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Seasonal occurrence of freshwater cyanobacteria in the four artificial tanks of Western Ghats of Karnataka

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ABSTRACT

The present study deals with identification of 43 cyanobacterial species belonging to 19 genera and 9 families in the four artificial tanks of Western Ghats of Karnataka. The study indicates the maximum occurrence of *Phormidiaceae* and *Microcystaceae* members in all the sites, whereas *Entophysalidaceae* the number of species was less. *Oscillatoria limosa* was found in all the sampling sites in all the three seasons, which showed 100% frequency and it was followed by *Oscillatoria princeps and Planktothrix perornata* which exhibited 83.3% frequency of occurrence. Species like, *Anabaena ballygunglii, Microcystis aeruginosa*, *Microcystis aeruginosa* var*. elongate* and *Nostoc ellipsosporum* showed lesser abundance exhibited 25 % frequency of occurrence, whereas the species *Aphanothece microscopia* showed very least frequency of occurrence (16.7 %). In this study, it was observed that Kowarkolli tank showed maximum species richness (35) followed by Lakkavali tank (31) during monsoon season and it was least in Belur tank (15) during pre-monsoon season. Among the cyanobacteria identified non-heterocystous filamentous forms (50.85%) were dominant followed by unicellular forms (32.20%) and the heterocystous forms were least (16.95%). Among the four artificial tanks studied, it was observed that cyanobacterial species richness was maximum during monsoon season followed by pre monsoon, where it was minimum during the post-monsoon season.

Key Words: Freshwater, cyanobacteria, water parameters, seasons, occurrence, tanks, Western Ghats.

Introduction

Cyanobacteria generally occur in freshwater, marine and in terrestrial habitats. Some fix atmospheric nitrogen and therefore are of great importance to agriculture. They are the important components of aquatic ecosystems because of primary productivity and thereby occupy the base of the food chain (Smith, 1988). Certain conditions in tropical region provide favorable environment for their good growth in the natural ecosystems (Thajuddin et al., 2002; Rajkumar, 2004; Chellappaet al., 2004).

The abundance and composition of cyanobacterial population in surface waters of ponds and lakes have been discussed by many workers (Vijayakumar et al., 2005; Muthukumar et al., 2007). The relationship of cyanobacteria with physico-chemical parameters in freshwater bodies has been investigated by few Indian limnologists (Bajpai et al., 2013; Jeyachitra et al., 2013). The qualitative and quantitative studies on cyanobacteria were actually the basis to assess the quality of water (Shekhar et al., 2008). The cyanobacterial occurrence of specific species in a water body varies considerably based on the change in physico-chemical parameters like pH, conductivity, BOD, COD, DO, salinity and alkalinity (Tiwari et al., 2001). Industrially discharged effluents to aquatic bodies especially streams, rivers, reservoirs etc. have alter the physico-chemical parameters of water. Some reports are available on the pollution of lakes and reservoirs (Costa et al., 2006; Dantas et al., 2011; Atoui et al., 2013).

There are only few studies made on the occurrence, species richness and diversity of cyanobacteria in the freshwater bodies of Western Ghats of Karnataka (Rajeshwari and Rajashekhar, 2012). There are very few reports available on the physico-chemical parameters and seasonal occurrence of cyanobacteria in some freshwater bodies and estuaries of Karnataka (Shruthi et al., 2011, Rajeshwari and Rajashekhar, 2012; Divya et al., 2013; Mamatha et al., 2013; Joishi, 2014). Hence a detailed study has been carried out to evaluate the distribution pattern and seasonal occurrence of cyanobacteria with respect to the prevailing physico-chemical characteristics of waters in some of the tanks and reservoirs of the Western Ghats of Karnataka.

Materials and Methods

***Study area*:** The study area includes four artificial tanks of four districts namely, Kodagu, Hassan, Chickmagalore and Shimoga in the Western Ghats region of Karnataka State, India (Fig. 1.1).

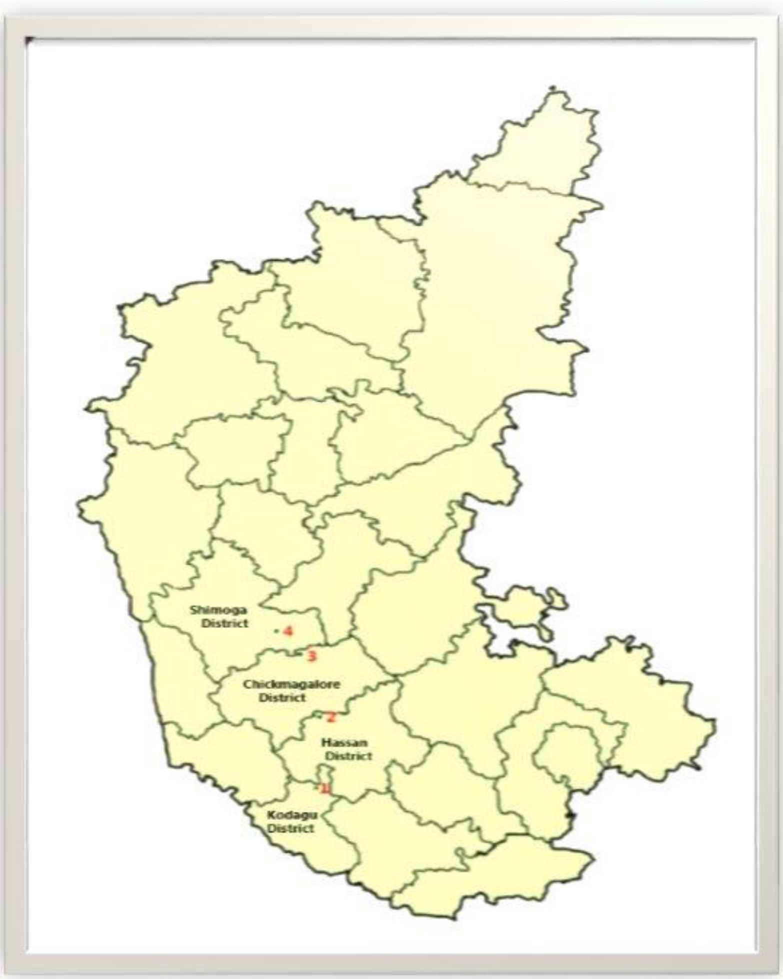

Fig. 1.1- Map showing the study area of four artificial tanks in the Western Ghats region of Karnataka state.

***Description of study sites*:**

1. **Kowarkolli tank** (**S_1**): It is an artificial pond situated at Kowarkolli, 0.5 Km from Somavarpet town of Kodagu District which is confined between 12° 36′ 0″ north latitude and 75° 52′ 12″ east longitude. The tank is distributed over an area of about 1.5 acres. The tank is surrounded by good number of trees. The tank water is mainly used for fish cultivation and irrigation purposes. The upper catchment area of the tank consisting of coffee (*Coffea Arabica* L.) plantations.

2. **Belur Tank (S_2)**: The tank is located very close to Belur town confined between 13° 9′ 46.44″ north latitude and 75° 51′ 25.56″ east longitude of Hassan District. It is a man made fishing tank. The surrounding topography of the tank area is comprised of the hilly and semi arid regions. The tank is distributed over an area of 0.5 acres, measuring a depth about 30 feet. The tank is surrounded by temples, agriculture fields and human settlements. The upper catchment area of the tank includes rural and agricultural areas.

3. **Lakkavalli tank (S_3):** It is a artificial fishing tank, situated between 13° 42′ 5.5″ north latitude and 75° 39′ 58.6″ east longitude, located very close to Bhadra reservoir and 1.0 Km. from Lakkavalli town in Tarikere taluk of Chickmagalore district. The surrounding vegetation is of wet deciduous type. This place receives the annual rainfall of more than 120 cm. There are many timber yielding tree species found nearer to the tank. The total area of the tank is about 3 to 5 hectares and depth is 5 meters.

4. Gajanoor tank (S_4): The tank is located between 13° 50′ 20″ north latitude and 75° 31′ 37″ east longitude of Gajanoor town of Shimoga district. The tank is situated very close to Tunga reservoir and is spread over an area about 2 hectares and measuring a depth of about 2 to 3 meters. It is a fishing tank, where fish breeding activities are quite common. Evergreen trees of 25-30 m height were numerous in the surrounding forest.

Sample collection

Seasonal sampling was done over a period of three years from August 2008 to March 2011. It was conducted in the forenoon between 9.00 A.M to 12.30 P.M. From each sampling site, the water was collected in five liters plastic cans for physico-chemical analysis in the laboratory. The temperature, pH, dissolved oxygen, free carbon dioxide, alkalinity, dissolved organic matter, biological oxygen demand (BOD), total dissolved solids (TDS), inorganic phosphate, nitrate, sulphate, silicate and chloride contents of the waters of different tanks were recorded.

Three methods of samplings were employed to study the cyanobacterial flora viz., leaf litter analysis, scrapings from the side walls of the tank and water analysis. For leaf litter analysis, leaves, twigs and bark were collected in polythene bags, they were brought to the laboratory and rinsed two to three times with double distilled water to remove the extraneous materials. The fragments of the leaves and twigs were taken in a petri plate with sterile distilled water and were examined under inverted microscope. The surface of the leaves were scraped to obtain the organisms adhered to them. About 10 ml of the scraping was collected in a clean Petri plate. The scrapings were examined under the low and high power objectives of the microscope and species were identified.

The sampling was also made by taking the scrapings from the surfaces of rock, pillars etc. from the tanks. They were collected in a sterile bottle and brought to the laboratory for identification. The other method employed was the direct examination of water. For this 10 ml of water was taken and was directly observed under the low and high power objective of the binocular microscope (Magnum- B, U. K.) for the presence of cyanobacteria.

Identification of Cyanobacteria

Morphological identification of the species was done by morphological variation studies and taxonomical approaches according to Desikachary (1959), Starmach (1966) and Anagnostidis and Komarek, (1998, 2005).

Quantitative analysis

About 1.0 ml of the sample was taken and added with one drop of 2% Lugol's Solution (100 g Potassium Iodide dissolved in 1000 ml of distilled water and then added 50 g of crystalline iodine to the solution. Finally 100 ml glacial acetic acid was added to the mixture (stored in a dark place) as fixative in order to kill cells. After thorough mixing 0.1ml of sample was placed on a counting chamber (Sedgewick-Rafter counting chamber) and a cover slip was placed over it and the cells were counted with the help of a compound microscope under 40 X objective. The total cell density was calculated using the formula.

$$\text{Total number of cells/ml} = \frac{\text{Number of cells counted}}{\text{Number of squares counted}} \times \text{Dilution factor} \times 10^4$$

Typically, unicellular cyanobacterial species are counted as cells per ml and filamentous species as number of filaments and quoted an average number of cells per filament. The cells per filament in the first 30 filaments encountered are often counted and averaged. Alternatively, the total filament length per ml was assessed as the sum of the extension of each filament within a counting grid placed in the ocular of the microscope.

Physico-chemical characteristics of waters

Analytical techniques as described in Standard Methods (Trivedy and Goel, 1986; APHA, 1998) were followed for the physico-chemical analysis of water. Water temperature of the samples collected from each sampling point was determined by mercury thermometer; while the pH, conductivity and total dissolved solids were assessed using a water analysis kit (Water Analyzer 371, Systronics, Gujarat, India).The dissolved oxygen concentration was determined by following Winkler's titration method, free carbon dioxide by titration method using phenolphthalein indicator (APHA 1998). The total alkalinity by titration method using strong acid and methyl orange and phenolphthalein indicator, total hardness by ethylene diaminetetraacetic acid (EDTA) titration method using eriochrome black-T and murexide indicators, chlorides by argentometric method, dissolved organic matter was determined by titrimetric method. The inorganic phosphate by stannous chloride method; nitrate by brucinesulfanilic acid method; silicate by molybdosilicate method and sulphate content by turbidimetric method (APHA 1998). The biological oxygen demand was determined by five day BOD test.

Physico-chemical characteristics of waters, like temperature, pH, dissolved oxygen, free carbon dioxide and total hardness were determined at the sampling sites immediately after the collection of water samples while rest of the parameters were analyzed in the laboratory within a period of six to twelve hours after the collection of water samples.

Statistics

The results of physico-chemical characteristics of water were expressed as the mean ± SD of three experiments. The significant differences between the physico-chemical characteristics of water in each sampling station was assessed by applying non parametric ANOVA (analysis of variance) by Kruskal – Wallis test to test for significant differences at $p < 0.05$) followed by multiple comparisons between different tanks were carried out by Mann-whitney U test. A multivariate hierarchical cluster analysis was done by Ward's method. Here, the number of clusters to be considered is decided. Then non hierarchical cluster analysis is done and dendrogram is generated. Non parametric ANOVA by Kruskal – Wallis test was also done to evaluate the distances between clusters and to compare non normal data. The data on the physico-chemical factors and list of species recorded in the different sampling sites were statistically analyzedby using SPSS (Statistical Package for Social Sciences) statistical software (Version 21.0 for Windows, Chicago, IL, USA). The Pearson correlation coefficient was applied to test the relationship between the physico-chemical factors and cyanobacterial species richness.

Species frequency, density and abundance were calculated as follows:

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

$$\text{Species Density (D)} = \frac{\text{Total number of individuals}}{\text{Total number of samples studied}}$$

$$\text{Species Abundance (A)} = \frac{\text{Total Number of individuals}}{\text{Total number of samples in which species occurred}}$$

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

The frequency of occurrence of each species of cyanobacteria in the four artificial tanks was calculated on the basis of their presence or absence in 324 samples (3 methods X 3 sampling sites X 4 habitats X 9 seasons) over a period of three years.

Results

The analysis of the physico-chemical characteristics of water samples from the four artificial tanks of Western Ghats region of Karnataka is shown in Table 1.1. The water temperature between 25 ºC and 32ºC was recorded in all the sampling sites throughout the study period. The maximum water temperature was noticed in Belur tank water during summer was 32ºC, which was minimum at Lakkavalli tank during monsoon season (25 ºC). The pH of the water samples was moderately alkaline (7.2-9.8) in all the four sampling sites and it was maximum in the Kowarkolli tank water during summer 9.8 ($p<0.05$) and it was least in Belur tank during monsoon (7.2). Water conductivity ranged between 85 and 707 µS/cm. Total dissolved solids (TDS) were found to be between 86 and 420 ppm. It was high during summer followed by winter and low during monsoon season. The dissolved oxygen content of water was found to be between 4.2 and 9.4 mg/l. It is noted that maximum dissolved oxygen content during monsoon season in all the sampling sites throughout the study period where high value for dissolved oxygen was noted in Lakkavalli tank during monsoon season (9.4 mg/l, $p<0.05$) and it was minimum during pre-monsoon. Free carbon dioxide is found to range between 18 and 92 mg/l., which was maximum during pre-monsoon and minimum during monsoon in all the sampling sites. The nutrient parameters such as inorganic phosphate, sulphate, nitrates and silicates were estimated. All these nutrients in the water were high during pre-monsoon and low during monsoon period in the sampling sites studied. Inorganic phosphate content has ranged between 10 and 42.5 mg/l where it was maximum in

Gajanoor tank water during pre-monsoon season (42.5 mg/l, $p<0.05$). Nitrate content was found to be range between 4.2 and 10.2 mg/l, it was more in Belur tank water during pre-monsoon season (10.2 mg/l) and low in monsoon season at Lakkavalli tank (4.2 mg/l). Similarly, silicates were recorded between 11 and 32 mg/l; dissolved organic matter was between 5 and 8.8 mg/l range. Sulphate content was found to be lower except in Gajanoor tank during summer (8.8 mg/l). Total hardness of water was found to be between 80 and 450 mg/l; similarly total alkalinity was noticed in 90-325mg/l. The biological oxygen demand (BOD) was more in Gajanoor tank (3.40 mg/l) during summer ($p<0.05$) and which was least in Belur tank during monsoon (1.10 mg/l). Chloride content was found between 14 and 38 mg/l; which was maximum in Belur tank (38 mg/l, $p<0.05$) during pre-monsoon period and minimum at Lakkavalli tank (14.8 mg/l).

Table 1.1: Physico-chemical characteristics of water from the four artificial tanks in the Western Ghats of Karnataka during different seasons.

Seas on	**Water parameters**	**Sampling stations**			
		S_1	**S_2**	**S_3**	**S_4**
Pre- monsoon	Temperature (ºC)	30.6 ± 0.6	32 ± 0.12*	30.6 ± 0.75	31 ± 0.20*
	pH	9.8 ± 0.32*	9.4 ± 0.45	9.6 ± 0.22	9.5 ± 0.5*
	Conductivity (µS/cm)	141 ± 0.6	707 ± 2.22*	210 ± 1.5	190 ± 5.52
	TDS (mg/l)	126 ± 1.2	313 ± 0.57*	420 ± 4.5**	345 ± 5.75**
	D.O. (mg/l)	7.2 ± 0.3	6.15 ± 0.50	6.2 ± 0.32	4.25 ± 0.60
	CO_2 (mg/l)	68 ± 2.2*	54.6 ± 0.52	92 ± 0.75*	56.2 ± 0.55
	Phosphate (mg/l)	22 ± 2.2	26.5 ± 0.80	30.3 ± 0.55	42.5 ± 0.32*
	Sulphate (mg/l)	2.8 ± 0.85	6.4 ± 1.50*	7.5 ± 0.80*	8.8 ± 0.20*
	Total hardness (mg/l)	195 ± 3.5	310 ± 1.06*	240 ± 7.10	450 ± 6.5**
	Total alkalinity (mg/l)	220 ± 3.53	325 ± 3.5*	155 ± 3.5	145 ± 5.5
	D.O.M. (mg/l)	7.8 ± 0.03	8.8 ± 0.21*	7.9 ± 0.28	8.8 ± 0.78*
	Nitrate (mg/l)	7.8 ± 0.21	10.2± 0.14*	7.8 ± 0.56	8.5 ± 0.15
	B.O.D. (mg/l)	3.30 ± 0.10	2.85 ± 0.60	3.30 ± 0.14	3.45 ± 0.25*
	Silicate (mg/l)	32.0 ± 1.55*	21.0 ± 1.10	32.0 ± 0.70*	20.8 ± 0.65
	Chloride (mg/l)	28.5 ± 1.55	38.0± 0.35*	26.4 ± 0.52	30.2 ± 1.5*
Monsoon	Temperature (ºC)	26 ± 0.2	26 ± 0.5	25 ± 0.8	27 ± 0.5
	pH	8.2 ± 0.05	7.2 ± 0.57	8.1 ± 0.35	7.6 ± 0.3
	Conductivity (µS/cm)	85 ± 0.4	256 ± 1.95	91.5 ± 5.5	147 ± 3.80
	TDS (mg/l)	86 ± 0.95	210 ± 0.25	230 ± 6.5	248 ± 8.35
	D.O. (mg/l)	8.5 ± 0.4*	8.2 ± 0.57	9.4 ± 0.44*	6.25 ± 0.65
	CO_2 (mg/l)	26 ± 0.75	18 ± 0.40	52 ± 0.50	32 ± 0.33
	Phosphate (mg/l)	10 ± 0.82	12.8 ± 0.55	18.4 ± 0.45	28.5 ± 0.25
	Sulphate (mg/l)	1.2 ± 0.65	1.2 ± 0.80	2.4 ± 0.30	3.12 ± 0.33
	Total hardness (mg/l)	80 ± 0.70	125 ± 2.10	145 ± 3.50	160 ± 8.50

Contd...

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	Total alkalinity (mg/l)	205 ± 5.7	195 ± 0.35	90 ± 0.14	85 ± 0.95
	D.O.M. (mg/l)	6.2 ± 0.14	7.2 ± 0.14	5.0 ± 0.55	6.2 ± 0.25
	Nitrate (mg/l)	5.4 ± 0.14	6.2 ± 0.20	4.2 ± 0.14	5.0 ± 0.20
	B.O.D. (mg/l)	2.20 ± 0.14	1.10 ± 0.45	1.60 ± 0.21	2.15 ± 0.18
	Silicate (mg/l)	26.5 ± 0.35	11.5 ± 0.35	12.2 ± 0.15	15.2 ± 0.70
	Chloride (mg/l)	18.4 ± 0.28	22.0 ± 0.70	14.8 ± 0.56	20.6 ± 0.30
Post-mons oon	Temperature (ºC)	28 ± 0.12	28 ± 0.32	28 ± 0.4	29 ± 0.6
	pH	9.0 ± 0.5	7.6 ± 0.5	9.0 ± 0.20	8.4 ± 0.44

Conductivity (µS/cm)	124 ± 0.5	439 ± 0.57*	140 ± 2.5	165 ± 2.20
TDS (mg/l)	92 ± 1.5	265 ± 0.57*	325 ± 2.5*	295 ± 2.90
D.O. (mg/l)	7.52 ± 0.85	6.8 ± 0.57	8.1 ± 0.25	5.1 ± 0.32
CO_2 (mg/l)	40 ± 1.6	32 ± 0.35	64 ± 0.30	48.4 ± 0.47
Phosphate (mg/l)	14.5 ± 0.33	18.5 ± 0.32	22.0 ± 1.70	33.5 ± 0.82*
Sulphate (mg/l)	1.65 ± 0.52	4.6 ± 0.52	5.5 ± 0.22	5.6 ± 0.25
Total hardness (mg/l)	115 ± 2.5	245 ± 2.15*	220 ± 8.6	280 ± 3.7*
Total alkalinity (mg/l)	110 ± 2.53	285 ± 1.06*	122 ± 0.16	115 ± 0.20
D.O.M. (mg/l)	7.1 ± 0.15	7.9 ± 0.28	6.5 ± 0.22	7.7 ± 0.30
Nitrate (mg/l)	6.2 ± 0.35	8.8 ± 0.25	6.3 ± 0.21	6.2 ± 0.14
B.O.D. (mg/l)	2.85 ± 0.10	1.95 ± 0.03	2.20 ± 0.14	2.85 ± 0.30
Silicate (mg/l)	28.0 ± 1.06	16.0 ± 0.70	23.0 ± 1.40	18.8 ± 0.22
Chloride (mg/l)	24.2 ± 0.16	31.5 ± 1.15	20.0 ± 0.70	26.2 ± 0.80

* S1: Kowarkolli tank, S2: Belur tank, S3: Lakkavaalli tank, S4: Gajanoor tank
** p<0.01; *p<0.05

In the present study 43 cyanobacterial species belonging to 19 genera and 9 families were identified in the four artificial tanks. The occurrence of these species in the four sampling sites is given in Table 1.2. Among the species, *Oscillatoria limosa* was found in all the sampling sites in all the three seasons, which showed 100% frequency and it was followed by *Oscillatoria princeps* and *Planktothrix perornata* which exhibited 83.3% frequency of occurrence. Species like, *Anabaena ballygunglii, Microcystis aeruginosa*, *Microcystis aeruginosa* var*. elongate* and *Nostoc ellipsosporum* showed lesser abundance exhibited 25 % frequency of occurrence, whereas the species *Aphanothece microscopia* showed very least frequency of occurrence (16.7 %). The study revealed that, occurrence of certain rare species which were noticed in a particular site during the study period. In the present study, among the four artificial ponds investigated, *Phormidium versicolor* was found only in Gajanoor tank. *Aphanocapsa koordersi* and *Anabaena ballygunglii* were found only in Belur tank. Species such as, *Aphanothece microscopia, Nostoc ellipsosporum* and *Anabaena iyengarii* were found only in Kowarkolli tank throughout the study period. *Merismopedia tenuissima* which was reported from Lakkavalli and Gajanoor fishing tanks. *Microcystis aeruginosa* and *Microcystis aeruginosa var.elongata* which were noticed in only Kowarkolli and Gajanoor tanks. Similarly, *Trichormus anomalus* occurred only in Belur and Gajanoor tanks.

A multivariate hierarchical cluster analysis was done for cyanobacterial species in the four artificial tanks (Figure 1.2). Non hierarchical cluster analysis for cyanobacteria based on their species density showed 2 clusters. The distance between the 2 clusters was found to be 5.065. The cluster 1 showed the 32 species of cyanobacteria whereas cluster 2 with 11 species of cyanobacteria. ANOVA test showed significant variation (p<0.01) between the species of four artifiacl tanks.

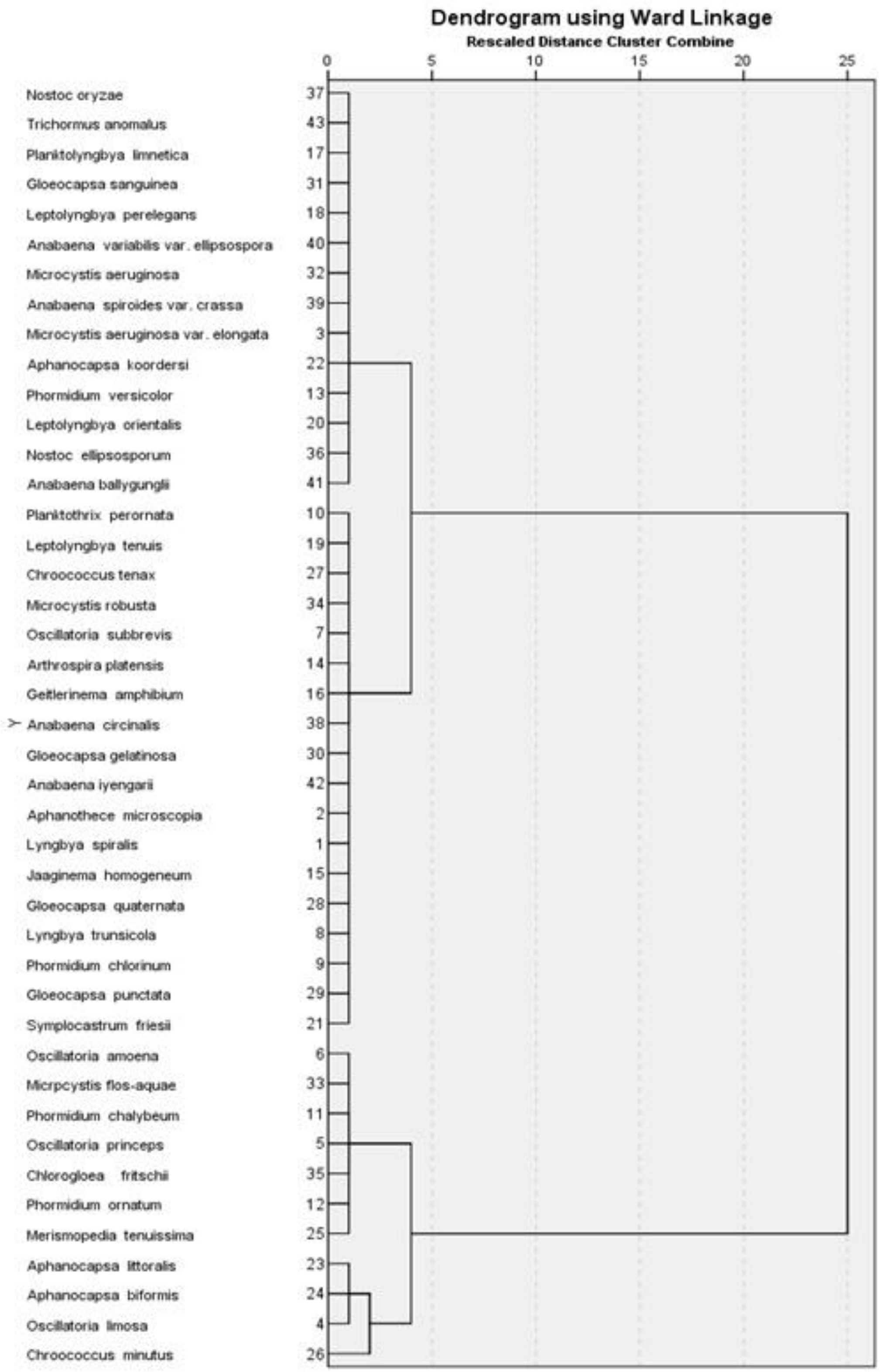

Figure 1.2: Dendrogram derived from cluster analysis for cyanobacteria in the four artificial tanks based on species density

Species richness of cyanobacteria in the four artificial ponds during different seasons is shown in Figure 1.3. In this study, it was observed that Kowarkolli tank of Kodagu district showed maximum species richness (35) followed by Lakkavali tank (31) at Chickmagalore district during monsoon season; whereas it was least in Belur tank of Hassan district (15) during pre-monsoon season. Among the cyanobacteria identified non-heterocystous filamentous forms (50.85%) were dominant followed by unicellular forms (32.20%) and the heterocystous forms were least (16.95%). Among the sampling sites selected maximum cyanobacterial species richness was recorded in Kowarkolli tank waters followed by Lakkavalli tank, whereas it was minimum in Belur tank. Among the four artificial tanks studied, it was observed that cyanobacterial species richness was maximum during monsoon season followed by pre monsoon, where it was minimum during the post-monsoon season.

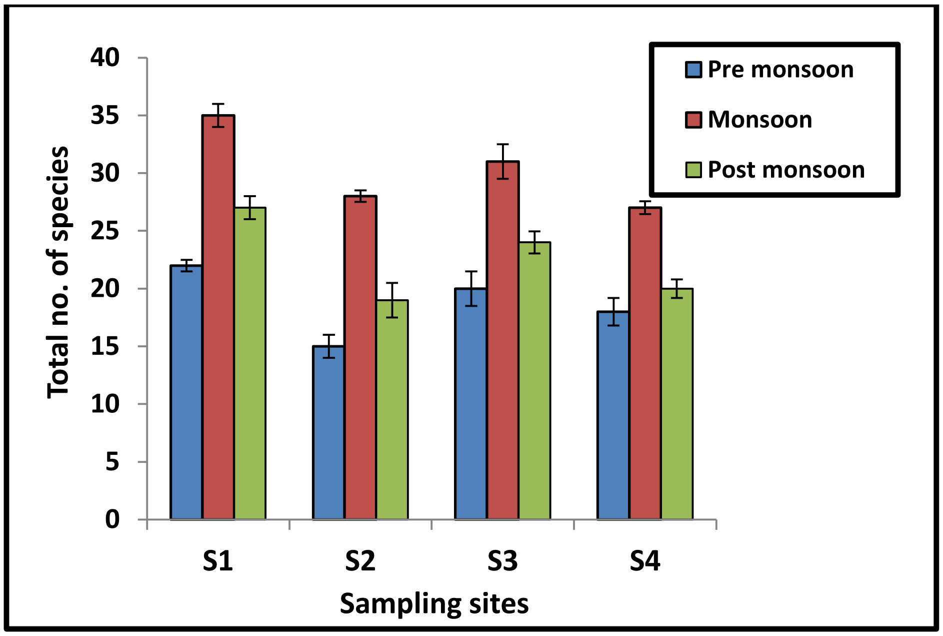

Figure 1.3: Number of species of cyanobacteria recorded in the four artificial tanks in the Western Ghats of Karnataka in different seasons. (S_1: Kowarkolli tank, S_2: Belur tank, S_3: Lakkavaalli tank, S_4: Gajanoor tank)

Correlation matrix of physico-chemical properties of the waters of four artificial tanks and species richness is given in Table 1.3. There is a significant positive correlation existed between species number and temperature, pH, water conductivity, inorganic phosphate and chloride content of tank waters ($p < 0.01$, $r > 0.910$). Similarly there was moderate positive correlation found between species number and dissolved oxygen, total hardness and total alkalinity of tank waters ($p<0.05$, $r > 0.70$). Free carbon dioxide and dissolved organic matter were negatively correlated with species number ($p<0.05$, $r > -0.820$). Similarly most of the water parameters (except BOD and sulphate contents) are significant with each other ($p< 0.05$).

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Table 1.2: Cyanobacterial species recorded from the four artificial tanks in the Western Ghats of Karnataka during different seasons.

S. No.	Species	Sampling sites*															
		S_1			S_2			S_3			S_4						
	Seasons**	1	2	3	1	2	3	1	2	3	1	2	3	F%	D	A	RF%
	Family: Oscillatoriaceae																
1	*Oscillatoria limosa* C. Agardh ex Gomont	+	+	+	+	+	+	+	+	+	+	+	+	100	9.3	9.3	4.33
2	*Oscillatoria princeps* Vaucher ex Gomont	+	+	-	+	+	+	-	+	+	+	+	+	83.3	7.66	9.2	3.61
3	*Oscillatoria amoena* Gomont	-	-	+	+	+	+	-	+	+	+	+	+	75.0	6.9	9.22	3.25
4	*Oscillatoria subbrevis* Schmidle	+	+	-	-	+	-	+	+	+	-	+	+	66.6	5.16	7.75	2.88
5	*Lyngbya trunsicola* Ghose	+	+	+	-	+	-	+	+	+	-	-	-	58.3	4.16	7.14	2.53
6	*Lyngbya spiralis* Geitler	-	+	+	-	+	-	-	-	+	-	+	-	41.7	3.33	8.0	1.81
	Family: Phormidiaceae																
7	*Planktothrix perornata* (Skuja) Anagnostidia & Komarek	+	+	+	-	-	+	+	+	+	+	+	+	83.3	5.66	6.8	3.61
8	*Phormidium chalybeum* (Martens ex Gomont) Anagnostidia & Komarek	-	+	+	-	+	-	+	+	+	+	+	+	75.0	6.5	8.66	3.25
9	*Arthrospira platensis* Gomont	+	+	+	-	+	+	-	+	-	+	+	-	66.6	5.33	8.0	2.88
10	*Phormidium chlorinum* (Kutzing ex Gomont) Umezaki & Watanabe	+	+	-	-	-	-	+	+	+	+	-	+	58.3	4.16	7.14	2.53
11	*Phormidium ornatum* (Kutzing ex Gomont) Anagnostidis & Komarek	+	+	+	-	+	-	+	+	+	-	-	-	58.3	7.33	11.8	2.53
12	*Phormidium 9ersicolour* Wartmann ex Gomont	-	-	-	-	-	-	-	-	-	+	+	+	33.3	2.3	9.3	1.41
	Family: Pseudoanabaenaceae																
13	*Jaaginema homogeneum* (Fremy) Anagnostidis & Komarek	-	+	+	-	-	+	+	+	+	+	+	+	75.0	4.66	6.22	3.25
14	*Planktolyngbya limnetica* (Lemmermann) J. Komarkova- Legnerova & G. Cronberg	+	+	+	-	+	-	+	+	+	-	+	-	66.6	2.66	4.0	2.89
15	*Geitlerinema amphibium* (C. Agardh ex Gomont) Anagnostidis	-	+	+	+	-	+	-	-	-	+	+	+	58.3	3.66	6.28	2.53
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Contd..																	
16	*Leptolyngbya perelegans* (Lemmermann) Anagnostidis & Komarek	-	-	-	-	+	-	+	+	+	+	+	+	58.3	2.75	4.71	2.53

17	*Leptolyngbya tenuis* (Gomont) Anagnostidis & Komarek	+	+	+	-	-	-	+	+	+	-	+	-	58.3	5.5	9.42	2.5
18	*Leptolyngbya orientalis* (G. S. West) Anagnostidis & Komarek	-	+	+	+	+	+	-	+	-	-	+	-	58.3	2.16	3.71	2.53
19	*Symplocastrum friesii* (Gomont ex Gomont) Kirchner	+	+	+	-	-	-	+	+	+	-	+	-	58.3	4.33	7.42	2.53
	Family: Merismopediaceae																
20	*Aphanocapsa littoralis* Hansg.	+	+	+	-	+	+	+	+	+	-	-	-	66.6	10.2	15.3	2.88
21	*Aphanocapsa biformis* A. Braun	-	-	-	-	+	-	+	+	+	-	+	+	50.0	10.0	20.0	2.17
22	*Aphanocapsa koordersi* K. Strom	-	-	-	+	+	+	-	-	-	-	-	-	33.3	2.33	9.33	1.44
23	*Merismopedia tenuissima* Lemmermann	-	-	-	-	-	-	+	+	+	-	+	-	33.3	8.16	24.5	1.44
	Family: Cyanobacteriaceae																
24	*Aphanothece microscopia* Nageli	-	+	+	-	-	-	-	-	-	-	-	-	16.7	3.5	21.0	0.72
	Family: Chroococcaceae																
25	*Chroococcus elongat* (Kutzing) Nageli	+	+	+	+	+	+	-	+	-	+	+	-	75.0	13.8	18.4	3.25
26	*Chroococcus tenax* (Kirchner) Hieronymus	-	+	-	-	+	-	+	+	+	+	-	-	50.0	5.16	10.3	2.17
	Family: Microcystaceae																
27	*Micrpcystis flos-aquae* (Wittrock) Kirchner	+	+	+	+	+	+	-	+	-	+	+	-	75.0	6.83	9.11	3.25
28	*Gloeocapsa quaternata* Brebisson ex Kutzing	+	+	+	+	+	+	-	-	-	-	-	+	58.3	4.83	8.28	2.53
29	*Gloeocapsa gelatinosa* Kützing	-	+	-	-	+	-	+	+	+	-	-	+	50.0	3.5	7.0	2.17
30	*Gloeocapsa elongate* (C. Agardh) Kützing	+	+	+	-	+	-	-	+	-	-	+	-	50.0	2.66	5.33	2.17
31	*Gloeocapsa punctata* Nägeli	-	+	+	-	-	-	-	+	-	+	+	-	41.7	4.0	9.60	1.81
32	*Microcystis robusta* (Clark) Nygaard	-	-	-	+	+	+	-	+	-	-	+	-	41.6	5.16	12.4	1.81
33	*Microcystis aeruginosa* (Kützing) Kützing	+	+	-	-	-	-	-	-	-	-	-	+	25.0	2.33	9.33	1.13
34	*Microcystis aeruginosa* var. *elongate* Rao	-	+	+	-	-	-	-	-	-	-	-	+	25.0	2.33	9.33	1.13
	Family: Entophysalidaceae																
35	*Chlorogloea fritschii* Mitra	-	+	-	+	+	+	-	-	-	-	+	+	50.0	7.66	15.3	2.17

Contd..

Contd..

	Family: Nostocaceae																
36	*Anabaena variabilis* var. *ellipsospora* Fritsch	+	+	+	-	+	-	+	+	+	-	+	+	75.0	2.5	3.33	3.25

37	*Anabaena spiroides* var. *crassa* Klebahm	+	+	+	+	+	+	-	-	-	+	-	-	58.3	2.33	4.0	2.53
38	*Nostoc oryzae* J. Komarek & K. Anagnostidis	+	+	+	-	-	+	-	+	-	-	+	+	58.3	2.66	4.57	2.53
39	*Trichormus anomalus* Komarek & Anagnostidis	-	-	-	+	+	+	-	-	-	+	+	+	58.3	2.66	5.33	2.53
40	*Anabaena circinalis* Rabenhorst ex Bornet & Flahault	-	+	-	-	+	-	+	+	+	+	-	-	50.0	3.75	7.5	2.17
41	*Anabaena iyengarii* Bharadwaja	+	+	+	-	-	-	+	+	+	-	-	-	50.0	3.5	7.0	2.17
42	*Nostoc ellipsosporum* Rabenh.	+	+	+	-	-	-	-	-	-	-	-	-	25.0	1.5	6.0	1.13
43	*Anabaena ballygunglii* Banerji	-	-	-	+	+	+	-	-	-	-	-	-	25.0	1.83	7.33	1.13
	Total	**22**	**35**	**27**	**15**	**28**	**19**	**20**	**31**	**24**	**18**	**27**	**20**				

* S1: Kowarkolli tank, S2: Belur tank, S3: Lakkavaalli tank, S4: Gajanoor tank

Seasons** 1: Pre monsoon; 2: Monsoon, 3: Post monsoon

F = Frequency, D = Density, A= Abundance, RF = Relative frequency

\+ = encountered, - = not encountered

Table 1.3: Correlation matrix of physico-chemical characteristics of water and species richness in the four artificial tanks of Western Ghats of Karnataka.

	TCSP	T	pH	DO	FCO_2	TH	TALK	DOM	TDS	COND	BOD	$InPO_4$	NO_3	Sil	SO_4	Chl
TCSP	1															
T	0.992**	1														
pH	0.998**	0.987**	1													
DO	0.712*	0.772*	0.670*	1												
FCO_2	-0.845*	0.921**	0.575	0.316	1											
TH	0.812*	0.467	0.542	0.592	0.649*	1										
TALK	0.710*	0.232	0.210	0.692*	0.981**	0.991**	1									
DOM	-0.832*	0.754*	-0.989*	0.769*	0.498	0.41	0.792*	1								
TDS	0.213	0.992**	0.212	0.445	-0.792*	0.515	0.378	0.391	1							
COND	0.914**	0.948**	0.882*	0.436	0.667*	0.837**	0.401	0.644*	0.379	1						
BOD	0.454	0.367	0.507	-0.298	0.307	0.391	0.481	0.379	0.257	0.054	1					
InPO4	0.973**	0.829**	0.957**	-0.565*	0.447	0.523	0.765*	0.788*	0.866**	0.612*	0.237	1				
NO3	0.589	0.393	0.478	0.809**	0.548	0.448	0.584	0.897**	0.690*	-0.542	0.318	0.696*	1			
Sil	0.862	0.874**	0.253	0.562*	0.796*	-0.386	0.462	0.586	0.294	0.685*	0.224	0.493	0.592	1		
SO4	0.484	0.992**	0.971**	0.321	0.388	0.243	-0.678*	0.295	-0.328	0.231	0.289	0.412	0.656*	0.276	1	
Chl	0.921**	0.452	0.388	0.547	-0.937	-0.396	0.983	0.412	0.415	0.726*	0.433	0.476	0.438	0.665*	0.423	1

TCSP – Total number of cyanobacterial species; T –Temperature; DO – Dissolved oxygen; FCO_2- Free carbon dioxide; 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 – Sulphate; Chl – Chloride.
* $p < 0.05$; ** $p < 0.01$

Discussion

When the physico-chemical parameters of artificial tanks were compared, it was noticed that there was slight variations in the temperature of waters during different seasons. It ranged from 25ºC in monsoon to 31ºC 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 for such species. This agrees with the findings of Hariprasad and Ramakrishnan (2003) and 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 favours the growth of cyanobacteria (Nasri et al., 2004; Waleron et al., 2006). Higher temperature may favour the bloom formation dominated by one or two species, but diversity of species decreases (Hosmani and Mallesh, 1985) which agrees with our results.

Some investigators reported that alkaline pH favors the growth of cyanobacteria which results in bloom formation (Vasconcelos and Pereira, 2001; Dwivedi and Pandey, 2002).pH is one of the important parameters as it plays an important role in the acid-base neutralization and water softening. The pH of water recorded in four artificial tanks of Western Ghats varied between 7.2 and 9.8. Generally, 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 between 7.5 and 8.5. In the present study, it was also observed that slight alkaline pH favored the species richness. However, Dwivedi and Pandey, (2002) found positive correlation of pH with cyanobacteria in pond ecosystem. In the present study, it was also observed that slight alkaline pH favored the cyanobacterial species richness and pH was positively correlated with species number. The high pH value of water is due to high photosynthetic activity during summer. It is well-known that pH can rise up to a value close to nine with excessive proliferation of *Microcystis*spand *Aphanizomenon*sp. as well as with increasing cyanotoxin production marked by the visual observation of cyanobacterial scum formation (Atoui et al., 2013).

Increase in the value of TDS and conductivity could be attributed to the increase in the amount of substances of anthropogenic origin dumped into the water bodies preceding cyanobacterial blooms in winter and early spring. Changes in the TDS and conductivity of these tanks may be due to changes in the amount of substances entering to these ponds from surface runoff, nature of bedrock material and activities around the catchment area (Chapman and Krammer, 1991; Akin-Oriola, 2003). Higher values of TDS, nitrates, conductivity, total hardness and alkalinity in these ponds particularly in pre-monsoon period could be the result of extended periods of summer season, evaporation and extent of usage (Chia and Bako, 2008).

The reduction in the concentration of dissolved oxygen may be due to respiration process by other organisms, high organic matter and sewage pollution especially during hot summer seasons (Rout and Das, 2001). In the present study, the dissolved oxygen concentration of water had greater influence on the occurrence of cyanobacteria. These results showed the positive correlation between the number of species and dissolved oxygen. The higher concentration of oxygen has resulted in increase in species number and richness. Some earlier studies have also led to similar conclusion (Hosmani, 1987; Bhave and Borse, 2001). When seasonal occurrence was studied, it was observed that dissolved oxygen concentration usually decreased from monsoon to summer in all the tanks. This may be due to the freshwater inflow bringing in 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).

Dissolved organic matter seems to affect the occurrence of different species of cyanobacteria. In case of artificial tanks, dissolved organic matter is positively correlated with species richness. Dissolved organic matter was negatively correlated in all habitats. This suggested that dissolved organic matter was not affecting species distribution much but moderate concentrations of dissolved organic matter were necessary for species occurrence and richness.

When values of alkalinity and hardness were compared in all habitats, there was an increase from monsoon to summer and species number was vice versa. This clearly suggested that alkalinity and hardness were not favourable for species occurrence and richness. Total alkalinity and hardness showed positive correlation in all habitats studied. The number of species was observed in most of the habitats were higher in monsoon and lower in summer. Alkalinity, total hardness and dissolved organic matter were positively 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) and Hosmani, (1987) noted that higher the dissolved organic matter lesser the species diversity and vice versa. However, earlier studies (Fogg, 1969) cited dissolved organic matter (DOM) was an important factor for the rapid multiplication of cyanobacteria. The number of species was negatively correlated with silicate content in majority of the habitats. Whitton et al. (1986) reported different species of cyanobacteria when the concentration of silicate was 12.2 mg l^{-1} and 10 to 35 mg l^{-1} respectively.

Sunkad and Patil (2004) reported the water quality of Fort lake at Belgaum, Karnataka and reported that phosphate in the lake was high (7.2 to 13.6 mg/L) due to the entry of sewage into the lake, which influenced the cause of eutrophication. The present study also showed the eutrophication in tanks particularly Lakkavalli (S_3) and Gajanoor (S_4) fishing tanks may be due to sewage discharges, where high phosphate content in the waters of these lakes ranged between (18 and 42 mg/L).

The abundance of cyanobacteria is attributed to favorable contents of nutrients. Besides calcium, high amounts of oxidizable organic matter, traces of dissolved oxygen, considerable amounts of nitrate were probably the factors favoring the growth of cyanobacteria as suggested by Boominathan et al., (2007), Murugesan (2005), Vijayakumar et al. (2007) and Gomathy et al., (2011), the data obtained in the four artificial tanks is in agreement with their results.

Singh et al. (1969) and Nazneen (1980) reported that high values of BOD, COD, phosphates and nitrates with very low DO favoured the growth of cyanobacteria, which was in agreement with our results except high dissolved oxygen favored the abundant growth of cyanobacterial species during monsoon. In the present study also, all the water samples showed a considerable amounts of nitrates and phosphates, with moderate level of BOD along with high DO level. Here it is the fact that, the study area, which is a part of Western Ghats where there is a very high rain fall during monsoon season, when this rain water containing high dissolved oxygen enters in to the freshwater bodies particularly in the tanks and reservoirs, which may favor the cyanobacterial species richness during monsoon period.

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