Algal diversity and distribution pattern adjoining Paper mill area

4.1 Introduction

Probably owing to their physiological flexibility and long evolutionary history, algae inhabit a large variety of terrestrial and aquatic habitats. However, the distribution and abundance of algae in the ecosystems are controlled by a wide range of physical, chemical and biological factors. Physico-chemical parameters and quantity of nutrients in water play significant role in the distributional patterns and species composition of algae in their habitats. The penetration of light, temperature, salinity, pH, hardness, phosphates, nitrates and water current velocity are the important factors for growth and density of phytoplanktonic species (Mahar *et al*., 2000). Nutrients are the main limiting factor for algal growth. The appearance, disappearance, density and pattern of distribution of algae depend on biotic and abiotic factors (Escaravage and Prins, 2002). Algae are ubiquitous in arable or virgin soils. Numerous soil microorganisms are potential bioindicators of soil quality (Pipe and Cullimore, 1980; Roper and Opel-Keller, 1997). These photosynthetically active microorganisms exhibit changeable community structure, depending on soil physico-chemical properties and on anthropogenic activities. Fresh water bodies in populated plains of tropical countries face various disturbances in the form of pollutant and nutrient inflow, heavy metal and elemental precipitation (wet or dry) and constant silt inflow (natural or anthropogenic). This affects the physic-chemical quality as well as the aquatic flora and fauna of the water bodies (Dwivedi and Pandey, 2002). Therefore the annual monitoring of water bodies by checking out the algal diversity and the physico-chemical characteristics provides a scientific way to manage water bodies. Though very few reports are available on algal abundance from paper mill polluted areas of North-Eastern India (Rout *et al*., 2010; Saikia and Lohar, 2012), information on the detail seasonal assessment of algal diversity and ecology of the industrially polluted and unpolluted areas of Panchgram are virtually scanty. Accordingly, the present chapter deals with seasonal variation and ecological assessment of algal community in the different polluted and unpolluted areas around Cachar Paper Mill in Hailakandi district of Assam, North-East India.

4.2 Methodology

For the study of seasonal variation and ecological assessment of algal communities, a total of 8 different types of ecosystems were selected. Water samples were collected monthly and a total of nine water parameters and two microclimatic conditions were analyzed. Water sampling could not be performed in the month of May, June and September for inaccessibility of the experimental sites due to flood event. Since the solid wastes, tree barks and uplands are devoid of source of water, water quality assessment was not possible in those areas. Soil samples were collected once in a year from 7 ecosystems (except uncooked knots) and a total of seven parameters were estimated. Algal samples were collected monthly for the seasonal assessment of algal diversity in the different ecosystems. Physico-chemical parameters and the algal samples were analyzed according to the standard procedures mentioned in **Chapter 3**.

The algal community structure was analyzed using the diversity indices. Shannon-Wiener diversity index_H, Simpson's dominance index_D and Pielou's evenness index_J were calculated by using the statistical software, PAST V-2.13. In order to determine significant difference, if any, in physico-chemical parameters of water between seasons and between stations, the results were analyzed using Two-factor ANOVA by Tukey multiple comparison of the means. Significant differences were indicated at $p < 0.05$. For soil data one way ANOVA was applied. To establish the interrelationship between different variables bivariate correlation, Principal Component Analyses (PCA) and Hierarchial cluster analysis were made. The statistical analyses were carried out using the statistical software package, SPSS V-19.

4.3 Results and discussion

4.3.1 Habitat characterization

4.3.1.1 Physico-chemical analyses of water

The seasonal variation of physico-chemical properties of water samples were studied in four sites of river sites (Site 1, Site 2, Site 3 and Site 4). A distinct seasonal variation of physico-chemical properties of the water samples was observed during the study period. **Fig. 4.1** and **4.3** shows seasonal variation of air and water temperatures in the study sites.

The fluctuation in river water temperature usually depends on the season, geographic location, sampling time and temperature of effluents entering the stream (Ahipathy, 2006). Summer maxima and winter minima of air and water temperatures were observed at all the sites with the moderate variations. The air temperature ranged between 23-41°C and the mean water temperature of the water varied from 17-31°C. However, the Site 2 exhibited higher values of temperature compared to other three stations irrespective of all the seasons. This may be due to direct mixing of partially treated effluents from the outfall of the mill. Such results are in agreement with the earlier investigations (Sudhakar *et al*., 1991; Karrasch *et al*., 2006; Malaviya and Rathore, 2007; Saikia and Lohar, 2012). Transparency (**Fig 4.4**) ranged from 8.05 – 55.12 cm. In the present study, it was observed that transparency was maximum at site 1 and minimum at site 2 with elevated values at station 3 and 4. It was found that values of transparency were high during the winter and early summer months, registering abrupt decrease in monsoon months. Transparency was more at site 1 as the water is clear at the upstream zone. It was less at the site 2 due to the dark color imposed by the effluent and gradually increased in station 3 and 4 with the dilution of effluent. The pH of river water represented in **Fig 4.5** was found to be slightly acidic to remarkably basic ranging from 6.22-8.62 in Site 1 to effluent releasing point (Site 2) respectively and again with increasing distance, pH showed a slight shift towards mild alkalinity to neutrality due to dilution effect. Similar trend in pH was observed by earlier workers (Karanth, 1987; Odoemelam, 1999; Rout and Sarma, 2010; Saikia and Lohar, 2012). Mixing of highly alkaline effluents, reduction in photosynthetic activity, carbon dioxide and bicarbonate assimilation are responsible for the rise in pH (Karanth, 1987). Dissolved oxygen (**Fig 4.7**) ranged from 0.34 mg/l-8.85 mg/l in upstream (Site 1) and effluent releasing zone (Site 2) respectively. Dissolved Oxygen in the river water showed marked variation at different stations. Dissolved oxygen reflected a higher value at Site 1 as compared to other stations. The amount of dissolved oxygen could not be determined at Site 2 for few months (premonsoon period) due to extreme effluent load in the river. High loads of organic pollution reaching the Barak from paper mill through pipe lead to low oxygen or even anaerobic conditions in the river water downstream. The river is able to recover from the organic pollution stress only after covering a distance of about half km at Site 3 probably through self purification system, where the mean range of DO was found to be 3.70 – 5.86 mg/L. The hydro biological conditions of river Cauvery in the vicinity of Seshsasayee Pulp and Board Ltd., Pallipalayam indicated the absence of dissolved oxygen in the sites of outfall region. Low values of dissolved oxygen are usually associated with high organic matter. Organic pollution of water leads to decrease of oxygen with increase of CO2. Free CO2 content (**Fig 4.8**) was observed to be highest at Site 2 (44.73 mg/l) in pre-monsoon period with a minimum value at Site 1 (5.95 mg/l) during post-monsoon. It may be due to decreased in productivity leading to decomposition forming more CO2 in the water.

Alkalinity (**Fig 4.6**) ranged between 44.17 -354.42 mg/l in Site 1 in post-monsoon and in Site 2 during pre-monsoon respectively. In our present study, the alkalinity reflected a higher value at all the downstream sites. Due to discharge of effluent containing bleach liquor (NaOH, Na_2S, etc.) the alkalinity is added up to the water body. The higher alkalinity was due to the increased organic decomposition thereby liberating carbon dioxide which reacts with water to form bicarbonate and thus increases the total alkalinity. Similar seasonal variations have been recorded by Mukherjee and Saha (2015) in river Hooghly at Kolkata. Nutrients displayed consistent seasonal behavior, which may be attributed to biological activities caused by topographic, microclimatic and different amounts of wastes discharged to the river. In the study, relatively higher NO_3 –N and PO_4-P concentrations (**Fig 4. 9** and **Fig 4.10**) in the water of the Site 2 was obtained compared to the water of upstream and two downstream stations. Higher ammonia concentration in the post-monsoon and winter seasons, at downstream in the river, reflects the leaching of nitrogenous fertilizers applied extensively to agricultural fields in the vicinity of the river mainly near by the Sites of 1 and 4. Also, wash out of soil during flood ads up elevated level of nitrate. Similar findings were also observed by Jain *et al*. (2003). The maximum concentration of phosphate was found to be 0.37 mg/l at Site 2 after the confluence of wastewater from paper mill. This is due to the presence of soapy mixtures in the wastewater, which contain phosphate as one of the important constituents. Silica concentration (**Fig 4.11**) ranged from 3.99 – 29.62 mg/l in Site 4 and Site 2 in respectively. The concentration of silica suddenly increased during monsoon as water flow increased due to rapid rain. When the rain effect subsided, silica decreased to pre-rain concentrations. The apparent decline in silica concentrations is caused by dilution from rapid, shallow flow (Kennedy 1971). Multiple comparison test shows that the water temperature varies significantly at 0.05 level between Site 2 and Site 4 ($p=.041$) $p<0.001$). Transparency varies significantly between study ite 1 and site 2 ($p<0.0001$), site 2 and site 3 ($p<0.0001$), Site 2 and site 4 ($p=0.003$). Dissolve oxygen does not varies significantly among the four studied study site ($F=1.025$ $p=0.397$). pH varies but statistically not significant ($F=0.568$ $p=0.641$) among the different four study site, whether pH varies statistically significantly among different months ($F=7.255$ $p<0.0001$). The Alkalinity varies significantly among the different study site ($F=9.766$ $p<0.00001$) and among the different months ($F=2.405$ $p=0.035$). Free CO_2 varies among the different study site statistically significantly ($F=5.023$; $p<0.001$) but in different month it varies but not statistical not significant ($F=1.010$ $p=0.415$). Nitrate varied statistically significantly among the different study site and among different months of the study periods ($F=9.962$; $p<0.0001$). Phosphate shows the among the different study site and among different months the concentration of phosphate varied statistically significantly ($F=9.041$; $p<0.00001$). Concentration of silica varied significantly among different study site and also among different studied months ($F=7.792$; $p=0.001$).

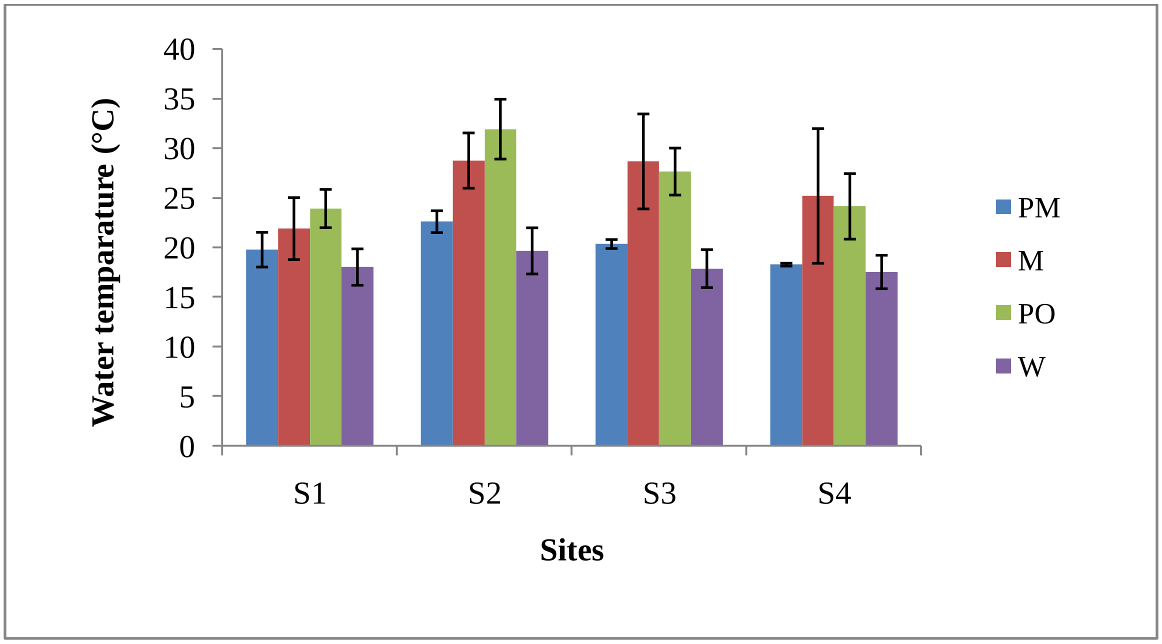


Fig. 4.1: Seasonal variation of water temperature (°C) in the of different study sites (Mean ±SD)

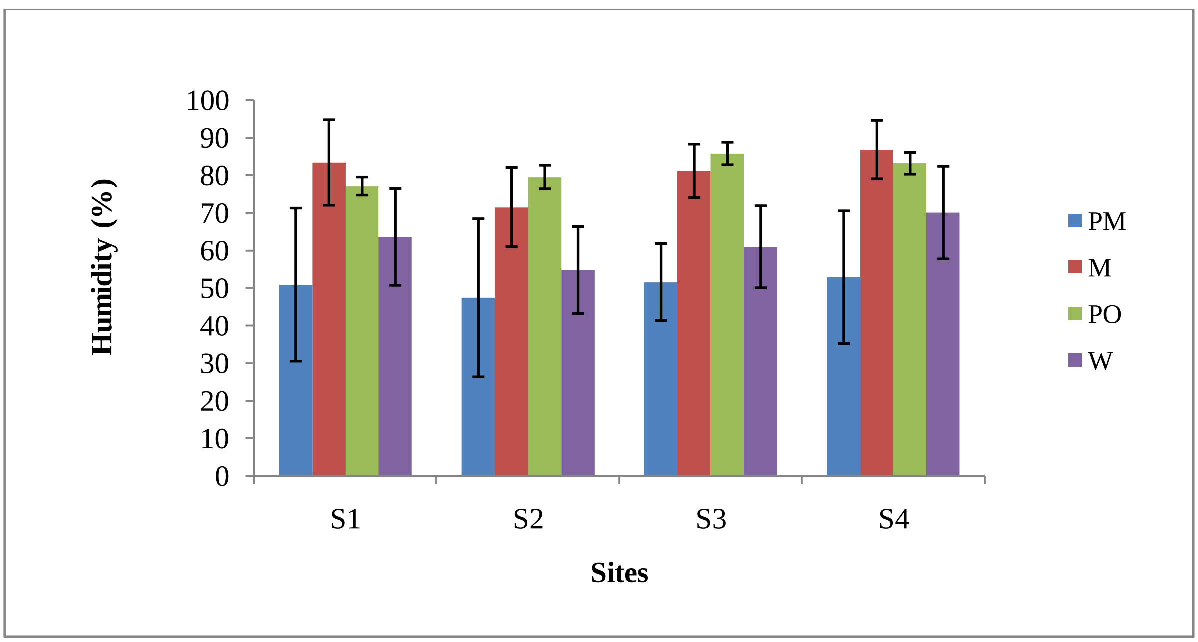


Fig. 4.2: Seasonal variation of humidity (%) in the of different study sites (Mean ±SD)

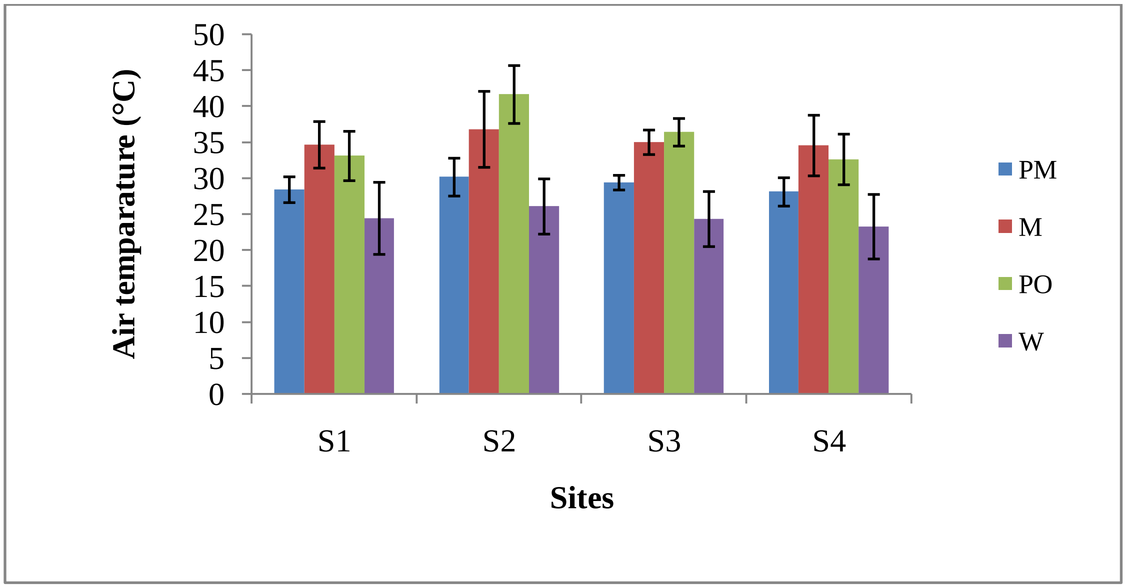


Fig. 4.3: Seasonal variation of air temperature (°C) in the of different study sites (Mean ±SD)

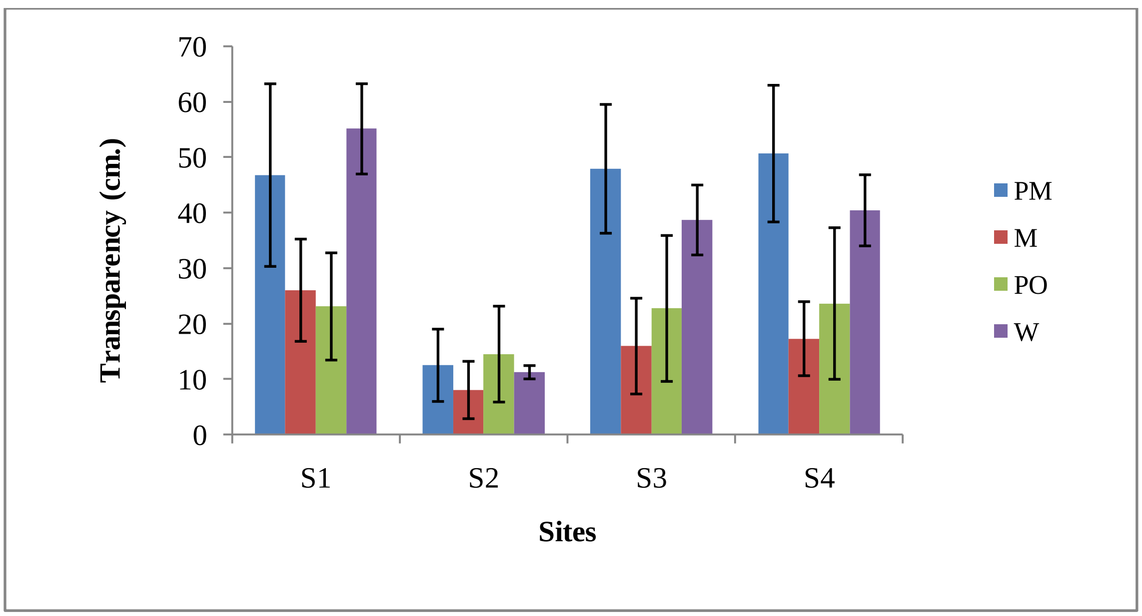


Fig 4.4 Seasonal variations of transparency (cm) of the study sites (Mean ±SD)

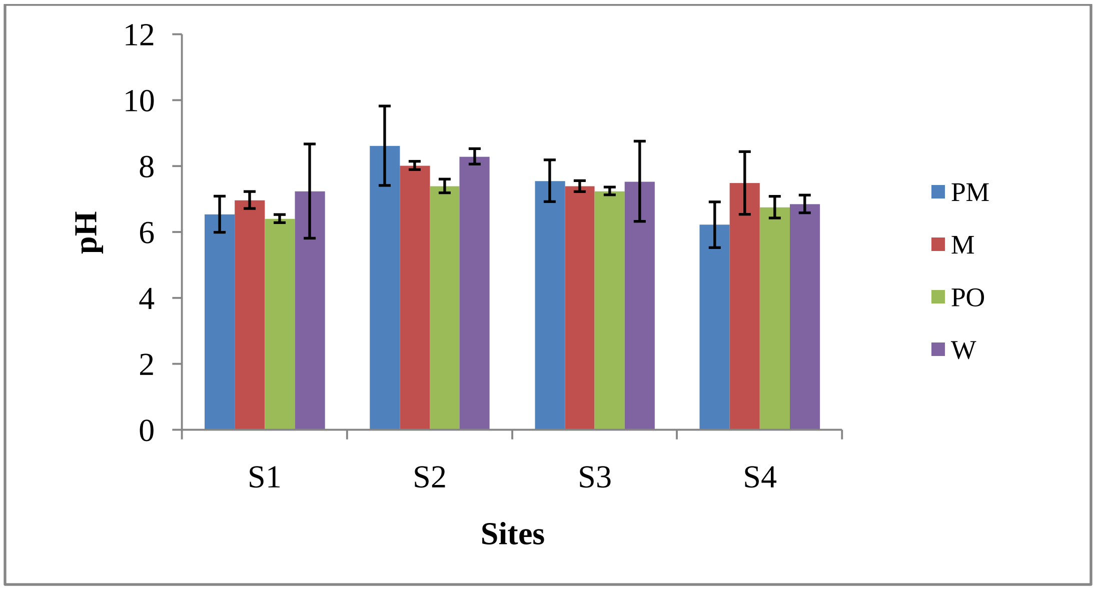


Fig. 4.5: Seasonal variation in pH of water of different study sites (Mean ±SD)

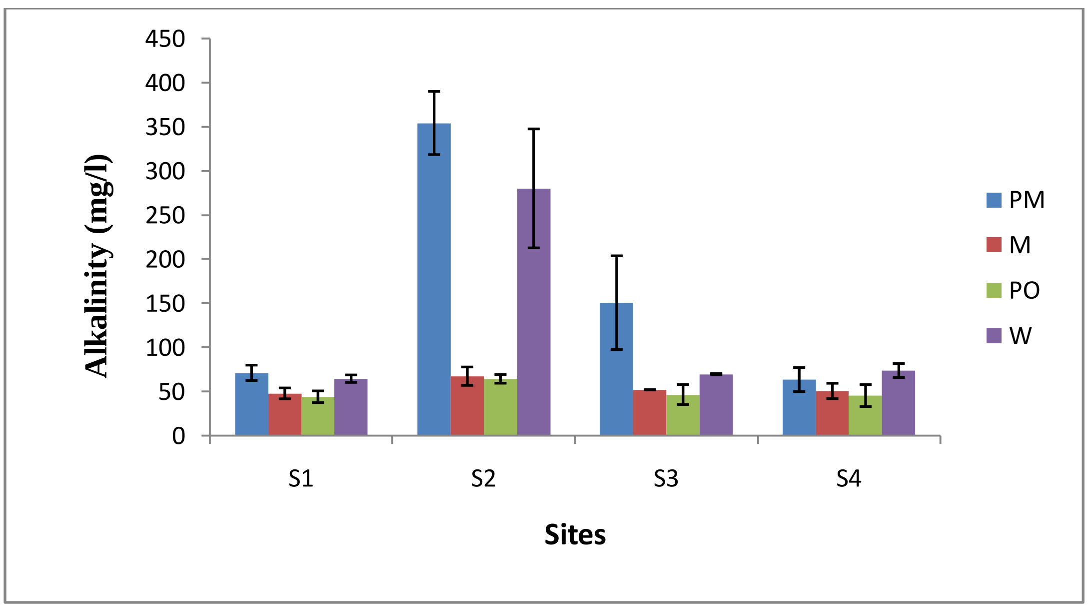


Fig. 4.6: Seasonal variation in total alkalinity (mg l^{-1}) of water in the of different study sites (Mean ±SD)

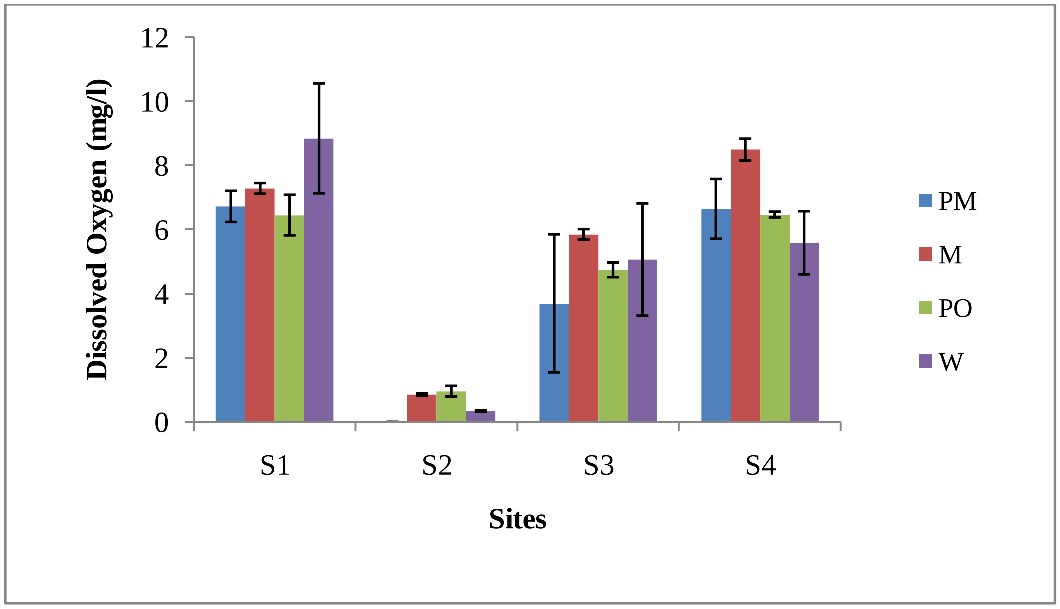


Fig. 4.7: Seasonal variation in dissolved oxygen (mg l^{-1}) of water in the of different Study sites (Mean ±SD)

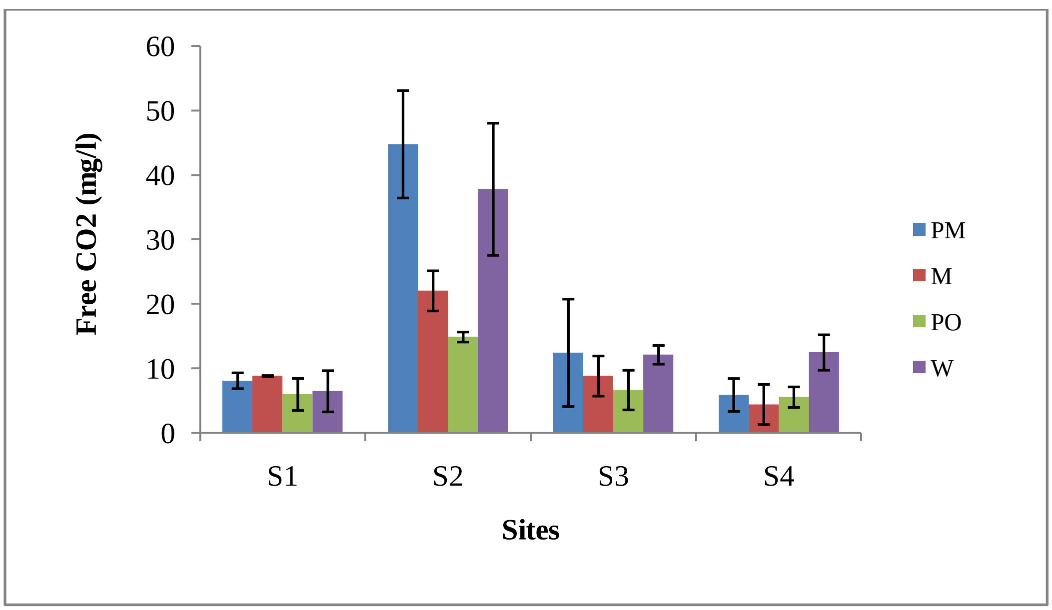


Fig. 4.8: Seasonal variation in free CO2 (mg l^{-1}) of water in the of different study Sites (Mean ±SD)

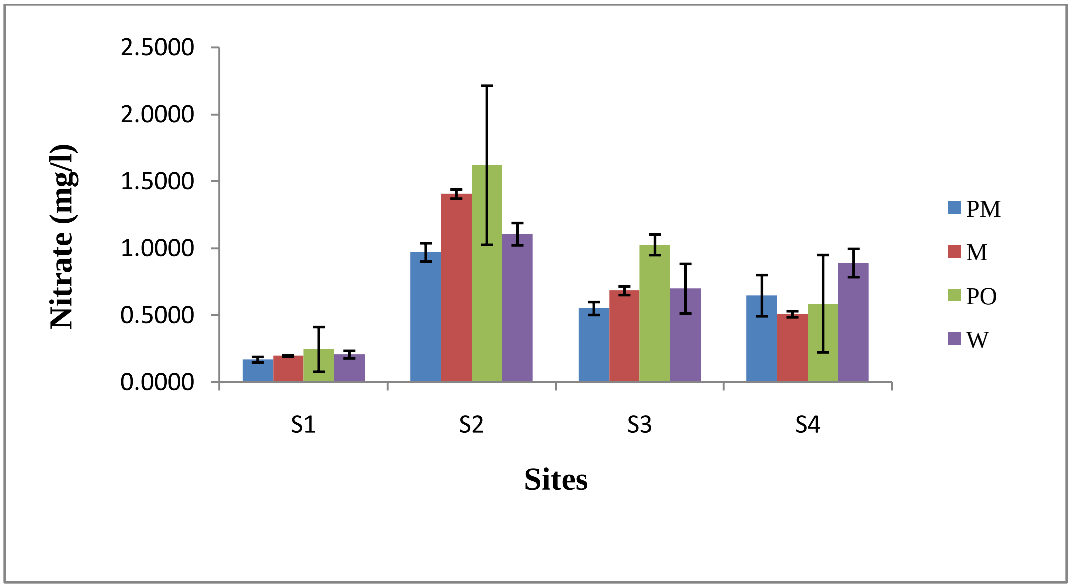


Fig. 4.9: Seasonal variation in NO_3 –N (mg l^{-1}) of water in the of different study Sites (Mean ±SD)

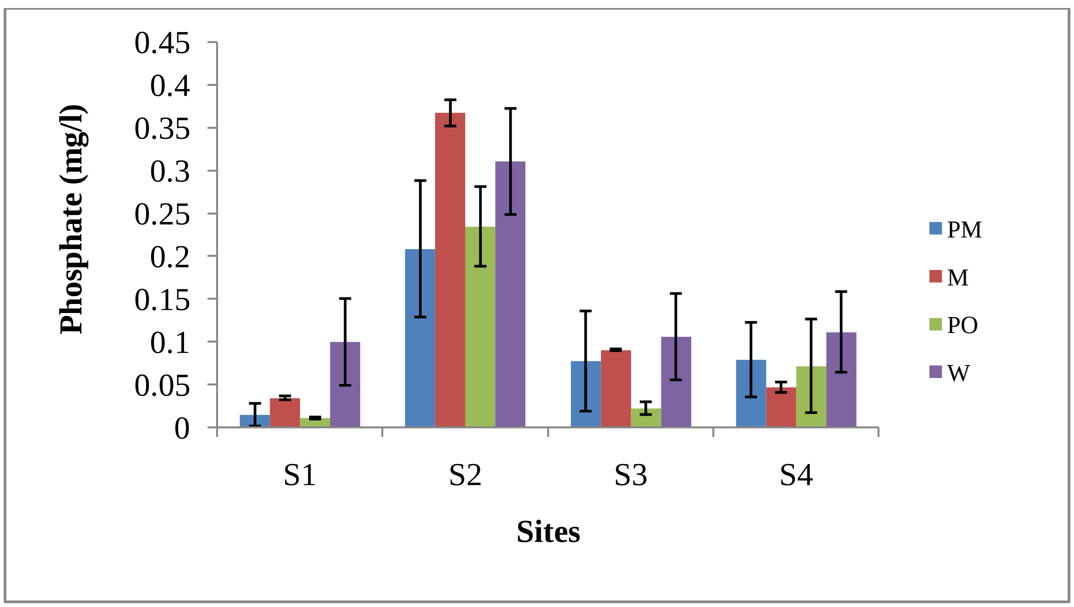


Fig. 4.10: Seasonal variation in soluble reactive phosphate (mg l^{-1}) of water in the of different study sites (Mean ±SD)

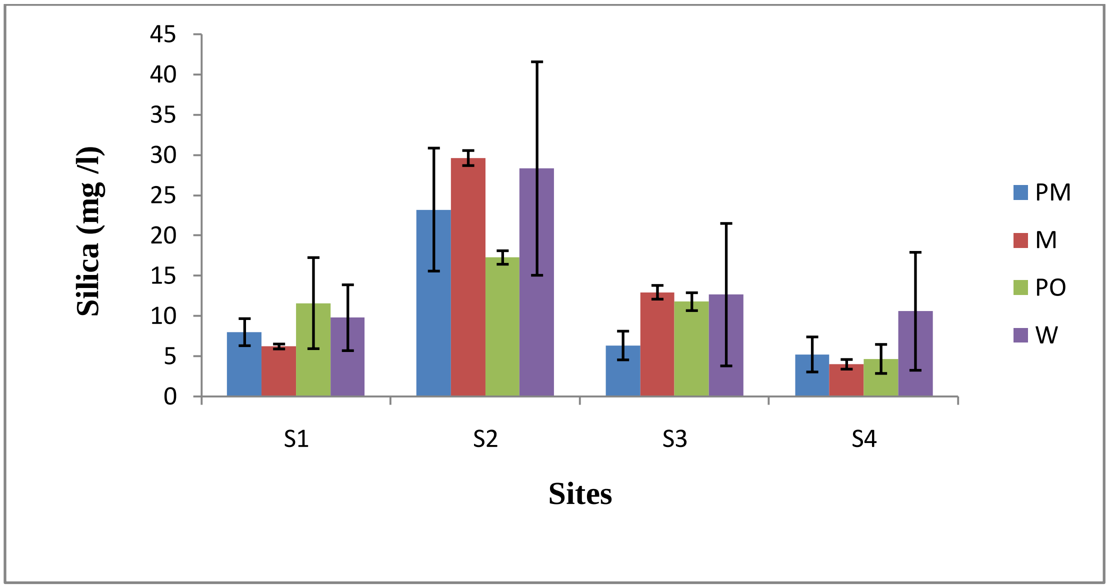


Fig. 4.11: Seasonal variation in dissolved silica (mg l^{-1}) of water in the of different study sites (Mean ±SD)

Table 4.1: One-way ANOVA of the physico-chemical parameters of water

Source	Dependent Variables	Sum of squares	df	Mean square	F	Sig
Site	Water temparature	66.267	4	1764.174	157.380	0.000
	Transparency	5291.167	4	.846	5.667	0.000
	Dissolved Oxygen	123.354	4	1.356	233.236	0.283
	pH	5.959	4	2645.583	2836.863	0.041
	Alkalinity	207015.640	4	69368.701	575.846	0.000
	Free CO_2	3510.308	4	1240.157	80.595	0.000
	Nitrate	.023	4	1755.154	5852.984	0.273
	Phosphate	.041	4	2.979	2306.077	0.174
	Silica	222.884.	4	103507.820	81.988	0.000
Season	Water temparature	65.597	4	42.495	99.087	0.000
	Transparency	8.351	4	61.677	67.574	0.000
	Dissolved Oxygen	4.132	4	2645.583	74.377	0.000
	pH	.078	4	1090.463	575.846	0.000
	Alkalinity	106.667	4	196.531	64.942	0.000
	Free CO_2	196.531	4	103507.820	55.991	0.000
	Nitrate	.010	4	.011	835.773	0.000
	Phosphate	.005	4	74.377	111.442	0.000
	Silica	74.377.045	4	99.087	4.748	0.000
Error	Water temparature	.876	280	.015	79.345	
	Transparency	76.920	280	.004	75.628	
	Dissolved Oxygen	196.531	280	.005	74.060	
	pH	4.132	280	.020	81.988	
	Alkalinity	.185	280	.000	544.342	
	Free CO_2	.119	280	99.087	139.220	
	Nitrate	1090.46	280	67.574	164.979	
	Phosphate	196.531	280	74.377	734.023	
	Silica	66.267	280	111.442	654.87	
Total	Water temparature	68.351	288			
	Transparency	5298.119	288			
	Dissolved Oxygen	128.150	288			
	pH	6.262	288			
	Alkalinity	208212.769	288			
	Free CO_2	3725.311	288			
	Nitrate	.035	288			
	Phosphate	.046	288			
	Silica	298.282	288			

4.3.1.2 Physico-chemical properties of soil samples

The nature of algal flora in different localities is the result of a complex influence of the local type of vegetation, soil properties and climatic conditions (Metting, 1981; Starks *et al.*, 1981; Lukesˇova´, 1993). Soil algae community structures are affected more by soil usage than by physico-chemical parameters. Soil samples were collected and analyzed during the dry period of the study sites. The variations of different soil parameters have been shown in **Fig. 4.12** to **4.18**. Irrespective of the ecosystems soils were found to be acidic **(Fig. 4.12)** in nature except solid waste deposits (lime sludge). The result is in agreement with the earlier report of Deb *et al.*, (2013) from the Cachar district of Barak valley. Breakdown of organic matter and minerals might have lead to the decrease in pH. Lowest pH was noticed in river bank soil of Site 2 (4.23) and highest was obtained for Site 4 (6.40). The lime sludge waste dump is characterized by a unique substrate quality, like very strong alkaline pH (~12). Several other reports mentioned optimum growth of algae including cyanobacteria to be favoured by neutral to slightly alkaline pH (Singh, 1961; Kaushik, 1964; Nayak and Prasanna, 2007; Hazarika *et al*., 2012 and Madhumathi *et al*., 2012). However, the present study reports the existence of luxuriant population of algae at lower pH range, similar to few earlier reports (Aiyer, 1965; Dominic and Madhusoodanan, 1965 and Hunt, 1979). Conductivity of the soils of the ecosystems was found to vary between 0.43 - 12.51 ms/cm in downstream river bank soil (Site 1) and lime sludge deposits respectively. Bulk density was found highest in the Site 2 (2.63 g/cm3) and lowest in Site 3 (0.48 g/cm3). Wastewater fed river soil sites were estimated for the highest soil organic carbon (SOC) than the other study sites during the study period. The range of organic carbon was 1.03% (Station 3) to 0.52% (Site 1) respectively. Moisture content was found highest (37.84%) in the soils of lime sludge and lowest in Site 2 (22.45%). The water holding capacity of the soils of the ecosystems was found to vary between 79.56 – 48.04% in lime sludge and soils around papermill respectively. The percentages of sand, silt, clay with the soil textural class have been shown in **Fig. 4.17**.

A total of six textural classes **(Fig. 4.10, Table 4.1)** of the soil viz. sandy, sandy clay loam, silt loam, silt clay, silt clay loam and clay loam were observed during the investigation. Silt proportion was found to be higher in all the sites except lime soil and soil surrounding tree barks area where sand was higher. Lund (1945) and Shield and Drouet (1962) mentioned the significant effect of soil texture on diatoms and blue-green algal species. Soil pH varied significantly ($F=757.316$; $p<0.00001$) among the different study site. Coefficient of variation of pH among the different study site is (CV %) 32.95. Soil conductivity varied significantly ($F=556.786$; $P<0.00001$) among the different study site. Average soil conductivity was observed among the studied study site was 46.97 with CV% 198.270. Moisture contents varied significantly among the different study site ($F=49.45$ $p<0.000001$). Average Moisture contents were recorded 30.42 with CV% 38.72 among the different study sites. Bulk density of the studied soil samples varied significantly among the different study site ($F=6.470$ $p<0.00001$). Average bulk density was recorded 1.16 with CV% 50.004. Water holding capacity varied significantly among the different study site ($F=37.550$; $p<0.00001$) with CV% 19.51%. Organic carbon varied significantly among the different study site ($F=62.461$ $p=0.00000001$) with a standard deviation 0.284 CV% 47.711.

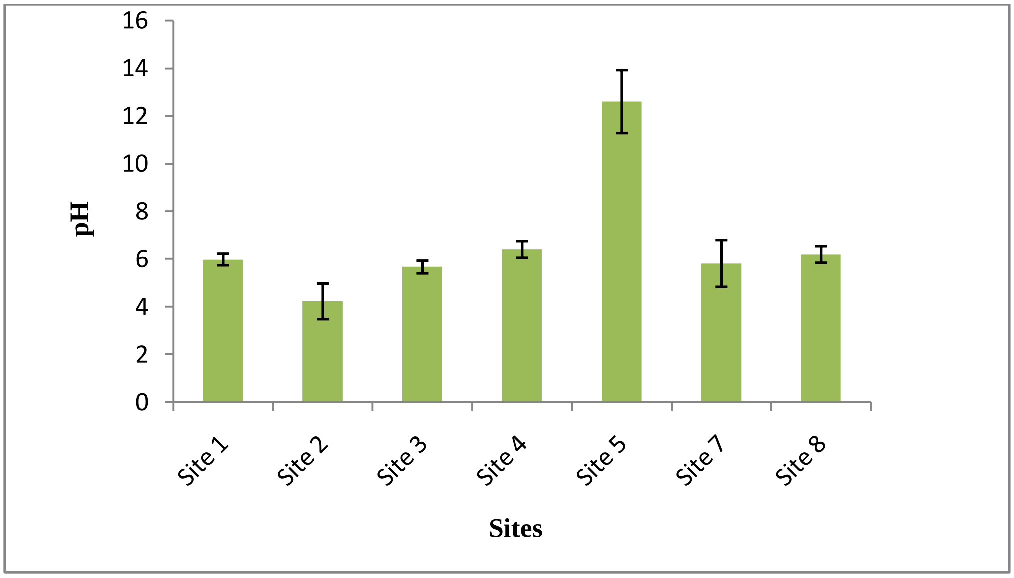


Fig. 4.12: Variation in pH of soil at the study sites (Mean ±SD)

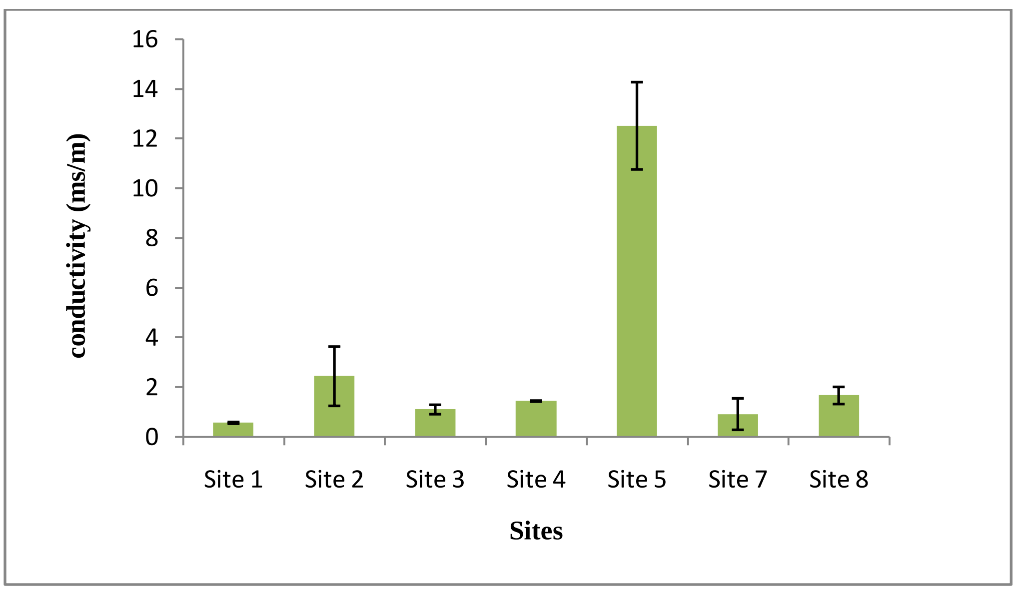


Fig. 4.13: Variation in conductivity (mS cm^{-1}) of soil at the study sites (Mean ±SD)

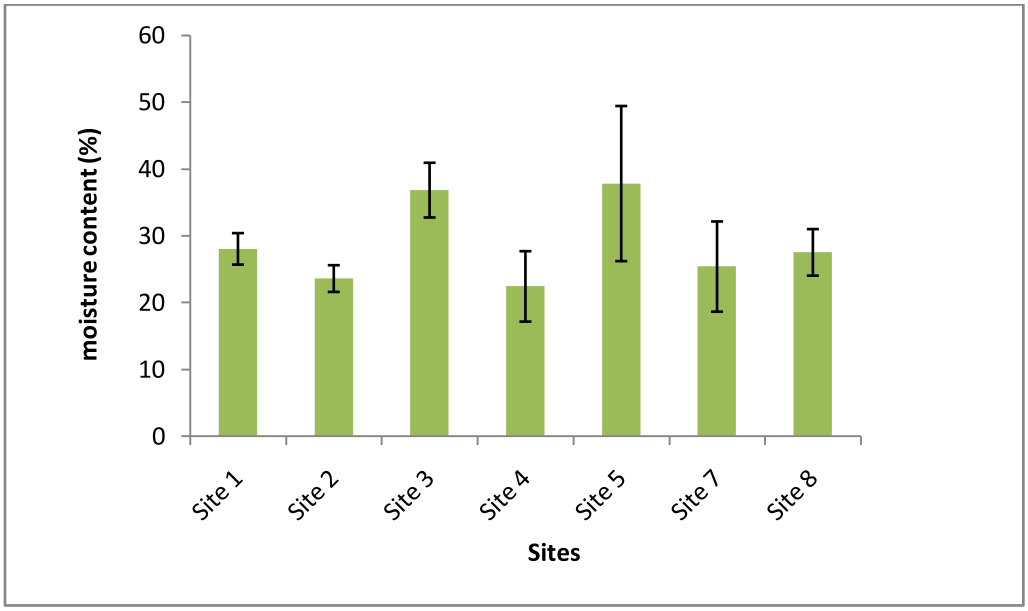


Fig. 4.14: Variation in moisture content (%) of soil of different study sites (Mean ±SD)

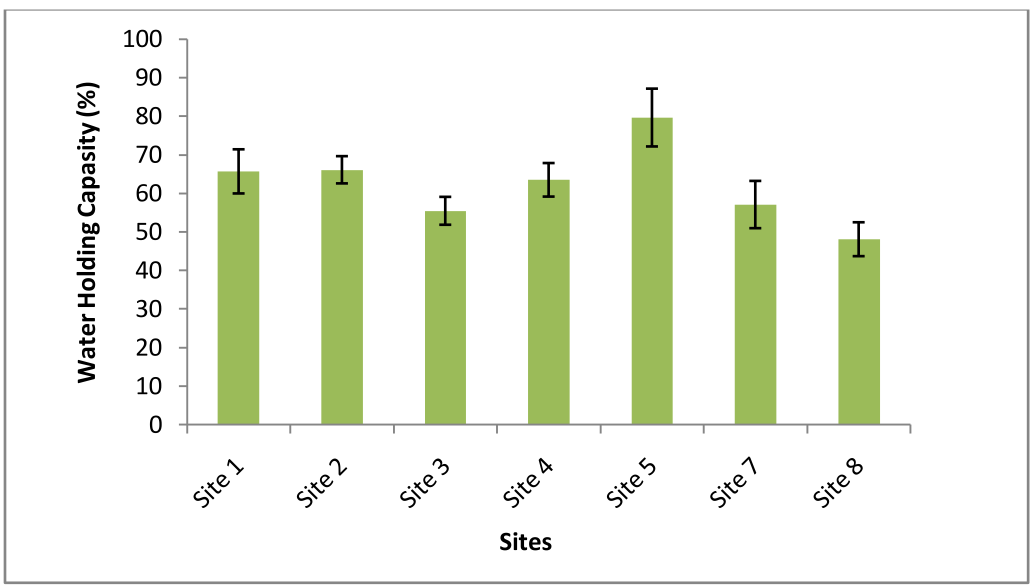


Fig. 4.15: Variation in water holding capacity (%) of soil at the study sites (Mean ±SD)

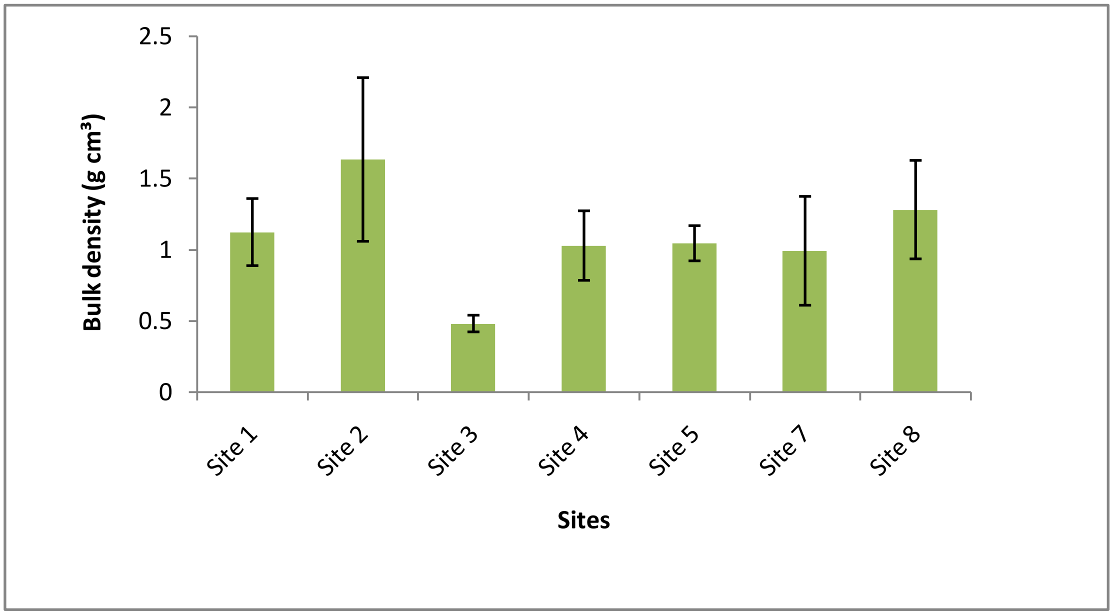


Fig. 4.16: Variation in bulk density (g cm^{-3}) of soil at the study sites (Mean ±SD)

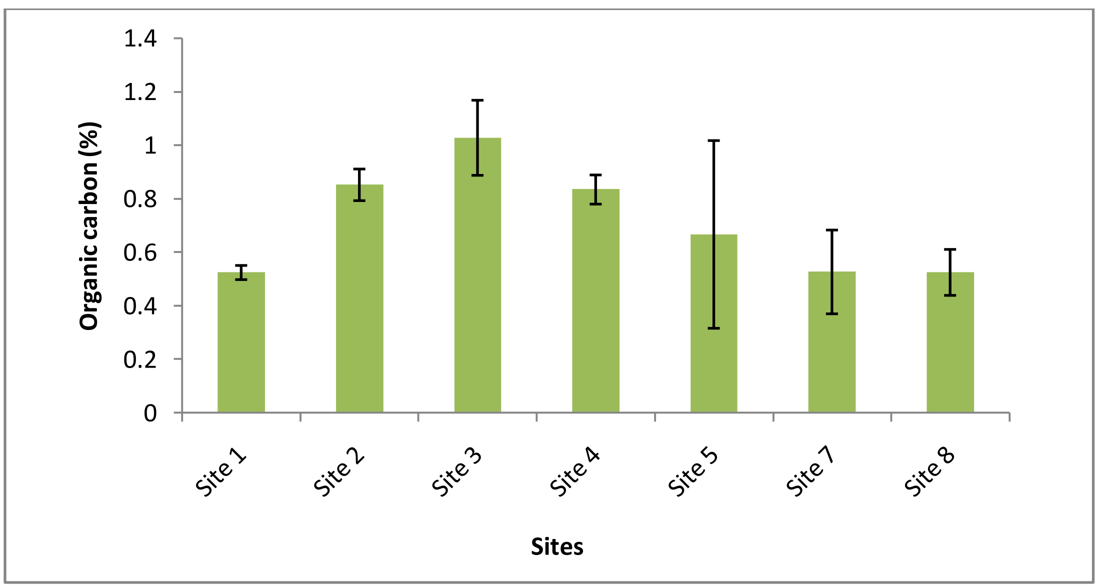


Fig. 4.17: Variation in organic carbon (%) of soil at the study sites (Mean ±SD)

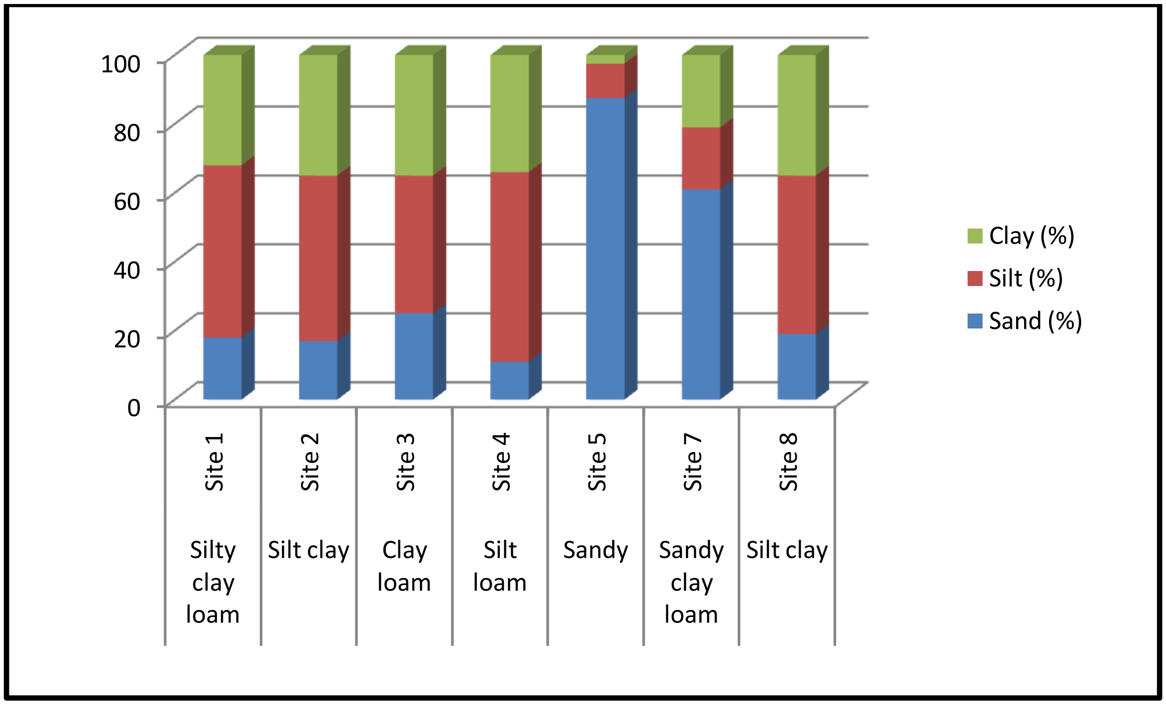


Fig. 4.18: Proportion of soil particles at the study sites

Table 4.2: One-way ANOVA of the physico-chemical parameters of soil

		Sum of squares	df	Mean square	F	Sig
pH	Sites Error Total	32.731 7.500 40.231	1 18 19	1.723 7.500	5.254	0.003
Bulk density	Sites Error Total	7.500 25.231 32.731	1 18 19	36.856 8.869	1.876	0.012
Organic carbon	Sites Error Total	700.260 540.610 1240.87	1 18 19	302.290 103.060	3.634	0.001
Moisture content	Sites Error Total	3888.420 1855.089 5743.508	1 18 19	.150 057	5.143	0.004
Conductivity	Sites Error Total	.057 2.787 2.843	1 18 19	64.971 594.225	854.23	0.001
Water holding capacity	Sites Error Total	594.225 640.227 1234.452	1 18 19	.155 35.568	28.403	0.003

4.3.2 Algal colonization and seasonal variation in the ecosystems

In the present study in order to estimate algal abundance, a combination of three principal methods: plating techniques, measurement of pigments and direct observation were applied to have a more acceptable picture of algal distribution.

For the study of seasonal variation and ecological assessment of algal communities, algal samples were collected monthly and enumerated from the selected 8 ecosystems. A total of 123 algal species **(Table 4.3)** under 47 genera were identified in the selected ecosystems of the study area. Highest number of algal species was obtained in around papermill (25) followed by Site 2 (23), Site 1 (21), Tree bark (20), Site 3 (19), Site 4 (18), Lime sludge deposits (18) and Uncooked knot deposits (14). A total of 4 classes of the algal community (Cyanophyceae, Chlorophyceae, Bacillariophyceae and Euglenophyceae) were observed during the investigation. Cyanophyceae proportion was found to be higher in all the sites. The class Cyanophyceae was represented by 18 genus and 51 species, Chlorophyceae (genus-13, species-25), Bacillariophyceae (genus-14, species-48) and Euglenophyceae (genus-2, species-2). The photomicrographs of algae encountered in this study are shown in plate **4.3 to 4.5** (Cyanophyceae), plate **4.6-4.7** (Chlorophyceae), plate **4.8, 4.10** and **4.11** (Bacillariophyceae), plate **4.9** (Euglenophyceae). The densities, abundance, frequency of the algal species were given on the Table **4.4-4.11**. The highest algal species was obtained in the class Cyanophyceae. Highest number of blue green algal species belonged to the genus *Oscillatoria* (12) followed by *Lyngbya* (6) and *Anabaena* (4) (**Table 4.3**). Genera under *Nostocaceae*, *Scytonemataceae*, *Rivulariaceae*, and *Oscillatoriaceae* are found to be distributed in all the study sites. The Blue green algae were more abundantly present during the post monsoon season at the sites of river bank irrespective of all the fields while in case of solid wastes, tree barks and upland soil, abundance of algae was higher during monsoon period. In the soil contaminated by wastewater, non-heterocystous forms were found to be dominant over the heterocystous forms. Lower availability of heterocystous cyanobacteria indicates the presence of higher level of combined nitrogen (Das and Panda, 2010; Jafari and Alavi, 2010; Sharma and Bhardwaj, 2011; Kshirsagar *et al*., 2012; Negi and Rajput, 2013; Kannan, 2008; Boominathan *et al*., 2007; Paranthaman and Karthikeyan, 2013). Although earlier investigations (Huber, 1986; Okmen *et al*., 2007) report growth inhibition of *Nodularia* at higher nitrogen concentration, in the present study *Nodularia* is present in the highly acidic soil (pH ~ 4.23) of river Barak. The relative abundance of blue green algae was highest at Site 8 (89.48%) during premonsoon and least in site 2 (5.19%) during monsoon (**Fig. 4.19**). **Fig. 4.20, 4.21, 4.22** and **4.23** represent the relative abundance of Cyanophyceae, Chlorophyceae, Bacillariophyceae and Euglenophyceae respectively. **Table 4.13** depicts the diversity indeces of algal communities at various seasons. Highest algal diversity was observed at site 2 during post premonsoon season with maximum Shannon-Wiener diversity index (H=2.21), minimum Simpson’s dominance index (D=0.14) and maximum Pielou's evenness index (J=0.86). The algal distribution at site 5 during premonsoon was observed to be least diverse with minimum Shannon-Wiener diversity index (H=0.65), maximum Simpson's dominance index (D=0.67) and minimum Pielou's evenness index (J=0.43).

Table 4.3: List of algae encountered

Algal species	Sl. no.	Name of the Species	Species code	Species	Genus
Cyanophyceae	**1**	*Anabaena spherica* v. *attenuate* Bharadw. (after Bharadwaja)	**C1**	51	18
	2	*Anabaena subcylindrica*	**C2**		
	3	*Anabaena orientalis* Dixit (after Dixit)	**C3**		
	4	*Anabaena oryzae* Fritsch (after Fritsch)	**C4**		
	5	*Aphanocapsa pulchra* (Kutz.) Rabenh. (after Smith)	**C5**		
	6	*Aphanothece microscopica* Nag. (after Fremy)	**C6**		
	7	*Aphanothece naegelii* Wartm (after Skuja)	**C7**		
	8	*Aphanothece thermicola after* Hindák	**C8**		
	9	*Calothryx marchica* var. *intermedia* Rao. C.B.	**C9**		
	10	*Calothryx marchica* V. *crassa* Rao, C.B. (after Rao, C.B.)	**C10**		
	11	*Crococcus sp.*	**C11**		
	12	*Croococcus limneticus* Lemm. (after Smith)	**C12**		
	13	*Croococcus minutus* (Kutz.) Nag. (after Skuja)	**C13**		
	14	*Croococcus turgidus* v. *maximus* Nygaard (after Nygaard)	**C14**		
	15	*Cylindrospermum majus* Kuetzing ex. Born ex. Flah	**C15**		
	16	*Cylindrospermum muscicola* Kuetzing	**C16**		
	17	*Cylindrospermum stagnale* (Kütz.) Born. et Flah (Frémy)	**C17**		
	18	*Leptolyngbya* sp.	**C18**		
	19	*Lyngbya hieronymusii* Lemm. (after Lemm.)	**C19**		
	20	*Lyngbya lutea* (Ag.) Gom.	**C20**		
	21	*Lyngbya polysiphoniae* Fremy (after Fremy)	**C21**		
	22	*Lyngbya rubida* Fremy (after Fremy)	**C22**		
	23	*Lyngbya taylorii* Drouet & Strickland	**C23**		
	24	*merismopedia punctata*	**C24**		
	25	*Tolypothryx byssoidea* (Berk.) Kirchn.	**C25**		
	26	*Microchaete calothicoides*	**C26**		
	27	*Nodularia spumigena* Mertens in Jürgens	**C27**		
	28	*Nostoc entophytum* Born. *et*. Flah.	**C28**		
	29	*Nostoc linckia* v. Arvense Rao, C. B. (After Rao, C. B.)	**C29**		
	30	*Nostoc sphaericum* Vaucher	**C30**		
	31	*Oscillatoria acuminata* Gom. (after Gomont)	**C31**		
	32	*Oscillatoria amphibia* Ag. (orig.)	**C32**		
	33	*Oscillatoria amphigranulata* van Goor (orig.)	**C33**		
	34	*Oscillatoria curviceps* C.A. Agarth	**C34**		

	35	*Oscillatoria formosa* Bory	**C35**		
	36	*Oscillatoria granulata* Gardner	**C36**		
	37	*Oscillatoria limnetica* Lemm. (orig.)	**C37**		
	38	*Oscillatoria pseudogeminata*	**C38**		
	39	*Oscillatoria subbrevis* Schmidle	**C39**		
	40	*Oscillatoria tenuis* var. *tergestina* (Kuetz.)	**C40**		
	41	*Oscillatoria terebreformis* Ag. (after Fremy)	**C41**		
	42	*Oscillatoria vizagapatensis* Rao (after Rao, C. B.)	**C42**		
	43	*Phormidium autumnale* (Ag.) Gom. (after Gomont)	**C43**		
	44	*Phormidium corium* (Ag.) Gom.	**C44**		
	45	*Phormidium stagnina* Rao, C. B. (after Rao)	**C45**		
	46	*Phormidium tenue* (Menegh.) Gom.	**C46**		
	47	*Scytonema milley* Born. (after Frémy)	**C47**		
	48	*Scytonema zeilerianum* Bruhl et Biswas (after Bruhl and Biswas)	**C48**		
	49	*Stigonema aerugineum* Tilden (after Tilden)	**C49**		
	50	*Spirullina major* Kutz. (after Skuja)	**C50**		
	51	*Synecoccus subselsus* (after Skuja)	**C51**		
Chlorophyceae	**52**	*Ankistrodesmus falcatus* (Corda) Ralfs.	**Ch52**	25	13
	53	*Bracteacoccus minor* (Chodat) Petrova	**Ch53**		
	54	*Closterium lanceolatum* Kuetzing	**Ch54**		
	55	*Cosmarium constrictum* Delponte	**Ch55**		
	56	*Cosmarium formosulum* Hoffman	**Ch56**		
	57	*Cosmarium granatum* Brébisson	**Ch57**		
	58	*Cosmarium pachydermum*	**Ch58**		
	59	*Cosmarium subimpressulum* Borge	**Ch59**		
	60	*Cosmarium triplatum* Wolle	**Ch60**		
	61	*Cosmarium* sp. a	**Ch61**		
	62	*Geminella mutabilis* (de Bréb) Wille	**Ch62**		
	63	*Microspora stagnorum* (Kuetz.) Lagerheim	**Ch63**		
	64	*Mougeotia* sp.	**Ch64**		
	65	*Oocystis eremosphaeria* G.M. Smith	**Ch65**		
	66	*Oocystis natansvar Major* G.M. Smith	**Ch66**		
	67	*Pediastrum integrum* Naegelii	**Ch67**		
	68	*Pediastrum tetras* (Ehrenb.) Ralfs	**Ch68**		
	69	*Protococcus viridis* C. A. Agardh	**Ch69**		
	70	*Scenedesmus denticulatus* Lagerheim	**Ch70**		
	71	*Scenedesmus quadricauda* var. *Westii* G.M. Smith	**Ch71**		
	72	*Spirogyra crassa* Kuetzing	**Ch72**		
	73	*Spirogyra punctiformis*Transeau	**Ch73**		
	74	*Trentepohlia aurea* De Wildmann	**Ch74**		
	75	*Trentepholia monilia* De Wildemann	**Ch75**		
	76	*Scenedesmus incrassatulus*Bohlin	**Ch76**		
Bacillariophyceae	**77**	*Amphora normani* Rabenhorst	**Ch77**	45	14
	78	*Amphora ovlis* Kuetz. v. *pediculus* Kuetz.	**B78**		
	79	*Cymbella hungarica* (Grun.) Pant. v. *signata* (Pant.) A.Cl.	**B79**		

	80	*Diploneis* sp.	**B80**		
	81	*Frustulia vulgaris* (Thwaites) De Toni	**B81**		
	82	*Gomphonema sphaerophorum* Her.	**B82**		
	83	*Gyrosigma baikalensis* Skv.	**B83**		
	84	*Gyrosigma maharashtrensis* Nov.	**B84**		
	85	*Melosira juergensii* Agarth	**B85**		
	86	*Navicula andium* Frenguelli	**B86**		
	87	*Navicula cuspidata* Kuetz. V. *ambigua* (Ehr.) Cleve	**B87**		
	88	*Navicula dicephala* (Ehr.) W. Smith v. *undulata*	**B88**		
	89	*Navicula laterostrata* Hustedt	**B89**		
	90	*Navicula minuta* (Cleve) A.Cl.	**B90**		
	91	*Navicula mutica* Kuetz. f. *goeppertiana* (Bleisch) Grun	**B91**		
	92	*Navicula platystoma* Ehrenberg	**B92**		
	93	*Navicula protracta* Grun.	**B93**		
	94	*Navicula pupula* Kuetz.	**B94**		
	95	*Navicula radiosa Kutz.*	**B95**		
	96	*Navicula radiosa Kutz.* v. *tenella* (Breb. Ex. Kutz.) Grun.	**B96**		
	97	*Neidium affine* (Ehr.) Cleve v. *longiceps* (Gerg.) Cleve	**B97**		
	98	*Nitzschia closterium* W. Smith	**B98**		
	99	*Nitzschia heufleriana* Grun.	**B99**		
	100	*Nitzschia hungarica* Grunow.	**B100**		
	101	*Nitzschia intermedia* Hantzsch	**B101**		
	102	*Nitzschia mediocris* Hustedt	**B102**		
	103	*Nitzschia obtusa* W. Smith	**B103**		
	104	*Nitzschia obtusa* W. Smith	**B104**		
	105	*Nitzschia vermicularis* (Kuetzing) Huntzsch	**B105**		
	106	*Pinnularia dolosa* Gandhi	**B106**		
	107	*Pinnularia eburnea* (Carlson) Zanon	**B107**		
	108	*Pinnularia episcopalis* Cleve	**B108**		
	109	*Pinnularia lonavlensis* Gandhi	**B109**		
	110	*Pinnularia lundii* Hustedt	**B110**		
	111	*Pinnularia mesolepta* Ehr. v. *stauroneiformis* Grun.	**B111**		
	112	*Pinnularia viridis* (Nitz.) Ehr. v. *fallax* Cleve	**B112**		
	113	*Pinnularia sp.*1	**B113**		
	114	*Pinnularia sp.*2	**B114**		
	115	*Pleurosigma salinarum* Grun.	**B115**		
	116	*Surirella maharastrensis* Nov.	**B116**		
	117	*Surirella tenera* Greg. v. *nervosa* A.S.	**B117**		
	118	*Synedra acus* Kuetz.	**B118**		
	119	*Synedra rumpens* Kuetzing	**B119**		
	120	*Synedra ulna* (Nitz.) Ehr.	**B120**		
	121	*Synedra ulna* (Nitzsch.) Elrenberg.	**B121**		
Euglenophyceae	**122**	*Euglena tuba*	**B122**	2	2
	123	*Phacus* sp.	**B123**		

Table 4.4: Distribution (presence and absence) of algae encountered in the present study

Class	Sl. no.	Species	S1	S2	S3	S4	S5	S6	S7	S8
Cyanophyceae	**1**	*Anabaena spherica*	+	+		+				
	2	*Anabaena subcylindrica*	+		+			+		
	3	*Anabaena orientalis*					+			
	4	*Anabaena oryzae*								+
	5	*Aphanocapsa pulchra*							+	
	6	*Aphanothece microscopica*					+			
	7	*Aphanothece naegelii*								+
	8	*Aphanothece thermicola*							+	
	9	*Calothryx marchica*	+							
	10	*Calothryx marchica*						+		
	11	*Crococcus* sp.							+	
	12	*Croococcus limneticus*					+			
	13	*Croococcus minutus*						+		
	14	*Croococcus turgidus*		+						
	15	*Cylindrospermum majus*								+
	16	*Cylindrospermum muscicola*					+			
	17	*Cylindrospermum stagnale*		+	+					
	18	*Leptolyngbya* sp.					+			
	19	*Lyngbya hieronymusii*	+							
	20	*Lyngbya lutea*						+		
	21	*Lyngbya polysiphoniae*		+						
	22	*Lyngbya rubida*						+		
	23	*Lyngbya taylorii*	+			+				
	24	*merismopedia punctata*				+				
	25	*Tolypothryx byssoidea*							+	
	26	*Microchaete calothicoides*							+	
	27	*Nodularia spumigena*		+						
	28	*Nostoc entophytum*							+	
	29	*Nostoc linckia*					+			
	30	*Nostoc sphaericum*					+			
	31	*Oscillatoria acuminata*								+

	32	*Oscillatoria amphibia*					+			
	33	*Oscillatoria amphigranulata*		+						+
	34	*Oscillatoria curviceps*	+		+					
	35	*Oscillatoria formosa*		+	+					+
	36	*Oscillatoria granulata*				+				
	37	*Oscillatoria limnetica*	+							+
	38	*Oscillatoria pseudogeminata*								+
	39	*Oscillatoria subbrevis*					+			
	40	*Oscillatoria tenuis*					+			
	41	*Oscillatoria terebreformis*		+		+				+
	42	*Oscillatoria vizagapatensis*	+			+				
	43	*Phormidium autumnale*								+
	44	*Phormidium corium*							+	
	45	*Phormidium stagnina*							+	
	46	*Phormidium tenue*			+					
	47	*Scytonema milley*							+	
	48	*Scytonema zeilerianum*					+			+
	49	*Stigonema aerugineum*								+
	50	*Spirullina major*			+					
	51	*Synecoccus subselsus*			+					
Chlorophyceae	**52**	*Ankistrodesmus falcatus*			+					
	53	*Bracteacoccus minor*							+	
	54	*Closterium lanceolatum*		+						
	55	*Cosmarium constrictum*		+						
	56	*Cosmarium formosulum*						+		+
	57	*Cosmarium granatum*						+		
	58	*Cosmarium pachydermum*					+			
	59	*Cosmarium subimpressulum*					+		+	
	60	*Cosmarium triplatum*	+			+				
	61	*Cosmarium* sp. a								+
	62	*Geminella mutabilis*			+					
	63	*Microspora stagnorum*	+			+				
	64	*Mougeotia* sp.	+			+				
	65	*Oocystis eremosphaeria*					+			
	66	*Oocystis natansvar*								+

	67	*Pediastrum integrum*					+			
	68	*Pediastrum tetras*	+							
	69	*Protococcus viridis*								+
	70	*Scenedesmus denticulatus*								+
	71	*Scenedesmus quadricauda*			+					
	72	*Spirogyra crassa*		+	+					
	73	*Spirogyra punctiformis*	+			+				
	74	*Trentepohlia aurea*							+	
	75	*Trentepholia monilia*							+	
	76	*Scenedesmus incrassatulus*						+		
Bacillariophyceae	**77**	*Amphora normani*	+			+				
	78	*Amphora ovlis*								+
	79	*Cymbella hungarica*							+	+
	80	*Diploneis* sp.							+	
	81	*Frustulia vulgaris*								+
	82	*Gomphonema sphaerophorum*							+	+
	83	*Gyrosigma baikalensis*			+					
	84	*Gyrosigma maharashtrensis*		+		+				
	85	*Melosira juergensii*					+			
	86	*Navicula andium*		+		+				
	87	*Navicula cuspidata*	+							
	88	*Navicula dicephala*	+		+	+				
	89	*Navicula laterostrata*		+						
	90	*Navicula minuta*	+							
	91	*Navicula mutica*					+			
	92	*Navicula platystoma*							+	
	93	*Navicula protracta*	+							
	94	*Navicula pupula*		+						
	95	*Navicula radiosa*		+	+					
	96	*Navicula radiosa*					+			
	97	*Neidium affine*				+				
	98	*Nitzschia closterium*								+
	99	*Nitzschia heufleriana*			+					
	100	*Nitzschia hungarica*		+						
	101	*Nitzschia intermedia*				+	+			

	102	*Nitzschia mediocris*							+	
	103	*Nitzschia obtusa*						+		
	104	*Nitzschia obtusa*		+	+	+				
	105	*Nitzschia vermicularis*		+	+	+				
	106	*Pinnularia dolosa*								+
	107	*Pinnularia eburnea*						+		
	108	*Pinnularia episcopalis*	+							
	109	*Pinnularia lonavlensis*		+						
	110	*Pinnularia lundii*	+					+		
	111	*Pinnularia mesolepta*	+							
	112	*Pinnularia viridis*							+	
	113	*Pinnularia sp.*1				+				
	114	*Pinnularia sp.*2						+		
	115	*Pleurosigma salinarum*								+
	116	*Surirella maharastrensis*						+		
	117	*Surirella tenera*			+					+
	118	*Synedra acus*	+							
	119	*Synedra rumpens*							+	
	120	*Synedra ulna*								+
	121	*Synedra ulna* (Nitzsch.)								+
Euglenophyceae	**122**	*Euglena tuba*		+						
	123	*Phacus* sp.	+							

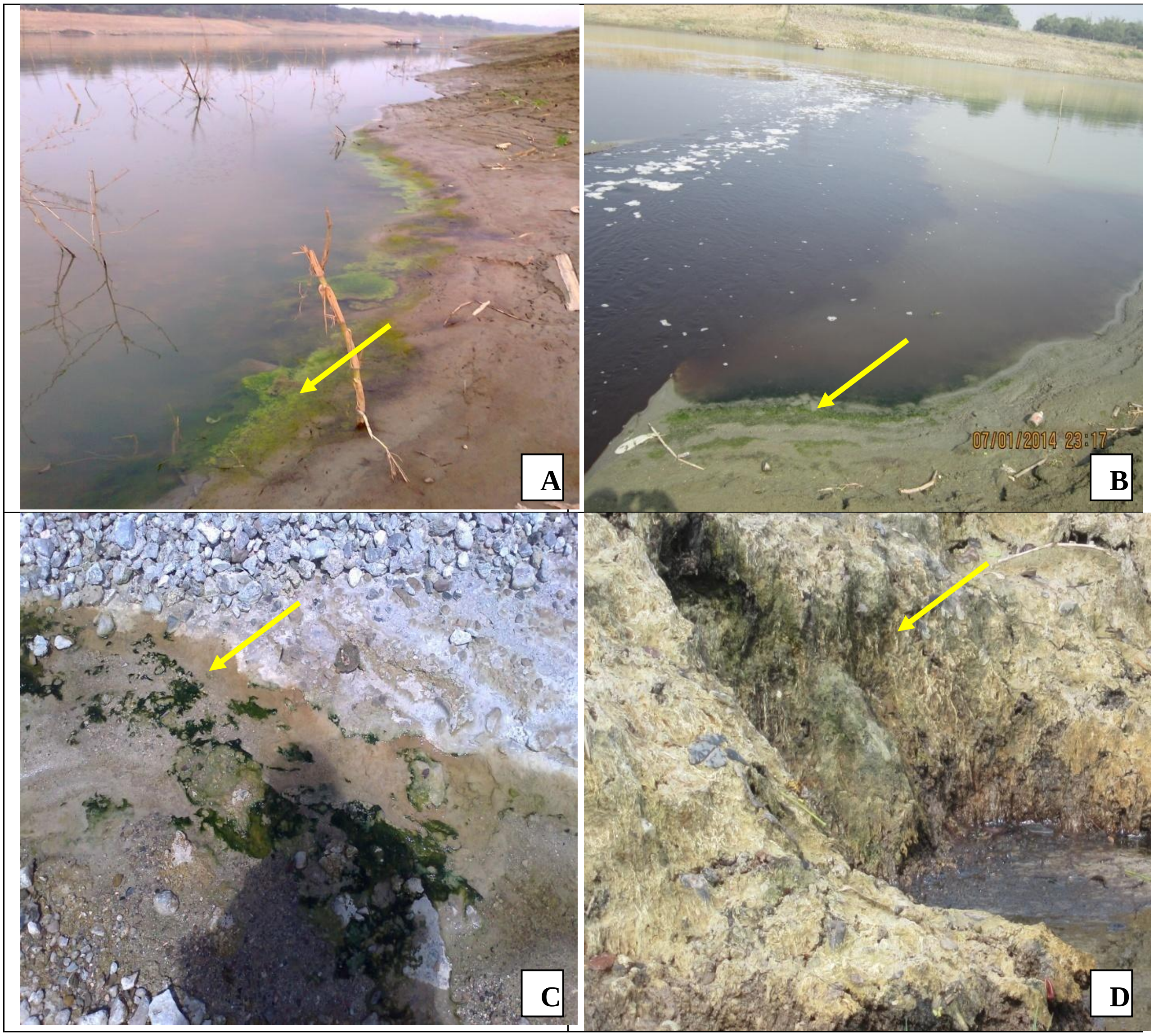


Plate 4.1: Floating flakes of *Lyngbya* mixed with *Spirogyra* (A) and attached flakes of *Lyngbya* mixed with *Spirogyra* (B) to the river bank soil at Site 1 (S1) and Site 2 (S2), jelly like mixed colony of *Scytonema* and *Oscillatoria* (C) growing on The lime mud and mixed colony of *Phormidium* and *Calothryx* growing on the uncooked knot (D).

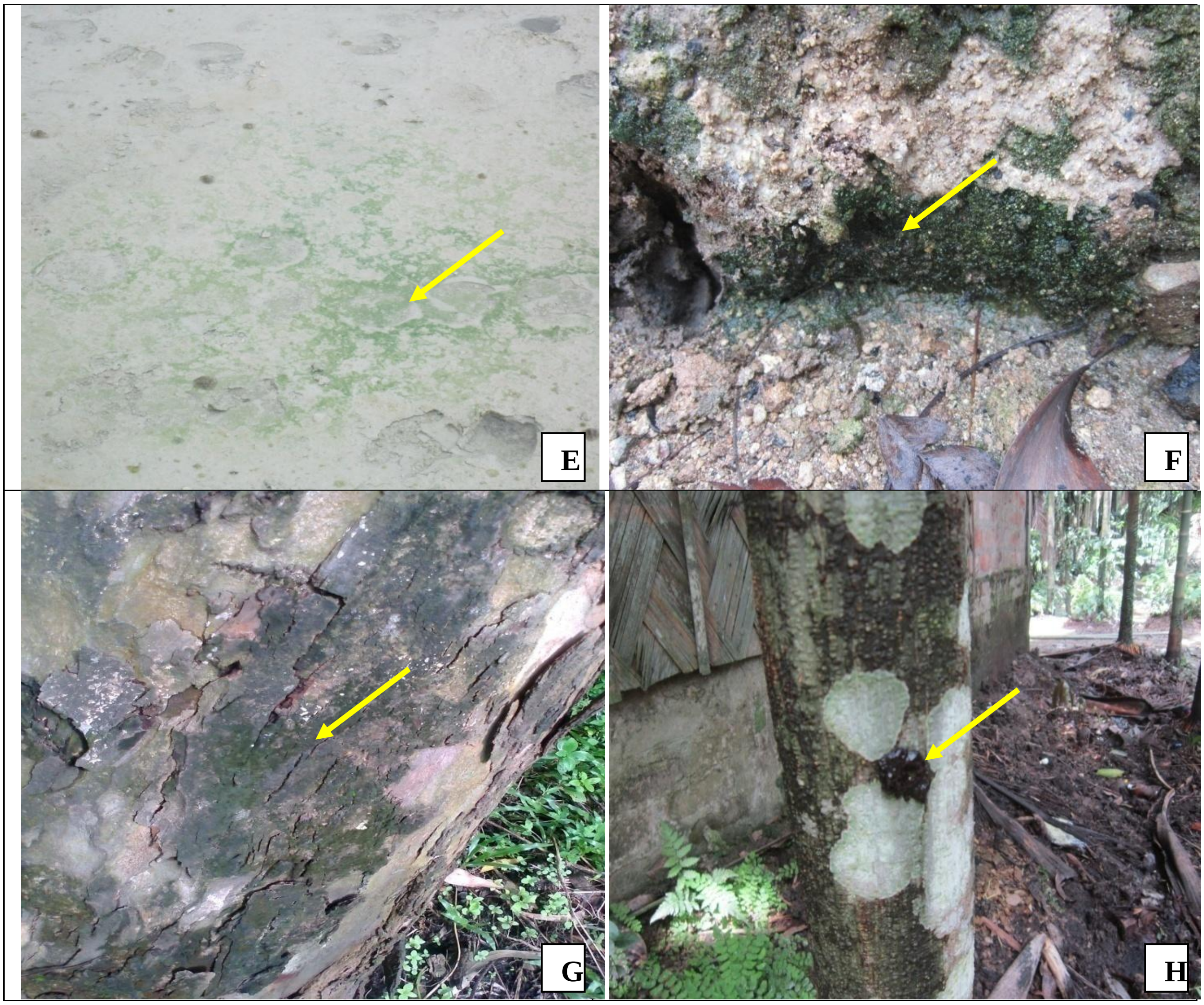


Plate 4.2: Growth of Anabaena (E) and the algal colony dominated by *Cylindrospermum* (F) on lime mud; Mixed colony of *Oscillatoria* and *Scytonema* (G) and growth of *Aphanocapsa* on tree barks

Table 4.5 Seasonal variation of algal density, abundance and frequency in site 1 (SI)

Sl no.	Class	Density (ind X 10^2cm^{-2})				Abundance (ind X 10^2cm^{-2})				Frequency (%)			
	Cyanophyceae	**PM**	**M**	**PO**	**W**	**PM**	**M**	**PO**	**W**	**PM**	**M**	**PO**	**W**
1	*Anabaena spherica*	10.58				17.75				54.17			
2	*Calothryx marchica*	20.66			14.77	29.34			21.53	72.22			66.67
3	*Lyngbya hieronymusii*	8.68	5.77	2.80	4.60	12.34	8.66	5.53	7.63	75.00	66.67	50.00	58.33
4	*Lyngbya taylorii*	30.11			10.18	32.38			13.71	83.33			79.17
5	*Oscillatoria curviceps*	5.34			5.48	8.67			6.20	59.33			66.67
6	*Oscillatoria limnetica*	45.94	16.55	9.60	21.55	81.04	49.65	24.56	18.94	62.50	33.00	58.33	49.83
7	*Oscillatoria vizagapatensis*	16.71	1.09	7.59		44.55	1.71	10.85		58.33	55.56	66.67	
	Chlorophyceae												
8	*Cosmarium triplatum*				4.05				7.36				41.67
9	*Microspora stagnorum*	2.19		0.17	8.31	2.74		0.42	24.76	68.44		41.67	45.83
10	*Mougasia* sp.	5.45	0.27	0.33		8.26		0.92		71.88		44.44	
11	*Pediastrum tetras*				4.58				5.82				50.00
12	*Spirogyra punctiformis*	15.70	3.07	0.66	8.39	24.82	4.41	1.99	12.61	*63.50*	74.44	33.00	58.33
	Bacillariophyceae												
13	*Amphora normani*	12.04	3.26		6.20	9.65	4.44		7.19	66.72	70.88		66.67
14	*Navicula cuspidata*			1.53	4.79			3.83	7.99			44.44	58.33
15	*Navicula dicephala*			1.55	1.62			3.42	3.66			41.58	45.83
16	*Navicula minuta*	4.48	8.23			4.84	9.00			79.25	88.89		
17	*Navicula protracta*	3.69		1.60	1.80	5.49		3.26	4.33	47.83		41.67	41.67
18	*Pinnularia episcopalis*	7.06	2.18		5.90	7.50	4.15		8.03	50.00	39.78		62.50
19	*Pinnularia lundii*		0.13	0.34			0.24	0.25			42.33	41.71	
20	*Synedra acus*	1.14		1.84		3.38		2.93		62.44		55.56	
	Euglenophyceae												
21	*Phacus* sp.	1.39		0.17	0.43	3.27		0.35	0.66	59.22		52.81	55.55

Table 4.6 Seasonal variation of algal density, abundance and frequency in site 2 (SII)

Sl. no.	Class	Density (ind X $10^2 cm^{-2}$)				Abundance (ind X $10^2 cm^{-2}$)				Frequency (%)			
	Cyanophyceae	**PM**	**M**	**PO**	**W**	**PM**	**M**	**PO**	**W**	**PM**	**M**	**PO**	**W**
1	*Anabaena subcylindrica*	8.66	9.34		7.47	12.99	9.34		22.42	66.67	100.00		33.33
2	*Chroccocus cf. turgidus*		1.64	1.34	11.99		4.94	9.34	11.99		33.00	100.00	100.00
3	*Cylindrospermum stagnale*	12.40		1.06		8.45		6.06		100.00		100.00	
4	*Lyngbya polysiphoniae*	4.08				12.25				33.33			
5	*Nodularia spumigena*	4.51				4.53				33.33			
6	*Nostoc linckia*	6.18			7.43	1.78			11.15	66.67			66.67
7	*Oscillatoria amphigranulata*	2.84			12.37	5.54			12.37	33.33			100.00
8	*Oscillatoria curviceps*		6.22		2.96		6.64		8.88		83.50		33.33
9	*Oscillatoria formosa*			3.80				3.38				100.00	
10	*Oscillatoria tererbiformis*	1.39		2.05	9.34	11.78		3.07	9.34	33.33		66.67	100.00
	Chlorophyceae												
11	*Closterium lanceolatum*		6.67		10.75		1.01		10.75		66.67		100.00
12	*Cosmarium constrictum*	16.21		1.02		16.20		1.02		100.00		100.00	
13	*Spirogyra crassa*	3.32	13.94	1.07	8.44	4.99	20.91	3.22	1.34	66.67	66.67	33.33	33.33
	Bacillariophyceae												
14	*Gyrosigma maharashtrensis*	0.34		0.24		1.03		0.72		33.33		33.33	
15	*Navicula andium*	7.94	3.94			23.84	5.91			33.33	66.67		
16	*Navicula laterostrata*	11.73		15.18	21.15	5.19		22.77	21.15	33.33		66.67	100.00
17	*Navicula pupula*			7.15	10.38			21.15	10.38			100.00	100.00
18	*Navicula radiosa*			3.38	1.70			10.38	5.11			100.00	33.33
19	*Nitzschia hungarica*	13.82				11.48				33.33			
20	*Nitzschia obtusa*	7.33			4.20	0.99			12.62	33.33			33.33
21	*Nitzschia vermicularis*	1.55	0.38			6.83	4.16			66.67	33.33		
22	*Pinnularia lonavlensis*		1.06		3.18		1.59		22.77		66.67		66.67
	Euglenophyceae												
23	*Euglena tuba*	3.32			0.67	4.99			2.03	66.67			33.33

Table 4.7 Seasonal variation of algal density, abundance and frequency in site 3 (III)

Sl. no.	Class	Density (ind X 10²cm⁻²)				Abundance (ind X 10²cm⁻²)				Frequency (%)			
	Cyanophyceae	**PM**	**M**	**PO**	**W**	**PM**	**M**	**PO**	**W**	**PM**	**M**	**PO**	**W**
1	*Anabaena subcylindrica*	4.76	1.41		5.89	7.14	3.19		7.66	67.00	66.50		75.25
2	*Cylindrospermum stagnale*				10.47				15.87				50.00
3	*Oscillatoria curviceps*	10.20			2.55	13.31			7.65	79.38			33.00
4	*Oscillatoria formosa*	7.82		2.63	9.96	8.46		7.12	13.75	340.96		41.50	69.67
5	*Phormidium tenue*	12.03	5.55	9.42	3.33	14.76	6.28	13.48	8.60	83.50	83.00	83.42	41.25
6	*Spirullina major*	5.18		2.24		10.70		6.20		50.00		77.67	
7	*Synecoccus subselsus*	3.24	1.66			4.85	3.29			66.67	49.75		
	Chlorophyceae												
8	*Ankistrodesmus falcatus*	11.39	1.16			5.83	2.13			75.13	41.50		
9	*Geminella mutabilis*	10.74		3.23		10.58		3.87		67.00		70.28	
10	*Scenedesmus quadricauda*		3.28	3.22	7.24		7.15	6.67	9.68		38.67	69.42	69.47
11	*Spirogyra crassa*	8.33	2.98		6.31	12.48	6.22		11.22	74.92	50.86		58.13
	Bacillariophyceae												
12	*Gyrosigma baikalensis*			1.72	12.00			4.58	12.00			50.00	100.00
13	*Navicula dicephala*	2.64	1.45		4.17	5.49	3.39		10.23	49.92	44.33		41.42
14	*Navicula radiosa*	3.82	2.36			5.73	4.92			67.00	50.00		
15	*Neidium affine*	10.31			5.44	15.36			9.03	71.13			55.50
16	*Nitzschia heufleriana*	10.61		1.79	4.29	19.82		3.91	7.28	66.50		56.79	50.00
17	*Nitzschia obtusa*			3.49				6.99				45.83	
18	*Nitzschia vermicularis*	7.33		6.06		10.70		10.15		63.92		70.75	
19	*Surirella tenera*		1.69		6.84		4.26		9.98		47.17		63.92

Table 4.8 Seasonal variation of algal density, abundance and frequency in site 4 (S4)

Sl. no.	**Class**	**Density (ind X 10^2 cm^{-2})**				**Abundance (ind X $10^2 cm^{-2}$)**				**Frequency (%)**			
	Cyanophyceae	**PM**	**M**	**PO**	**W**	**PM**	**M**	**PO**	**W**	**PM**	**M**	**PO**	**W**
1	*Anabaena spherica*	10.03		1.66	3.83	11.85		2.49	5.02	58.25		67.00	62.75
2	*Lyngbya taylorii*	15.47				7.21				62.38			
3	*Merismopedia punctata*	4.86	0.99		2.22	13.52	2.96		6.66	41.50	33.00		33.00
4	*Oscillatoria granulata*			3.72	13.82			5.75	6.63			83.38	58.50
5	*Oscillatoria terebreformis*	9.42	2.85	4.94	5.17	10.11	2.85	5.80	13.11	79.17	100.00	83.50	50.00
6	*Oscillatoria vizagepatensis*	14.22			5.94	16.94			7.05	66.75			83.50
	Chlorophyceae												
7	*Cosmarium triplatum*	5.77	2.54		9.18	9.25	5.31		2.58	58.25	50.00		83.50
8	*Microspora stagnorum*	0.80				3.04				50.00			
9	*Mougasia* sp.			2.10				3.15				67.00	
10	*Spirogyra punctiformis*	10.75	2.43		5.85	10.75	3.46		6.02	100.00	72.22		89.00
	Bacillariophyceae												
11	*Amphora normani*		0.54	3.56	5.58		9.31	9.12	6.66		58.25	44.33	78.00
12	*Gyrosigma maharashtrensis*	1.71		3.00		5.12		5.46		33.00		66.67	
13	*Pinnularia* sp. a	14.63			3.59	6.98			4.68	58.25			73.06
14	*Navicula andium*	11.07	3.05	5.34		14.60	6.76	8.26		66.67	54.13	64.92	
15	*Navicula dicephala*	4.21	2.89	4.25	3.88	12.63	4.37	6.38	6.65	33.00	75.13	67.00	78.00
16	*Nitzschia intermedia*	19.28		2.79	10.75	9.76		8.37	15.07	91.75		33.00	71.13
17	*Nitzschia obtusa*	5.19				8.34				58.25			
18	*Nitzschia vermicularis*	1.49		0.10	0.57	10.02		4.08	4.18	67.64		54.13	68.04

Table 4.9 Seasonal variation of algal density, abundance and frequency in Site 5 (S5)

Sl. no.	Class	Density (ind X 10^2cm^{-2})				Abundance (ind X 10^2cm^{-2})				Frequency (%)			
	Cyanophyceae	**PM**	**M**	**PO**	**W**	**PM**	**M**	**PO**	**W**	**PM**	**M**	**PO**	**W**
1	*Anabaena orientalis*	2.72	5.56	47.70		3.50	22.23	82.98		56.25	33.00	40.33	
2	*Aphanothece microscopica*		43.38	13.66			152.53	22.08			46.22	50.00	
3	*Croococcus limneticus*			10.29	2.01			18.53	4.00			50.00	50.00
4	*Cylindrospermum muscicola*		31.71	37.54	6.21		62.66	20.53	10.39		54.12	50.00	60.42
5	*Leptolyngbya* sp.		38.40		14.46		106.52		28.92		62.28		50.00
6	*Nostoc sphaericum*	3.75	11.18	22.52	2.47		25.89	46.02	4.94		56.50	44.62	50.00
7	*Oscillatoria amphibia*	2.20	23.20	9.62		4.41	48.32	22.58		50.00	45.75	58.50	
8	*Oscillatoria subbrevis*	4.78	3.86	12.43	4.09	7.32	9.39	47.17	9.91	63.58	56.25	58.50	50.00
9	*Oscillatoria tenuis* v. *tergestina*			22.88	5.94			33.52	8.60			64.25	62.50
10	*Scytonema zeilerianum*	1.53	14.05			2.51	49.38			53.42	43.75		
	Chlorophyceae												
11	*Cosmarium pachydermum*		4.03	13.54	1.81		7.60	22.46	4.97		66.88	50.06	50.00
12	*Cosmarium subimpressulum*	0.82	0.83	0.93		1.45	2.37	3.49		59.72	51.33	37.50	
13	*Oocystis eremosphaeria*		14.62	41.36	15.75		34.33	92.16	58.26		49.25	47.33	44.44
14	*Pediastrum integrum*		0.85	1.77			1.73	4.43			54.33	34.38	
	Bacillariophyceae												
15	*Melosira juergensii*		2.27	1.80			6.77	4.69			56.25	34.38	
16	*Navicula mutica*	0.47	1.79	5.28	0.96	0.86	3.43	9.69	1.85	53.33	64.67	52.83	48.61
17	*Navicula radiosa*			2.18	4.55			4.56	14.27			45.83	41.67
18	*Nitzschia intermedia*		2.31	2.57			4.62	3.43			67.00	75.00	

Table 4.10 Seasonal variation of algal density, abundance and frequency in Site 6 (S6)

Sl no.	**Class**	**Density (ind X 10^2cm^{-2})**				**Abundance (ind X 10^2cm^{-2})**				**Frequency (%)**			
	Cyanophyceae	**PM**	**M**	**PO**	**W**	**PM**	**M**	**PO**	**W**	**PM**	**M**	**PO**	**W**
1	*Anabaena subcylindrica*	3.95	14.37	25.01	9.07	7.71	28.49	84.86	13.47	44.20	42.69	47.98	60.02
2	*Calothryx marc*	3.79	14.45	5.29	6.93	7.51	40.45	11.00	19.22	51.96	46.33	47.01	69.57
3	*Croococcus minutus*	-	9.45	3.70	-	-	32.23	10.34	-	-	41.48	37.94	-
4	*Lyngbya lutea*	-	4.27	5.83	0.97	-	10.89	+	+	-	33.29	41.71	41.10
5	*Lyngbya rubida*	10.32	-	13.30	-	30.43	-	34.60	-	50.04	-	39.25	-
6	*Lyngbya* sp.	-	2.56	2.83	-	-	7.88	61.75	-	-	47.41	41.71	-
	Chlorophyceae												
7	*Cosmarium formosulum*	0.78	1.41	1.43	-	2.36	3.73	6.62	-	40.12	34.61	23.97	-
8	*Cosmarium granatum*	-	2.70	4.46	6.90	-	15.48	11.37	2.04	-	26.12	35.57	35.25
9	*Scenedesmus incrassatulus*	0.34	0.68	1.31	-	1.18	2.51	6.90	-	33.04	28.22	24.22	-
	Bacillariophyceae												
10	*Nitzschia obtusa*	-	1.39	0.85	0.16	-	5.10	2.25	0.73	-	27.27	26.99	26.19
11	*Pinnularia* sp. b	-	1.62	1.89	-	-	7.25	4.57	-	-	24.13	36.62	-
12	*Pinnularia eburnea*	-	-	4.73	3.58	-	-	13.74	8.99	-	-	29.87	28.71
13	*Pinnularia lundii*	1.11	0.80	2.95	-	8.49	2.50	9.00	-	13.39	24.53	32.62	-
14	*Surirella maharastrensis*	0.13	5.29	2.59	-	0.34	14.64	7.77	-	40.18	32.39	33.40	-

Table 4.11 Seasonal variation of algal density, abundance and frequency in Site 7(S7)

Sl no.	**Class**	**Density (ind X 10^2cm^{-2})**				**Abundance (ind X 10^2cm^{-2})**				**Frequency (%)**			
	Cyanophyceae	**PM**	**M**	**PO**	**W**	**PM**	**M**	**PO**	**W**	**PM**	**M**	**PO**	**W**
1	*Anabaena oryzae*	10.00	10.47	31.27	8.64	19.65	22.74	107.78	77.74	50.47	51.50	37.41	14.00
2	*Aphanothece naegelii*		57.84	42.55			172.03	169.53			40.17	32.39	
3	*Cylindrospermum majus*			25.20	13.62			98.13	23.29			27.46	28.22
4	*Oscillatoria acuminata*	0.78		5.86		1.77	8.30	12.53		50.32	30.05	40.44	
5	*Oscillatoria amphigranulata*		3.86	6.77			14.07	30.53			31.88	27.30	
6	*Phormidium autumnale*		11.13		29.48		34.50	26.79	63.57		40.83	29.42	58.84
7	*Oscillatoria formosa*		6.80	2.36			12.19	16.27			45.54	19.67	
8	*Oscillatoria limnetica*	1.00			7.12	1.58			11.26	60.50			61.50
9	*Oscillatoria terebriformis*	6.32	14.07	21.53	17.18	16.85	8.55	58.24	35.38	38.00	41.67	38.62	45.36
10	*Stigonema aerugineum*	17.88		2.06	1.40	26.33		10.37	8.01	52.67		19.70	25.00
	Chlorophyceae												
11	*Cosmarium formosulum*		1.22	2.22			5.25	10.89			28.53	18.69	
12	*Cosmarium* sp. a		0.26	14.66			0.81	55.14			23.71	20.45	
13	*Oocystis natansvar major*	4.96		36.23	27.22	10.48		147.88	90.91	45.33		24.03	44.03
14	*Protococcus viridis*	6.57			2.77	14.33			9.49	28.44			30.51
15	*Scenedesmus denticulatus*		3.18	8.53			19.92	24.10			24.14	33.33	
	Bacillariophyceae												
16	*Amphora ovlis* v. *pediculus*		10.47				31.41				33.00		
17	*Cymbella hungarica*			5.13	6.39			20.30	44.60			26.00	23.50
18	*Frustulia vulgaris*			11.45				41.33				28.00	
19	*Gomphonema sphaerophorum*	1.42	13.24		21.07	5.05	48.98		63.20	33.74	462.74		33.33
20	*Nitzschia closterium*			9.76	0.69			26.13	2.46			33.74	27.80
21	*Pinnularia dolosa*		5.89	2.56			56.33	9.40			23.50	27.00	
22	*Pleurosigma salinarum*			1.42	2.98			3.78	12.29			38.00	50.00
23	*Surirella tenera*	1.17	0.78		0.56	7.80	3.27		2.57	20.89	27.31		
24	*Synedra ulna*		2.08	0.45	0.30		6.38	2.69	1.13		68.00	17.80	25.21
25	*Synedra ulna*			1.21				4.45				27.27	21.31

Table 4.12 Seasonal variation of algal density, abundance and frequency in Site 8 (S8)

Sl. no.	**Class**	**Density (ind X $10^2 cm^{-2}$)**				**Abundance (ind X $10^2 cm^{-2}$)**				**Frequency (%)**			
	Cyanophyceae	**PM**	**M**	**PO**	**W**	**PM**	**M**	**PO**	**W**	**PM**	**M**	**PO**	**W**
1	*Aphanocapsa pulchra*	7.28	22.04	28.47	12.26	14.14	48.00	92.15	25.16	54.38	50.42	32.53	49.09
2	*Aphanothece thermicola*	4.27	10.16		3.71	8.75	37.50		10.45	47.50	26.42		40.42
3	*Crococcus* sp.	2.74	5.45	9.76	9.14	5.63	19.01	29.07	31.12	56.80	35.86	31.06	43.09
4	*Microchaete calothicoides*			10.12				37.28				35.48	
5	*Nostoc entophytum*			3.44	2.84			8.34	8.34			40.34	37.22
6	*Phormidium corium*		7.01	8.84			16.79	24.22			41.33	37.36	
7	*Phormidium stagnina*		12.56	19.61	4.96		31.70	37.16	8.16		43.16	55.09	58.51
8	*Scytonema milley*	1.67	8.67	2.98		4.11	16.97	7.71		43.39	41.54	37.12	
9	*Tolypothryx byssoidea*	0.90	8.16	3.02		4.54	17.57	12.22		20.00	43.23	23.27	
	Chlorophyceae												
10	*Bracteacoccus minor*		3.16	5.60			9.83	22.02			36.01	27.27	
11	*Cosmarium subimpressulum*		1.82	1.38			4.88	4.73			42.79	32.58	
12	*Trentepohlia aurea*	2.55	0.98	3.41	3.42	5.32	6.06	22.80	10.01	44.12	17.77	28.03	36.09
13	*Trentepholia monilia*	5.30	1.27	3.57	2.81	12.00	6.04	10.25	5.44	46.31	20.04	27.40	50.00
	Bacillariophyceae												
14	*Cymbella hungarica*			2.78				8.53				29.38	
15	*Diploneis* sp.		0.58	1.57			1.86	8.10			32.39	27.84	
16	*Gomphonema sphaerophorum*	0.39	1.25	2.06	0.81	1.21	4.70	6.99	2.62	40.00	32.28	35.02	29.35
17	*Navicula platystoma*		0.88	0.68			2.65	2.89			31.72	28.41	
18	*Nitzschia mediocris*	0.28	1.90		2.19	0.73	5.69		8.95	38.75	29.21		21.59
19	*Pinnularia viridis*			1.63	1.11			4.62	3.87			29.49	27.73
20	*Synedra rumpens*		0.87	1.76			4.16	4.79			20.21	36.93	

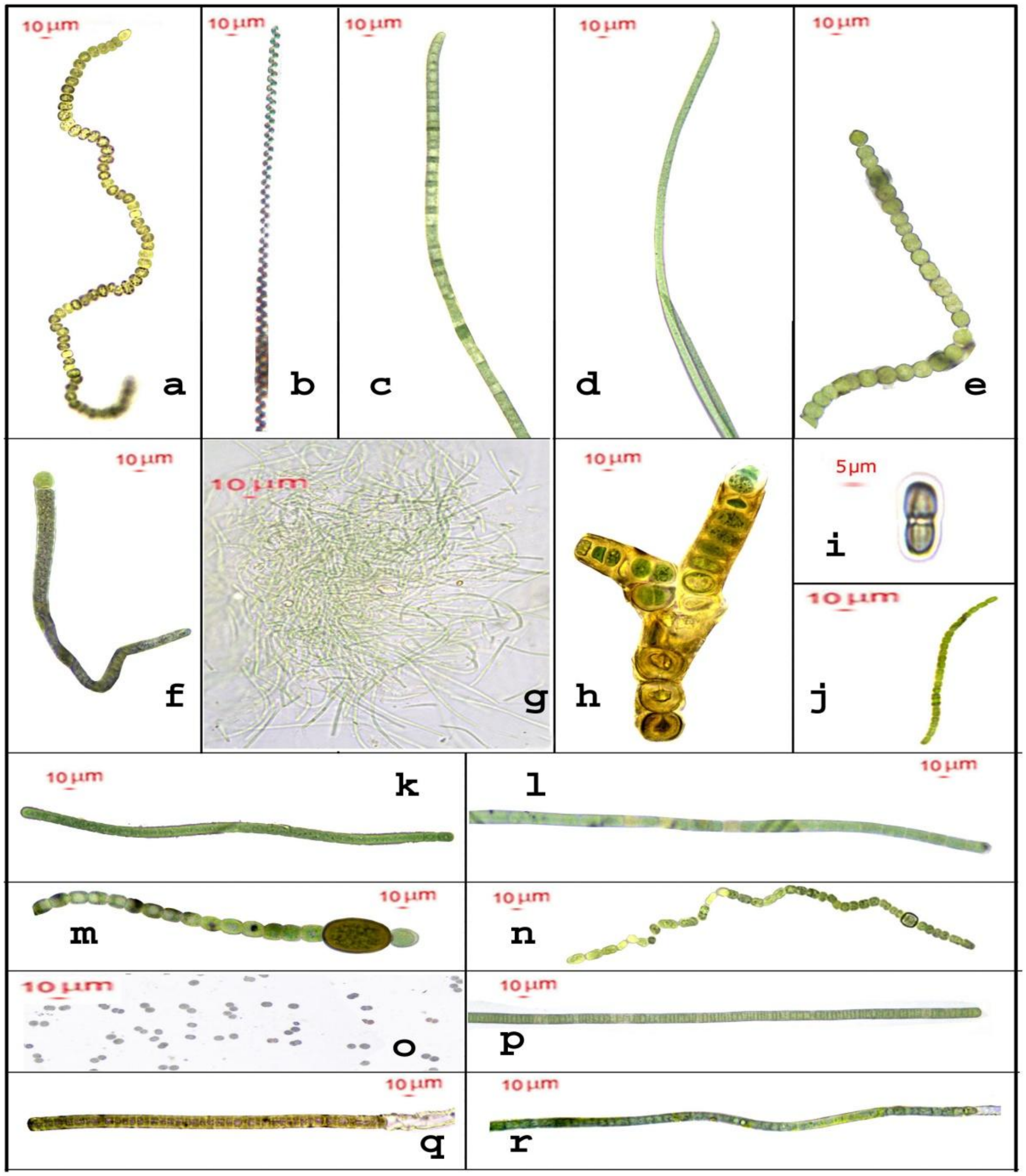


Plate 4.3: Microscopic photographs of Cyanobacteria a. *Nostoc linkia*; b. *Spirullina major* Kutz. (after Skuja); c. *Oscillatoria granulata* Gardner; d. *Oscillatoria acuminata* Gom. (after Gomont); e. *Anabaena spiroides* Klebahn; f. *Calothryx marchica* V. crassa Rao, C.B. (after Rao, C.B.); g. *Leptolyngbya* sp.; h. *Stigonema aerugineum* Tilden (after Tilden); i. *Synecoccus subselsus*: after Skuja (1939); j; *Phormidium tenue*; k. *Oscillatoria* sp.; l. *Oscillatoria limnetica*; l. *Cylindrospermum muscicola* Kuetzing; m. *Anabaena oryzae* Fritsch (after Fritsch); n. *Aphanocapsa pulchra*; o. *Oscillatoria subbrevis* Schmidle; p. *Lyngbya lutea* (Ag.) Gom.; q. *Phormidium corium* (Ag.) Gom.

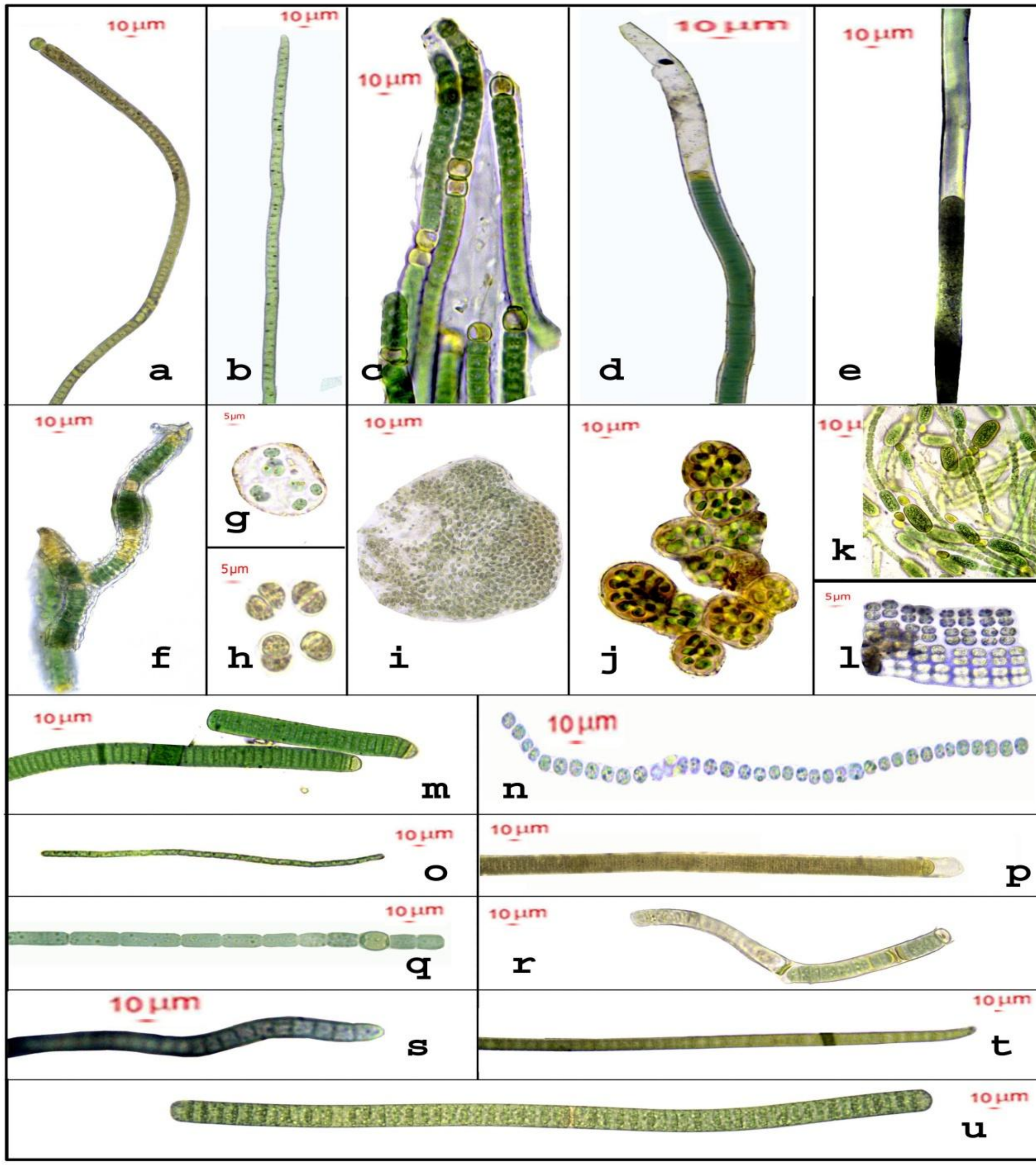


Plate 4.4: Microscopic photographs of Cyanobacteria a. *Calothryx marchica* var. intermedia Rao. C. B.; b. *Oscillatoria amphibia* Ag. (orig.); c. *Microchaete calothicoides*; d. *Phormidium stagnina;* e. *Lyngbya rubida* Fremy (after Fremy); f. *Scytonema milley*; g. *Gleothece* sp. h. *Croococcus* sp.; i. *Aphanothece microscopica*; j. *Nostoc entophytum* Born. et Flah.; k. *Cylindrospermum stagnale*; l. *Merismopedia punctata*; m. *Oscillatoria vizagapatensis*; n. *Anabaena spherica*; o. *Oscillatoria limnetica*; p. *Lyngbya hieronymusii* Lemm. (after Lemm.); q. *Anabaena subcylindrica*; r. *Tolypothryx byssoidea* (Berk.) Kirchn. s. *Oscillatoria terebreformis* Ag. (after Fremy); t. *Oscillatoria formosa* Bory; u. *Oscillatoria curviceps* C. A. Agarth.

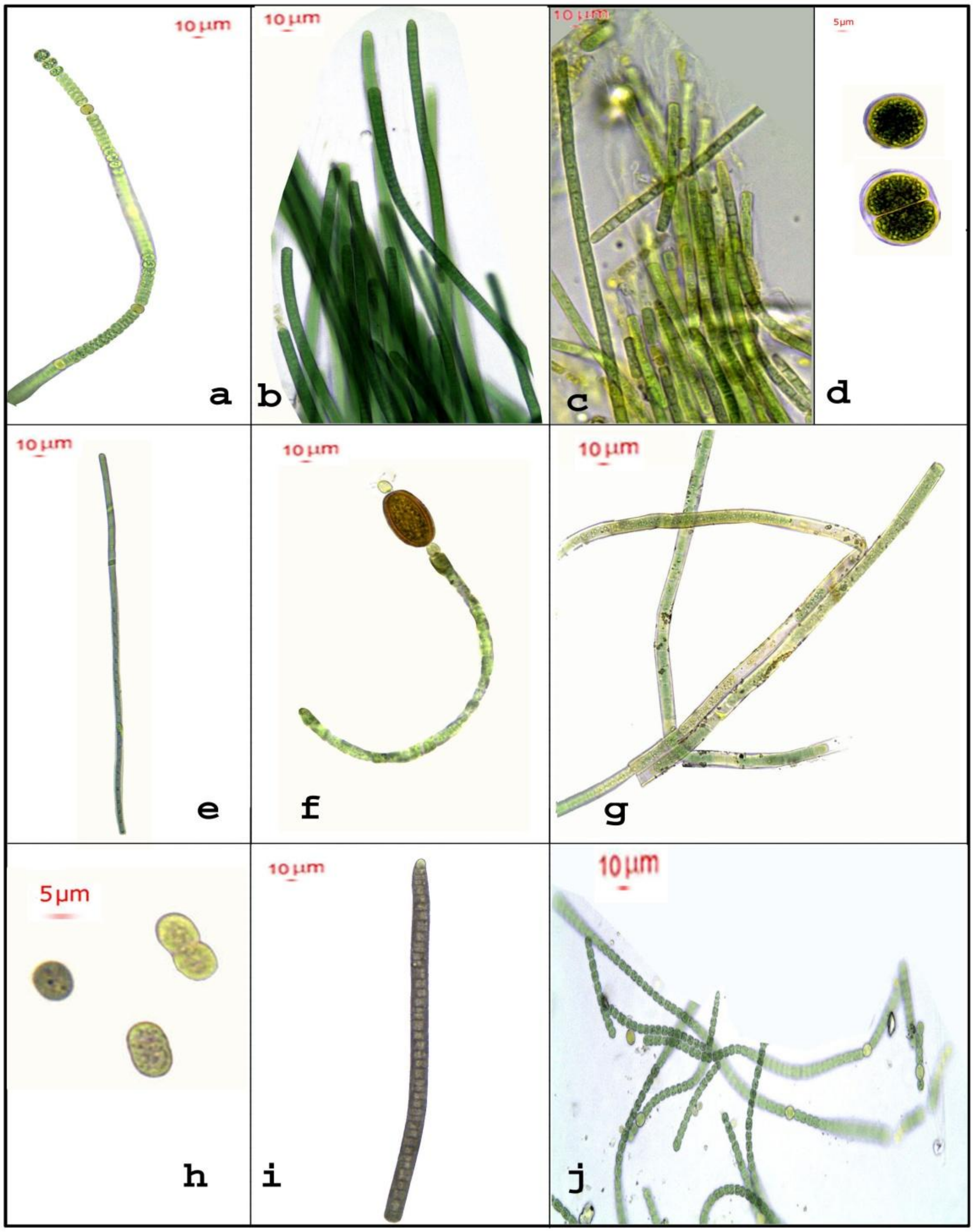


Plate 4.5: Microscopic photographs of Cyanobacteria a. *Nodularia spumigena* Mertens in Jürgens; b. *Lyngbya polysiphoniae*; c. *Lyngbya taylorii*; d. *Croococcus cf. turgidus*; e. *Oscillatoria amphigranulata*; f. *Cylindrospermum majus* Kuetzing ex. Born ex. Flah; g. *Scytonema zeilerianum*; h. *Aphanothece naegelii* Wartm (after Skuja); i. *Phormidium autumnale* (Ag.) Gom. (after Gomont); j. *Anabaena orientalis* Dixit (after Dixit).

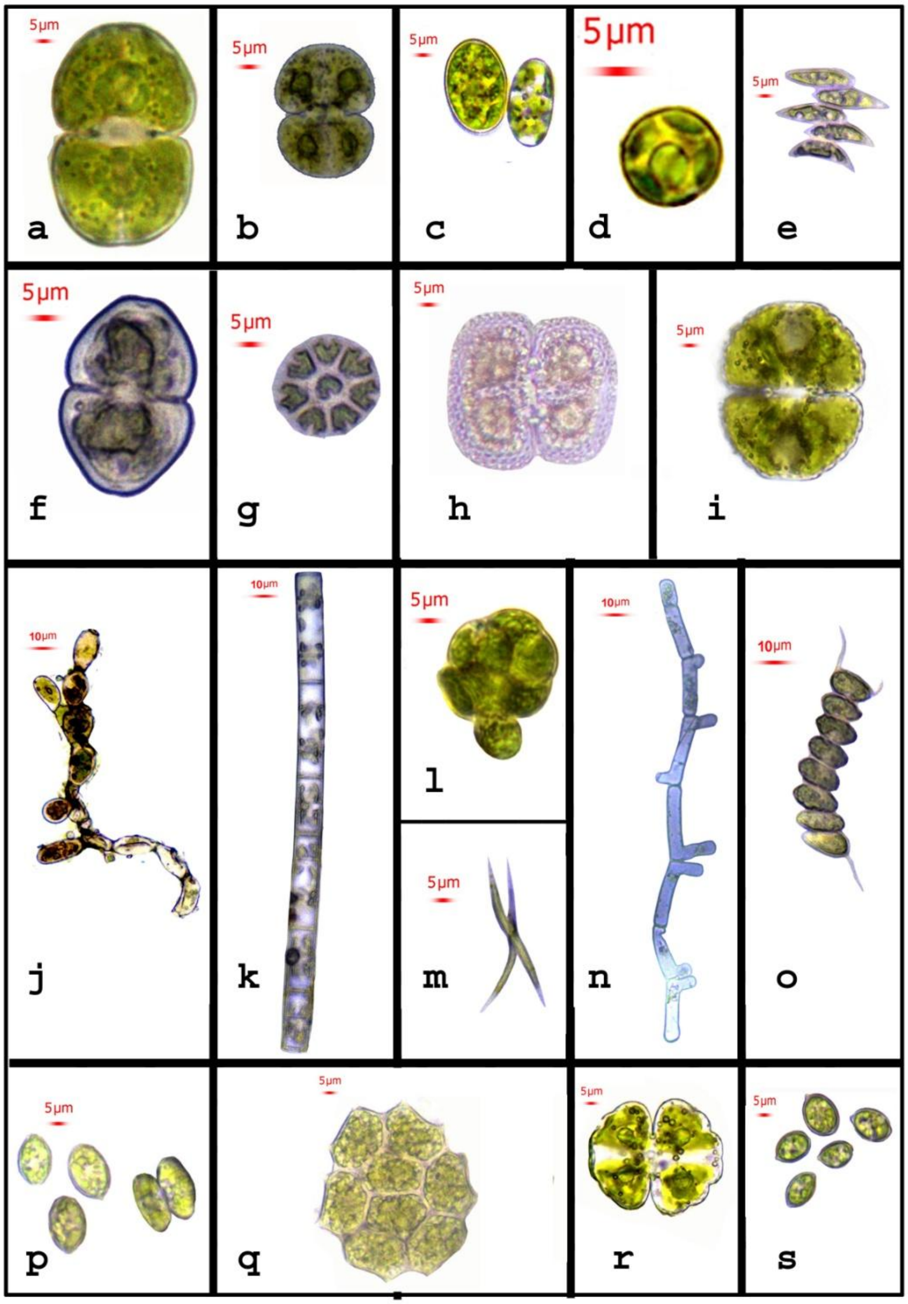
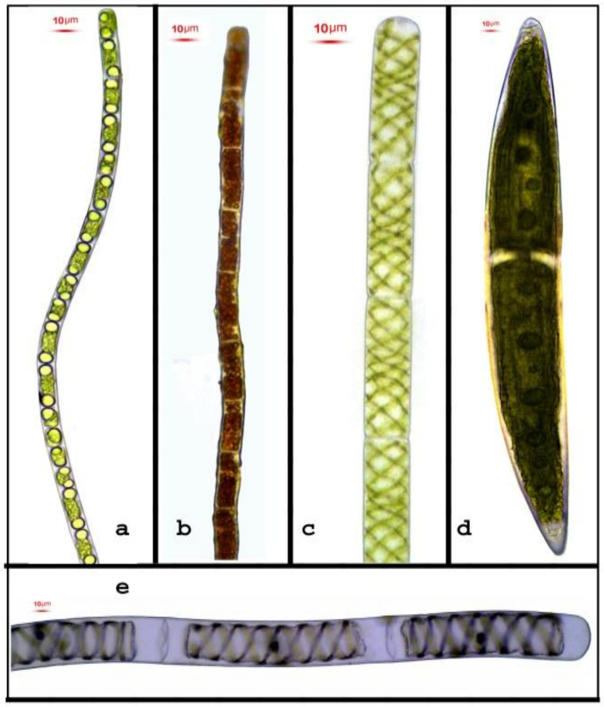


Plate 4.6: Microscopic photographs of Chlorophyceae a. *Cosmarium constrictum* Delponte; b. *Cosmarium pachydermum*; c. *Oocystis natansvar*. major G.M. Smith; d. *Bracteacoccus minor*; e. *Scenedesmus incrassatulus* Bohlin; f. *Cosmarium granatum* Brébisson; g. *Pediastrum tetras* (Ehrenb.) Ralfs; h. *Cosmarium triplatum* Wolle; i. *Cosmarium formosulum* Hoffman; j. *Trentepholia monilia* De Wildemann; k. *Microspora stagnorum* (Kuetz.) Lagerheim; l. *Protococcus viridis*; m. *Ankistrodesmus falcatus* (Corda) Ralfs.; n. *Mougeotia* sp.; o. *Scenedesmus quadricauda* (Trup.) de Brébisson; p. *Oocystis eremosphaeria* G. M. Smith; q. *Pediastrum integrum*; r. *Cosmarium subimpressulum* Borge; s. *Oocystis* sp.



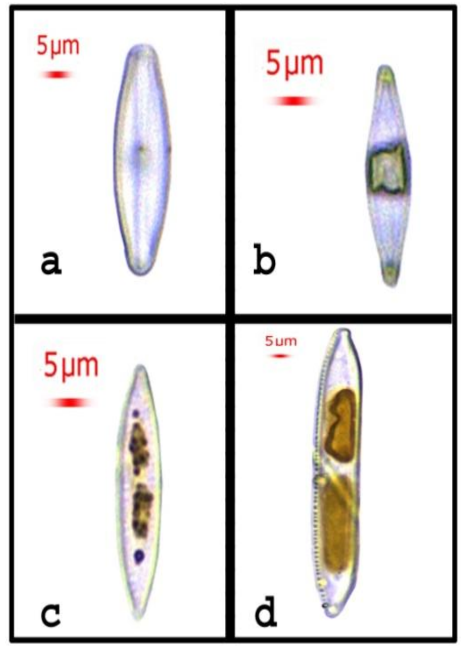


Plate 4.7: Microscopic photographs of Chlorophyceae a. *Geminella mutabilis* (de Bréb) Wille; b. *Trentepohlia aurea*; c. *Spirogyra crassa*; d. *Closterium lanceolatum*; e. *Spirogyra punctiformis*Transeau.

Plate 4.8: Microscopic photographs of Bacillariophyceae a. *Navicula andium* Frenguelli; b. *Navicula* sp.; c. *Navicula* sp. d. *Nitzschia hungarica* Grun.

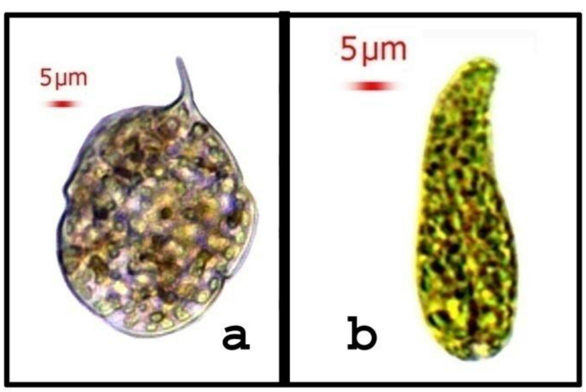


Plate 4.9: Microscopic photographs of Euglenophyceae a. *Phacus* sp.; b. *Euglena tuba*

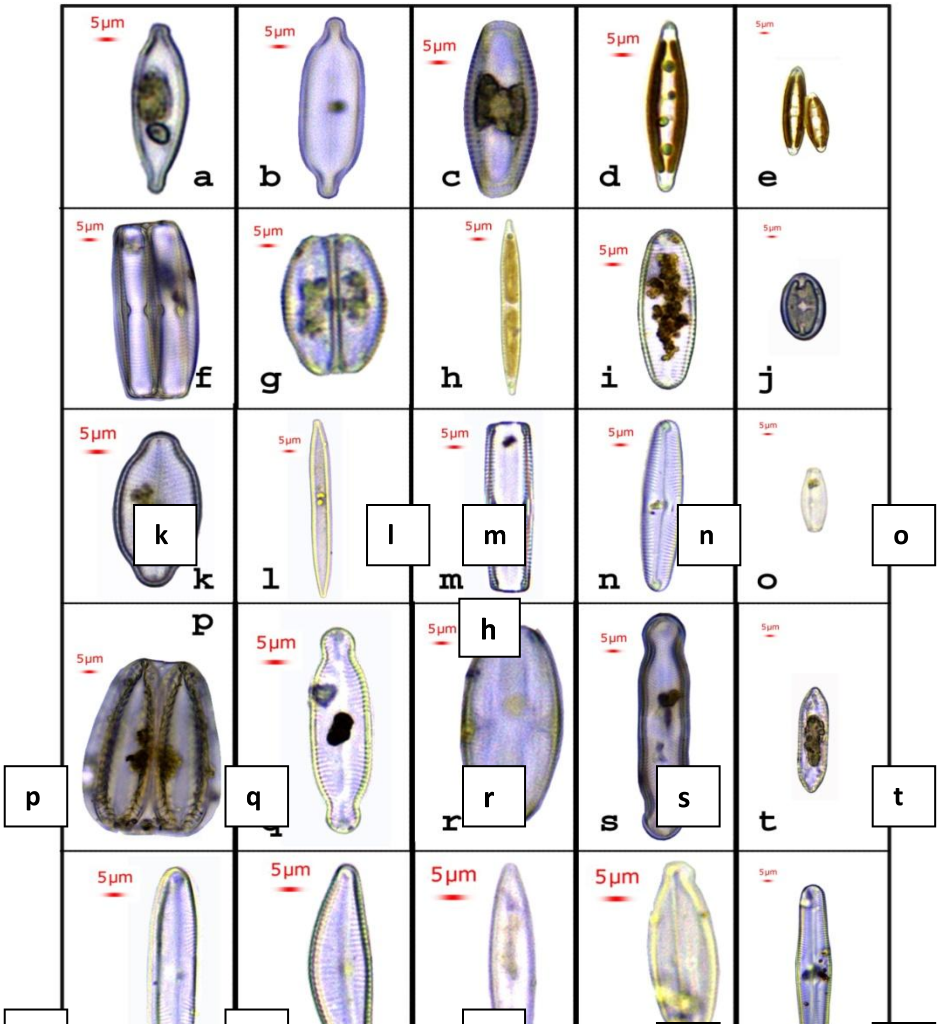


Plate 4.11: Microscopic photographs of Bacillariophyceae a. *Gyrosigma maharashtrensis* sp. Nov. b. *Nitzschia obtusa* W. Smith; c. *Nitzschia vermicularis* (Kuetzing) Huntzsch; d. *Synedra ulna* (Nitzsch.) Ehrenberg; e. *Gyrosigma baikalensis* Skv. ; f. *Synedra ulna* (Nitz.) Ehr. ; g. *Melosira juergensii* Agardh; h. *Synedra rumpens* Kuetzing; i. *Synedra acus* Kuetz.;

Plate 4.10 *Navi* *Navi* goep *Nitzs* *platy* Grur Hust Grur *hung* Hust

Plate 4.10: Microscopic photographs of Bacillariophyceae a. *Gomphonema sphaerophorum*; b. *Navicula dicephala* (Ehr.) W. Smith v. *sphaerophora* A. Cl.; c. *Navicula protracta* Grun.; d. *Navicula radiosa* Kutz. v. tenella (Breb. Ex. Kutz.) Grun.; e. *Navicula mutica* Kuetz. f. goeppertiana (Bleisch) Grun; f. Pinnularia sp.; g. *Amphora ovlis* Kuetz. v. pediculus Kuetz.; h. *Nitzschia intermedia* Hantzsch; i. *Pinnularia episcopalis* Cleve; j. *Diploneis* sp.; k. *Navicula platystoma* Ehrenberg; l. *Nitzschia heufleriana* Grun.; m. *Pinnularia* sp.; n. *Nitzschia heufleriana* Grun.; o. *Navicula pupula* Kuetz.; p. *Surirella tenera* Greg. v. *nervosa* A.S.; q. *Pinnularia lundii* Hustedt ; r. *Amphora normani* Rabenhorst; s. *Pinnularia mesolepta* Ehr. v. *stauroneiformis* Grun.; t. *Surirella maharastrensis* sp. Nov.; u. *Pinnularia eburnea* (Carlson) Zanon; v. *Cymbella hungarica* (Grun.) Pant. v. *signata* (Pant.) A. Cl.; w. *Navicula* sp.; x. *Navicula laterostrata* Hustedt; y. *Pinnularia dolosa* Gandhi.

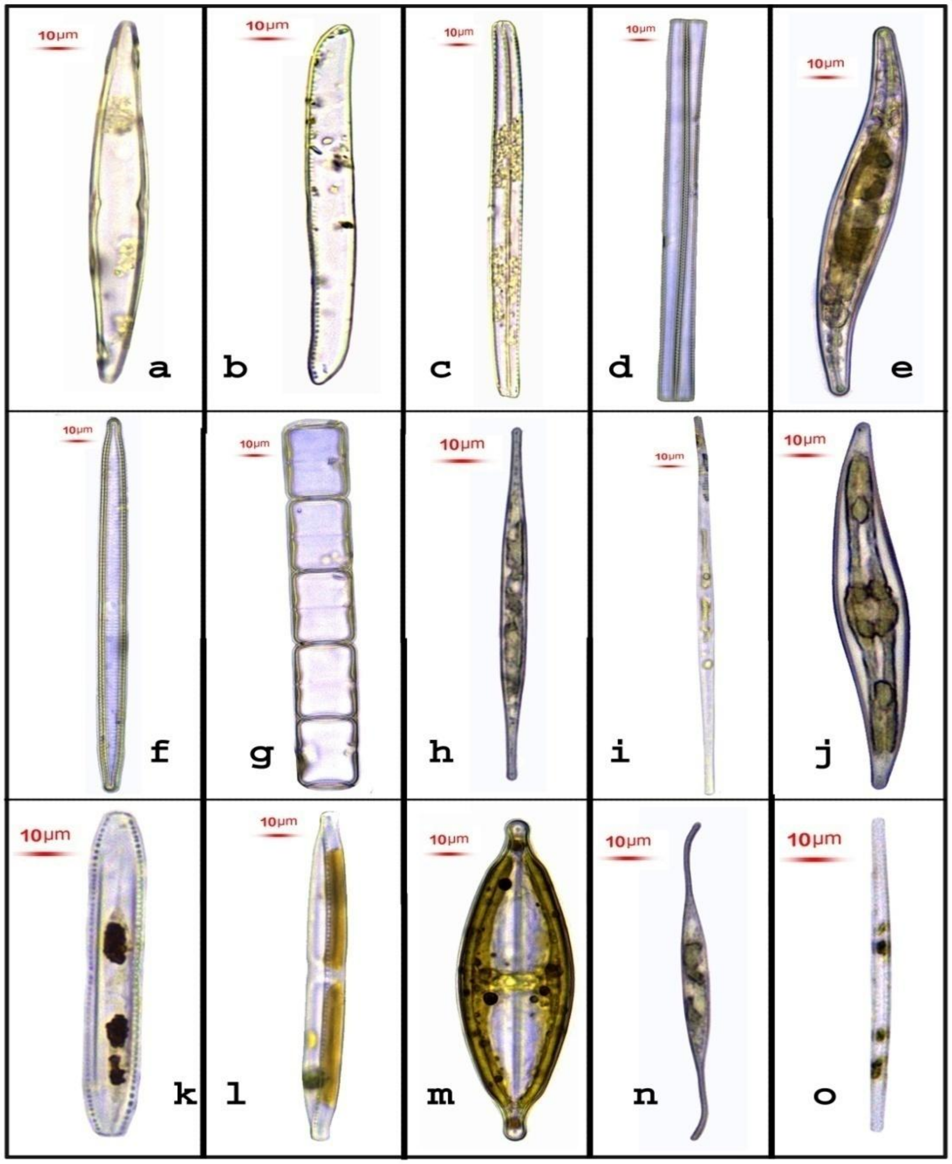
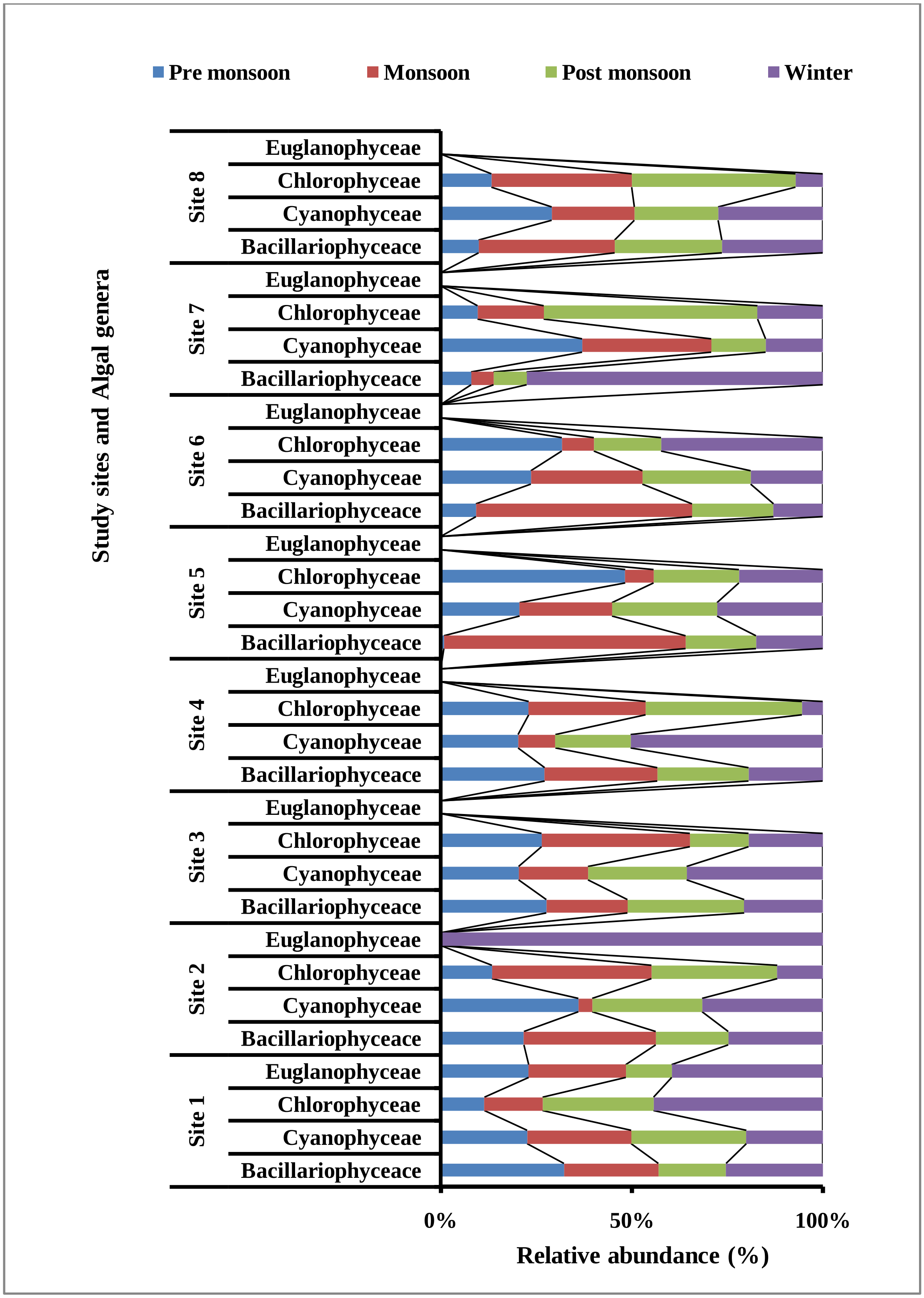


Plate 4.11: Microscopic photographs of Bacillariophyceae a. *Gyrosigma maharashtrensis* sp. Nov. b. *Nitzschia obtusa* W. Smith; c. *Nitzschia vermicularis* (Kuetzing) Huntzsch; d. *Synedra ulna* (Nitzsch.) Ehrenberg; e. *Gyrosigma baikalensis* Skv. ; f. *Synedra ulna* (Nitz.) Ehr. ; g. *Melosira juergensii* Agardh; h. *Synedra rumpens* Kuetzing; i. *Synedra acus* Kuetz.; j. *Pleurosigma salinarum* Grun.; k. *Pinnularia lonavlensis* Gandhi; l. *Nitzschia hungarica* Grun.; m. *Navicula cuspidata* Kuetz. V. *ambigua* (Ehr.) Cleve; n. *Nitzschia closterium* W. Smith; o. *Nitzschia mediocris* Hustedt.

Fig 4.19: Relative abundance (%) of different algal groups at the study sites



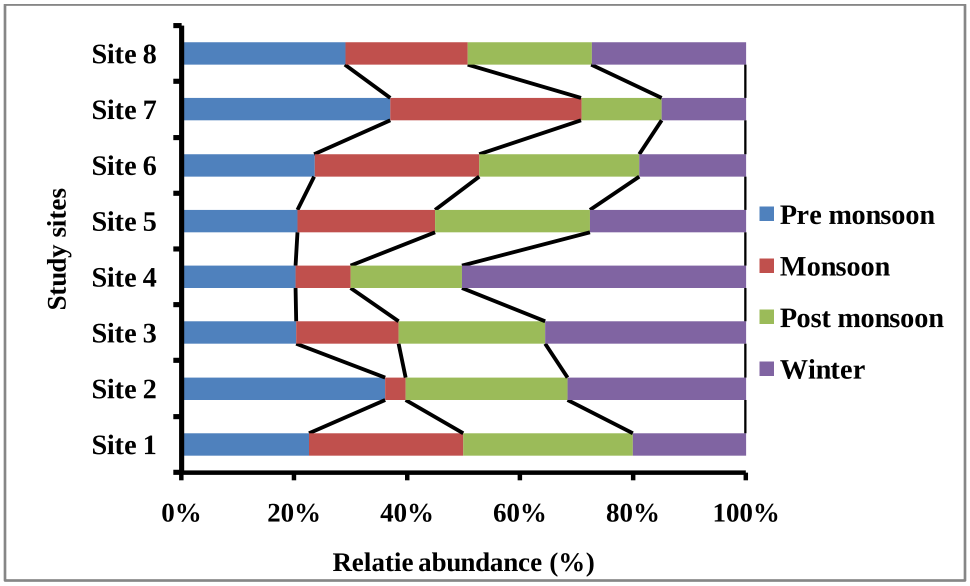


Fig 4.20: Relative abundance of *Cyanophyceae* at different study site in different seasons

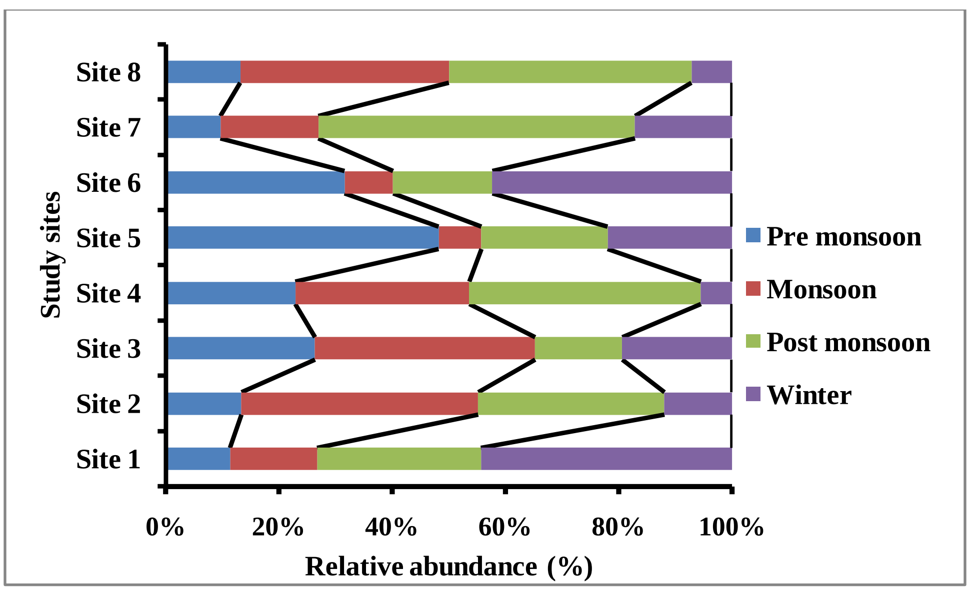


Fig 4.21: Relative abundance of *Chlorophyceae* at different study site in different seasons

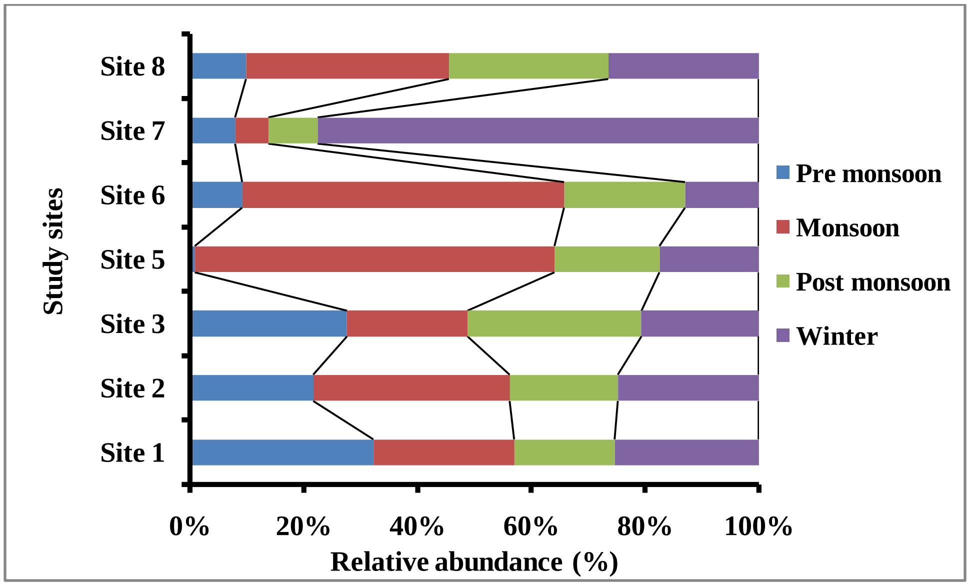


Fig 4.22: Relative abundance of *Bacillariophyceae* at different study site in different seasons

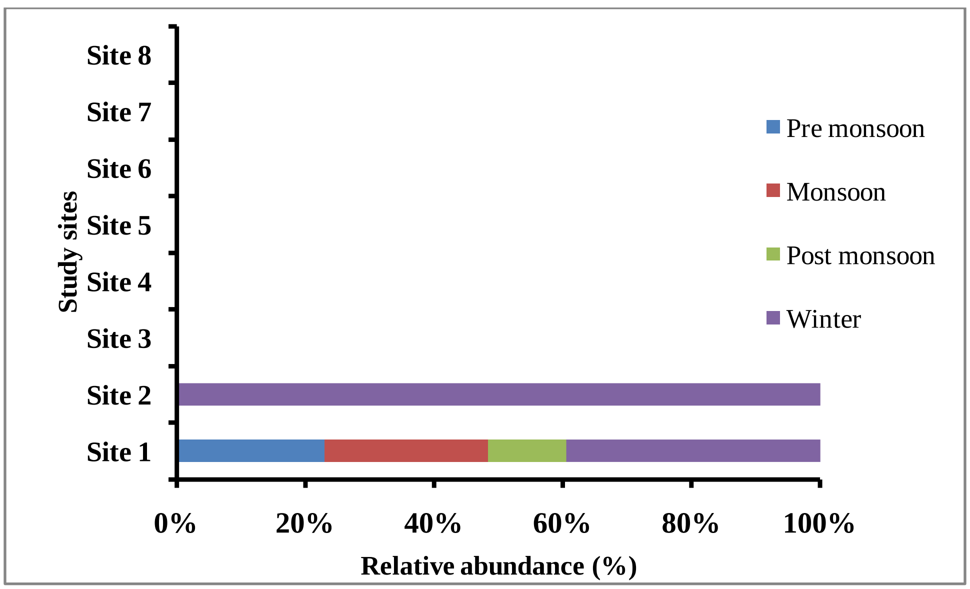


Fig 4.23: Relative abundance of *Euglanophyceae* at different study site in different seasons

Table 4.13: Variation of diversity indices at the study sites

Diversity index	Sites	Pre monsoon	Monsoon	Post monsoon	Winter
Shannon-Wiener Diversity Index (H)	Site 1	1.2 ± 0.15	0.90 ± 0.25	1.06 ± 0.25	1.43 ± 0.62
	Site 2	2.21 ± 0.24	0.99 ± 0.15	1.34 ± 0.16	2.00 ± 0.34
	Site 3	1.69 ± 0.06	1.29 ± 0.44	1.22 ± 0.35	1.50 ± 0.38
	Site 4	1.65 ± 0.13	1.90 ± 0.41	1.09 ± 0.21	1.37 ± 0.22
	Site 5	0.65 ± 0.71	1.17 ± 0.03	1.43 ± 0.24	0.74 ± 0.14
	Site 6	0.67 ± 0.28	1.20 ± 0.14	1.38 ± 0.07	0.66 ± 0.11
	Site 8	0.93± 0.16	1.38 ± 0.16	1.40 ± 0.22	1.04 ± 0.33
	Site 7	0.83 ± 0.21	1.20 ± 0.21	1.26 ± 0.10	1.12 ± 0.34
Simpson's dominance index (D)	Site 1	0.46 ± 0.08	0.51 ± 0.11	0.49 ± 0.10	0.35 ± 0.20
	Site 2	0.14 ± 0.03	0.42 ± 0.06	0.32 ± 0.26	0.18 ± 0.06
	Site 3	0.22 ± 0.02	0.35 ± 0.14	0.36 ± 0.10	0.29 ± 0.12
	Site 4	0.20 ± 0.03	0.49 ± 0.16	0.37 ± 0.06	0.31 ± 0.07
	Site 5	0.67 ± 0.34	0.45 ± 0.01	0.37 ± 0.08	0.58 ± 0.08
	Site 6	0.63 ± 0.18	0.41 ± 0.09	0.34 ± 0.01	0.64 ± 0.07
	Site 8	0.48 ± 0.08	0.34 ± 0.07	0.33 ± 0.04	0.46 ± 0.13
	Site 7	0.55 ± 0.14	0.41 ± 0.09	0.40 ± 0.04	0.45 ± 0.14
Pielou's evenness index (J)	Site 1	0.54 ± 0.07	0.64 ± 0.10	0.58 ± 0.12	0.66 ± 0.19
	Site 2	0.86 ± 0.01	0.83 ± 0.38	0.81 ± 0.03	0.85 ± 0.03
	Site 3	0.87 ± 0.03	0.85 ± 0.09	0.84 ± 0.07	0.85 ± 0.04
	Site 4	0.89 ±0.005	0.83 ± 0.15	0.92 ± 0.05	0.82 ± 0.02
	Site 5	0.43 ± 0.35	0.56 ± 0.02	0.66 ± 0.07	0.66 ± 0.12
	Site 6	0.55 ± 0.24	0.66 ± 0.14	0.70 ± 0.03	0.51 ± 0.05
	Site 8	0.73 ± 0.10	0.67 ± 0.06	0.71 ± 0.03	0.69 ± 0.07
	Site 7	0.61 ± 0.15	0.64 ± 0.13	0.64 ± 0.13	0.64 ± 0.11

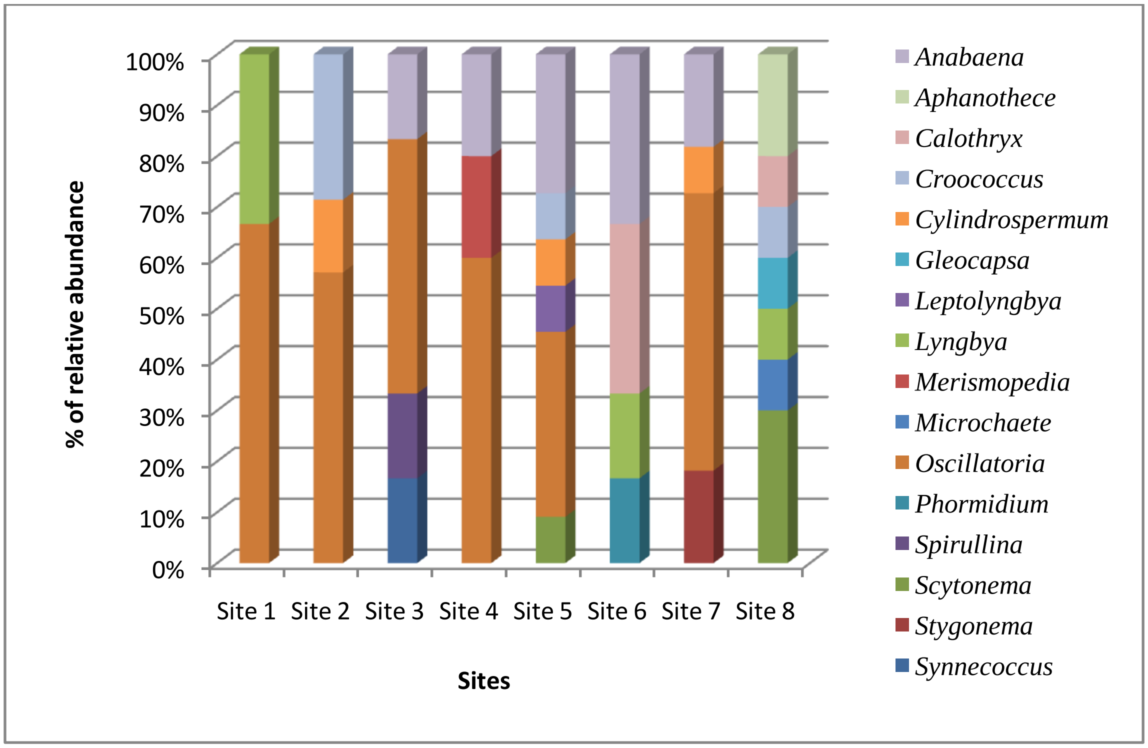


Fig. 4.24: Variation of cyanobacterial distribution and its abundance by dilution plate method at the study sites

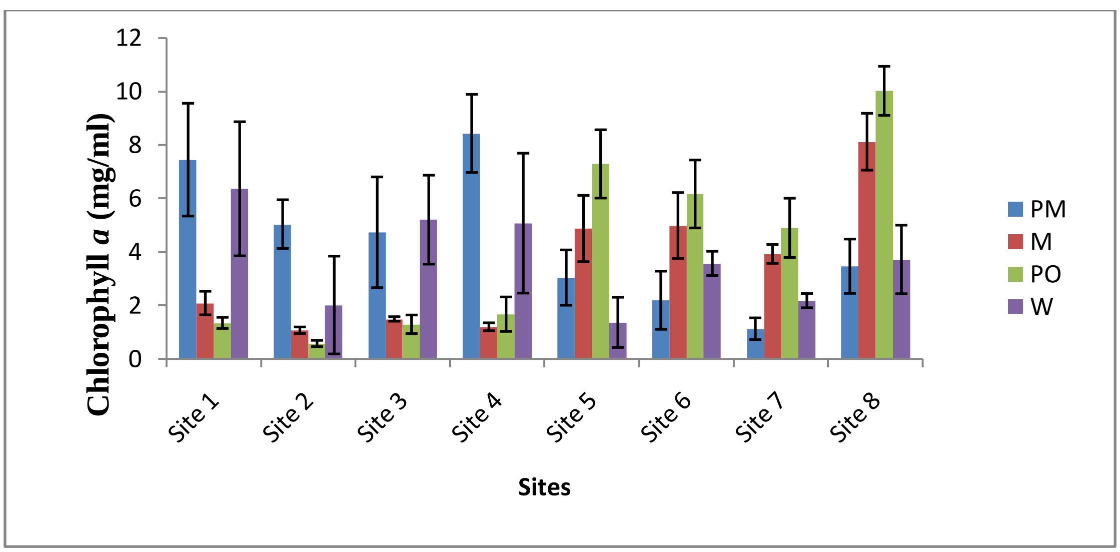


Fig. 4.25: Seasonal variation of chlorophyll *a* concentration at the study sites

In Site 1, a total of 7 cyanobacterial species under 4 genera were observed. In Site 1 highest algal density was obtained for *Oscillatoria limnetica* in winter (45.94× 10^3 ind/ml) and lowest was obtained for the *Oscillatoria vizagepatensis* (1.09× 10^3 ind/ml). *Lyngbya hieronymusii* and *Oscillatoria limnetica* were encountered throughout the season. In Site 2, highest algal density was obtained for *Cylindrospermum stagnale* (12.40× 10^3 ind/ml) in premonsoon and lowest was obtained for the same species (0.07× 10^3 ind/ml) in post monsoon. *Nodularia spumigena* (4.51× 10^3 ind/ml) was encountered only in Site 2 and found only in premonsoon. With 100% frequency in monsoon, *Oscillatoria amphigranulata* showed highest abundance (22.42× 10^2 ind/ml) in winter. In Site 3, *Phormidium tenue* was found throughout the year while *Cylindrospermum stagnale* was observed only in winter. In Site 4 highest algal density was obtained for *Lyngbya taylorii* in pre monsoon (15.47× 10^3 ind/ml) and lowest was obtained for the *Merismopedia punctata* (0.99× 10^2 ind/ml) in monsoon. In the soil around papermill, a total of 10 cyanobacterial species under 5 genera were encountered. Comparatively less number of species was found in the upland soils in premonsoon than monsoon season. Water limiting condition during winter months might have lead to the lower species richness during the season. *Anabaena oryzae* and *Oscillatoria terebriformis* were found to colonise throughout the year on the soil. *Aphanothece naegelii* was having the both highest density (57.84× 10^2 ind/ml) as well as highest abundance (172.03× 10^2 ind/ml) in monsoon among all the species. Highest cyanobacterial species diversity was observed in the lime sludge deposits with 10 genera and 7 species. *Nostoc sphaericum* and *Oscillatoria subbrevis* was found throughout the year while in case of uncooked knot deposits, *Anabaena subcylindrica* (25.01× 10^2 ind/ml) and *Calothryx marchica*

(14.45×10^2 ind/ml) was found to have highest density. Nine species of cyanophyceae under 8 genera were encountered in tree bark algae. *Aphanocapsa pulchra* (28.47×10^2 ind/ml) was having highest density in post monsoon and the species was not found to be restricted to the seasons while *Microchaete calothicoides* (10.12×10^2 ind/ml) was found to colonize in post monsoon only. Chlorophyceae included 25 numbers of species **(Plate 4.6-4.7)** under 13 genera. Taxa under the order *Cosmarium*, *Spirogyra* and *Scenedesmus* are well distributed in the study sites. Highest numbers of green algal species were estimated in site 1 (5), soil around papermill (5) and lowest was found in site 2 (3) and uncooked knot (3). The wastewater contaminated soils are dominated by the genera *Cosmarium* and *Spirogyra*. *Geminella mutabilis* is present only in the Station 3 in premonsoon and post monsoon. *Oocystis natansvar* was observed to be dominating throughout the year except monsoon in the upland soils of around papermill. The solid wastes deposits are dominated by the *Cosmarium* and *Oocystis* species while in case of tree barks, *Trentepholia* and *Cosmarium* were more abundant. A total of 45 Bacillariophyceae species **(Plate 4.8-4.10** and **4.11)** under 14 genera were observed in the study sites. In the soils of river sites, diatom abundance was the highest in winter and premonsoon. For upland soils, post monsoon season was found to be the most favorable months for the diatom flora in the study sites. The genera *Navicula* (12) and *Pinnularia* (10) accounted for the highest numbers of species in the study sites during the study period. In the sites of river soils (Site 1, Site 2, Site 3 and Site 4) algal diversity and abundance was estimated to be the highest in premonsoon. Wash out of the river bank soil during monsoon period is responsible for the lower abundance of algal diversity. In case of upland soils, highest abundance and diversity was found during post monsoon period and are dominated by the genus *Pinnularia, Synedra* and *Nitzschia*.

4.3.2.2 Cyanobacterial distribution and diversity estimation from soil

Despite the existence of morphologically diverse cyanobacteria in a wide variety habitats, work with these bacteria has been restricted to a relatively few representatives. The cosmopolitan distribution of cyanobacteria indicates that they can cope with a wide spectrum of global environmental stresses. There was not any visible cyanobacterial colonization at the field during the monsoon period in river site soil and winter period in upland soil respectively. This happens due to the unfavorable environmental conditions. The cyanobacterial abundance from soil during this stress period was enumerated by dilution plate method **(Fig. 4.24)**. The filamentous forms like *Oscillatoria, Lyngbya* and *Phormidium* and heterocystous *Nostoc* and *Calothryx* were ubiquitous and were the major genera. The ecological study of soil algae is limited due to the lack of satisfactory methods for estimating biomasses of the different algal groups. Algal enumerations are also often limited due to poor sampling methodology. Plating techniques, used in our study is most frequently used and are advantageous in providing qualitative and also quantitative results.

4.3.2.3 Algal biomass analysis in terms of chlorophyll *a*

An understanding of the algal population and its distribution provides valuable insights regarding the ecological status of a particular habitat. Monitoring chlorophyll levels is a direct way of tracking algal growth. Measurement of pigments is one of commonly used method for determination of algal abundance. Chlorophyll *a* pigment is found in all algae and is an indicator of productivity. In case of river site soil, algal biomass was observed to be more during pre monsoon while post monsoon period is found to be most favorable for upland algal biomass (**Fig. 4.25**). The fluctuation of algal biomass was observed to be high at the study sites due to rapid microclimatic changes, seasonal variation and existing physicochemical fluctuations. The highest chlorophyll *a* content (10.01 mg cm^{-2}) was obtained from soil around the papermill while tree bark exhibited the lowest algal biomass (0.57 mg cm-2). **Table 4.14** and **4.15** depicts the bivariate correlation analysis of algal groups with water parameters (Site 1, 2, 3 and 4) and soil properties (Site 5, 6, 7 and 8). The abundance of algae have a positive relation with dissolved oxygen, nitrate and phosphate concentration of the study site 1 , 2, 3 and 4 while they showed an inverse relation with both free CO_2 concentration. The abundance of algae have a positive relation with Water Holding Capacity (WHC) and Organic carbon(OC) concentration of the study site 5, 6, 7 and 8 while they showed an inverse relation with pH and Bulk density. **Fig 4.26** represents the loading plots for Principal Component Analysis (PCA) of the relative abundance of algal groups. The influence of water parameters is more on cyanophyceae and Chlorophyceae than Bacillariophyceae.

4.3.4 Statistical analysis of physico-chemical parameters effecting algal growth

Table 4.14: Bivariate correlation analysis of physico-chemical and biological parameters using Pearson correlation coefficients of site 1-4

	Density	Abundance	Frequency	Humidity	Air temp.	Water temp.	Transparency	D.O	**pH**	Alkalinity	free CO2	Nitrate	Phosphate	Silica
Density	1													
Abundance	0.926	1												
Frequency	0.176	0.063	1											
Humidity	-0.002	-0.013	-0.010	1										
Air temp.	-0.004	-0.002	-0.062	0.768	1									
Water temp.	-0.001	0.002	-0.065	0.686	0.894	1								
Transparency	0.044	0.056	0.000	-0.233	-0.060	-0.253	1							
D.O	0.58*	0.46*	0.35*	0.251	0.032	-0.077	0.371	1						
pH	0.7*	0.522*	0.627*	-0.163	-0.406	-0.269	-0.319	0.313	1					
Alkalinity	0.42*	0.517*	0.005	-0.754	-0.464	-0.430	0.041	-0.478	-0.280	1				
free CO_2	-0.062	-0.075	-0.015	-0.482	-0.353	-0.319	-0.255	-0.803	-0.337	0.693	1			
Nitrate	0.52*	0.48*	0.3*	-0.084	0.013	0.220	-0.579	-0.560	0.324	0.147	0.261	1		
Phosphate	0.46	0.624*	0.36	-0.183	-0.429	-0.281	-0.294	0.284	0.970	-0.261	-0.307	0.340	1	
Silica	0.019	0.21	0.4	-0.382	0.338	0.063	-0.698	-0.59	0.203	0.475	0.579	0.585	0.183	1

*correlation is significant at 0.05 level

Table 4.15: Bivariate correlation analysis of physico-chemical and biological parameters using Pearson correlation coefficients of site 5-8

	Density	Abundance	Frequency	PH	Conductivity	M. Contents	Bulk Density	W.H.C	O. Carbon
Density	1								
Abundance	-0.896	1							
Frequency	0.563	0.138	1						
pH	**-0.722***	**-0.359***	**-0.956***	1					
Conductivity	**-0.606***	**-0.896***	0.316	-0.082	1				
Moisture Contents	0.156	-0.293	0.881	-0.706	0.679	1			
Bulk Density	**-0.717***	**-0.892***	**-0.084***	-0.054	-0.887	-0.368	1		
W.H.C	**0.82***	**0.502***	**0.735***	0.508	-0.814	-0.968	0.499	1	
O. Carbon	**0.96***	**0.70***	0.023	0.146	-0.043	0.211	0.459	0.273	1

*correlation is significant at 0.05 level

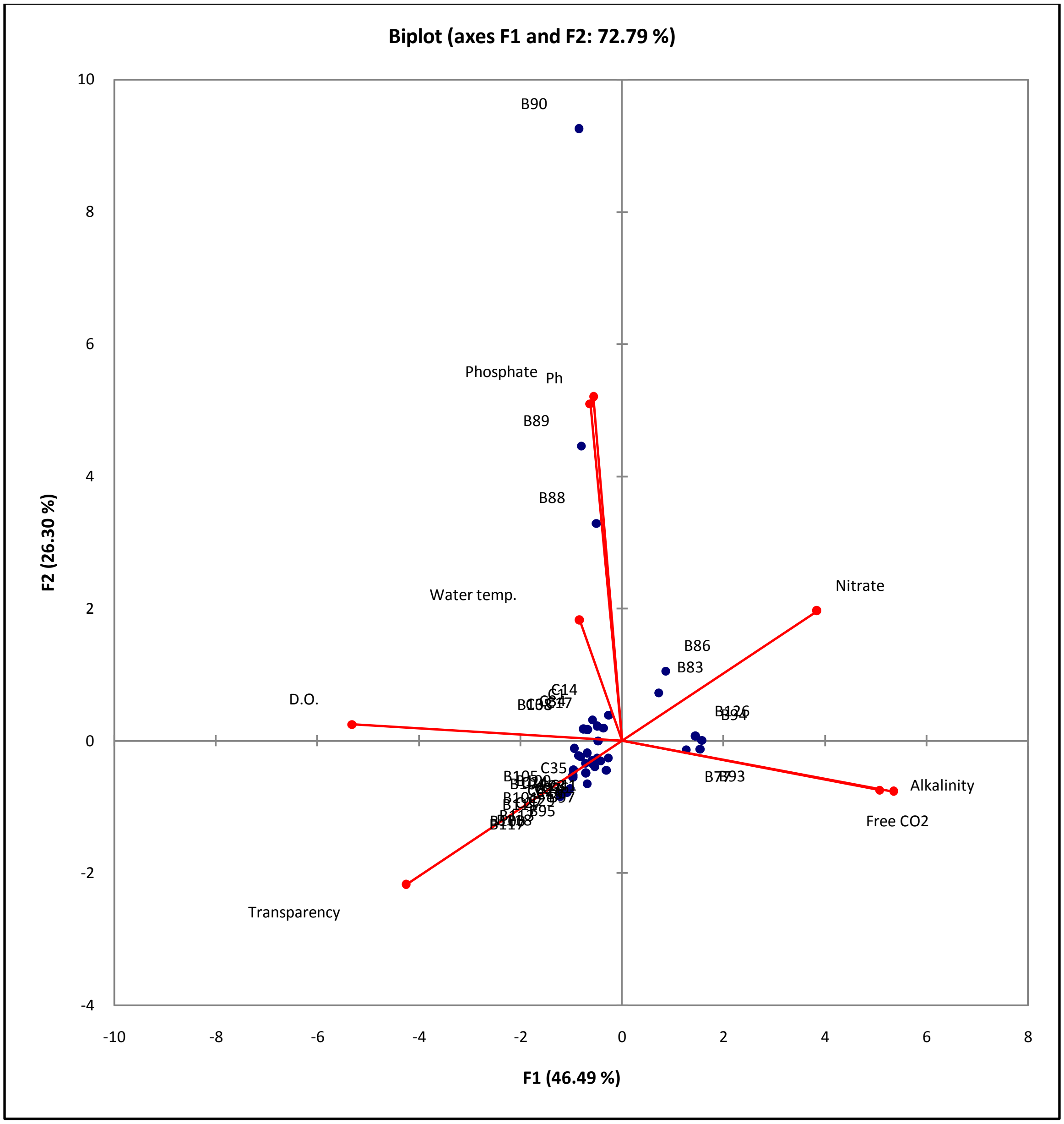


Fig 4.26: Loading plots for Principal Component Analysis of the relative abundance of algal groups.

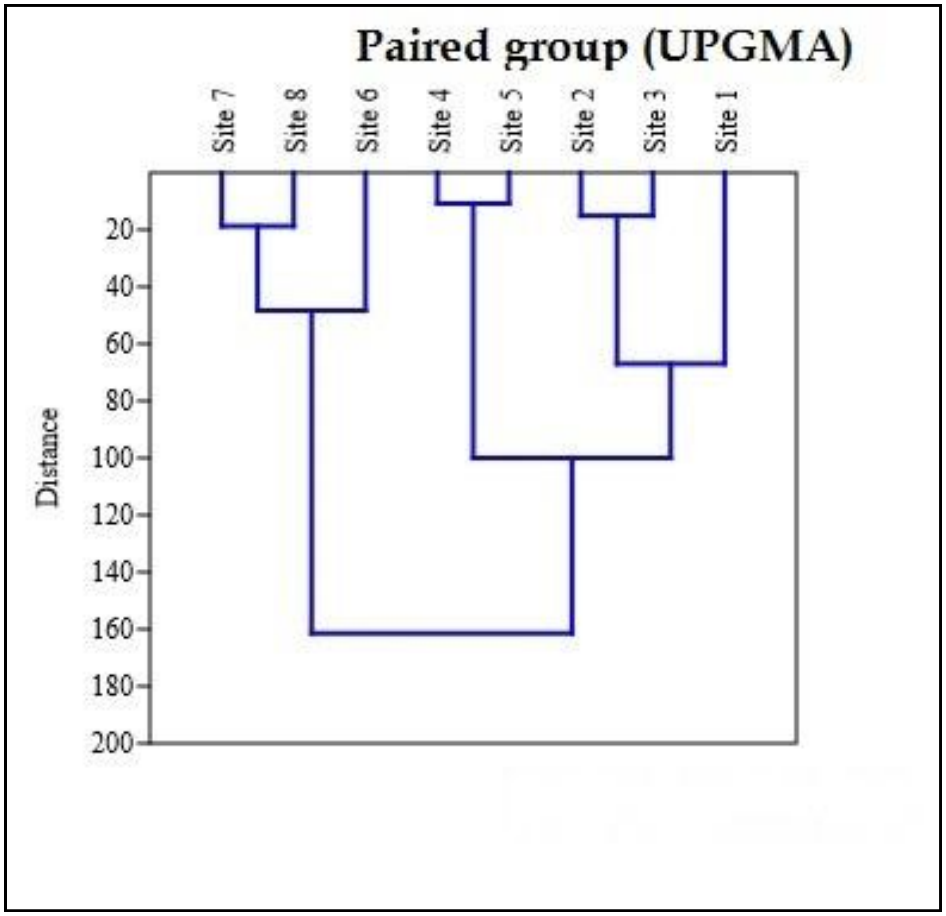


Fig. 4.27: Dendrogram showing the clusters of relative abundance among the selected study sites

4.4 Conclusion

Both the polluted and unpolluted ecosystems were found to be rich in algal diversity. A distinct seasonal and temporal variation of both environmental factors and algal abundance was observed in upland soils and low lying soils of river bank. Where upland soils were found to hold the richest algal diversity in post monsoon period of the year, the low lying soils of river bank were found to possess highest algal diversity and abundance during winter and premonsoon seasons. In the effluent fed river bank soil enriched with nitrate and phosphate, nonheterocystous cyanobacterial species were found to be dominant over the heterocystous species. The physicochemical parameters of polluted river water was totally distinct from the water of control zone and was found to harbour a large number of diatoms and some dominant forms of cyanobacteria which might prove helpful in developing wastewater specific indigenous inoculums for cyanobacterial bioremediation.