatoms	Temperature, transparency, nutrients enrichment	Chattopadhyay & Banerjee, 2007
Santragachi lake	Blue-green algae	Climatic conditions	Ghosh et al., 2012
Ramgarh lake	Diatoms	Seasonality	Jhingran, 1989
Dhom lake	Green algae	Nutrient enrichment	Trivedi, 1993
Masunda lake	Green algae, Blue-green algae	Seasonality, Nutrient enrichment	Somani et al., 2007
Phutala, Ambazari lakes	Blue-green algae	Nutrient enrichment	Maske et al., 2010

Table 2.A Summary of dominant groups and influencing factors referred in the review

Region of India	State/Union territory	Lakes	Geographical Location of lake	Area (Sq. km.)	Maximum depth (m)	Water variables	
						pH	Conductivity (µmho/cm)
Northern freshwater lakes	Delhi	Damadama	77°2'E,28°14'N	24.1	18.04	8.75	109.892
		Badkhal	77°17'E,28°26'N	8	11.1	8.06	151.73
		Peacock	77°17'E,28°29'N	11.4	8.4	8.73	647.07
	Bihar	Badua	86°30'E,25°30'N	296	32	7.5-8.1	-
		Ranchi	85 °31'E,23º36'N	0.157	10	9.11	827
	Jammu & Kashmir	Dal	74°86'E,34°12'N	18	6	8.6	328
		Waskur	74°79'E,34°08'N	-	6	8.5	150
		Anchor	74°78'E,34°14'N	66	3.5	8.5	491
	Uttar Pradesh	Kitham	78 ° 4'E,27°12'N	7.13	9	7.0-8.6	-
Southern freshwater lakes	Tamil Nadu	Red Hills	80°10'E,13°10'N	18.2	4.5	-	-
		Kodaikanal	77°28'E,10°13'N	21.45	11	6.37	-
		Bhavanisagar	77°07'E,11°30'N	0.070	33	-	-
	Andhra Pradesh	Osman sagar	78°30'E,17°38'N	22.12	-	8.7	-
		Mir-alam	78°43'E,17°34' N	1.69	13.41	8.12	-
	Kerala	Sasthamcottah	76°35'E,9°5'N	12.69	15.2	7.3	-
Eastern freshwater	Meghalaya	Nongmahir	-	0.7	5.28	6.90	108.07
	Sikkim	Khecheopalri	88°12'E,27°22'N	12	11.2	6.8 -8.2	94

lakes	West Bengal	Krishnasayer	87°54'E,23°16'N	0.135	10	7.6-9.8	-
		Santragachi	88°17'E,22°34'N	0.108	2.13	7.2	244-262
Western freshwater lakes	Rajasthan	Ramgarh	75°32'E,27°12'N	769	18	8.4	513.0
	Maharashtra	Dhom	73°33'E,17°5'N	217.5	-		50 -90
		Masunda	72°97'E,19°19'N	0.011	2.5	-	-
		Phutala	79°23'E,21°91'N	0.40	5	-	-
		Ambazari	79°22'E,21°75'N	1.185	-	-	-



	Lakes	Reference
1	Damadama lake, Badkhal lake Peacock lake, Delhi	Dakshini & Gupta, 1979
2	Badua lake, Bihar State	Verma & Munshi, 1983
3	Dal lake, Wasikur lake, Anchor lake, Jammu & Kashmir State	Sarwar, 1996
4	Kitham lake, Agra, Uttar Pradesh State	Tiwari & Chauhan, 2006
5	Ranchi lake, Ranchi, Bihar State	Mukherjee *et al*., 2010
6	Red Hills lake, Tamil Nadu State	Ganapati, 1940
7	Bhavanisagar lake, Tamil Nadu State	Sreenivasan, 1964b; Sreenivasan *et al*., 1964; Abraham, 1980b
8	Osman sagar lake, Mir-alam lake, Hyderabad, Andhra Pradesh State	Mohan, 1987
9	Sasthamcottah Lake, Kerala State	Chaudhary & Pillai, 2009
10	Kodaikanal lake, Tamil Nadu State	Singh & Balasingh, 2011
11	Nongn ahir lake Meghalaya State	Sugunan & Yadava, 1991b
12	Khecheopalri lake, Sikkim State	Jain *et al*., 1999
13	Krishnasayer lake, Burdwan, West Bengal State	Chattopadhyay & Banerjee, 2007
14	Santragachi Lake West Bengal, State	Ghosh *et al*., 2012
15	Ramgarh lake, Rajasthan State	Jhingran, 1989b
16	Dhom lake, Maharashtra State	Trivedi, 1993
17	Masunda lake, Thane, Maharashtra State	Somani *et al*., 2007
18	Phutala lake, Ambazari lake, Nagpur, Maharashtra State	Maske *et al*., 2010

Figure 3: A map of Indian freshwater lakes referred in this review

4.1 Northern freshwater lakes

Dakshini & Gupta (1979) reported the relation between population of phytoplankton and seasonality of three freshwater lakes of Delhi in 1976. In July and August months, dense phytoplankton decreased in all the study lakes, due to high flushing of rainwater. On the other hand, in the month of September, the phytoplankton count increased with low turbidity and wavy actions in the lakes. In Damadama,Badkhal and Peacock lakes of Delhi, *Microcystis* blooms dominated between October and December and between May and July. The authors concluded that physical, chemical and biological factors of three lakes varied from each other while, their climatic and geological conditions were same.Verma & Munshi (1983) described phytoplankton composition in Badua lake of Bihar. Phytoplankton composition dominated the blue-green algal blooms which influenced with Seasonal variations. Sarwar, 1996 presented that, the epiphytic algal flora

attached to *Myriophyllum spicatum L.* in Dal, Waskur, Anchor lakes of Kashmir. Rich and varied epiphytic algae derived moisture and nutrients from the air and rain (Sarwar,1996). Algae usually developed on *Myriophyllum spicatum L.* most likely due to its greater surface area. Algae dominated diatom population along with green algal blooms. According to the author, these outcomes resulted from the variations in hydrographic properties of lakes influenced the variations in epiphytic algal colonization. Tiwari & Chauhan (2006) described densities of phytoplankton in Kitham lake, Agra. Authors observed phytoplankton density in two highest peaks of winter (November to March) and summer (April to June). All the peaks dominated with green algae and diatoms (Tiwari & Chauhan, 2006). Sreenivasan presented the rich phytoplankton community in Bhavanisagar Lake, where phytoplankton communities dominated blue-green blooms, diatoms and green blooms and influenced with Seasonal variations (Sreenivasan et al., 1964; Sreenivasan, 1964). Mukherjee et al.,2010 presented details of phytoplankton dynamics of a lake in Ranchi. The distribution of phytoplankton in March, May and August was relatively least. However, in November month, all variant phytoplankton blooms occurred abundantly. Authors noted that, Ranchi lake has organic matter with high concentrations. Blue-green algae and diatom blooms were dominant phytoplankton communities in Ranchi lake.

4.2 Southern freshwater lakes

Ganapati in 1940 introduced the first paper on phytoplankton from the red hills lake, a water supply reservoir near Chennai in southern India. Author made foundation for Limnology in India through his significant paper. The paper served with the phytoplankton cycles with the water and climatic factors. Author reported that, by 1979, blue-green bloom diversity and addition of other algal species reduced in the lake. The authors concluded that, these events resulted from the transient eutrophication stage of the lake. In 1987, Mohan reported a two-year study (1977-1978) on diatom blooms of two tropical southern Indian lakes i.e. Osmansagar and Mir-alam lakes of Hyderabad. Population of phytoplankton in Mir-alam Lake was higher as compared to the Population of flora in Osmansagar Lake. Blue-green algal blooms were dominant in both the lakes. The author reported that, Osmansagar lake occurred more sodium, magnesium, potassium and oxygen. However, more Phosphorus, Calcium, Sodium and total solids were found only in Mir-alam Lake. The author noted that, population of diatom blooms changed with the order of concentrations of

cation, anions and silicates and density of diatoms changed with periodicity. Author emphasized that, temperature, seasonality of phytoplankton and chemical complexes affected the diatoms periodically (Mohan, 1987). Chaudhary and Pillai, 2009 described the relation between some physical-chemical characteristics and phytoplankton distribution of Sasthamcottah Lake during June 2006 to May 2007. All the peaks of algae dominated green alga during October and lower during June. The authors noted that, diatom flora were also affected by the pH of the lake water. During summers, green algae and dinoflagellates dominated throughout the lake when phosphates and nitrates also increased in lake water. Moreover, phytoplankton assemblages were mainly influenced by the physical, chemical and biological factors. Singh and Balasingh (2011) presented data on the phytoplankton population of the Kodaikanal Lake for a period of one year. During summer, phytoplankton dominated and declined in monsoon. Count of flora in turn increased during winter. The high nutrient concentrations with shallow depth of lake indirectly added concentrations of phosphate and nitrates, induced phytoplankton growth. Lake was predominated with green algae. In summer, the high density of algal assemblages imparted dark green color of lake. These events resulted from high temperature, pH, light intensity and low depth of the lake.

4.3 Eastern freshwater lakes

Small data reported on the phytoplankton of freshwater lakes of eastern region are as compared to other parts of the country. Sugunan and Yadava (1991) reported the phytoplankton distribution in Nongmahir lake, Meghalaya state.The average count of phytoplankton was 5440 units/L and dominated the chlorophyceae group. Authors concluded that the shallow depth of the lake created conditions. Jain et al., 1999 presented data on the phytoplankton productivity, hydrology and nutrient dynamics of a Khecheopalri lake in the western part of the Sikkim Himalaya. The author concluded that the species of phytoplankton found in Khecheopalri lake was characteristic feature of a eutrophic stage. These outcomes resulted from agricultural activities, grazing and forest resource extraction from the watershed. Chattopadhyay and Banerjee in 2007 described the temporal changes in species composition, seasonal variation and diversity of phytoplankton community, related to some factors of water and sediment of Krishnasayer lake, Burdwan. Diatoms were dominated and factors such as temperature, transparency, dissolved oxygen, dissolved chloride, phosphate-phosphorus and organic carbon positively co-related to phytoplankton.

Recent study of Ghosh et al.,2012 reported diversity and seasonal variation of phytoplankton community. This condition related to physical-chemical components of Santragachi Lake of West Bengal between November 2009 and July 2010. Green algae were dominated and euglenoid population was in lower numbers. Authors concluded that in addition to climatic conditions, moderate level of pollution of lake affects phytoplankton growth.

4.4 Western freshwater lakes

The reports about composition and abundance of phytoplankton were more for western region. Jhingran (1989) gave brief description of phytoplankton population of Ramgarh lake in Rajasthan state. Dominant diatom blooms formed an average 19.08% of the total population. Author reported that events from seasonal changes in Ramgarh lake.Trivedi (1993) presented an account of phytoplankton distribution of Dhom lake in Maharashtra state. Dhom lake turned from mesotrophic to eutrophic conditions. Somani et al. 2007 presented the co-relation of seasonality and distribution of phytoplankton in lake Masunda, Thane (Maharashtra). Green and blue-green algal assemblages dominated the lake. Authors concluded that nutrient richness related the phytoplankton blooms in the lake. Maske et al., 2010 presented the outcomes of cyanobacteria in Nagpur city lakes from April to December 2006. Cyanobacterial genera such as *Microcystis* was common in lakes of Nagpur. The lakes in Nagpur city contain diversity of cyanobacteria. The authors concluded that, more nutrient richness than temperature variations of lakes associated dominant *Microcystis* blooms in lakes. *Microcystis* blooms resulted negative allelopathic effect and affected the diversity of phytoplankton.

5 DISCUSSION

This review study discussed the ecology of phytoplankton in the result section.Factors played an important role to regulate the phytoplankton in Indian freshwater lakes, focussed on the factors (Figure 1 and Figure 2). The phytoplankton groups such as green and blue-green algae varied with the nutrient availability in the freshwater lakes. Phytoplankton diversified with the effect of factors in lakes of different regions of India (Table 2). During summer, the phytoplankton count progressively increased in lake water. Chiefly, blue-green algae such as *Microcystis* blooms suddenly occurred in the lake water. The increase in phytoplankton density started

from spring to late summer. During summer, highest sun intensity occurred in freshwater lakes, led to thermal stratification. During the summer, blue-green assemblages were prevalent in the lake water. During monsoon, normal rainfall induced uniform temperatures ranges in two third portions of the country and population of phytoplankton decreased with less sunshine hours and non-uniform intensity of sunlight. During winters, temperature variation played important role in phytoplankton distribution. However, it had not vary much in southern region's lakes because the temperature of the peninsula never drops below 16C. During the post-monsoon and early winter, reduced turbulence resulted in clean lake water. In central and northwest region of India, authors observed the highest count of phytoplankton even in the winter because high sunshine led to warmer winters. Conversely, phytoplankton productivity rate declined in northern lakes because of its low rate of sunshine and effect of continental winds leading to low temperature of the water (Jain et al.,2007). Nationwide, diatoms such as *Navicula* sp., *Nitzschia* sp., *Synedra* sp., *Melosera* sp. contributed to the phytoplankton composition in early winters. Diatoms occurred in unpolluted part of the lakes which were good indicators of pollution. Phytoplankton group substituted diatom flora by green and blue-green algae with increased pollution in the lake. Phytoplankton distribution majorly forced by factors such as seasonal fluctuations in lake water. Factors such as seasonality, period of sunshine, wind patterns, depth of lake, temperature, pH, turbidity, dissolved oxygen, nutrient enrichment like dissolved chloride, phosphate and organic carbon ultimately influenced the occurance phytoplankton in the freshwater lake. We also focussed on influence of biotic factors on phytoplankton population.

Reports have shown pray–predator relation between phytoplankton and zooplankton affected phytoplankton in Indian freshwater lakes. The blooms of phytoplankton grazed by zooplankton, reduced the count of phytoplankton in the lakes. Authors considered that the green algae is favourable for fish culture in the lake water (Pradhan et al., 2008). The data of Table 1 showed that the lakes are not very similar in terms of their area, maximum depth and water chemistry. That might influence on the distribution pattern of phytoplankton. Authors reported differences in phytoplankton due to regional influences, but also be a function of lake types included in each region. The factors discussed earlier in the review as important to algae composition may or may not be related to itself. Differences in watershed features between regions help in separating them. Differences within regions complicated to interprete the algal communities. Substantial range of watershed sizes or land use make up that might itself represent an important influence on algae. Surrounding watersheds of

Upper Lake of Bhopal influenced the lake ecosystems with the entry of nutrients and organic substances due to human activities (Tamot & Sharma, 2006). Climate differences is not only influence the algal communities but also geology and soils differences influence on algae. Geochemical features in lake water showed relation between evaporation, chemical weathering. Pandoh Lake (Mandi, India) ecosystem influenced with regional factors such as chemical weathering and atmospheric precipitation which showed lake water chemistry with illumination of seasonal behavior on ions (Ramanathan et al., 2007). Authors considered the study as an incomplete research. Henceforth, to develop an improved understanding of the ecology of phytoplankton in Indian freshwater lakes further research should be attempted. In this review; authors discussed different factors influenced the phytoplankton in freshwater lakes of India. Each lake habitat is different from other. So, lakes needed their suitable management plans to control algal blooms from identified factors. Some lake studies showed diffused nutrient sources from land cover changes. Such studies are likely to manage but needs many years for restoration.

6 CONCLUSION

It is clear from the review; phytoplankton ecology in freshwater lakes of India is greatly influenced by factors. Review study reported most of the studies on phytoplankton ecology in India are related to climatic conditions. But, climatic conditions are not only affected phytoplankton assemblages. Watershed features, land use, geochemical features, soil or sediment also affected phytoplankton ecology. Research works on these factors or other unknown factors are not clearly reported in studies of Indian freshwater lakes. Research works required further investigation to explain the relation between phytoplankton communities and lake water chemistry and other factors in Indian scenario. However, most of the discussed case studies are basic and provides necessary information to develop protection and management plans. Authors considered phytoplankton ecology of Indian lakes as an indicator for evaluating the impact of influencing factors. This review study provides a framework for the improved understanding of research and management strategies in fresh water lakes. Phytoplankton ecology plays an important role for indicating the eutrophication. Indian freshwater lakes provide an assessment of cultural eutrophication which controls light and temperature on phytoplankton. This may change the response of lake ecosystems to global warming.

ACKNOWLEDGEMENT

Authors are grateful to the CSIR-National Environmental Engineering Research Institute, Nagpur, India for providing resources for successful conduct of this work.

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