Journal of Environmental Sciences Vol.14, No.1, pp.54—62, 2002

ISSN 1001-0742
CN11—2629/X

Article ID: 1001-0742(2002)01-0054-09 **CLC number**: X131.2 **Document code**: A

Cyanobacterial flora and the physico-chemical environment of six tropical fresh water lakes of Udaipur, India.

J. Pandey[1*], Usha Pandey[2]

(1. Department of Environmental Sciences, M.L.Sukhadia University, Udaipur-313001, India; 2. Department of Botany, G.N. Girls College, Udaipur-313002, India)

Abstract: The cyanobacteria and physico-chemical environments of six tropical fresh water lakes of Udaipur, India were investigated. These lakes receive varying nutrient inputs from different sources. Altogether 51 species of cyanobacteria were recorded. Species composition varied between lakes and between seasons. Lake VI (Baghdara), which receives nutrients from natural sources only, differed considerably from the others in water chemistry and composition of dominant species. Lake II (Swaroop Sagar), eutrophied due to sewage inputs, was species poor. Non-diazotrophs, represented by 27 species, dominated during summer. With few exceptions, N_2-fixing species, both heterocystous and unicellular diazotrophs (represented by 24 species), were dominant during winter. *Microcystis aeruginosa*, *Phormidium* sp. and *Anabaena flos-aque* were the dominant taxa of lakes characterized by sewage eutrophication. The study shows that both species diversity and community composition were affected by water chemistry.

Keywords: cyanobacteria; eutrophication; species diversity

Introduction

The algae of tropical freshwater lakes consist of a diverse assemblage of nearly all major taxonomic groups. The cyanobacteria (blue-green algae) have been among the most studied of all algal groups. One general attribute of cyanobacteria is that they are morphologically quite conservative (procaryotic cell organisation) but metabolically versatile (N fixation and photosynthetic metabolism). In this respect, they differ from most eucaryotic algae, which tend to be structurally versatile but metabolically conservative. Cyanobacteria, perhaps the most widely distributed photosynthetic organisms, can be seen in diverse habitats ranging from alkaline hot springs to polar ice. Cyanobacteria differ in their physiological requirements and vary in response to physical and chemical factors such as light, temperature and nutrients. Despite this diversity, many cyanobacterial species coexist in the same water body. Dominant cyanobacterial genera change as the characteristics of a water body change.

Cyanobacteria are important not only in global CO_2 flux, but also many of these add sizeable amounts of fixed N to ecosystems including agricultural land (Whitton, 1986; Brönmark, 1998). Furthermore, certain cyanobacteria may be useful field indicators on which major water management practices, pollution studies and water quality analyses can be keyed (Palmer, 1969; Tilman, 1982; Schubert, 1984; Reynolds, 1984; Loez, 1998; Pandey, 1999).

Information on cyanobacterial diversity is important for the study of C and N sequestering in nature (Schindler, 1997), understanding the factors influencing changes in cyanobacterial populations (Harris, 1986), describing interactions of cyanobacteria with other organisms (Hansson, 1998), and for the study of effects of anthropogenic pressure upon aquatic habitats (Frempong, 1981; Goldman, 1983; Whitton, 1986a; 1986b; Kumar, 1990; Pandey, 1998a). Information on cyanobacteria in tropical lakes of India is limited, although nutrient status is most frequently cited as a factor responsible for the timing of cyanobacterial blooms (Vyas, 1968; Kumar, 1990; Venugopalan, 1998).

Our data are the result of two consecutive years of study of six freshwater tropical lakes located in the Udaipur range of Aravalli hill tract of India. Udaipur, "the city of lakes", is known globally for its picturesque surrounding and tourism. Because of the arid nature of much of the Rajasthan, permanent and

* Corresponding author

semipermanent water bodies contribute significantly to State water needs. However, increasing inputs of organic and inorganic wastes to lake systems of this region has become a major concern. Studies conducted on the ecology of certain tropical lakes in India (Vyas, 1968a; 1968b; Gopal, 1978; Singh, 1979; Parvateesam, 1991; Venugopalan, 1998; Pandey, 1998b; 2000; Johari, 1999) have indicated changes in water quality and related effects on phytoplankton communities. Data on cyanobacterial diversity in relation to physico-chemical characteristics of Udaipur lakes, however, are fragmentary. To the best of our knowledge, no attempt has been made to provide a comparative account of cyanobacteria and their possible relation with water chemistry in all six lakes of this region. Our aim was to study the major patterns of variation in cyanobacterial assemblages and relate such variations to water chemistry of six lakes of Udaipur.

1 Materials and methods

1.1 Study area

The study area is located in Udaipur district of Rajasthan, India, between 24°35′ to 24°58′ N lat. and 73°42′ to 73°86′E long. The elevation is 510 – 580m above msl. Soils of the region are alfisols derived from parent materials high in limestone and have pH > 7. Natural vegetation is composed of seasonal grasses, scattered trees and shrubs. A few small stretches of land are cultivable and receive applications of fertilizers (N, P and K) and pesticides. Lodha and Saxena (Lodha, 1989) have provided a useful outline of the topographic features and vegetation of the region. The research was done on six lakes, numbered I to VI, situated within a radius of about 24 km of Udaipur (Fig. 1). In general, all these lakes are under similar climatic control. Another common feature of these lakes, except Swaroop Sagar, is that they are flushed by rain water drainage through limestone rocks. Lake Pichola and Udai Sagar have, at their one margin, exposed beds of limestone separated by bands of sandstones. Being located in different areas, lakes receive nutrients from different sources. Except for Baghdara, all the lakes receive anthropogenic inputs. Lake Baghdara, located away from human settlement, has not been subjected to human activities (Table 1).

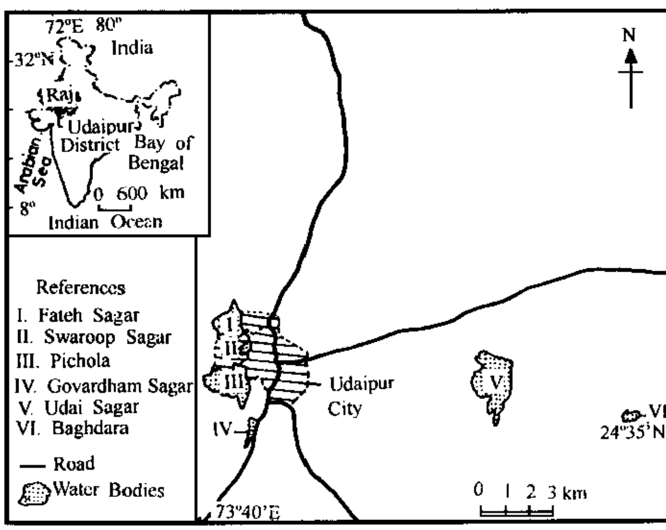

Fig. 1 Location of the lakes

1.2 Climate

The climate of the region is tropical. The year is divisible into three distinct seasons, a hot and dry summer (March – June), a warm and wet rainy (July—October) and a cool and dry winter (November – February). The first half of the summer season experiences strong, hot, dry winds and high temperatures, while the second half is generally hot and humid. During the study period, annual rainfall averaged 630 mm, about 90% of which occurred during the rainy season from southwest monsoon. Relative humidity ranged between 20% (summer) to 90% (monsoon season). During summer, daytime temperatures were from 34° – 46.2°. During winter, temperature varied from 10 – 23°C and night temperatures sometimes dropped below 4℃. Wind direction shifted predominantly westerly and north-westerly in October to April and to easterly and south-westerly in the remaining months.

Table 1 General characteristics of the lakes

Lakes		Size, km^2	Depth, m	Sources of wastes/nutrient input	Dominant macrophytes
Ⅰ	Fateh Sagar	4.0	13.4	Seasonal overflow from Swaroop Sagar & Pichola; tourist activities	*Hydrilla verticillata*, *Potamogeton crispus*, *Chara corallina* and *Vallisneria spiralis*
Ⅱ	Swaroop Sagar	1.2	11.2	Urban sewage effluent; detergents through washermen's activities	*Lemna minor*, *Azolla pinnata Pistia* sp., *Eichhornia crassipes*, *Typha* sp. and *Eleoch aris capitata*
Ⅲ	Pichola	7.0	10.5	Urban sewage effluent; sediments (during flood) through Sisarma River	*E. crassipes*, *H. verticillata*, *P. crispus*, *V. spiralis* and *Cyperus iria*
Ⅳ	Govardhan Sagar	1.6	7.5	Urban sewage effluent, agricultural run-off, road drainage	*L. minor*, *P. perfoliatus*, *Ceratophyllum demersem*, *E. capitata* and *Typha* sp.
Ⅴ	Udai Sagar	7.7	11.2	Urban industrial effluent; agricultural runoff	*A. pinnata*, *E. crassipes*, *Pistia stratiolis*, *L. minor*, *P. perfoliatus* and *Typha* sp.
Ⅵ	Baghdara	1.2	8.5	Leaf litter; animal excreta; bird droppings	*H. verticillata*, *C. corallina*, *P. crispus*, *Cyperus iria* and *V. spiralis*

1.3 Sampling program

Samples were collected from four sites in each of the six lakes. Two visits were made each month on the 14th, 15th and on 29th, 30th (with the exception of February). Water samples (10 – 20 cm depth) were collected between 08:00 and 10:00h. Data for each sampling site are based on at least five subsamples.

Water temperature, transparency, pH and conductivity were all measured in the field. Remaining water quality parameters were measured following standard methods (APHA, 1985). Dissolved oxygen (DO) was estimated by the modified Winkler method (Wetzel, 1979). Water samples for element analyses were allowed to stand for 5 min and the uppermost layer of liquid was used. For silica, polyethylene bottles were used.

Phytoplankton samples were collected by towing a fine conical net of bolting silk for 5 min at approximately uniform speed. At least 5 samples were collected at each site. Phytoplankton samples were also collected using small sampling bottles. Samples containing dilute cyanobacterial populations were concentrated by centrifugation for microscopic identification and counting. Phytoplankton samples were examined fresh and also fixed in 4% formalin. Systematic identification of cyanobacteria was done with the help of standard works of Fritsch (Fritsch, 1945), Prescott (Prescott, 1951) and Desikachary (Desikachary, 1959).

Relative frequencies (RF) and densities (RD) of a species were determined as per Pandey *et al*. (Pandey, 1995). The average relative frequency and density (RFD) for a species was calculated as (RF + RD)/2. The maximum value at a site was considered as 100% and all species at that site were divided into 4 classes, i.e., (1) 0 – 25% (taxon present); (2) 26% – 50% (common constituent); (3) 31% – 75% (important) and (4) 76% – 100 % (dominant). Similarity indices (SI) were calculated by the formula given by Sörenson (Sörenson, 1948). Species diversity was estimated by the Shannon-Weiner index (Shannon, 1963). For an evenness index (e), the formula given by Pielou (Pielou, 1966) was used. The species richness index (d) was calculated using the formula of Margalef (Margalef, 1958). Concentration of dominance (Cd) was calculated according to Simpson (Simpson, 1949).

2 Results

The results of physico-chemical analysis of water samples are presented in Tables 2 – 4. Average temperatures ranged from 16.8℃ (winter) at lake Ⅵ to 26.7° (summer) at Ⅴ. Water at lake VI was clearest (Secchi disc transparency 1.4m) and that of lake Ⅱ was the least clear (Secchi disc transparency as low as 0.3 m). The pH were > 7. Lake Ⅱ contained the highest concentration of Cl^- and lake Ⅵ contained the lowest. Conductivity of lake waters ranged from 325 $\mu s \cdot cm^{-1}$ during summer (lake Ⅰ) to 480 $\mu s \cdot cm^{-1}$ during monsoon (lake Ⅴ). Concentrations of Ca^{2+}, Mg^{2+}, Na^+ and K^+ were high in lake Ⅴ. Samples collected during mansoon season contained high amounts of these elements (Table 3). Silicate ranged from 1.9 mg/L during summer (lake Ⅴ) to 8.5 mg/L during monsoon (lake Ⅵ). NO_3^--N concentrations ranged from 89.3 μg/L (lake Ⅵ) to 1650.6 μg/L (lake Ⅱ), and PO_4^{3-}-P from 10.5 μg/L (lake Ⅵ) to 200.4 μg/L (lake Ⅱ). Concentrations of N and P were highest during monsoon and lowest during summer (Tables 2 and 4). Dissolved oxygen ranged from 2.1 mg/L during summer (lake Ⅱ) to 8.7 mg/L during winter (lake Ⅵ). Free CO_2 concentrations were higher during summer.

Cyanobacteria were conspicuous in all lakes. Cyanobacterial patches with copious mucilage were abundant on soil surfaces near the edges of lakes and beneath small rocks and stones. Nostoc commune and N. calcicola grew luxuriantly on wet rock surfaces. The major patterns of variation in cyanobacterial assemblages are given in Table 5. Altogether 51 cyanobacterial taxa were identified from these water bodies. Out of 27 taxa of non-diazotrophs, *Microcystis* and *Phormidium* were dominant. Anabaena flos-aquae was the most dominant taxon among diazotrophs. Lakes differed in species composition. The unicellular colonial *Microcystis aeruginosa* and *filamentous Anabaena* flos-aquae were the most common taxa in lakes Ⅱ, Ⅲ, Ⅳ and Ⅴ. Lake Ⅰ and Ⅵ were dominated by *Aphanocapsa biformis*, *Calothrix gracilis* and *Tolypothrix* sp. Species such as *Anabaena constricta*, *Aphanocapsa biformis*, *Aulosira prolifica*, *Calothrix gracilis*, *Fischerella epiphytica*, *Gloeocapsa punctata*, *Haplosiphon baronii*, *Merismopedia convoluta*, *M. minima*, *Nostoc muscorum*, *Stigonema harmoides*, *S. ocellatum* and *Spirulina* major were absent from lake Ⅱ. Three taxa, namely *Merismopedia convoluta*, *M. minima* and *Stigonema harmoides* were restricted to lakes Ⅰ and Ⅵ. Diazotrophs dominanted during winter and non-diazotrophs during summer. Species distributions during monsoon season were quite variable (Table 5). *Anabaena constricta*, *Haplosiphon baronii* and *Merismopedia minima* were not observed during monsoon season.

Table 2 Physico-chemical characteristics of water samples collected during summer (March-June) from six different lakes of Udaipur (values in parentheses represent 1 SE)

Physico-chemical characteristics	Lakes					
	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ	Ⅵ
Temperature, ℃	26.5 (1.52)	26.7 (1.80)	26.7 (1.65)	26.5 (1.76)	26.7 (1.78)	25.8 (1.82)
Transparency, m	1.1 (0.06)	0.7 (0.05)	1.1 (0.05)	1.0 (0.07)	0.7 (0.06)	1.2 (0.08)
pH	7.6 (0.54)	7.8 (0.72)	7.6 (0.65)	7.6 (0.70)	7.8 (0.76)	7.5 (0.59)
Conductivity, μs/cm	325 (25.60)	340 (31.50)	425 (38.30)	386 (38.10)	360 (41.00)	440 (40.50)
Cl^-, mg/L	17.4 (1.35)	40.1 (2.82)	30.0 (2.15)	28.2 (3.10)	32.5 (2.76)	15.1 (1.10)
Ca^{2+}, mg/L	15.5 (1.25)	16.0 (1.18)	25.5 (2.10)	20.7 (1.12)	32.5 (3.10)	21.5 (1.80)
Mg^{2+}, mg/L	6.8 (0.44)	12.6 (1.05)	8.3 (1.02)	21.1 (1.86)	24.5 (1.90)	16.1 (1.52)
Na^+, mg/L	7.9 (0.66)	12.2 (1.02)	8.1 (0.71)	13.7 (1.10)	18.1 (1.70)	14.6 (1.24)
K^+, mg/L	3.3 (0.22)	7.1 (0.57)	3.9 (0.26)	6.2 (0.48)	8.1 (0.71)	6.2 (0.55)
Silicates, mg/L	2.8 (0.21)	2.8 (0.19)	3.5 (0.24)	3.0 (0.21)	3.9 (0.19)	3.2 (0.26)
Nitrate-N, μg/L	186.0 (14.50)	710.0 (64.20)	365.8 (31.50)	222.9 (20.20)	572.7 (51.40)	89.3 (7.80)
Phosphate-P, μg/L	24.0 (1.70)	90.5 (7.25)	48.1 (4.12)	30.2 (3.10)	72.6 (6.55)	10.5 (1.02)
Dissolved oxygen, mg/L	3.2 (0.24)	2.1 (0.20)	2.5 (0.21)	3.0 (0.26)	3.1 (0.24)	3.6 (0.33)
Free CO_2, mg/L	6.2 (0.51)	7.5 (0.54)	6.7 (0.56)	7.0 (0.62)	7.1 (0.58)	6.5 (0.47)

Table 3 Physico-chemical characteristics of water samples collected during monsoon season (July – October) from six different lakes of Udaipur (values in parentheses represent 1 SE)

Physico-chemical characteristics	Lakes I	II	III	IV	V	VI
Temperature, ℃	24.0 (2.02)	24.1 (1.82)	24.1 (2.00)	24.0 (2.00)	24.0 (1.90)	23.3 (1.78)
Transparency, m	0.5 (0.04)	0.3 (0.03)	0.4 (0.03)	0.4 (0.03)	0.4 (0.04)	0.6 (0.04)
pH	7.5 (0.61)	7.6 (0.66)	7.6 (0.62)	7.5 (0.71)	7.6 (0.65)	7.4 (0.59)
Conductivity, μs/cm	421 (39.50)	415 (35.10)	462 (41.00)	418 (40.10)	480 (41.20)	450 (40.00)
Cl^-, mg/L	13.2 (1.12)	36.1 (3.15)	24.3 (2.10)	22.8 (1.72)	25.1 (1.81)	10.6 (0.82)
Ca^{2+}, mg/L	35.5 (3.21)	33.1 (3.10)	48.0 (3.56)	40.0 (3.51)	60.1 (5.52)	40.9 (3.86)
Mg^{2+}, mg/L	18.2 (1.53)	25.2 (2.10)	19.5 (1.52)	37.0 (3.10)	44.2 (4.12)	31.5 (3.02)
Na^+, mg/L	8.8 (0.72)	14.9 (1.05)	9.2 (0.68)	15.8 (1.12)	20.2 (2.02)	16.0(1.26)
K^+, mg/L	3.9 (0.31)	7.5 (0.49)	4.1 (0.33)	7.1 (0.62)	10.1 (0.80)	8.0(0.66)
Silicates, mg/L	8.2 (0.65)	6.5 (0.45)	10.2 (0.76)	7.2 (0.58)	10.8 (0.79)	8.5(0.71)
Nitrate-N, μg/L	600.3 (48.30)	1650.6 (112.50)	1100.0 (102.00)	660.2 (52.10)	1120.5 (96.5)	154.1(12.10)
Phosphate-P, μg/L	70.0 (6.20)	200.4 (14.89)	130.0 (11.20)	70.9 (7.00)	140.0 (10.50)	20.0(1.60)
Dissolved oxygen, mg/L	4.1 (0.26)	2.9 (0.15)	3.1 (0.23)	3.8 (0.22)	4.0 (0.27)	4.8 (0.19)
Free CO_2, mg/L	5.9 (0.33)	7.2 (0.56)	6.5 (0.43)	6.1 (0.41)	6.2 (0.38)	6.0 (0.40)

Table 4 Physico-chemical characteristics of water samples collected during winter (November-February) from six different lakes of Udaipur (values in parentheses represent 1 SE)

Physico-chemical characteristics	Lakes I	II	III	IV	V	VI
Temperature, ℃	17.0 (1.25)	17.1 (1.45)	17.0 (1.25)	17.0 (1.30)	17.1 (1.42)	16.8 (1.31)
Transparency, m	1.4 (0.11)	0.8 (0.05)	1.2 (0.08)	1.1 (0.80)	0.8 (0.06)	1.4 (0.12)
pH	7.5 (0.63)	7.8 (0.69)	7.5 (0.57)	7.4 (0.55)	7.5 (0.61)	7.4 (0.71)
Conductivity, μs/cm	408 (34.60)	390 (34.30)	450 (41.40)	410 (37.20)	460 (42.00)	435 (40.50)
Cl^-, mg/L	16.2 (1.12)	38.5 (3.20)	30.0 (2.72)	26.1 (2.10)	32.6 (3.02)	14.7 (1.05)
Ca^{2+}, mg/L	33.2 (3.10)	30.1 (2.60)	42.2 (3.50)	32.6 (2.55)	55.3 (5.10)	36.2 (3.12)
Mg^{2+}, mg/L	16.1 (1.12)	20.8 (1.66)	16.8 (1.45)	30.1 (2.71)	40.0 (3.26)	27.6 (2.22)
Na^+, mg/L	3.0 (0.26)	7.1 (0.49)	4.2 (0.31)	10.0 (1.00)	10.6 (0.92)	7.9 (0.61)
K^+, mg/L	1.6 (0.15)	3.6 (0.31)	2.1 (0.16)	5.1 (0.36)	5.0 (0.37)	3.9 (0.29)
Silicates, mg/L	3.0 (0.26)	3.0 (0.26)	3.6 (0.32)	3.2 (0.19)	3.4 (0.28)	2.8 (0.21)
Nitrate-N, μg/L	400.4(36.10)	1005.0(90.10)	820.5(70.50)	410.0(38.20)	1001.0(88.60)	145.0 (11.20)
Phosphate-P, μg/L	50.7(4.62)	144.6(12.25)	106.2(9.60)	56.8(4.82)	120.5(10.15)	15.2(1.10)
Dissolved oxygen, mg/L	6.8(0.55)	3.9 (0.33)	4.7 (0.39)	5.3 (0.51)	4.1(0.40)	8.7 (0.69)
Free CO_2, mg/L	3.4 (0.30)	4.1 (0.36)	3.5 (0.29)	3.9 (0.32)	4.0 (0.40)	3.2 (0.28)

Cyanobacterial communities of lakes Ⅰ and Ⅵ were most similar ($SI = 0.97$), and lakes Ⅱ and Ⅵ were least similar ($SI = 0.44$, Table 6). The data presented in Table 7 show that the Shannon-Wiener diversity index was highest in lake Ⅰ and lowest in lake Ⅱ. Species richness and evenness were high in lakes Ⅰ and Ⅵ. Concentration of dominance was highest in lake Ⅱ and lowest in Ⅵ.

3 Discussion

Our observations on physico-chemical characteristics of lakes are consistent with those of other studies on tropical lakes in India (Singh, 1979; Sankhla, 1980; Srivastava, 1993; Kausik, 1995; Pandey, 1998b; Venugopalan, 1998). The data on water chemistry indicated altered water quality of lake systems of Udaipur region. Differences in element concentrations in different lakes reflect varying chemistry of inflow waters. Waters of lakes Ⅲ and Ⅴ were highly calcareous. High element concentrations during monsoon indicate additional flux through land drainage.

Table 5 Distribution patterns of cyanobacteria at 6 different lakes of Udaipur

Taxon / Season	W						S						R					
Lake	I	II	III	IV	V	VI	I	II	III	IV	V	VI	I	II	III	IV	V	VI
Anabaena constricta Geitler	1	–	–	1	1	1	1	–	–	1	–	1	–	–	–	–	–	–
A. flos-aquae Breb ex Born et Flah	1	4	4	4	4	1	1	4	3	3	3	1	1	2	1	2	2	1
A. oscillaroides Bory ex Born et Flah	1	4	3	3	3	1	1	3	2	2	3	1	1	2	1	1	1	1
Aphanocapsa biformis A. Br.	4	–	1	1	–	4	3	–	1	1	–	4	1	–	–	–	1	2
A. grevillei (Hass) Rabenh	2	1	1	–	–	3	–	1	1	–	4		1	–	–	–	1	2
A. microscopica Nag	1	1	1	–	–	2	1	–	1	1	–	3	1	–	1	1	1	1
Arthrospira jenneri Slizenb ex Gomont	1	3	2	2	2	1	1	4	3	2	2	1	1	2	1	1	1	1
A. platensis (Nordst.) Gomont	1	2	1	1	2	1	1	2	2	1	2	1	1	2	1	1	–	–
Aulosira prolifica Bharadwaja	2	–	1	2	–	2	1	–	–	1	–	1	1	–	–	1	1	1
Calothrix gracilis Bharadwaja	4	–	1	1	1	4	3	–	1	1	–	3	2	–	1	–	–	2
C. parientina Thuret ex Born et Flah	2	1	1	3	3	3	1	–	1	2	1	2	1	1	1	1	1	2
Chroococcus turgidus (Kütz.) Nag	1	1	1	1	1	3	1	–	1	–	–	3	1	–	1	1	–	1
C. various A. Br.	1	–	1	2	1	2	1	1	1	1	1	1	1	1	1	2	1	2
C. dispersus (V. Keissler) Lemm.	1	–	1	1	–	2	1	1	1	2	–	1	1	1	1	2	1	2
C. minutus (Kütz.) Nag	2	1	2	1	1	3	3	1	2	2	1	3	2	1	1	1	1	2
Cylindrospermum majus Kütz ex Born et Flah	2	1	1	1	–	2	1	–	–	1	–	2	1	–	–	1	1	1
Fischerella epiphytica Ghose	1	–	1	1	1	1	1	–	–	–	–	1	1	–	–	1	1	1
Gloeocapsa punctata Näg	2	1	1	1	–	2	1	–	1	1	–	2	1	–	–	–	1	2
G. aeruginosa (Carm) Kütz.	3	1	2	2	1	3	2	1	2	1	1	2	2	1	1	1	1	2
Gloeotrichia natans Rabenh	2	1	1	2	1	2	2	1	1	1	–	2	1	–	1	–	–	1
Haplosiphon baronii et G. S. West	1	–	1	–	1	1	1	–	1	–	1	2	–	–	–	–	–	–
Lyngbya contorta Lemm.	1	1	1	1	1	1	1	–	1	1	1	1	1	1	1	1	1	1
L. martensiana Menegh ex Gomont	2	1	1	1	1	2	1	–	1	1	1	2	1	–	1	–	–	1
L. stagnina kützing	–	1	1	1	1	–	–	1	1	1	1	–	–	1	–	1	1	–
Merismopedia convoluta Breb.	1	–	–	–	–	1	1	–	–	–	–	1	1	–	–	–	1	1
M. minima Beek.	1	–	–	–	1	1	1	–	–	–	–	1	–	–	–	–	–	–
Microcystis aeruginosa Kütz.	2	4	3	3	3	1	2	4	4	4	4	1	1	3	2	1	2	–
M. viridis (A. Br.) Lemn.	–	–	–	2	–	–	–	1	1	2	1	–	–	–	–	–	2	–
Nostoc calcicola Brebisson ex Born et Flah	2	1	4	3	4	3	2	1	2	2	2	2	1	1	1	2	1	2
N. commune Vaucher ex Born et	3	1	1	2	2	3	2	–	–	1	1	2	1	–	–	1	1	2
N. muscorum Ag. ex Born et Flah	2	–	–	1	1	2	1	–	–	1	–	1	1	–	–	–	–	1
N. punctiformae (kütz) Hariot.	2	1	1	1	1	2	1	–	–	1	1	1	1	–	–	–	–	1
Oscillatoria acuminata Gomont	1	1	1	–	–	1	1	–	2	–	1	1	1	1	1	–	–	1
O. acuta Bruh et Biswas	1	1	1	1	1	1	1	–	1	1	1	1	2	1	1	2	1	2
O. boryana Bory ex Gomont	1	3	1	1	3	–	–	4	2	1	4	–	1	2	1	1	2	–
O. raciborskii Wolosz.	1	1	1	1	1	2	1	1	1	1	1	1	2	2	3	3	2	2
O laete-virens (Crouan) Gomont	2	1	2	2	1	2	3	1	2	3	1	3	1	1	1	1	1	1
Phormidium ambiguum Gomont	1	3	2	2	3	1	1	4	3	3	4	1	1	2	1	2	2	1
P. calcicola Gardner	1	1	2	3	3	3	1	1	3	4	4	4	1	1	1	2	2	2
P. uncinatum (Ag.) Gomont.	1	3	2	2	2	1	1	4	2	3	3	1	1	2	1	1	2	1
P. tenue (Menegh) Gomont.	1	2	2	2	2	1	1	4	2	3	4	1	1	2	1	1	1	1
Plectonema wollei Farlous ex Gomont.	2	3	2	2	3	1	1	3	2	3	4	1	1	2	1	2	2	1
Raphidiopsis indica Singh, R.N.	1	2	1	2	2	–	1	3	2	3	3	–	1	1	1	1	2	–
R. curvata Fritsch et Rich	1	3	1	2	3	–	1	4	2	2	4	–	1	2	1	2	2	–
Stigonema hormoides (Kütz.) Born et Flah	2	–	–	–	–	2	1	–	–	–	–	1	1	–	–	–	–	1
S. ocellatum (Dillw) Thuret ex Born et Flah	2	–	–	1	1	3	2	–	–	–	–	2	1	–	–	1	–	2
Spirulina gigantea Schmidle	2	1	1	1	–	2	2	–	2	–	–	3	1	–	1	–	–	2
S. major Kütz. ex Gomont	2	–	1	–	–	2	1	–	1	–	–	2	1	–	–	–	–	1
Tolypothrix nodosa Bharadwaja	3	1	2	1	–	3	2	–	1	1	–	2	2	–	1	1	–	3
T. tenuis (Kütz) Johs. Schmidtem	4	1	1	1	–	4	3	–	1	–	–	3	2	–	1	–	–	2
Scytonema iyengari Bharadwaja	2	1	1	1	2	3	1	–	1	1	1	2	1	–	1	1	1	1

W. winter; S. summer; R. rainy; 4. dominant species of the community; 3. important species; 2. dominant but not as above; 1. just present

Table 6 Similarity matrix (Sörenson coefficient) of cyanobacteria based on the presence or absence between six different fresh water lakes of Udaipur

Lakes	Sörenson coefficient																	
	Winter						Summer						Rainy					
	I	II	III	IV	V	VI	I	II	III	IV	V	VI	I	II	III	IV	V	VI
I	1.00	0.80	0.88	0.89	0.82	0.95	1.00	0.47	0.67	0.78	0.61	0.97	1.00	0.54	0.70	0.67	0.68	0.89
II		1.00	0.88	0.86	0.81	0.78		1.00	0.52	0.58	0.58	0.44		1.00	0.59	0.58	0.58	0.44
III			1.00	0.90	0.80	0.87			1.00	0.78	0.65	0.78			1.00	0.71	0.58	0.60
IV				1.00	0.86	0.83				1.00	0.71	0.76				1.00	0.71	0.56
V					1.00	0.76					1.00	0.61					1.00	0.66
VI						1.00						1.00						1.00

Table 7 Species richness, evenness, Shannon-Wiener index and concentration of dominance for cyanobacteria at six different fresh water lakes of Udaipur

Lake	Total No. of species * observed	Species richness index	Evenness index	Shannon Wiener index	Concentration of dominance
I	49	8.23	0.82	3.21	0.221
II	38	4.68	0.75	2.73	0.562
III	44	6.42	0.76	2.86	0.328
IV	45	6.56	0.77	2.92	0.383
V	46	6.10	0.75	2.86	0.360
VI	46	8.12	0.81	3.10	0.187

* Based on Table 5

Calcium concentration in lakes V and III, together with high amounts of silica, suggest that rainwater draining limestone and sandstone is relatively more important for these lakes. Concentrations of N and P were maximum in lake II which receives urban sewage effluent and detergents. Wild (Wild, 1977) has indicated that urban sewage effluent alone contributes up to 40 % of NO_3^- present in some surface waters. Detergents are particularly rich in P (Kumar, 1990). The water in lake V, receiving urban-industrial effluent (through Ahar stream) and agricultural runoff, had high N and P contents.

Cyanobacteria were conspicuous in all lakes studied. Magnificent cyanobacterial blooms occurred in lakes rich in nutrients. A number of the species observed have been recorded from other freshwater environments. Species diversity and dominance varied considerably with lake and season. Factors that may cue massive cyanobacterial growth, in a proximate sense, include light, temperature and timing of nutrient release (Harris, 1986). Tropical lakes provide good conditions for cyanobacterial growth as a result of optimum temperatures, ample light and nutrients (Singh, 1955). Since all lakes are under similar climatic control but differ in their exposure to inflow waters and land use, nutrient regimes seem to be of key importance for variations in species diversity and community structure. Several lines of evidence have indicated that N and P have particular importance in this respect (Harris, 1986; Kumar, 1990; Hansson, 1992; Brönmark, 1998; Pinckney, 1999).

Dominance of such species as *Anabaena flos-aquae*, *A. oscillaroides*, *Microcystis aeruginosa*, *Phormidium ambiguum* and *P. uncinatum* are known to indicate increased nutrient enrichment of aquatic bodies (Palmer, 1969; Bush, 1972; Kumar, 1990; Pandey, 1998b). We observed prolific growth of such species, particularly at lakes II and V. Some species were restricted to certain lakes or seasons only. Kann (Kann, 1982) noted that the population size of *Calothrix* and *Rivularia* decreased in Traunsee, Austria, over a period of time associated with increased sewage eutrophication. In the present study *Calothrix* was dominant only at lakes I and VI. At lake II, which receives high amounts of sewage effluent, this species was absent.

Seasonal, as well as between-lake variations indicated that low concentrations of nutrients (specially N and P) coincide with excessive cyanobacterial blooms during summer. It could be that a greater proportion of these nutrients was used by rapidly growing species making the ambient water nutrient poor. Studies have indicated that the time of peak concentrations of N and P do not coincide with the period of excessive algal growth but rather precede it (Tucker, 1957; Lund, 1965). Most phytoplankton populations exhibit a marked seasonal periodicity, related to changing physico-chemical factors. Bloom-forming species can maintain their abundance from two to several weeks (Kalff, 1978; Wetzel, 1983). During this period soluble nutrient content in waters may decline as they are extracted by growing cells.

Dry months were characterized by prolific cyanobacterial growth and the composition of dominant forms showed two distinct pulses. With few exceptions, diazotrophs were dominant during winter and non-diazotrophs during summer. A high standing crop of cyanobacteria during summer, in which functional importance shifted from diazotrophs to non-diazotrophs, was associated with high temperature, high light intensity, relatively low DO, reduction of water volume and nutrient release from dead organic remains including that of littoral macrophytes. On the other hand, a high standing crop of N_2-fixers was associated with low temperature, low light intensity, high DO and comparatively slow nutrient release through bacterial decomposition. Release of high amounts of fixed-N by diazotrophs could make an additional N-pool for cyanobacterial blooms to continue during warmer months. N_2 fixation by cyanobacteria may, in some cases, contribute up to 50% of annual N input to a lake (Brönmark, 1998). The ability to capitalize on conditions conducive for growth plays an important role in the timing, extent, and species involved with blooms. Two separate periods of blooming, with variable species composition, may be a mechanism by which cyanobacteria avoid interspecific competition for resources.

Nutrient rich lake Ⅱ, receiving high amounts of urban sewage effluent and detergents, was species poor. Several investigators have established a direct relationship between nutrient enrichment in water and growth of cyanobacteria (Bush, 1972; Tilman, 1982). However, it has also been observed (Tilman, 1982; Turpin, 1991) that a few species exploit such conditions more effectively, eliminating less adapted taxa from the habitat. With this competitive advantage such species grow prolifically and form blooms. Lake Ⅱ was dominated by *Microcystis aeruginosa* and *Anabaena flos-aquae*.

The Shannon-Wiener diversity index was the highest in lake Ⅰ and the lowest in lake Ⅱ. Species richness (Margalef index) also suggested that lake Ⅰ supported growth of a wide variety of cyanobacteria. A high similarity index (SI = 0.97) indicated that lakes Ⅰ and Ⅵ contained similar cyanobacterial groups. Lake Ⅵ maintained cyanobacterial diversity similar to lake Ⅰ. Lake Ⅰ receive nutrients from anthropogenic sources and lake Ⅵ from natural sources including bird droppings. Studies have indicated that animal excreta including bird droppings are rich in N and P (Andersson, 1988; Venugopalan, 1998).

The present study indicates that the nutrient status of most of the lakes of the Udaipur region have reached a level very close to eutrophic (Wetzel, 1975). Species such as *Microcystis aeruginosa*, *Anabaena flos-aquae* and *Phormidium ambiguum* may be used as bioindicators of eutrophication in tropical lakes. The data further indicate elimination of sensitive cyanobacteria from lakes receiving high amounts of urban effluent. This has ecological implications since cyanobacteria contribute to global CO_2 flux and add sizeable amounts of fixed N to ecosystems. Furthermore, prolific growth of nuisance cyanobacteria such as *Microcystis aeruginosa* and *Anabaena flos-aquae* have degraded some of these lakes for water use. These species impart a foul odour and are toxic to cattle and other animals (Kumar, 1990). This is a serious concern since these lakes are the most important source of drinking and irrigation water in this region. We conclude that increased human discharge, as expected in future, will limit water uses and aesthetic values of these lakes. It will therefore, be important to consider special measures for conservation of these water bodies. Reducing nutrient inputs would be an effective measure to restore these degraded lakes. For instance, diverting Ahar (the only stream that brings urban-industrial effluent to lake Ⅴ), and altering in agricultural methods will reduce external loading of nutrients to lake Ⅴ. Natural eutrophication is a slow process often taking place over a period of thousands of years. However, as observed for lake Ⅵ, nutrient input through bird droppings could accelerate natural eutrophication. This has important bearings for aquatic bodies not subjected to anthropogenic discharges.

References:

APHA, 1985. Standard methods for examination of water and waste water[M](16th Edn). Washington D C: APHA, AWAA, WPCF.
Andersson G, Graneli W, Stenson J, 1988. Hydrobiologia[J], 170:267.
Brönmark C, Hansson L A, 1998. The biology of lakes and ponds [M]. Oxford:Oxford University Press.
Bush R M, Welch E B, 1972. Water Air Soil Pollut[J], 1:257.
Desikachary T V, 1959. Cyanophyta[M]. New Delhi: Indian Council of Agricultural Research.
Frempong E, 1981. Arch Hydrobiol[J], 92:457.
Fritsch F E, 1945. The structure and reproduction of the algae [M]. London:Cambridge University Press.
Goldman C R, Horne A J, 1983. Limnology [M]. Japan:Mc Graw Hill, Inc.
Gopal B, Sharma K P, Trivedi R K, 1978. Glimpses of ecology (J S Singh and B Gopal ed.)[M]. Jaipur:Intil. Sci. Pubis.
Hansson L A, 1992. Ecology[J], 73:241.
Hansson L A, Bergman E, Cronberg G, 1998. Oikos[J], 81:337.
Harris G P, 1986. Phytoplankton ecology-structure, function and fluctuation[M]. New York:Chapman and Hall.
Johari S, Chaudhary U S, Chaudhary P R, 1999. J Ecotoxicol Environ Monit[J], 9:35.
Kalff J, Knoechel R, 1978. Ann Rev Ecol Syst[J], 9:475.
Kann E, 1982. Arch Hydrobiol Suppl[J], 62:440.
Kausik S, Saksena D N, 1995. J Environ Biol [J], 16:283.
Kumar H D, 1990. Introductory Phycology[M]. New Delhi : Affiliated East-West Press Pvt. Ltd.
Lodha R M, Saxena V, 1989. Pesticides and Environmental Pollution [M]. Udaipur:Himansu Publications.
Loez C R, Salibian A, Topalian M L, 1998. Reveu des sciences de I'Eau [J], 11:315.
Lund J W G, 1965. Biol Rev[J], 40:231.
Margalef R, 1958. Perspective in marine biology [M] (A A Buzzati-Traverso ed.). Berkel: University of California Press.
Palmer C M, 1969. British Phycology Bull [J], 5:78.
Pandey J, Pandey U, Tyagi H R, Rai N, 1998a. Ind J Environ Sci [J], 2:83.
Pandey J, Pandey U, Tyagi H R, Rai N, 1998b. Phykos [J], 37:29.
Pandey J, Pandey U, Tyagi H R, 2000. J Environ Biol [J], 21:133.
Pandey K D, Kashyap A K, Gupta R K, 1995. Hydrobiologia[J], 299:83.
Pandey U, Chatterjee C, 1999. Ann Appl Biol[J], 143:259.
Parvateesam M, Mathur M, Sharma M, 1991. J Phytol Res[J], 4:33.
Pielou E C, 1966. J Theoretical Biol [J], 10:370.
Pinckney J L, Paerl H W, Harrington M B, 1999. J Phycol[J], 35:1455.
Prescott G W, 1951. Algae of western great lake areas[M]. Cranbrook Institute of Science Bulletin, No. 33. 496.
Reynolds C S, 1984. The ecology of freshwater phytoplankton[M]. London: Cambridge University Press.
Sankhla S K, Jain S L, Dhakar M L *et al.*, 1980. Acta Limnologica Indica [J], 1:11.
Schindler D E, Carpenter S R, Cole J J *et al.*, 1997. Science [J], 277:248.
Schubert L E, 1984. Algae as ecological indicators[M]. London: Academic Press.
Shannon C E, Weaver W, 1963. The mathematical theory of communication[M]. Illinois:University of Illinois Press.
Simpson E E, 1949. Nature[J], 163:688.
Singh R N, 1955. Proc Int Assoc Limn[J], 12:831.
Singh S R, Swaroop K, 1979. J Ind Bot Soc[J], 58:319.
Sörenson T, 1948. Det Kongelige Danske Videnskhabernes Selskabs Biologiske Skrifter [J], 5:1.
Srivastava P N, Odhawani B R, 1993. Phykos[J], 32:121.
Sylvester R O, 1961. Tech Rep Taft Sanit Eng Center [J], W-61-3 : 80.
Tilman D, Kilham S S, Kilham P, 1982. Ann Rev Ecol Syst [J], 13:347.
Tilman D, Kiesling R, Sterner R *et al.*, 1986. Archiv fur Hydrobiologie[J], 106:473.
Tucker A, 1957. Am Midland Naturalist [J], 57:300.
Turpin D N, 1991. Growth and reproductive strategies in freshwater phytoplankton(C D Sandgren ed.)[M]. London: Cambridge University Press.
Venugopalan V P, Nandakumar K, Rajamohan R *et al.*, 1998. Cur Sci [J], 74:915.
Vyas L N, Kumar H D, 1968a. Hydrobiologia[J], 31: 421.
Vyas L N, 1968b. Proc symp recent adv trop ecol(R Misra and B Gopal ed.)[C]. Varanasi:Banaras Hindu University.
Wetzel R G, 1975. Limnology[M]. Philadelphia: W B Saunders Co.
Wetzel R G, Likens G E, 1979. Limnological analysis[M]. Philadelphia: W B Saunders Co.
Whitton B A, Catling H D, 1986a. Arch Hydrobiol [J], 105:289.
Whitton B A, Khoja T M, Arif I A, 1986b. Hydrobiologia[J], 133:97.
Wild A J, 1977. Nature[J], 268:197.

(Received for review December 27, 2000. Accepted February 14, 2001)