Original Article

Journal of Phytology 2015, 7: 10-18
http://scienceflora.org/journals/index.php/jp/
doi: 10.5455/jp.2015-09-17

Distribution pattern of freshwater cyanobacteria in Kaiga region of Western Ghats of Karnataka

Sharath Chandra K., M. Rajashekhar*

Department of Studies in Biosciences, Mangalore University, Mangalagangothri, Karnataka, India

Received: 27.09.2015
Accepted: 19.10.2015
Published: 26.10.2012

***Address for correspondence:**
M. Rajashekhar, Department of Studies in Biosciences, Mangalore University, Mangalagangothri, Karnataka, India.
Fax: 0091-824-2287367.
E-mail: profmrajashekhar@yahoo.co.in

ABSTRACT

This study deals with the identification of 59 cyanobacterial species belonging to 27 genera from different freshwater habitats of Kaiga in Uttara Kannada district of Karnataka during the period from June 2009 to May 2011. Samplings were made during pre-monsoon; monsoon and post-monsoon seasons for the duration of 2 years. The study deals with the occurrence of cyanobacterial species in five different aquatic habitats in Kaiga region, with respect to a change in the physico-chemical properties of water. The cyanobacterial diversity is maximum in monsoon season compared to post-monsoon; it was least during pre-monsoon. Among cyanobacteria non-heterocystous filamentous forms were dominant followed by unicellular forms, whereas heterocystous forms were least in number. It was also found that the physico-chemical properties of water have the influence on the richness of cyanobacterial community. This study indicates the maximum occurrence and abundance of *Chroococaceae* (23.73%) and *Phormidaceae* (18.64%) members in all the sites, whereas *Stigonemataceae* (1.7%) shows very less occurrence. Among the cyanobacteria identified non-heterocystous filamentous forms were dominant followed by unicellular forms; whereas heterocystous forms were least in number.

KEY WORDS: Distribution, diversity, freshwater cyanobacteria, Kaiga, physico-chemical characteristics, Western ghats of karnataka

INTRODUCTION

Cyanobacteria occur in freshwater, marine, and terrestrial habitats. Some are capable of nitrogen fixation and are therefore of great importance for the balance in ecosystems. They are the major phytoplankton group in freshwater ecosystems capable of producing toxic blooms (Carmichael *et al.*, 1990). Their communities are an essential component of all aquatic ecosystems because primary production by phytoplankton forms the base of the food chain in water. Despite these beneficial aspects, most water quality problems are the result of the unmanaged growth of phytoplankton communities (Smith, 1988). Conditions, such as sunlight, nutrients, pH, temperature, and dissolved oxygen (DO), are required for their optimum growth.

The abundance and composition of the cyanobacterial population in surface waters of ponds and lakes have been investigated by many workers (Philipose, 1960; Vijayakumar *et al.*, 2005; Muthukumar *et al.*, 2007). The relationships of cyanobacteria with physico-chemical parameters in freshwater bodies were revealed by many Indian limnologists (Munawar, 1970; Pingle, 2003; Hujare, 2008). Although considerable work has been done on the limnological studies on the tanks and ponds. The occurrence of cyanobacteria from the freshwaters of Uttara Kannada region has still unknown. Therefore, an attempt has been made to study the distribution pattern and diversity of cyanobacteria in different freshwater bodies of Kaiga region of Uttara Kannada district of Karnataka. A comparative study was made by assessing the physico-chemical characteristics of water with species richness.

MATERIALS AND METHODS

Physiography

The study area, Kaiga, situated on the Southern bank of the river Kali. It is located at the foothills of the Western Ghats, confined between 74° 25’ 30” and 74° 28’ 30” east longitude and 14° 50’ 00” and 14° 52’ 20” north longitude.

Sampling

Cyanobacterial samples were collected from different water bodies at Kaiga near Karwar in the Uttara Kannada district of Karnataka. Cyanobacterial diversity was recorded in five sampling sites namely, Kadra reservoir, Hartuga, Virje, Thermal water discharge channel, and labor colony. The samples/collections were made once in every 4 months over a period of 2-year in three seasons (2009-2011). The water sample was observed for the presence/absence of cyanobacteria.

Identification of Cyanobacteria

Identification of organisms was made using morphological variation studies and taxonomical approaches (Anagnostidis and Komarek, 1998; Komárek and Anagnostidis, 2005; Desikachary, 1959).

Physico-chemical Characteristics of Waters

Water temperature of samples collected from each sampling point was determined by mercury thermometer; while the pH, salinity, conductivity, and total dissolved solids (TDS) were assessed using a water analysis kit (Water Analyzer 371, Systronics, Gujarat, India). The DO concentration was determined by following Winkler's titration method (APAPHA, 1995). The total alkalinity, total hardness, chloride, dissolved organic matter (DOM), and free carbon dioxide were determined by the titrimetric method. The inorganic phosphate by stannous chloride method; nitrate by the brucine method; silicate by molybdosilicate method, and sulfate content by turbidimetric method (Hariprasad and Ramakrishnan 2003). The biological oxygen demand (BOD) was determined by 5 days BOD test.

Species frequency, density, and abundance were calculated as follows:

$$\text{Species frequency } (\%)\ (\text{F}) = \frac{\text{Total number of samples in which species occurred}}{\text{Total number of samples studied}} \times 100$$

$$\text{Relative frequency } (\%)\ (\text{RF}) = \frac{\text{Frequency of a particular species}}{\text{Total frequency of all the species}} \times 100$$

Statistical Analysis

The results of physico-chemical characteristics of water were expressed as the mean ± standard deviation of three experiments. The data on the physico-chemical factors and list of species recorded in the five sampling sites were statistically analyzed using PAST statistical package. The correlation coefficient was applied to test the relationship between the physico-chemical factors and cyanobacterial species richness. Shannon (H), Simpson (1-D) diversity, Margalef richness, and Pielou evenness indices were analyzed for cyanobacteria in different location and seasons using PAST statistical package.

RESULTS

The physico-chemical characteristics of water samples from various locations of Kaiga are shown in Table 1. The water temperature of 26-34.5°C was recorded in all the sampling sites throughout the study period. The maximum water temperature was noticed in discharge channel water during summer (34.5°C), which was minimum at Hartuga stream during monsoon season (26°C). Moderate alkaline pH of 7.4-9.2 was noticed in all the five sites, in which maximum pH of 9.2 found in the Virje river water during summer and it was least in Hartuga stream (7.4) during monsoon. Conductivity was ranging between 44-130 µS/cm. TDS were found to be ranging between 20 and 95 ppm. It was high during summer followed by winter and low during monsoon. Sulfate content was found to be in the lower level except in Kadra reservoir during summer (10.5 mg/l). Total hardness of water was ranged between 8 and 32 mg/l; similarly, total alkalinity was noticed in 9-22 mg/l. The BOD was more in Kadra reservoir (20.0 mg/l) during summer and which was least in labor colony stream during monsoon (3.5 mg/l). Chloride content was varied between 10 and 32.5 mg/l; which was maximum in labor colony stream water (32.5 mg/l) and minimum at thermal discharge canal (10.2 mg/l). It was revealed that DO found to be 5.6-8.9 mg/l. It was recorded that maximum DO content during monsoon season in all the sampling sites throughout the study period, and it was minimum during pre-monsoon. The nutrient parameters, such as inorganic phosphate, sulfate, nitrates, and silicates, were estimated. Inorganic phosphate content was ranged between 8 and 30.5 mg/l. Nitrate content was found to be ranging between 2.5 and 10.8 mg/l, it was high during summer, and low in monsoon among the sites studied. Similarly, silicates were recorded between 8.0 and 28.0 mg/l; DOM was noticed in between 2.8 and 8.7 mg/l range.

In the present study, 59 cyanobacterial species belonging to 17 genera have been identified. The occurrence of these species in different five sampling sites is given in Table 2. Monsoon, post-monsoon, and pre-monsoon sampling have been carried out for the duration of 2 years. The study indicates the maximum occurrence and abundance of *Oscillatoriacea*e and *Chroococaceae* members in all the sites, whereas *Stigonemataceae* shows very less occurrence. Among the *Oscillatoriaceae* members, *Oscillatoria rubescens* found only in labor colony stream during

Table 1: Physico-chemical characteristics of water at different sampling sites of Kaiga, Uttara Kannada during different seasons

Season	Water parameters	Sampling stations				
		S1	S2	S3	S4	S5
Pre-monsoon	Temperature (°C)	27.6±0.75	28.6±0.6	30±0.1	34.6±0.6	30.3±0.5
	pH	8.8±0.4	8.65±0.4	9.2±0.22	8.65±0.2	8.45±0.3
	Conductivity (μS/cm)	64.9±0.5	64.5±0.4	130±0.20	90±0.5	58±0.8
	TDS (mg/l)	52.5±0.4	25±0.8	92±1.4	52±2.1	48±0.7
	DO (mg/l)	7.1±0.28	6.2±0.85	6.2±0.8	5.6±0.02	6.2±0.35
	CO_2 (mg/l)	39.5±0.4	45±1.20	32.0±0.22	52.0±0.8	32.0±0.02
	Phosphate (mg/l)	12.0±1.5	15.5±0.1	17.2±0.3	12.8±0.05	16.0±0.9
	Sulfate (mg/l)	10.5±0.12	8.8±0.44	3.15±0.87	3.6±0.9	2.2±0.3
	Total hardness (mg/l)	32±0.33	18±0.55	21.0±0.25	18.0±0.9	16.0±0.6
	Total alkalinity (mg/l)	9.0±1.8	12.0±2.5	15.0±0.95	21.5±0.6	19.5±0.8
	DOM (mg/l)	7.9±0.55	7.3±0.35	8.7±0.2	7.8±0.1	8.2±4.08
	Nitrate (mg/l)	6.8±0.75	7.8±0.3	9.5±0.10	8.8±0.05	10.8±0.4
	BOD (mg/l)	20.0±0.3	18.0±0.9	18.5±0.2	18.0±0.5	10.5±0.7
	Silicate (mg/l)	15.6±0.9	16.2±0.84	14.±0.35	18.8±0.15	22.8±0.12
	Chloride (mg/l)	20.0±0.3	32.0±0.1	24.0±0.5	22.0±0.7	32.5±0.4
Monsoon	Temperature (°C)	27.6±0.6	26±0.57	30.6±0.5	30±1.0	28.3±0.6
	pH	8.5±0.2	7.4±0.1	8.4±0.05	8.43±0.2	8.15±0.1
	Conductivity (μS/cm)	72.8±0.5	55.5±0.2	74±0.1	70.6±0.4	60.5±0.1
	TDS (mg/l)	32.5±3.5	23.2±0.2	30.9±0.2	31±1.4	26±1.4
	DO (mg/l)	8.56±0.3	7.8±0.09	8.8±0.42	7.8±0.20	8.9±0.72
	CO_2 (mg/l)	14±0.14	20.8±1.0	18.0±0.30	20.8±0.5	10.0±0.10
	Phosphate (mg/l)	24.5±0.4	20.4±0.8	30.5±0.2	18.0±0.9	20.0±0.30
	Sulfate (mg/l)	1.6±0.2	0.24±0.5	1.25±0.1	1.2±0.3	0.55±0.5
	Total hardness (mg/l)	16.0±0.1	15.0±2.5	21.0±3.0	14.0±0.4	12.0±0.6
	Total alkalinity (mg/l)	16.5±3.0	14.0±3.6	22.0±0.88	17.0±0.2	13.5±0.8
	DOM (mg/l)	6.1±0.07	2.8±0.4	4.8±0.5	5.4±0.4	5.1±0.01
	Nitrate (mg/l)	2.6±0.45	4.1±0.41	5.2±0.30	2.5±0.4	4.8±0.5
	BOD (mg/l)	8.0±0.5	14.0±0.5	7.0±0.22	15.0±0.01	3.5±0.1
	Silicate (mg/l)	8.5±0.72	11.0±0.06	9.0±0.10	12.0±0.35	12.5±0.1
	Chloride (mg/l)	12.8±0.14	18.0±0.10	16.8±0.42	12.8±0.3	20.5±0.5
Post-monsoon	Temperature (°C)	27.8±0.7	27.3±1.2	32±1	32.6±0.6	29.6±0.6
	pH	8.7±0.3	8.5±0.2	8.6±0.1	8.65±0.2	8.2±0.12
	Conductivity (μS/cm)	79.3±0.6	71.3±0.25	44.7±0.35	82±0.2	44±0.4
	TDS (mg/l)	32.7±0.2	32.3±1.2	66.6±1.5	46±0.7	28±0.35
	DO (mg/l)	8.2±0.56	6.58±0.20	7.3±0.10	6.6±0.20	7.3±0.05
	CO_2 (mg/l)	26±0.70	36.5±1.1	24.8±0.1	44.0±0.15	18.5±0.05
	Phosphate (mg/l)	8.0±1.50	8.5±0.06	10.0±0.6	10.5±0.12	12.2±0.4
	Sulfate (mg/l)	0.85±0.4	1.5±0.2	2.52±0.8	2.2±0.35	2.0±0.3
	Total hardness (mg/l)	18.5±0.4	8.0±0.5	23.0±1.5	16.5±1.0	14.0±0.4
	Total alkalinity (mg/l)	17.0±0.3	14.0±0.55	17.0±0.88	21.0±0.2	16.5±0.6
	DOM (mg/l)	6.8±0.11	5.8±0.2	6.3±0.20	6.6±0.25	6.7±0.30
	Nitrate (mg/l)	5.2±0.35	6.2±0.25	7.5±0.9	5.5±0.22	8.4±0.06
	BOD (mg/l)	13.4±0.2	15.0±0.25	13.0±0.4	14.0±0.12	18.5±0.1
	Silicate (mg/l)	12.0±0.8	14.4±0.44	12.8±0.9	15.2±0.41	28.6±0.20
	Chloride (mg/l)	11.9±0.6	10.8±0.32	12.6±0.73	10.2±0.10	12.0±0.4

S1: Kadra Reservoir, S2: Hartuga forest, S3: Virje River, S4: Kaiga discharge channel, S5: Labor colony stream, DOM: Dissolved organic matter, DO: Dissolved oxygen, BOD: Biological oxygen demand, TDS: Total dissolved solids

monsoon and post-monsoon seasons; similarly, *Planktothrix perornata* was found only in discharge channel. *Oscillatoria trichoides* found only in Hartuga and Virje river during post-monsoon; *Geitlerinema calcuttense* was present only at discharge channel waters, *Phormidium baculum* found only at labor colony and discharge channel water. *Leptolyngbya polysiphoniae* present only in Haruga stream. Among the *Chroococaceae* members, *Chroococcus minor* which was presents in all the sites in all the seasons throughout the study period. *Chroococcus varius* found only in labor colony, whereas *Chroococcus tenax* found in Kadra reservoir and Hartuga stream. *Gleocapsa decorticans* found in Kadra and labor colony waters. *Microcystis bengalensis* found only in Hartuga stream; *Aulosira aenigmatica,* and *Microchaete elongate* were found only at discharge channel; similarly, *Scytonema coactile, Scytonema simplex,* and *Scytonema pseudopunctatum* were observed only in discharge channel waters.

Species richness of cyanobacteria in various sampling sites of Kaiga in different seasons is shown in Figure 1. In this study, it was observed that Kaiga discharge channel showed maximum species richness (27) followed by Kadra reservoir (26) during monsoon season; whereas it was least in Virje river during the post-monsoon season (16).

Table 2: Distribution pattern of cyanobacteria during different seasons in the five sampling sites at Kaiga, Uttara Kannada

S. No.	Seasons	Pre-monsoon					Monsoon					Post-monsoon					F %	RF %
	Sampling stations*	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5		
1	*Oscillatoria subbrevis* Schmidle	-	-	-	-	++	++	-	+	-	-	++	+	+	++	-	46.6	2.23
2	*Oscillatoria princeps* f. maxima Rabenhorst ex Frémy	+	+	++	-	+	++	+	+ +	-	-	+	-	++	-	+	40	1.92
3	*Oscillatoria rubescens* F. Forma	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	46.6	2.23
4	*Oscillatoria limosa* C. Agardh ex Gomont	+	-	-	+	++	++	+	+++	++	+	-	++	+	-	-	66.6	3.188
5	*Oscillatoria curviceps* C. Agardh ex Gomont	+	++	-	-	+	+	-	++	-	-	-	-	+	-	-	40	1.915
6	*Oscillatoria trichoides* Szafer	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	13.3	0.636
7	*Oscillatoria tenuis* Agardh.	-	-	-	+	-	++	+	-	+	++	-	-	-	-	+	40	1.915
8	*Oscillatoria willie* Gardner em.Drouet	-	-	-	-	-	-	-	+	-	+	-	-	-	+	-	20	0.957
9	*Oxynema acuminatum* Chatchawan, Komárek, Strunecky, Smarda and Peerapornpisal	++	+	+++	-	+	+	-	+	+	-	-	-	++	-	+	60	2.872
10	*Lyngbya spiralis* Geitler	++	+	+	-	+	+	-	-	++	-	-	-	+	-	+	53.3	2.55
11	*Arthrospira platensis* (Nordstedt) Gomont	-	-	-	-	-	+	-	+	-	-	-	-	-	-	-	13.3	0.636
12	*Phormidium chalybeum* Anagnostidis and Komárek	-	+++	+	-	-	-	++	+	+	-	-	-	-	+	-	40	1.915
13	*Phormidium ornatum* (Kützing ex Gomont) Anagnostidis and Komárek	-	+	+	+	-	-	-	-	-	-	-	-	-	++	+	33.3	1.594
14	*Phormidium boryanum* (Bory ex Gomont) Anagnostidis and Komárek	-	++	+	+	-	+	++	-	-	-	+	-	-	-	-	40	1.915
15	*Phormidium anomala* Rao C.B.	-	-	-	-	+	+	-	-	-	++	-	+	+	+	++	46.66	2.23
16	*Phormidium tenue* Gomont.	+	+	++	+	-	-	++	-	-	+	+	-	-	-	-	46.66	2.23
17	*Phormidium rubidum* (Frémy) Anagnostidis and Komárek	-	-	-	-	-	-	-	+	-	+	-	-	-	+	+	26.6	1.273
18	*Phormidium baculum* (Gomont) Anagnostidis	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-	13.3	0.636
19	*Phormidium allorgei* (Frémy) Anagnostidis and Komárek	+	-	-	-	+	-	-	-	++	-	-	-	-	-	-	20	0.957
20	*Porphyrosiphon kashyapii* (Ghose) Anagnostidis and Komárek	-	-	-	+	-	-	+	-	-	-	+	-	-	-	-	20	0.957
21	*Planktothrix perornata* (Skuja) Anagnostidis and Komárek	-	-	-	-	-	-	-	-	+	-	-	-	-	++	-	13.3	0.636
22	*Leptolyngbya fragilis* (Gomont) Anagnostidis and Komárek	-	-	-	+	-	-	-	-	+	-	+ +	-	-	+++	-	26.6	1.27
23	*Planktolyngbya limnetica* J. Komárková-Legnerová and G.Cronberg	-	-	-	-	-	+ +	-	-	-	+	-	+	-	-	+	26.6	1.27
24	*Planktolyngbya contorta* (Lemmermann) Anagnostidis and Komárek	-	+	-	-	+	-	-	+	-	-	+	+	-	-	-	33.3	1.60
25	*Leptolyngbya polysiphoniae* (Frémy) Anagnostidis	-	-	-	-	-	-	-	-	-	-	-	++	-	-	-	13.3	0.636
26	*Jaaginema quadripunctulatum* Anagnostidis and Komárek	+	-	++	+	-	-	-	-	+	-	+	-	+	-	-	40	1.92
27	*Jaaginema homogeneum* Anagnostidis and Komárek	-	-	++	+	+	+	-	+	-	+++	+	+ +	-	-	-	53.3	2.55
28	*Geitlerinema calcuttense* (Biswas) Anagnostidis	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	6.66	0.318
29	*Geitlerinema amphibium* (C.Agardh ex Gomont) Anagnostidis	++	-	-	-	+	-	-	+++	-	-	+	-	-	-	-	26.66	1.286
30	*Geitlerinema bigranulatum* Anagnostidis	++	+	-	-	-	+	+	-	+	-	-	+	+	+	-	53.33	2.552
31	*Chroococcus minor* (Kützing) Nägeli	+	+	+	++	+	+ +	+	+	++	+	++	+	+	+++	+	100	4.787
32	*Chroococcus tenax* (Kirchner) Hieronymus	-	+	-	-	-	-	-	-	-	-	+	++	-	+	-	26.5	1.268
33	*Chroococcus giganteus* West	+	-	+	++	-	+	-	+	-	-	-	-	++	-	+	46.5	2.226
34	*Chroococcus turgidus* v. Solitarius Ghose	-	-	+	-	+	+	+	+	-	-	-	+	-	-	-	40	1.915
35	*Chroococcus minutus* Kutzing Nageli	-	-	-	-	-	+	+	+	-	+	-	-	-	++	+	42	2.012
36	*Chroococcus varius* A. Braun	-	-	+	-	-	-	-	-	-	-	-	-	-	+	-	13.5	0.646
37	*Limnococcus limneticus* Komárková	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	13.3	0.636

(Cont…)

Table 2: ***(Continued...)***

S. No.	Seasons	Pre-monsoon					Monsoon					Post-monsoon					F %	RF %
	Sampling stations*	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5		
38	*Chroococcus montanus* nus C. B. Rao	+	+	+	+	+	+++	-	+	+	-	++	+	+	+	-	86.6	4.146
39	*Gleocapsa levida* Kutzing	++	+	++	-	-	+	+	-	-	+	+	-	++	-	-	53.3	2.55
40	*Gleocapsa decorticans* Richter	-	++	+	+	-	++	-	+	-	-	-	+++	-	-	-	46.6	2.231
41	*Gleocapsa fuscolutea* Nageli	-	-	-	-	-	+	-	-	-	-	-	-	-	++	-	13.5	0.646
42	*Chloroglea fritschii* Mitra	-	-	+	-	+	-	+++	-	+	+	-	-	-	-	+	42.5	2.034
43	*Cyanosarcina spectabilis* Kovácik	-	+	-	+	-	-	+	+	+	-	-	-	+	-	-	40	1.915
44	*Synechocystis aquatilis* Sauv.	+	-	-	+	-	+	+	-	+	-	+	-	-	+	-	46.5	2.226
45	*Aphanocapsa littoralis* Hansag.	+	-	-	+	+	+	+	+	-	+	-	-	-	-	+	53.3	2.551
46	*Aphanocapsa biformis* A. Braun	+	-	+	-	-	-	-	-	+	-	-	-	+	-	-	26.7	1.278
47	*Merismopedia punctata* Meyen	-	-	-	-	+	+	-	+	+	+	-	+	-	-	+	46.7	2.235
48	*Microcystis bengalensis* Banerji	-	-	+	-	-	-	-	-	-	-	-	+	-	-	-	13.75	0.658
49	*Microcystis aeruginosa*	+	+	-	-	+	-	+	+	+	-	-	-	+	-	-	46.65	2.233
50	*Nostoc piscinale* Kützing ex Bornet and Flahault	-	+	-	-	+	-	++	-	+	-	-	-	-	+++	-	46.6	2.231
51	*Nostoc carneum* C. Agardh ex Bornet	-	-	-	++	-	-	-	-	++	+	+	-	-	+	-	33.3	1.594
52	*Anabaena spiroides* var. crassa Klebahn	-	-	-	+	-	-	+	+	+	-	-	-	-	-	-	25.5	1.220
53	*Anabaenopsis arnoldii* var. indica Ramanathan	-	-	-	+	-	-	-	-	++	+	-	++	-	-	+++	33.4	1.600
54	*Aulosira aenigmatica* Fremy	-	-	-	-	-	-	-	-	+	-	-	-	-	++	-	13	0.622
55	*Microchaete elongata* Comb. nov	-	-	-	+++	-	-	-	-	+	-	-	-	-	+	-	25	1.196
56	*Scytonema coactile* Mont.	-	-	-	+	-	-	-	-	+	-	-	-	-	+	-	20	0.957
57	*Scytonema simplex* Bharadw	-	-	-	+	-	-	-	-	++	-	-	-	-	+++	-	22.5	1.08
58	*Scytonema pseudopunctatum* skuja	-	-	-	+	-	-	-	-	+	-	-	-	-	++	-	25.5	1.220
59	*Stigonema lavardei* Fremy	-	+	-	-	-	++	-	-	-	+	-	-	-	++	-	26.67	1.276
	Total number of species	18	19	19	24	18	26	20	23	27	20	16	17	17	24	16		

+++: Dominant, ++: Common; +: Rare; -: absent. F: Frequency, RF: Relative frequency, *S1: Kadra Reservoir, S2: Hartuga forest, S3: Virje River, S4: Kaiga discharge channel, S5: Labor colony stream

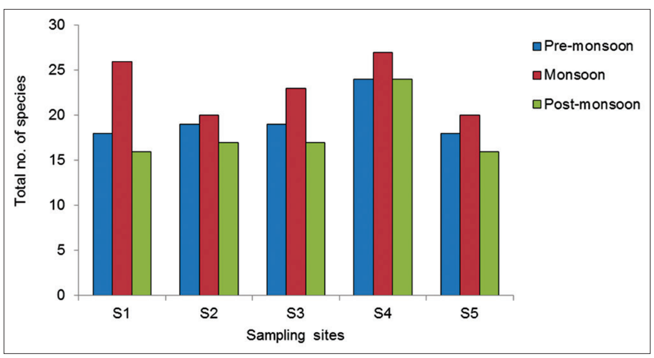

Figure 1: Number of species of cyanobacteria identified at different sites at Kaiga. S1: Kadra Reservoir, S2: Hartuga forest stream, S3: Virje River, S4: Kaiga discharge channel, S5: Labor colony stream

Among the cyanobacteria identified non-heterocystous filamentous forms (50.85%) were dominant followed by unicellular forms (32.20%); where heterocystous forms (16.95%) were least in number. It was also observed that most of the heterocystous cyanobacterial species present in discharge channel waters. Among the sampling sites, selected maximum cyanobacterial species richness was recorded in discharge channel waters followed by Kadra reservoir; it was minimum in Hartuga stream.

Correlation matrix of physico-chemical parameters of water and species richness is given in Table 3. There is positive correlation exists between species richness and water temperature, TDS, chloride, and sulfate content ($P < 0.05$). Alkalinity, total hardness, and DOM were negatively correlated in most of the habitats. Inorganic phosphate, nitrate, and DOM were highly significant with species richness ($P < 0.001$). There is also significant correlation existed among the water parameters.

By this study, it was noticed that cyanobacterial diversity is maximum in monsoon season compared to post-monsoon; it was least during pre-monsoon. Diversity indices such as Shannon (H), Simpson (1-D), Pielou evenness, and Margalef richness indices were calculated for cyanobacteria at Kaiga region in various seasons (Figure 2). The study showed maximum cyanobacterial diversity index in discharge channel waters, followed by Kadra reservoir; while it was least in Hartuga stream. Shannon's diversity index was ranged from 1.010 to 1.122 during monsoon, 0.89-1.06 in post-monsoon and it was low during pre-monsoon, where it was ranged from 0.84 to 0.96; similarly, Simpson diversity index was higher during monsoon (0.6566-0.6740) followed by post-monsoon (0.5543-0.6655) and lower in pre-monsoon season (0.4992-0.6642). Margalef richness index was found to be more in monsoon (0.3734-0.4977), followed by post-monsoon (0.2963-0.3901) and which

Table 3: Correlation matrix of physic-chemical characteristics of water and species richness in different freshwater bodies of Kaiga

	TCSP	T	pH	DO	TH	TALK	DOM	TDS	COND	BOD	$InPO_4$	NO_3	Sil	SO_4	Chl
TCSP	1														
T	0.532*	1													
pH	−0.039	0.365	1												
DO	0.128	−0.291	−0.244	1											
TH	−0.118	0.163	0.441*	−0.288	1										
TALK	0.418*	0.762**	0.0320	−0.309	−0.1979	1									
DOM	−0.209	0.317	0.0981	0.846**	0.2692	0.293	1								
TDS	−0.131	0.411	0.6817*	0.0247	−0.502*	0.070	−0.031	1							
COND	0.260	0.225	0.6257*	0.0785	0.1210	0.158	−0.111	0.585*	1						
BOD	−0.167	0.0065	0.274	0.0354	0.371	−0.213	−0.075	0.1895	0.265	1					
$InPO_4$	−0.046	0.221	0.0812	−0.401	0.539*	0.0542	−0.759**	0.0945	−0.319	−0.492*	1				
NO_3	0.0210	0.219	0.1193	0.762**	0.379	0.092	−0.828**	−0.109	−0.1158	0.092	0.735**	1			
Sil	0.394*	−0.261	−0.020	0.296	−0.123	0.016	−0.353	−0.1558	0.0044	−0.598*	−0.131	−0.303	1		
SO_4	−0.187	−0.035	0.4456*	−0.175	0.661*	−0.533*	0.182	0.2081	0.0178	0.622*	0.096	0.660*	−0.157	1	
Chl	0.131	0.577*	0.575*	−0.022	0.232	0.272	0.1190	0.6898*	0.632*	0.503*	−0.149	0.200	−0.288	0.312	1

TCSP: Total number of cyanobacterial species, T: Temperature, DO: Dissolved oxygen, TH: Total hardness, TALK: Total alkalinity, DOM: Dissolved organic matter, TDS: Total dissolved solids, COND: Conductivity, BOD: Biological oxygen demand, In.PO_4: Inorganic phosphate, NO_3: Nitrate, Sil: Silicate, SO_4: Sulfate, Chl: Chloride. *$P<0.05$; **$P<0.001$

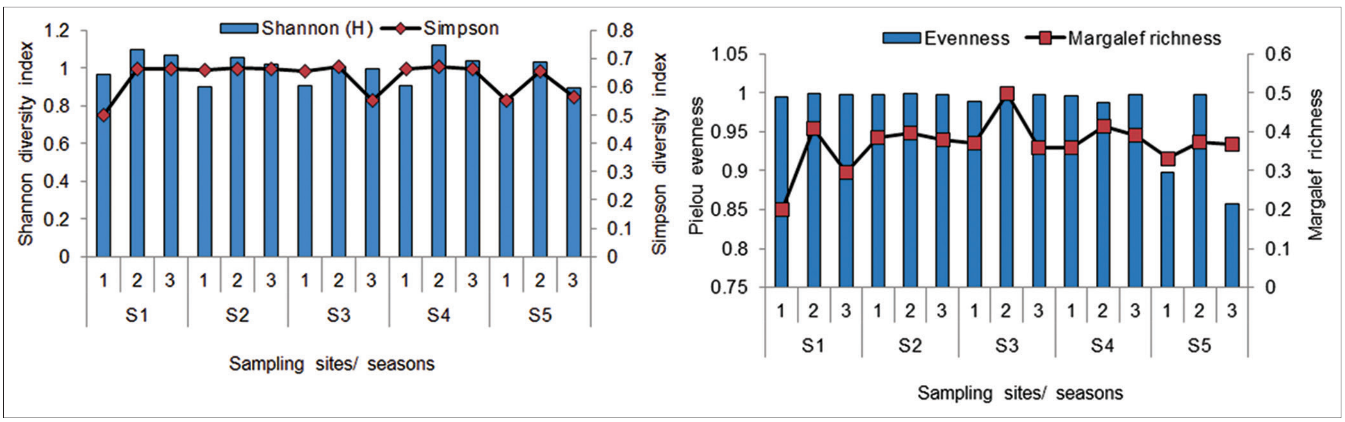

Figure 2: Diversity indices of cyanobacteria found at different sampling sites of Kaiga region during different seasons. Seasons 1, 2, 3: 1 - Pre-monsoon; 2 - Monsoon; 3 - Post-monsoon. S1: Kadra Reservoir, S2: Hartuga forest stream, S3: Virje River. S4: Kaiga discharge channel, S5: Labor colony stream

was less during summer season (0.2007-0.3851). Pielou evenness values ranged between 0.8577 and 0.9995, where it was maximum in Hartuga stream water during monsoon season.

DISCUSSION

When the physico-chemical parameters of different habitats were compared, it was noticed that there was many variations in temperature during different seasons. It ranged from 26°C in the monsoon to 34°C in summer. In this study, more number of species was recorded in monsoon than other seasons which may be due to the moderate temperature required for growth of such species. This agrees with the findings of Hariprasad and Ramakrishnan (2003), Waleron *et al.* (2006) who are of the opinion that temperature being a major factor limits the geographic distribution of cyanobacteria into temperate and tropical species. The temperature was positively correlated to number of species. Most of the workers noted that optimum temperature and warm weather favors the growth of cyanobacteria (Waleron *et al.,* 2006; Nasri *et al*., 2004). Higher temperature may favor the bloom formation dominated by one or two species, but the diversity of species decreases which agrees with our results (Hosmani and Mallesh, 1985).

The abundance of cyanobacteria is attributed to favorable contents of nutrients. pH is one of the important parameters as it plays an important role in the acid-base neutralization and water softening. Besides calcium, high amounts of oxidizable organic matter, traces of DO, considerable amounts of nitrate and were probably the factors favoring the growth of cyanobacteria as suggested by Rai and Kumar (1979), Boominathan *et al*. (2007), Murugasen and Sivasubramaniyan (2005), Vijayakumar *et al*. (2007), Gomathy *et al*. (2011). Singh *et al*. (1969) reported that high values of BOD, chemical oxygen demand, phosphates and nitrates with very low DO favored the growth of cyanobacteria, which was in agreement with our results except high DO favored the abundant growth of cyanobacterial species during monsoon. In the present study also, all the water samples showed considerable amounts of nitrates and phosphates, with increased level of BOD along with high DO level. Here, it is the fact that Kaiga region it is a part of Western Ghat where is a very high rain fall during monsoon season when this rainwater containing high DO enters into the freshwater bodies it may be favors the cyanobacterial species richness.

The pH of water recorded in five different water bodies varied between 7.0 and 9.2. In general, cyanobacteria prefer neutral or slightly alkaline environments for their optimum growth (Whitton and Sinclair, 1975; Chikkaswamy, 2001). Prasad *et al*. (1978) reported that cyanobacteria grew well in the pH range of 7.5-8.5. In the present study, it was also observed that slight alkaline pH favored the species richness. However, Dwivedi and Pandey (2002) found a positive correlation of pH with cyanobacteria in a pond ecosystem. In the present study, it was also observed that slight alkaline pH favored the species richness. The reduction in the concentration of DO may be due to respiration process by other organisms, high organic matter, and sewage pollution, especially during the hot summer seasons (Rout and Das, 2001). DOM seems to affect the occurrence of different species of cyanobacteria. In the present study also DOM is negatively correlated with species richness.

In the present study, the DO concentration of water had great influence on the occurrence of cyanobacteria. These results showed the positive correlation between the number of species and DO. This means that higher oxygen favors the species number and richness. Some earlier studies have also led to a similar conclusion (Hosmani, 1987; Bhave and Borse, 2001). When seasonal occurrence was studied, it was observed that DO concentration usually decreased from monsoon to summer in the majority of habitats. This may be due to the fresh water inflow bringing in a larger amount of waters in monsoon (Sasamal *et al*., 1986). However, the reduction in the oxygen level in summer may be due to the abundance of organic matter, decreased penetration of light, and reduced circulation of water. The increased temperature in summer may also reduce the dissolved oxygen levels (Gowda and Panigrahi, 1995).

When values of alkalinity and hardness were compared in all habitats, there was increase from monsoon to summer and species number was vice versa. This clearly suggested that alkalinity and hardness were not favorable for species occurrence and richness. Total alkalinity and hardness showed a negative correlation in all habitats studied. The number of species was observed in most of the habitats were higher in monsoon and lower in summer. DOM was negatively correlated in all habitats. This suggested that DOM was not affecting species distribution much, but moderate concentrations of DOM were necessary for species occurrence and richness. Alkalinity, total hardness, and DOM were negatively correlated in most of the habitats. These three factors were in direct relationship with temperature and pH and inverse with oxygen. Hosmani and Mallesh (1985); Hosmani (1987) noted that higher the DOM lesser the species diversity and *vice versa*. However, earlier studies (Fogg, 1969) cited DOM was an important factor for the rapid multiplication of cyanobacteria. The number of species was negatively correlated with silicate content in the majority of the habitats. Whitton *et al*. (1986) and Santra (1990) reported different species of cyanobacteria when the concentration of silicate was 12.2 mg/l and 10-35 mg/l, respectively.

However, physical factors are play an important role in determining which genera and species become established and dominant in specific ecosystems (Pacrl and Tucker, 1995). In any ecosystem, not a single species grows independently and indefinitely, because all the species are interlinked and has a cyclic transformation of nutrients. The physico-chemical changes in the water may affect particular species and induce the growth and abundance of other species, which leads to the succession of several species in a course of time. The specific ability of cyanobacteria to be very tolerant when subjected to various stress factors suggest that cyanobacteria are likely to benefit from environmental changes associated with global warming (Pearl, 2008; Paerl and Huisman, 2009).

The differences in cyanobacterial species composition could be related to differences in physico-chemical parameters between the sampling sites. Nutrient accumulation may have different forces on the ecosystem at different periods (Glibert *et al*., 2007). It is known that the eutrophication which results from environmental degradation favors the development of cyanobacteria (Scheffer *et al*., 1997). It has also been reported that environmental factors, nutrient, and hydrologic conditions may also influence the morphological and cyanobacterial bloom dynamics in aquatic ecosystems (Silva and Pienaar, 2000; Paerl and Huisman; 2009). In this study, the results of the physico-chemical composition of sampling sites reveal that they were nutrient rich environments; in particular, total phosphorous, ammonia, and nitrate concentrations were higher and may have greatly supported the abundance of different cyanobacterial species. Among the different cyanobacteria, the genus *Oscillatoria* was dominant; this may have been influenced by the higher availability of nutrient, particularly nitrate, and phosphate, due to the discharge of sewage.

In our study, the cyanobacterial abundance was high at sites S1 (Kadra reservoir) and S4 (Discharge channel). Total phosphorous, silicates, and nitrate concentrations of site 1 and 4 were higher than the other sampling sites. It has been suggested that environmental nutrient positively influences the diversity of cyanobacterial species. High phosphate and nitrates have been widely reported as major factors affecting cyanobacteria abundance (Akn-Oriola, 2003) which was in agreement with our results. The study showed maximum cyanobacterial diversity index in discharge channel waters, followed by Kadra reservoir; while it was least in Hartuga stream. Shannon's diversity index (H') was ranged from 1.010 to 1.122 during monsoon, 0.89-1.06 in post-monsoon, and it was low during pre-monsoon, where it was ranged from 0.84 to 0.96. The lower the index value might be the lack of species richness and degraded state of the ecosystem. A high value of diversity index generally implies healthy ecosystem, while low value indicates degraded state (Manna *et al.*, 2010).

Interestingly, the species namely, *P. perornata, G. calcuttense, A. aenigmatica, M. elongate*, *S. coactile, S. simplex,* and *S. pseudopunctatum* were observed exclusively in discharge channel waters, which could be the reason that those species may be thermo tolerant because the water temperature in their living environment is ranging between 32°C and 34°C. This was in agreement with results obtained by Rajeshwari and Rajashekhar (2012) where species namely, *S. coactile* and *S. simplex* were observed in sulfur spring water where the water temperature always remains constant at 38°C.

CONCLUSIONS

Hence, the present study concluded in spite of the fact that cyanobacterial population dynamics are often influenced by the available nutrients and the physico-chemical conditions of the ecosystem. These particular environmental conditions may favor the dominance of cyanobacteria. Biotic and abiotic factors influence the distribution of cyanobacteria in a freshwater environment. Bearing this in mind, freshwater cyanobacteria were studied from different water bodies of Kaiga region. The present basic information of the cyanobacterial distribution and abundance would be a useful tool for further ecological assessment and monitoring of these freshwater bodies in the Kaiga region.

ACKNOWLEDGMENT

The authors are thankful to NPCIL Mumbai and Kaiga for funding the present study.

REFERENCES

Akn-Oriola GA. On the phytoplankton of Awba reservoir, Ibadan, Nigeria. Rev Biol Trop 2003;51:99-106.

Anagnostidis K, Komarek G. Modern approach to the classification system of cyanobacteria. Arch Hydrobiol Suppl 1998;80:372-470.

APAPHA. Standard Methods for the Examination of Water and Wastewater. 14th ed. Washington, D.C: American Public Health Association; 1995.

Bhave SK, Borse PV. Seasonal variation in temperature, dissolved oxygen, pH and salinity and their influence on planktons in Aner river water, Jalgaon, Maharastra. Pollut Res 2001;20:79-82.

Boominathan M, Sundaraman M, Manhoharan C. Biodiversity of microbes in dairy effluent. Pollut Res 2007;26:271-6.

Carmichael WW, Mahmood NA, Hyde EG. Natural toxins from cyanobacteria (blue-green algae). In: Hall S, Strichartz G, editors. Marine Toxins: Origin, Structure, and Molecular Pharmacology. Washington, DC: American Chemical Society; 1990. p. 87-106.

Chikkaswamy BK. Nitrogen fixing blue green algae from mulberry cultivated fields of Kanakapur. Toxicol Environ Monit 2001;11:153-6.

Desikachary TV. Cyanophyta. New Delhi: Indian Council of Agricultural Research; 1959.

Dwivedi BK, Pandey GC. Physicochemical factors and algal diversity of two ponds (Girija Kund and Maqubara pond), Faizabad, India. Pollut Res 2002;21:361-71.

Fogg GE. The physiology of an algal nuisance. In: Proceedings of Royal Society. Vol. 173. London: Taylor and Francis; 1969. p. 175-89.

Glibert PM, Wazniak CE, Hall MR, Sturgis B. Seasonal and interannual trends in nitrogen and brown tide in Maryland's coastal waters. Ecol Appl 2007;17:79-87.

Gomathy R, Deepa P, Jeyachandran S, Manoharan C, Vijayakumar S. Biodiversity of cyanobacteria from different freshwater ponds, Thiruvarur. Indian Hydrobiol 2011;8:12-7.

Gowda R, Panigrahi RC. Seasonal distribution and behavior of nitrate and phosphate in Rushikulya estuary, East coast of India. Indian J Marnais Sci 1995;24:233-5.

Hariprasad P, Ramakrishnan N. Algal assay used for the determination of organic pollution level in a freshwater body at Tiruvannamalai, India. J Ecotoxicol Environ Monit 2003;13:241-8.

Hosmani SP, Mallesh BB. Observation on pond life with special reference to algal species diversity indices indicating water pollution. Plant Nat 1985;3:41-4.

Hosmani SP. Algal species diversity indices as a measure of water pollution. Acta Bot Indic 1987;15:320-2.

Hujare MS. Limnological studies of the perennial water body, Attigre Tank, Kolhapur District, Maharashtra. Nat Environ Pollut Technol 2008;7:43-8.

Komárek J, Anagnostidis K. Cyanoprokaryota. 2. Teil: Oscillatoriales. In: Büdel B, Gärtner G, Krienitz L, Schagerl M, editors. Süßwasserfl ora von Mitteleuropa. Vol. 19/2. New Delhi: Spektrum Akad Verlag (Elsevier); 2005. p. 758.

Manna S, Chaudhuri K, Bhattacharyya S, Bhattacharyya M. Dynamics of Sundarban estuarine ecosystem: Eutrophication induced threat to mangroves. Saline Systems 2010;6:1-16.

Munawar M. Limnological studies on freshwater ponds of Hyderabad India II. The biocenose. Distribution of unicellular and colonial Phytoplankton in polluted and unpolluted environments. Hydrobiologia 1970;36:105-28.

Murugasen S, Sivasubramaniyan V. Cyanobacteria of Porur Lake, Chennai, Tamil Nadu. Indian Hydrobiol 2005;8:49-54.

Muthukumar C, Muralitharan G, Vijayakumar R, Panneerselvam A, Tajuddin N. Cyanobacterial biodiversity from different freshwater ponds of Thanjavur, Tamil Nadu, India. Acta Bot Malacitana 2007;32:17-25.

Nasri AB, Bouaicha N, Fastener J. First report of a microcystin containing bloom of the cyanobacteria *Microcystis* sp. in Lake Oubeira, Eastern Algeria. Arch Environ Contam Toxicol 2004;46:197-202.

Pacrl HW, Tucker CS. Ecology of blue-green algae in aquaculture ponds. J Aquac Soc 1995;26:109-31.

Paerl HW, Huisman J. Climate change: A catalyst for global expansion of harmful algal blooms. Environ Microbiol Rep 2009;1:27-37.

Pearl HW. Nutrient and other environmental controls of harmful cyanobacterial blooms along the freshwater-marine continuum. In: Hudnell KH, editor. Cyanobacterial Harmful Algal Blooms: State of the Science Research Needs Series: Advances in Experimental Medicine and Biology. Vol. 619 XXIV. New York: Springer; 2008. p. 950.

Philipose MT. Freshwater Phytoplankton of Inland Fisheries. New Delhi: Proceedings Symposium Algol, ICAR; 1960. p. 272-91.

Pingle SD. Periodicity and succession of phytoplankton of Pashan Lake. Indian Hydrobiol 2003;6:101-9.

Prasad BN, Mehrotra RK, Singh Y. Four new taxa of the genus *Lyngbya* from paddy fields of Uttarpradesh. Acta Bot Indic 1978;6:75-80.

Rai LC, Kumar HD. Studies on some algae of polluted habitats. In: Birr SS, editor. Recent Researches in Plant Sciences. New Delhi: Kalyani; 1979. p. 11-8.

Rajeshwari KR, Rajashekhar M. Diversity of cyanobacteria in some polluted aquatic habitats and a sulfur spring in the Western Ghats of India. Algol Stud 2012;138:37-56.

Rout J, Das B. Impact of municipal sewage on River Barak (S. Assam). Bull Natl Inst Ecol 2001;11:25-31.

Santra SC. Freshwater algae of West Bengal. Prof. M.O.P. Iyengar Centenary Celebration Volume. New Delhi: Today and Tomorrow's Printers and Publishers; 1996. p. 189-94.

Sasamal SK, Sahu BK, Panigrahi RC. Textural and composition of sediments of Oogly estuary and nearshore environment. Indian J Marnais Sci 1986;15:129.

Scheffer M, Rinaldi S, Gragnani A, Mur LR, Van Nes EH. On the dominance of filamentous cyanobacteria in shallow, turbid lakes. Ecology 1997;78:272-82.

Silva SM, Pienaar RN. Benthic Marine Cyanophyceae from Kwa-Zulu Natal, South Africa. Berlin: Gebrüder Borntraeger Verlagsbuchhand Lung; 2000. p. 456.

Singh VP, Sexena PN, Tewari A, Lonsane BK, Khan MA, Arora I. Algal flora of sewage of Utter Pradesh in relation to physic-chemical variables. Environ Health 1969;11:208-19.

Smith DW. Phytoplankton and catfish culture: A review. Aquaculture 1988;74:167-89.

Vijayakumar S, Thajuddin N, Manoharan C. Biodiversity of cyanobacteria in industrial effluents. Acta Bot Malacitana 2007;32:27-34.

Vijayakumar S, Thajuddin N, Manoharan C. Role of cyanobacteria in the treatment of dye industry effluent. Pollut Res 2005;24:79-84.

Waleron M, Waleron K, Vincent WF, Wilmotte A. Allochthonous inputs of riverine picocyanobacteria to coastal waters in the Arctic Ocean. FEMS Microbiol Ecol 2007;59:356-65.

Whitton BA, Sinclair C. Ecology of blue green algae. Sci Prog 1975;62:429-46.

Whitton BA, Talat MK, Ibrahim A. Water chemistry and algal vegetation of streams in the Asir Mountains, Saudi Arabia. Hydrobiologia 1986;133:97-106.