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Algal flora of the water bodies around Dhaka Export Processing Zone (DEPZ), Savar, Dhaka, Bangladesh

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Abstract: *The composition, distribution, diversity and seasonal variations of five water bodies around DEPZ area were studied between January 2018 to November 2018. A total of 73 phytoplankton species under 47 genera were recorded belonging to the Cyanophyceae, Chlorophyceae, Bacillariophyceae, Euglenophyceae, Cryptophyceae and Dinophyceae classes. Chlorophyceae dominated the studied sites at both generic and species level. Oscillatoria, Chlamydomonas, Synedra and Euglena occured significantly throughout the study period. Diversity indices provide important information about rarity and commonness of species in a community. The diversity indices in the present study revealed that the water of the studied sites was moderately polluted with less phytoplankton diversity and highest possible equal number of different species of phytoplanktons. The less diversity of phytoplankton indicates the greater impact of pollution.*

Keywords: *Diversity index, DEPZ, Phytoplankton, Pollution, Algae, Seasonal variations.*

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I. Introduction

Algae have been known to human being since times immemorial. They are a ubiquitous group of predominantly aquatic photosynthetic organisms of the kingdom Protista having photosynthetic pigments. They are inseparable associates of the environment; they are purifiers of the environment on one hand and polluting organisms on the other. Phytoplankton, being primary producers, holds a significant place in aquatic food chain and all the life forms including zooplanktons are dependent on them (Pace *et al*, 2004).

Algal flora varies from season to season and an important feature of freshwater algal flora is its cosmopolitanism. Physicochemical parameter of water greatly affects the distribution of algae and their variation at different zones of a water body. The algal growth in a habitat influences the ecosystem and also it directly affects the aquatic environment mainly the nutrient contents. Phytoplanktons are valuable indicators of environmental conditions in chemical and biological changes in such ecosystem because they respond directly and sensitively to many physical, chemical and biological changes in such ecosystem (Stevenson and Pan, 1999). Batterbee *et al*. (1999) demonstrated phytoplankton as an indicator of surface water acidity. It has also stated that phytoplankton in acid water is often poorly developed and acidified water bodies often completely lack a planktonic diatom component. Wunsam *et al*. (2002) considered a study on phytoplankton as bioindicators for environmental changes such as nutrient enrichment, pH and water color. Roy (1995) and Vankteswarlu (1969) stated that the higher concentration of pH generally found in summer season was closely related to phytoplankton. Sing (1965) reported that phytoplankton like *Microcystis aeruginosa* was used as the best single indicator of civic population.

Algae are very sensitive indicators of water quality. These phytoplanktons vary considerably in distribution with respect to different seasons and pollution load. The hydrogen ion concentration i.e., pH is an important parameter of aquatic system. Water temperature is also a significant parameter which regulates the species of composition, metabolism and reproduction of the aquatic organism.

In Bangladesh the level of water pollution is increasing at an alarming rate. In Surface Water Pollution recent years, the river systems in Bangladesh have become more polluted as a consequence of rapid population growth, uncontrolled development on the riverbanks, urbanization, unplanned industrialization and agricultural operations. Industries are prime polluters because they utilize a huge amount of water and release untreated wastewater throughout the production cycle of a product.

Newly booming processing industries such as tanneries, steel plants, battery producers, engineering and textiles also contribute to this problem. The careless disposal of untreated wastewater and solid waste to the water system significantly contributes to the poor quality of the water.

The Dhaka Export Processing Zone (DEPZ) situated besides the Chandra-Baipile roadside of Savar Upazilla which is 46.40 km from the Dhaka city being the second Export Processing Zone and the largest industrial belt of Bangladesh has started its operation in 1993 and at present houses 92 industrial units which are categorically the leading pollution creators. These industrial units in number are as follow: Cap/accessories/garments (42); textile knitting (22); plastic goods (6);footwear/leather goods(4); metal products (2); electronic goods (2); paper products (1); chemicals and fertilizers (1); and miscellaneous (11) (Islam and Muktatir, 2011). Every industrial unit is supposed to haveEffluent Treatment Plant (ETP) to treat the respective wastewater they generate. However, only a few industries have installed such plants. Pollution from DEPZhas already affected the wetland and some of the streams running aquatic habitats and natural fisheries (Khanam *et al*., 2011). Recently it has been reported that the surface water bodies connected to DEPZ disposal site have been steadily contaminated with a huge number of heavy and toxic metals (Kisku *et al.* 2000). The pollution status of Dhaka Export Processing Zone was investigated and the measured value of the physico-chemical parameters was found to lie above the permissible levels as recommended by the Department of Environment, Bangladesh (Kabir, *et al*. 2002).

Discharges from various anthropogenic activities badly affect the aquatic environment. The polluted water becomes a threat to public health, livestock, wildlife, fish and other biodiversity. These pollutants have potential to retard the growth and aquatic flora and fauna . With these backgrounds, present research was undertaken to determine the water quality and algal diversity of some low lying wetlands around the Dhaka Export Processing Zone (DEPZ), Savar, Dhaka, Bangladesh.

II. Materials And Methods

The present experiment was conducted from January to November, 2018 in five aquatic bodies, including four polluted sites and one control site around Dhaka Export processing Zone (DEPZ), Dhaka. A pond about fifty meters far from DEPZ was selected as control site. Site A is the main disposal area where water color was deep black. Site B was located at northwest side and about a half kilometer far from site A. Site C was located at northeast side and a half kilometer far from sit B. Site D was located at north side and a half kilometer far from site C (Fig. 1 and Photograph 1).

A one liter capacity plastic bottle was dipped manually under the surface to collect water sample for physic-chemical analyses. A total of two liter water sample from each of the five sites was collected and from it, one liter sample was fixed by using Lugol's Iodine and sedimented for concentrating plankton. The second one liter sample was transported to laboratory for analyses. The sampling was carried out in every month from January 2018 to November 2018.

Field meter was used to measure air temperature, water temperature and pH. Conductivity, TDS and DO were determined on the same day after reaching the laboratory within 45 minutes of collection. Phytoplankton cell number was counted using a Hawksley microplankton counting chamber with improved Neubauer Ruling (Hawksley Ltd. Lancing, England) under a Nikon Microscope (Japan) at a magnification of 400× in the National Professor A.K.M. Nurul Islam Laboratory, Department of Botany, University of Dhaka.

Density/l = [units/3.015µl ×{(10000÷3.015)} × (50÷9.7)}÷100]

Where,

Units/3.015 µl = sum of the counts in triplicate of the phytoplankton individuals for each sample made by Hawkleys Counting Chamber, 3.015 µl = vol. of the Hawkleys Chamber (1.005) × 3 in µl.

10000 = 10 ml sub-sample of phytoplankton concentrate as obtained after passing of sample water through plankton net, in µl.

50 = Volumes of phytoplankton concentrate, in ml obtained after filtering 100 liter of sample water through plankton net.

Seasons (Rashid 1991) was considered as follow:

1. Summer (March to May)
2. Monsoon (June to early October)
3. Autumn (Late October - November)
4. Winter (December-February)

Diversity indices

Two diversity indices Shannon–Wiener and Simpson were taken to explain the diversity of phytoplankton (Chaturvedi *et al*. 1999). A widely used diversity index is the Shannon–Wiener index. It is calculated from the proportional abundances p_i of each species (abundance of the species/total abundances, noted here as $p_i=n_i/N$) as

$$H = -\sum_{i=1}^{s} pi\ In\ pi$$

Biologists proposed a different scale of pollution in terms of species diversity index, which states a negative correlation between Shannon–Wiener index and pollution.

Diversity level	Shannon-Wiener index	Pollution level
High	3.0-4.5	Slight
Moderate	2.0-3.0	Light
Less	1.0-2.0	Moderate
Very less	0.0-1.0	Heavy pollution

The Simpson index is another diversity indexcalculated from species proportions. Its formula is

$$H = -\sum_{i=1}^{s} pi2$$

Simpson index value also represents the level of diversity.

Index Value	Comment
0 (0 to 0.5)	Lowest possible diversity (when species are same)
1 (0.5 to 1)	highest possible equal number of different species.

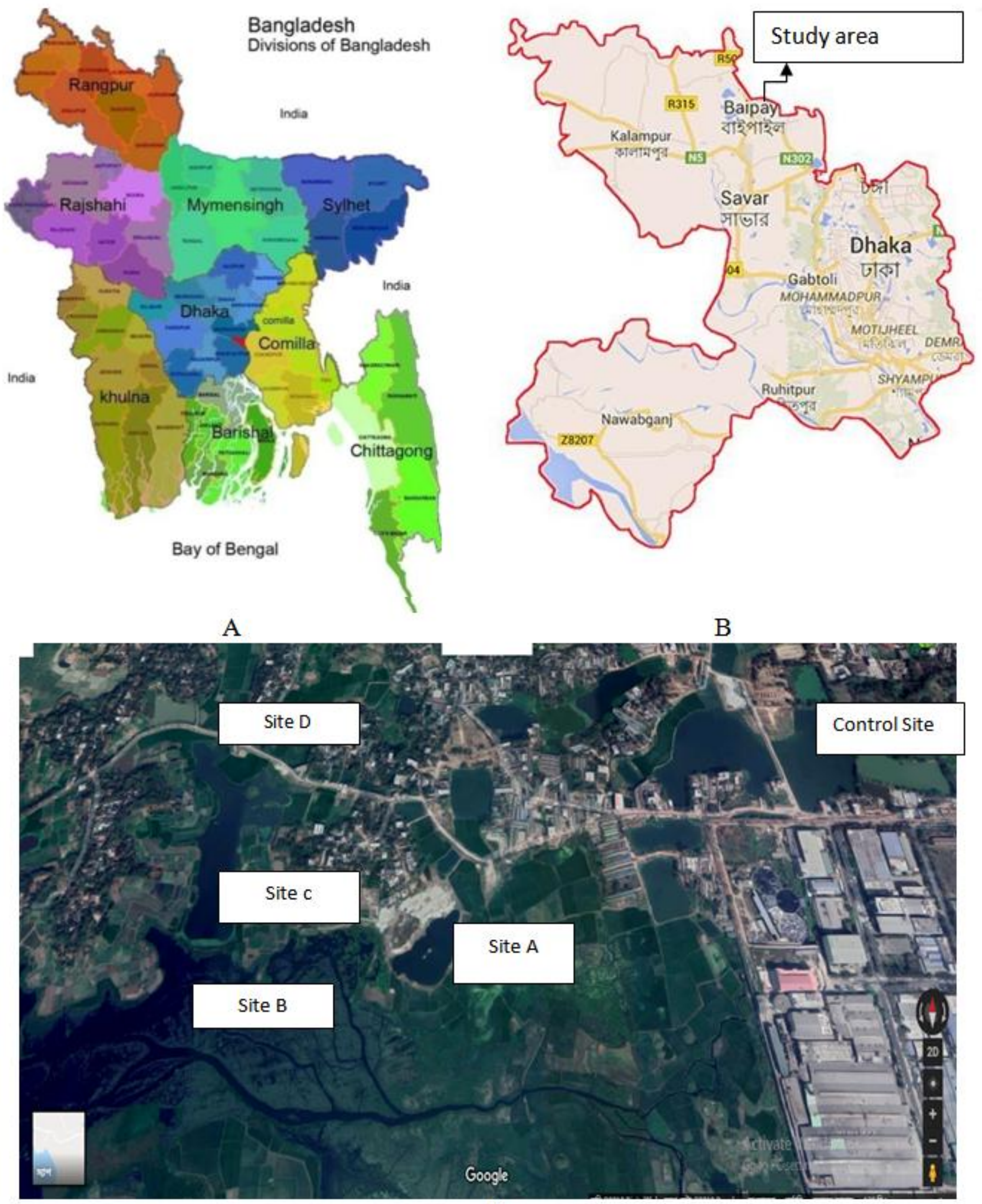


Fig. 1: Map of Bangladesh (A) and studied sites (B & C)

Site- Control

Site-A

Site-B

Site-C

Site-D

Photograph 1: Five studied sites of DEPZ area

III. Results And Discussion

The Composition of Phytoplankton

A total of 73 phytoplankton species under 47 genera were found, belonged to 7 classes from the selected five sites. Among them, 7genera and 7 species belonging to Class Cyanophyceae; 23 genera and 32 species belonging to Chlorophyceae; 10 genera and 14 species belonging to Bacillariophyceae; 6 genera and16 species belonging to Euglenophyceae; 2 genera and 4 species belonging to Cryptophyceae;, 1 genus and 2 species belonging to Dinophyceae (Table-1 and 2).

At the generic level percentage composition shows that Chlorophyceae dominated the studied sites and occupied 49%, followed by Bacillariophyceae (21%), Cyanophyceae (15%), Euglenophyceae (9%), Cryptophyceae (4%) and Dinophyceae (2%) (Fig. 2).

At the species level Chlorophyceae dominated the studied sites and occupied 43%, followed by Euglenophyceae (22%), Bacillariophyceae (19%), Cyanophyceae (10%), Cryptophyceae (5%) and Dinophyceae (1%) (Fig. 3).

Khan *et al.* (2008) reported a total 36 genera of phytoplankton dominated by Chlorophyceae (35.68%); followed by Bacillariophyceae (34.35%); followed by Cyanophyceae (26.74%) and Euglenophyceae (3.21%) in a wetland of Dhaka Export Processing Zone (old) (DEPZ) which is unanimously similar to the present study. On the contrary, phytoplankton genera of six freshwater wetlands of Dhaka was dominated by diatoms, green, blue green and euglenoids (Alam *et al*. 2003). In 1973, Schoeman (1973) reported certain diatoms indicating definite type of organic pollution.

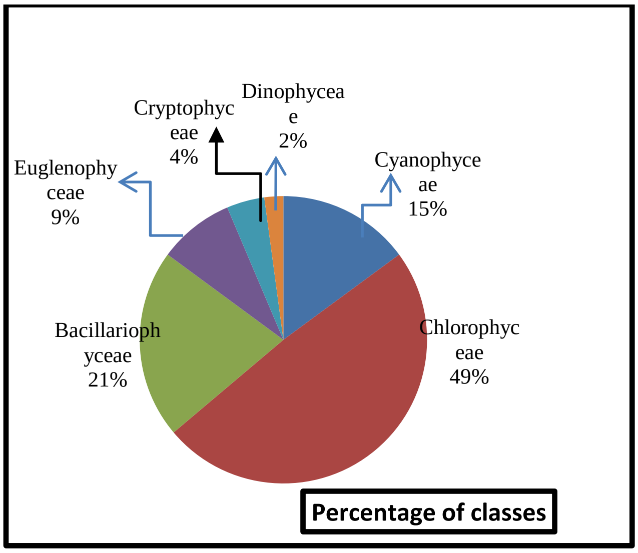


Fig. 2: Percentage of different classes at the generic level

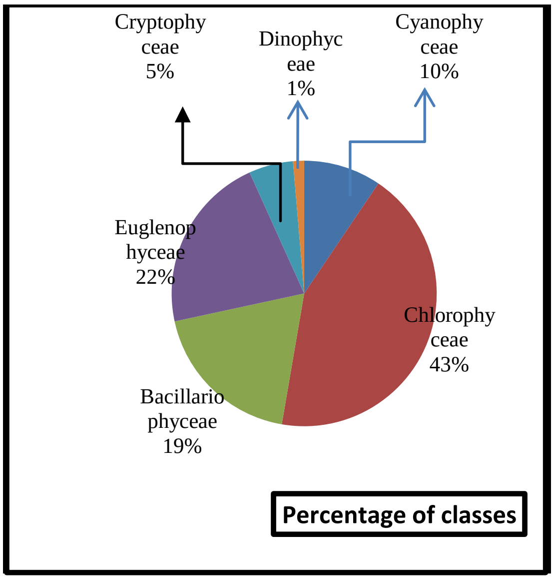


Fig. 3: Percentage of different classes at the species level

Table 1: Cumulative composition of phytoplankton flora of the studied sites.

Class	Recorded Species	No. of genus
Cyanophyceae	*Oscillatoria, Anabaena, Microcystis, Arthrospira, Merismopedia, Chroococcus, Anabaenopsis*	7
Chlorophyceae	*Eudorina, Pandorina, Scenedesmus, Pediastrum, Chlamydomonas, Ourococcus, Characium Tetraedron, Cosmarium, Selanastrum, Hyaloraphidium, Planktosphaeria, Monoraphidium, Crucigenia, Schroederia, Oocystis, Staurastrum, Mougeotia, Carteria, Closterium, Coelastrum, Actinastrum Nephrocytium,Dictyosphaerium, Crucigenia*	23
Bacillaiophyceae	*Melosira, Cyclotella, Synedra, Fragilaria, Navicula, Nitzschia, Achnanthes, Gomphonema, Pinnularia, Gyrosigma,*	10
Euglenophyceae	*Euglena, Phacus, Trachelomonas, Lepocynclis.*	4
Cryptophyceae	*Rhodomonas, Cryptomonas*	2
Dinophyceae	*Peridinium*	1

Table 2: List of the phytoplankton species in the studied water bodies.

Class	Genus	Species
Cyanophyceae Genera: 7 Species: 7	*Merismopedia*	*Merismopedia punctata* Meyen in Wiegman
	Oscillatoria	*Oscillatoria chalybea* Martens *ex* Gomont
	Arthrospira	*Arthrospira jenneri* Stizenberger *ex* Gomont
	Anabaena	*Anabaena utermöhlii* Geitler
	Anabaenopsis	*Anabaenopsis* sp.
	Chroococcus	*Chroococcus disperses* (V. Keissler) Lemm.
	Microcystis	*Microcystis aeruginosa* (Kützing) Kützing
Chlorophyceae	*Scenedesmus*	*Scenedesmus acutus* var. *acutus* Meyen

Genera: 23 Species: 32		*Scenedesmus acuminatum* (Lagerh.) Chodat
		Scenedesmus dimorpha (turp.) Kütz.
		Scenedesmus quadricauda (Turp.) de Brébisson
		Scenedesmus regularis Svir.
	Pediastrum	*Pediastrum tetras* var. *tetraedron* (Corda) Hansgirg
		Pediastrum duplex var. *gracillimum* West & West
		Pediastrum boryanum var. *brevicorne* A.Braun
	Tetraedron	*Tetraedron bifircatum* (Wille) Lagerheim
	Actinastrum	*Actinastrum hantzschii* Lagerheim var. *subtile* Wolosz.
	Nephrocitium	*Nephrocytium lunatum* W. West
		Nephrocytium spirale Bek-Mannag.
	Chlamydomonas	*Chlamydomonas pulchra* Skvortz.
		Chlamydomonas pertyi Gor.
	Cosmarium	*Cosmarium obsoletum* (Hantz.) Reinsch
		Cosmarium sp.
	Dictyosphaerium	*Dictyosphaerium granulatum* Hind.
	Monoraphidium	*Monoraphidium griffithii* (Berkeley) Kom.Legn.
	Crucigenia	*Crucigenia quadrata* Morren
	Oocystis	*Oocystis borgei* Snow
	Coelastrum	*Coelastrum microporum* Nägeli
	Schroederia	*Schroederia* sp.
	Pandorina	*Pandorina* sp.
	Ourococcus	*Ourococcus* sp.
	Tetraedron	*Tetraedron* sp.
	Characium	*Characium* sp.
	Hyaloraphidium	*Hyaloraphidium* sp.
	Planktosphaeria	*Planktosphaeria* sp.
	Mougeotia	*Mougeotia* sp.
	Staurastrum	*Staurastrum* sp.
	Carteria	*Carteria* sp.
	Closterium	*Closterium* sp.
Bacillariophyceae Genera: 10 Species:14	*Synedra*	*Synedra ulna* var. *danica* (Kütz.) Van Heurck
	Gyrosigma	*Gyrosigma spenceri* (W. Smith) Cleve
	Melosira	*Melosira granulate* (Ehrenberg) Ralfs in Pritchard
	Navicula	*Navicula radiosa* Kütz
	Pinnularia	*Pinnularia krookei* (Grun.) Cleve
		Pinnularia gibba Ehr.
	Cyclotella	*Cyclotella comta* (Ehrenberg) Kütz. var. *affinis* Grunow in Van Heurck
		Cyclotella kuetzingiana Thwaites
		Cyclotella comensis Grunow in Van Heurck
		Cyclotella meneghiniana Kütz.
	Fragilaria	*Fragilaria* sp.
	Gomphonema	*Gomphonema* sp.
	Achnanthes	*Achnanthes* sp.
	Nitzschia	*Nitzschia* sp.
Euglenophyceae Genera:4 Species: 16	*Euglena*	*Euglena australica* var *claviformis* Playfair
		Euglena mainxii Defl.
		Euglena exilis Gojdics
		Euglena sanguinea Ehrenberg
		Euglena rostifera Johnson
	Trachelomonas	*Trachelomonas planctonica* Swir.
		Trachelomonas texta (Duj.) Lemn.
		Trachelomonas bernerdi Woloszynska
		Trachelomonaslongistriata Islam *et* Alfasane
		Trachelomonas lismorensis var. *inermis* Playfair
		Trachelomonas lacustris Drez.
	Lepocinclis	*Lepocinclis teres* var. *parvula* Conr.
		Lepocinclis ovum var. major (Huber-Pestalozzi) Conr.
		Lepocinclis texta (Duj.) Lemn.
	Phacus	*Phacus acuminatus* var. *granulate* (Roll) Huber-Pest
		Phacus hamelii Allorgae and Lafevre
Cryptophyceae Genera: 2 Species:4	*Cryotomonas*	*Cryotomonas erosa* Ehrenberg
		Cryotomonas obovata Czosnowski
		Cryotomonas lucens Skuja
	Rhodomonas	*Rhodomonas minuta* Skuja
Dinophyceae Genera: 1 Species:2	*Peridinium*	*Peridinium gatunenese* Nygaard
		Peridinium cinctum Ehrenberg

Density of Total Phytoplankton:

In control site, the highest phytoplankton density was in the month of May, 2018 (21.5×10^6/L) and lowest one was in the month of November, 2018 (2.78×10^6/L). In Site-A, the number of phytoplankton was zero except the season of monsoon. In monsoon, due to heavy rain the water of the Site-A become diluted with rain water. So, the phytoplankton was found to grow the moths of monsoon. Among them, the highest density was found in the month of June (7.13×10^6/L) and lowest was in September (6.19×10^6/L). Both the sites of B and C showed highest density in the month of June, i.e.8.78×10^6/L and 12.2×10^6/L, respectively and Site-D showed the highest density in the month of May (19.3×10^6/L). Among all the sites, the plankton density was highest in the control site where there was no source of pollution. In the month of September, all the sites showed the increased phase and in November all the sites showed decreased phase (Fig.4). In a research of perennial pond of water body, named Dharma Sagar in Bangladesh, the highest phytoplankton density was found in the month of May and the lowest one in October (Bhuiyan *et al.* 2017). This finding has quite similarity to the present study.

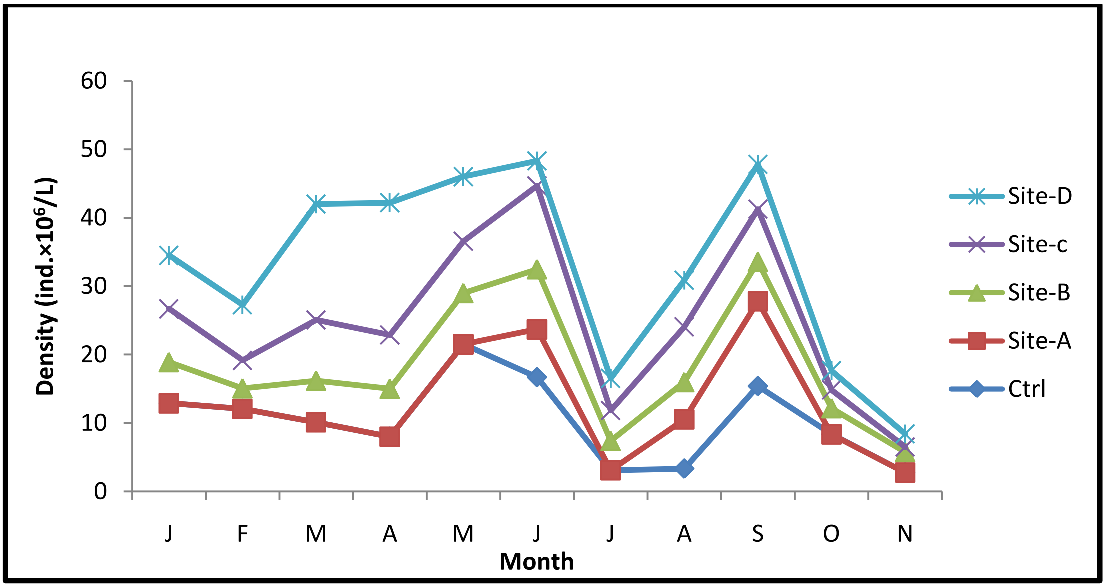


Fig. 4: Phytoplankton density of the studied sites at the generic level

Table 3: Diversity and occurrence of phytoplankton of the studied sites during winter.

Class	Genera	No. of each cells/L				Total number of cells/L				Grand total of phytoplankton /L				Percent Composition of each group (%)			
		Crtl	B	C	D	Crtl	B	C	D	Crtl	B	C	D	Crtl	B	C	D
Cyanophyceae	*Merismopedia* sp.	1462	-	-	-	1498	850	240	166	5494	2354	2096	3548	27.27	36.11	11.4	4.6
	Anabaena sp.	4	-	-	--												
	Oscillatoria sp.	18	848	240	166												
	Arthrospira sp.	4	2														
	Microcystis sp.	10															
Chlorophyceae	*Chlamydomonas* sp.	44	544	544	862	708	560	612	910					12.89	23.79	26.7	25.6
	Pediastrum sp.	6	-	-	-												
	Scenedesmus sp.	500	4	24	4												
	Monoraphidium sp.	14	4	18	4												
	Crucigenia sp.	42	-	10	2												
	Actinastrum sp	4	-	-	-												
	Carteria sp.	16	-	-	24												
	Oocystis sp.	6	2	2	4												
	Selenastrum sp.	8	2	6	-												
	Closterium sp.	-	-	-	4												
	Tetrastrum sp.	6		4	2												
	Ourococcus sp.	2															
	Cosmarium sp.	12		4													
	Hyaloraphidium sp.	4															
	Schroederia sp.		2														
	Kirchneriella sp.		2														
	Pandorina sp.	44			4												
Bacillariophyceae	*Cyclotella* sp.	24	4	494	-	1096	978	1190	1696					19.95	28.80	29.78	47.8
	Melosira sp.	12	20	32	12												
	Synedra sp.	1040	606	240	1652												
	Nitzschia sp.	14	28	362	22												
	Navicula sp.	6	18	22	-												
	Achnanthes sp.	-	2	2	-												
	Gomphonema	-	-	4	-												
	Fragilaria sp.	-	-	28	10												
	Pinnularia			4													
	Cymbella			2													
Euglenophyceae	*Euglena*	1508	240	32	760	1568	266	48	776					28.54	11.29	1.8	21.8
	Lepocinclis	-	-	-	-												
	Trachelomonas	60	26	6	14												
	Phacus	-	-	10	2												
Cryptophyceae	*Cryptomonas*	520	-	-	-	524	0	6	0					9.53	0	0.28	0
	Rhodomonas	4	-	6	-												
Dinophyceae	*Peridinium*	100	-	-	-	100	0	0	0					1.82	0	0	0

Table 4: Diversity and distribution of phytoplankton of the studied sites during summer.

Class	Phytoplankton	Total no. of each cells /L				Total number of cells/L				Grand total of phytoplankton /L				Percent Composition of each group (%)			
		Crtl	B	C	D	Crtl	B	C	D	Crtl	B	C	D	Crtl	B	C	D
Cyanophyceae	*Merismopedia* sp.	1224	-	402	16	1231	1730	1106	2036	7166	4294	6410	4434	17.05	40.24	17.25	45.91
	Anabaena sp.	2	-	-	-												
	Oscillatoria sp.	-	1720	700	2020												
	Arthrospira sp.	2	-	-													
	Microcystis sp.	-	2	4													
	Chroococcus	3	8	-	-												
Chlorophyceae	*Chlamydomonas* sp.	1930	220	1680	8	2027	258	3018	1122					28.07	0.17	47.08	25.30
	Pediastrum sp.	6	-	-	-												
	Scenedesmus sp.	53	24	1162	1104												
	Monoraphidium sp.	-	-	-	-												
	Actinastrum sp	4	-	-	-												
	Carteria sp.	4		130	-												
	Oocystis sp.	10	6	22	-												
	Closterium sp.	-	4	-	2												
	Staurastrum sp.	2	2	-	-												
	Tetraedron sp.	4	-	-	-												
	Pandorina sp.	2	-	22	8												
	Cosmarium sp.	10		2													
	Planktophaeria sp.		2														
	Selenastrum sp.	2															
Bacillariophyceae	*Cyclotella* sp.	21	8	40	26	649	1638	2252	1062					9.00	45.13	35.13	23.95
	Melosira sp.	4	28	16	30												
	Synedra sp.	622	1580	1684	620												
	Nitzschia sp.	-	-	460	328												
	Navicula sp.	2	8	12	14												
	Achnanthes sp.	-	-	10	20												
	Gomphonema sp.	-	-	2	6												
	Fragilaria sp.	-	14	26	18												
	Gyrosigma sp.			2													
Euglenophyceae	*Euglena* sp.	3288	646	-	206	3304	664	30	214					45.67	15.46	0.46	4.82
	Lepocinclis sp.	6	6	-	2												
	Trachelomonas sp.	10	4	22	-												
	Phacus sp.	-	8	8	6												
Cryptophyceae	*Cryptomonas* sp.	-	-	-	-	4	0	0	0					0.05	0	0	0
	Rhodomonas sp.	4	-	-	-												
Dinophyceae	*Peridinium* sp.	4	6	4	-	4	6	4	0					0.05	0.13	0.06	0

Table 5: Diversity and occurrence of phytoplankton of the studied sites during monsoon.

Class	Phytoplankton	Total no. of each cells /L					Total number of cells/L					Grand total of phytoplankton /L					Percent Composition of each group (%)				
		Crtl	A	B	C	D	Crtl	A	B	C	D	Crtl	A	B	C	D	Crtl	A	B	C	D
Cyanophyceae	*Merismopedia* sp.	1060	360	-	254	694	1060	1140	1384	1422	834	4588	3924	3716	4974	3030	23.1	29.05	37.26	28.58	27.52
	Oscillatoria sp.		780	1384	1160	140															
	Microcystis sp.			-	-	-															
	Chroococcus sp.				8																
Chlorophyceae	*Chlamydomonas* sp.	1416	130	40	410	308	1510	974	66	614	990						32.91	24.82	1.77	12.34	32.67
	Staurastrum sp.	4		-	12	2															
	Scenedesmus sp.	14	40	-	178	12															
	Monoraphidium sp.	6	800	12	-	10															
	Tetraedron sp.	12		-	2	-															
	Actinastrum sp	10		-	-	4															
	Pandorina sp.	4		-	4	6															
	Cosmarium sp.	14			4																
	Crucigenia sp.	18				4															

	Selenastrum sp.	12				4															
	Pediastrum sp.		2																		
	Schroederia sp.		2	8																	
	Closterium sp.				4																
	Tetraedron sp.			6																	
	Carteria sp.					640															
Bacillariophyceae	*Cyclotella* sp.	18	6	30	16	12	78	1778	1792	2924	1176						1.7	45.31	48.22	58.78	38.81
	Melosira sp.	32	16	208	12	20															
	Synedra sp.	26	1480	788	2080	972															
	Nitzschia sp.	2	250	726	800	140															
	Navicula sp.	-	10	8	6	14															
	Achnanthes sp.	-	4	6	2	-															
	Gomphonema sp.	-		4	-	-															
	Pinnularia sp.			4	4																
	Fragilaria sp.	-	12	18	4	16															
	Gyrosigma sp.					2															
Euglenophyceae	*Euglena* sp.	1780	4	460	6	12	1940	24	472	14	26						42.28	0.61	12.7	0.28	0.85
	Lepocinclis sp.	8	6			4															
	Trachelomonas sp.	140	4	10	6	6															
	Phacus sp.	12	10	2	2	4															
Cryptophyceae	*Cryptomonas* sp.	-		-			0	0	0	0	0						0	0	0	0	0
	Rhodomonas sp.	-		-	-	-															
Dinophyceae	*Peridinium* sp.	-	8	2	-	4	0	8	2	0	4						0	0.2	0.05	0	0.06

Table 6: Diversity and occurrence of phytoplankton of the studied sites during autumn.

Class	Phytoplankton	Total no. of each cells /L				Total number of cells/L				Grand total of phytoplankton /L				Percent Composition of each group (%)			
		Crtl	B	C	D	Crtl	B	C	D	Crtl	B	C	D	Crtl	B	C	D
Cyanophyceae	*Merismopedia* sp.	800	26		14	818	26	4	14	2406	370	478	642	34	7.02	0.83	2.18
	Oscillatoria sp.	18	-	4	-												
Chlorophyceae	*Chlamydomonas* sp.	26	24	20	16	506	302	260	48					21.03	81.82	54.39	7.47
	Carteria sp.	-		240	-												
	Scenedesmus sp.	460	240	-	10												
	Monoraphidium sp.		20	-	10												
	Pandorina sp.	4		-													
	Cosmarium sp.	4	4	-	2												
	Crucigenia sp.	8		-	4												
	Pediatrum sp.	4		-													
	Schroederia sp.		4	-													
	Tetrastrum sp.		10	-	6												
Bacillariophyceae	*Cyclotella*	6	4	-	10	1074	4	204	20					44.6	1.08	42.67	3.1
	Melosira sp.	8	-	2	6												
	Synedra sp.	1040	-	200	-												
	Nitzschia sp.	14	-	-	-												
	Navicula sp.	6		2	4												
Euglenophyceae	*Euglena* sp.	8	32	2	560	8	32	6	560					0.33	8.64	1.25	87.22
	Phacus sp.	-	-	4													
Cryptophyceae	*Cryptomonas* sp.	-		4	-	0	0	4	0					0	0	0.83	0
Dinophyceae	*Peridinium* sp.	-	6	-	-	0	6	4	0					0	1.62	0.0	0

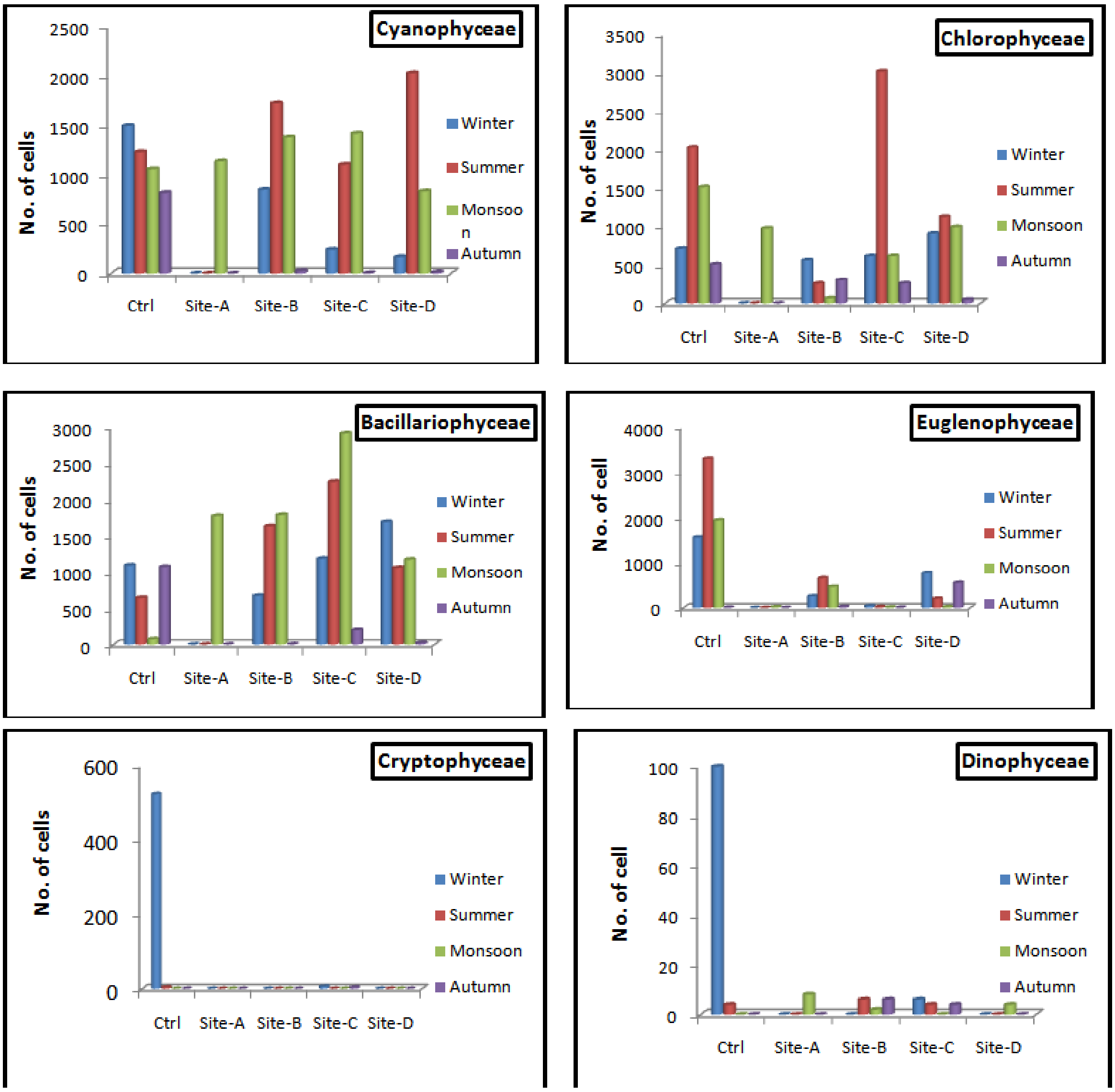


Fig.5: Occurrence of various phytoplankton classes in four seasons

Seasonal Occurrence of Phytoplankton Classes

The genera belonging to Cyanophyceae, Chlorophyceae and Euglenophyceae attained their maximum development during summer season and lowest in autumn whereas those of Bcillariophyceae showed the highest growth duning monsoon and lowest in autumn. According to Shanthala *et al.* (2009), Cyanophycean algae form bloom from February to May and the Bacillariophycean algae developed maximum in number during October to January and totally absent in February to May. From the Fig. 5 and Table 3 to Table 6, it was observed that the number of phytoplankton differ from and season to season and site to site as well, which can be summarized as follow:

No.	Class	Season (Highest growth)	Name of the site (Highest growth)	Season (Lowest growth)	Name of the site (Lowest growth)
01.	Cyanophyceae	Summer	Site-D	Autumn	D
02	Chlorophyceae	Summer	Site-C	Autumn	D
03.	Bacillariophyceae	Monsoon	Site-C	Autumn	B
04.	Euglenophyceae	Summer	Control site	Autumn	C
05.	Cryptophyceae	Winter	Control site	Monsoon	A, B, C, D
06.	Dinophyceae	Winter	Control site	Summer and Autumn	A, D

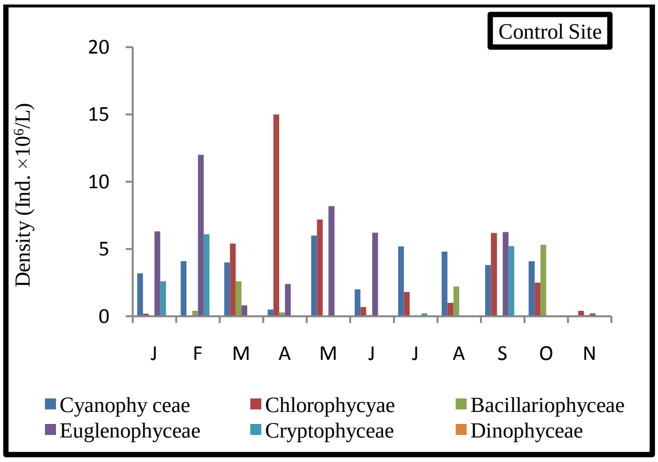
Diversity and Distribution of Phytoplankton

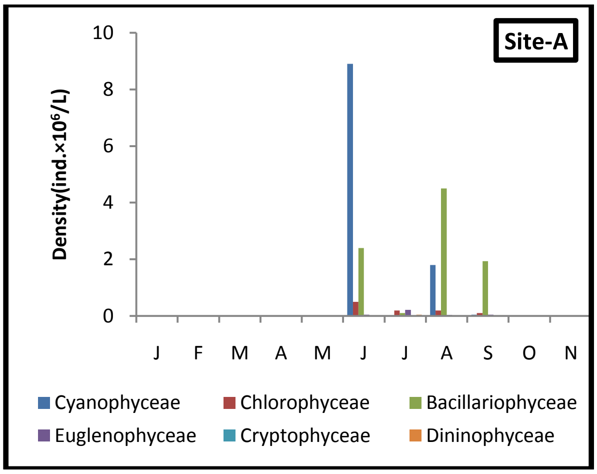
The most common species of algae occurring in the DEPZ were *Oscillatoria*, *Chlamydomonas, Scenedesmus, Carteria, Cyclotella, Synedra, Nitzschia* and *Euglena*. *Euglena* and *Synedra* were found in more number than others. Euglenoids exhibit a great deal of adaptability to varying levels of BOD and different nutrients (Hossetti and Patil 1987). The diversity of phytoplankton was higher in the control site, whereas it was very less in Site-A. From the above study it was found that the density of algae belonging to Bacillariophyceae was more than other classes (Fig.6). Blue green algal forms dominated the DEPZ adjacent water bodies throughout the year were *Oscillatoria*, whereas it was *Merismopedia* in the control water body. In Site-A, where pollution level may be very high (water is deep black in color), the density of Cyanophyceae was more than any other classes which is very similar to the findings by Shanthala *et al*. in 2009. According to them, the higher density of Cyanophyceae indicated that the phytoplankton of blue green algae can tolerate high rate of pollution. Development of Cyanophyceae is due to the higher concentration of organic matter in tropical oxidation ponds (Kumar 2002). Ramaswamy and Somashekar(1982) stated that the formation of blue green algae is due to the increased oxidizable organic matter, CO_2, Phosphate and Calcium.

Important green algal forms were *Chlamydomonas, Scenedesmus* and *Monoraphidium* in the DEPZ water bodies whereas it was *Chlamydomonas* in control water body. *Synedra* and *Nitzschia* occurred more in number in the DEPZ adjacent water bodies than control water body. Among Euglenophyceae *Euglena, Lepocinclis*, *Trachelomonas* and *Phacus* were important flora in all the sites. This result is unanimous with the findings by Nayak and Khare 1993. They found *Euglena*, *Lepocinclis*, *Trachelomonas* and *Phacus* as important Euglenoids due to rich oxidizable organic matter in water lakes of Panna.

Diversity Index

Diversity indices are important tools for various phytoplankton. The species diversity indices decrease with the increase in pollution. Rich diversity of organisms has significant role in the purification process in the pond system. The present study revealed that the DEPZ water bodies were dominated by green, blue green and diatoms. Except Site-A, all the water bodies showed moderate level of pollution with less diversity during all the four seasons and highest possible equal number of different species whereas, during autumn all the sites showed lowest possible equal number of different species (Table 7). Site-A showed heavy pollution with very less diversity, whether only during monsoon there was less diversity with moderate pollution level. So lesser the diversity greater is the impact of pollution. In the present study there is less diversity of phytoplankton in the DEPZ adjacent water bodies and control water body and that is might be due to high impact of pollution. The waste stabilization pond system represented less diversity of phytoplanktons and also dominated by green and blue green algae which are adapted to polluted waters (Shanthala *et al.* 2009





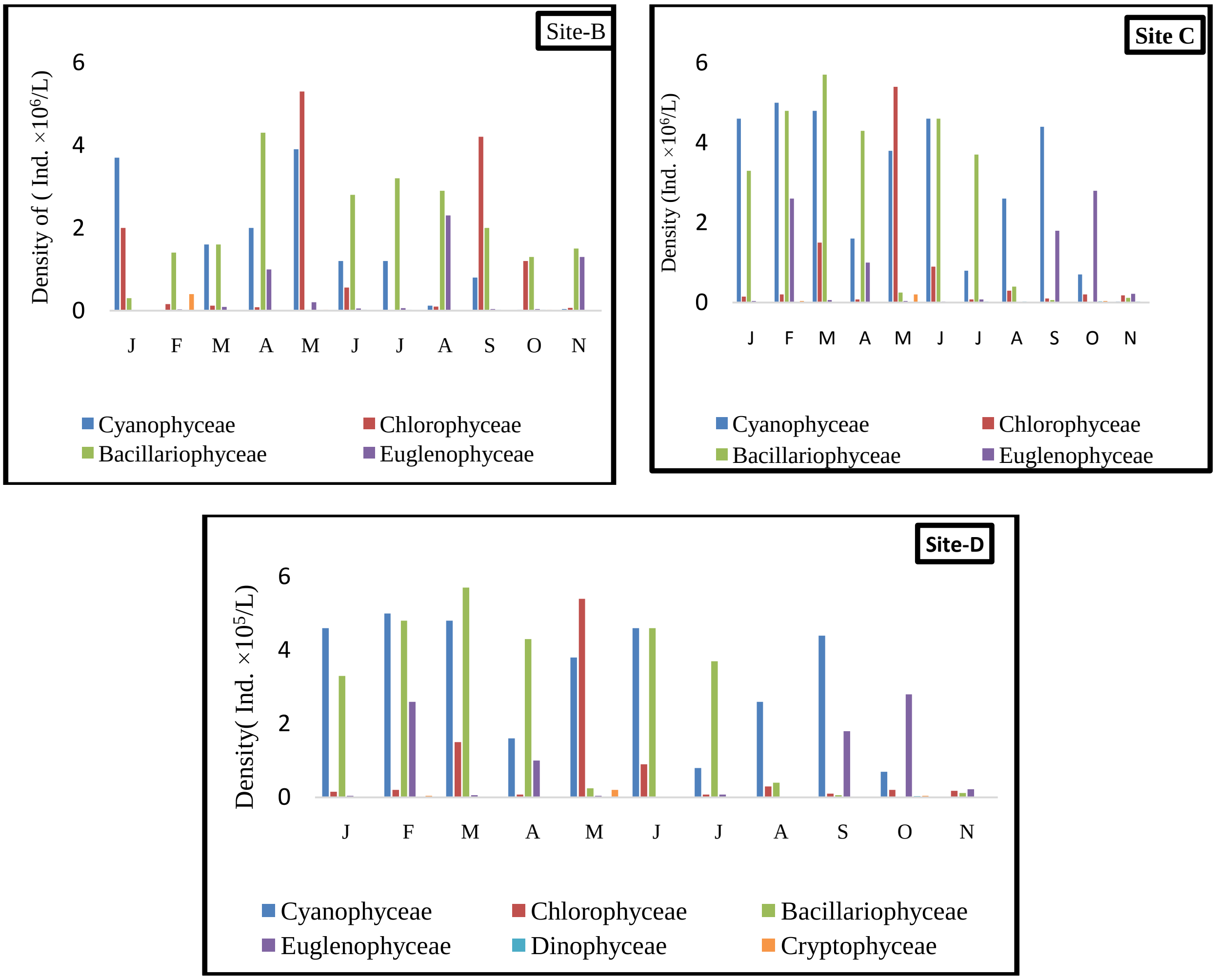


Fig. 6: Phytoplankton density of the studied sites at the generic level

Table 7: Season-wise diversity indices of phytoplankton dring January 20018 – November 2018.

Season	Shannon – wiener Index					Simpson Index				
	Ctrl	Sit-A	Site-B	Site-C	Site-D	Ctrl	Sit-A	Site-B	Site-C	Site-D
Summer	1.357	0	1.341	1.870	1.511	0.685	0	0.679	0.808	0.703
Monsoon	1.413	1.695	1.651	1.595	1.804	0.700	0.762	0.772	0.734	0.786
Autumn	1.279	0	1.325	1.032	0.658	0.666	0	0.560	0.572	0.237
Winter	1.897	0	1.537	1.985	1.345	0.800	0	0.740	0.820	0.676

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