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Seasonal variations of phytoplankton in Mahanadi estuary, east coast of India

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Seasonal variations of phytoplankton and chlorophyll-a along with its environmental variations including nutrients were studied from June-2004 to March-2007. Samples were collected in three different seasons pre-monsoon (May-June), post-monsoon (October-November) and summer (February-March) from the Mahanadi estuary. Seventy seven species of phytoplankton were encountered during the study period of which, diatoms (Bacillariophyceae) was the dominant group followed by dinoflagellates (Dinophyceae) and cyanobacteria (Cyanophyceae). Higher phytoplankton counts and chlorophyll-a concentrations were recorded in post-monsoon season. Nutrient concentration was also very high in the above season as compared to other two seasons. Cyanobacteria population was more during post-monsoon season. Positive correlations of phytoplankton, with chlorophyll-a and dissolved oxygen were recorded in all three sampling seasons. Positive correlation of phytoplankton population with Chl-a, DO, NO_2-N, NH_4-N indicated that the phytoplankton population in the estuary is controlled by above nutrients. Diatoms are dependent on NO_2-N and NH_4-N, dinoflagellates depend on NO_2-N and SiO_4. Cyanobacteria in the estuary depend on NO_2-N, NH_4 and PO_4.

[**Keywords:** Phytoplankton; species abundance; chlorophyll-a; water quality; Mahanadi estuary]

Introduction

Estuaries may be specially enriched by nutrients from river water, organic pollution (locally within the estuary or remotely through runoff) and by the entrainment of coastal waters in a subsurface counter-current, transporting nutrients into the estuary[1]. The phytoplankton composition is affected by various environmental factors such as pH, light, temperature, salinity, turbidity and nutrients[2]. Besides, their importance as the primary producers in food webs and ensuring ecological balance, species of phytoplankton are useful indicators of water quality[3,4]. The relative availability of nutrients plays a major role in inducing the community structure of phytoplankton[5-7].

Mahanadi river system is the third largest in the peninsula of India and the largest river in Orissa state. The basin extends over an area of approximately 141,600 km^2, with a total length of 851 km and peak discharge of 44,740 m^3s^{-1} water[8]. There is heavy industrial activity in Paradip, and up stream of Mahanadi estuary. It also receives a large amount of agricultural run-off along its course. Human influences are pronounced at Sambalpur, Cuttack and Paradip where the proliferation of industries and sewage discharges are prominent. The nutrient rich water after traveling all the distances enters Bay of Bengal through the Mahanadi river mouth at Paradip. A lot of work has been carried out on the water quality of the Mahanadi estuarine system[9-12], however, literatures on phytoplankton composition and Chlorophyll-a from Mahanadi are very scanty. The present investigation deals with the seasonal variations of phytoplankton, chlorophyll-a and their relationship with physico-chemical parameters in the estuary.

Materials and Methods

Water samples were collected from Mahanadi river mouth as a station (Lat. 20° 17′ 16″ and Long. 86° 42′ 28″) during 2004-05 to 2006-07 (Fig. 1). The surface sampling was carried out at an interval of 3 hrs in three different seasons such as, pre-monsoon (May-June), post-monsoon (October-November) and summer (February-March). Surface water temperature, pH were measured *in situ* by using WTW Kit. Salinity, total suspended solid (TSS), dissolved oxygen (DO) were measured by standard methods[13]. The samples for the analysis of nutrients and Chl-a were preserved in icebox and brought to the laboratory and analysed immediately. For phytoplankton estimation, the samples were preserved with lugol's iodine solution and brought to laboratory for identification and counting under microscope. The

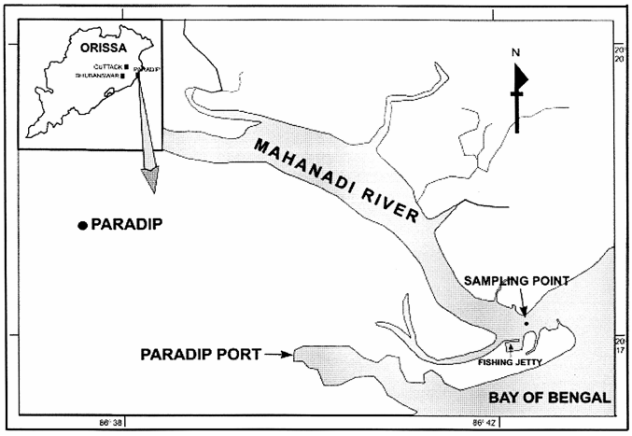

Fig. 1—Sampling location of Mahanadi estuary

water samples were filtered through GF/C filter paper and the filtrates were taken for the analysis of nutrients and the residues for Chl-a analysis. The nutrient contents (NO_3-N, NO_2-N, NH_4-N, SiO_4-Si, PO_4-P) were determined in duplicate samples by UV visible spectrophotometer (Perkin-Elmer model No. Lambda 35) as described in standard methods of seawater analysis[14]. Measurement of the acetone extract was done by means of a UV-visible spectrophotometer for Chlorophyll-a analysis[15]. The phytoplankton species were identified by biological microscope and cells counted with the help of Sedgwick-Rafter counting chamber taking 1 ml of sample aliquot as per the phytoplankton identification protocol[16-17]. The phytoplankton species identified belongs to three taxonomic classes viz. diatoms (Bacillariophyceae), dinoflagellates (Dinophyceae) and cyanobacteria (Cyanophyceae). In total 36 no. of samples for each parameter were collected.

Results and Discussion

Environmental parameters

Seasonal environmental variables are presented in Table 1. The water temperature during study period, varied from 27.18±0.77°C to 30.85±0.31°C, while the pH varied between 7.68±0.07 and 8.39±0.04. The temperature and pH values were found to be lower during the post-monsoon seasons. The DO values ranged between 6.57±0.44 mg/l and 7.81±0.57 mg/l. Salinity values ranged between 3.09±2.01‰ and 26.69±2.54‰. The lowest and highest values are associated with flood and ebb tides. TSS varied from 6.73±0.83 mg/l to 28.07±19.07 mg/l and higher value was recorded during post-monsoon.

Table 1—Environmental conditions of Mahanadi estuary

	Pre-monsoon M ± SD	Post-monsoon M ± SD	Summer M ± SD
	Year 2004-05		
Temp (°C)	30.5 ± 0.28	24.92 ± 0.66	27.88 ± 0.57
PH	8.20 ± 0.07	7.68 ± 0.07	7.82 ± 0.10
DO (mg/l)	6.66 ± 0.29	6.76 ± 0.81	6.57 ± 0.44
Salinity (ppt)	21.07 ± 8.55	3.09 ± 2.01	14.44 ± 4.91
TSS (mg/l)	6.73 ± 0.83	19.67 ± 8.03	7.02 ± 1.40
Phytoplankton (no/l)	31615 ± 6557	40880 ± 21863	35695 ± 13958
Chl-a (mg/m^3)	1.95 ± 0.59	2.28 ± 1.22	1.43 ± 0.34
	Year-2005-06		
Temp (°C)	30.85 ± 0.31	27.43 ± 1.07	28.53 ± 0.83
PH	8.07 ± 0.05	7.91 ± 0.19	7.95 ± 0.05
DO (mg/l)	7.12 ± 1.36	7.78 ± 0.36	7.65 ± 0.29
Salinity (ppt)	9.34 ± 6.4	3.11 ± 5.82	18.38 ±8.35
TSS (mg/l)	12.83 ± 5.41	28.07 ±19.07	20.71 ± 8.58
Phytoplankton (no/l)	41280 ± 10192	44275 ± 16575	29961 ± 5981
Chl-a (mg/m^3)	1.99 ± 0.48	6.07 ± 1.20	2.12 ± 0.50
	Year. 2006-07		
Temp (°C)	29.8 ± 0.83	27.98 ± 0.64	24.92 ± 0.66
PH	8.15 ± 0.08	7.98 ± 0.56	8.39 ± 0.04
DO (mg/l)	7.81 ± 0.57	7.25 ± 0.77	7.27 ± 0.80
Salinity (ppt)	9.60 ± 6.83	10.92 ± 6.49	26.69 ± 2.54
TSS (mg/l)	13.63 ± 4.80	23.99 ± 8.55	8.04 ± 2.02
Phytoplankton (no/l)	43072 ± 10366	51089 ± 14259	40732 ± 6476
Chl-a (mg/m^3)	4.09 ±1.89	3.71 ± 0.20	2.47 ± 0.25

M = Mean, SD = Standard deviation

Nutrients

Seasonal variations of nutrient contents in Mahanadi estuary are given in Table 2. Dissolved inorganic nitrogen (DIN = NO_3-N+NO_2-N+NH_4-N) concentration during the sampling period ranged between 4.29±1.02 µmol/l and 11.07±1.32 µmol/l. Higher DIN concentrations were recorded during the post-monsoon seasons followed by summer and pre-monsoon. In pre-monsoon and summer seasons, the DIN concentration is dominated by NO_3-N, while in post-monsoon NH_4-N is the major constituent. The PO_4-P concentration during the study period varied from 2.97±1.42 µmol/l to 20.97±5.61 µmol/l and its concentration was generally higher in summer. The highest value recorded in post-monsoon of 2004-05 could be due to the effluent discharge from

Table 2—Seasonal variation of nutrient content (µmol/l) in Mahanadi estuary

	Pre-monsoon M ± SD	Post-monsoon M ± SD	Summer M ± SD
	2004-05		
NO_2-N	0.38 ± 0.08	0.81 ± 0.23	0.44 ± 0.08
NO_3-N	4.20 ± 0.27	2.93 ± 0.70	5.64 ± 0.74
NH_4-N	1.39 ± 0.39	7.32 ± 0.54	3.90 ± 1.45
DIN	5.96 ± 0.74	11.07 ± 1.32	9.97 ± 2.13
PO_4-P	2.97 ± 1.42	20.97 ± 5.61	9.76 ± 3.74
SiO_4-Si	2.70 ± 0.40	3.82 ± 0.56	4.28 ± 1.90
	2005-06		
NO_2-N	0.63 ± 0.25	0.44 ± 0.22	0.28 ± 0.15
NO_3-N	2.14 ± 0.23	3.38 ± 0.52	2.40 ± 0.77
NH_4-N	4.82 ± 0.97	4.99 ± 0.80	1.85 ± 0.60
DIN	7.59 ± 1.42	8.18 ±1.41	4.53 ± 1.49
PO_4-P	3.41 ± 0.38	4.41 ± 1.08	8.04 ± 1.02
SiO_4-Si	3.43 ± 0.19	3.99 ± 0.81	7.48 ± 3.19
	2006-07		
NO_2-N	0.62 ± 0.27	0.55 ± 0.11	0.94 ± 0.22
NO_3-N	1.86 ± 0.46	5.14 ± 0.65	2.63 ± 0.34
NH_4-N	1.81 ± 0.39	3.18 ± 0.47	4.45 ± 0.67
DIN	4.29 ± 1.02	8.86 ± 1.18	8.01 ± 1.22
PO_4-P	3.11 ± 0.58	6.81 ± 1.25	7.14 ± 0.83
SiO_4-Si	4.66 ± 0.12	5.21 ± 0.62	8.22 ± 0.69

phosphatic industries. The dissolved SiO_4-Si concentration was higher in summer and the values varied between 2.70±0.40 µmol/l and 8.22±0.69 µmol/l.

Phytoplankton

Seventy seven species of phytoplankton were encountered during the investigated period from Mahanadi estuary. It consists 63 (81.8%) species of bacillariophyceae, 8 (10.4%) species from dinophyceae and 6 (7.8%) species of cyanophyceae. The diatoms were the most dominant group during the entire study period (Table 3). The total number of phytoplankton species in the estuary was recorded always higher during the post-monsoon season. The phytoplankton abundance in Mahanadi estuary varied from 31615±6557 to 43072±10366 no/l in pre-monsoon, 40880±21863 to 51089±14259 no/l in post-monsoon and 29961±5981 to 40732±6476 no/l in summer. The species recorded during the study period and their seasonal abundance are presented in Table 4. The major diatoms species are *Asterionella japonica, Biddulphia heteroceros, Coscinodiscus gigas, Melosira sulcata, Rhizosolenia alata, Skeletonema costatum, Leptocylindrus danicus,* and *Thalassiothrix longissima*. The dinoflagellates recorded were *Ceratium tripos, Dinophysis caudata, Gonialux minima, Noctiluca miliaris, Peridinium sp., Prorocentrum micans* while cyanobacteria was represented by *Anabaena sp., Mycrocystis sp., Oscillatoria sp.* and *Trichodesmium sp.* Higher phytoplankton population during post-monsoon period was attributed to availability of higher nutrients (DIN concentration). The influence of nutrients on phytoplankton growth has also been reported from southern part of the Orissa at Gopalpur[18]. The variations in different seasons could be due to the temperature and nutrients in the estuarine water[19-20]. A few pollution indicating species, viz. *Anabaena sp., Chlorococcus sp., Dinophysis sp., Gymnodium sp., Mycrocystis sp., Nitzschia seriata, Oscillatoria sp., Prorocentrum micans, Phaeocystis sp.,* and *Trichodesmium sp.* were also recorded from the Mahanadi estuary. Higher number of pollution indicator species were recorded during the post-monsoon season of 2004-05 (Table 4). Phytoplankton counts in summer was

Table 3—Phytoplankton composition recorded from the Mahanadi estuary

Taxonomic Group	Sampling Period					
	Pre-monsoon		Post-monsoon		Summer	
	No	%	No	%	No	%
	2004-05					
Bacillariophyceae	18	75.00	22	75.86	15	71.43
Dinophyceae	2	8.33	2	6.90	2	9.52
Cyanophyceae	4	16.67	5	17.24	4	19.05
Total	24	100.00	29	100.00	21	100.00
	2005-06					
Bacillariophyceae	17	85.00	27	87.10	27	93.10
Dinophyceae	3	15.00	2	6.45	2	6.90
Cyanophyceae	0	0.00	2	6.45	0	0.00
Total	20	100.00	31	100.00	29	100.00
	2006-07					
Bacillariophyceae	26	89.66	27	81.82	24	80.00
Dinophyceae	2	6.90	4	12.12	5	16.67
Cyanophyceae	1	3.45	2	6.06	1	3.33
Total	29	100.00	33	100.00	30	100.00

No = Number

Table 4—Seasonal variations of phytoplankton species recorded in Mahanadi estuary

Species	2004-05			2005-06			2006-07		
	PRM	POM	SUM	PRM	POM	SUM	PRM	POM	SUM
Diatoms									
1. *Amphora costatum*	-	+	-	-	-	+	+	-	+
2. *Amphora lineolata*	+	-	-	-	-	+	-	+	-
3. *Asterionella japonica*	-	-	-	-	-	-	+	-	+
4. *Aulacodiscus sp.*	-	-	-	+	-	-	-	-	-
5. *Auliscus reticulatus*	-	-	-	-	+	+	+	+	-
6. *Bacillaria paradoxa*	-	+	+	-	-	+	+	+	+
7. *Bacteriastrum hyalinum*	-	-	-	-	-	+	-	+	+
8. *Biddulphia aurita*	-	-	+	-	+	-	+	-	-
9. *Biddulphia heteroceros*	-	-	-	+	-	+	+	+	+
10. *Biddulphia mobiliensis*	+	+	-	-	+	+	-	-	-
11. *Biddulphia sinensis*	-	-	-	-	-	-	-	+	-
12. *Caloneis elongata*	+	-	-	-	-	-	-	-	-
13. *Campylodiscus sp.*	-	-	+	+	+	-	-	+	-
14. *Chaetoceros elongata*	+	-	-	-	+	+	-	-	-
15. *Chaetoceros lorenzianus*	-	+	-	-	+	+	+	+	+
16. *Climacosphaenia moniligera*	-	+	-	+	-	+	+	-	+
17. *Cocconeis sp.*	-	+	-	-	-	-	-	-	-
18. *Coscinodiscus centralis*	-	-	+	+	+	+	-	-	-
19. *Coscinodiscus conscinnus*	-	-	-	-	+	+	+	-	-
20. *Coscinodiscus gigas*	+	+	+	-	+	+	-	+	+
21. *Coscinodiscus hyalinum*	-	-	+	+	+	-	-	-	-
22. *Coscinodiscus linearis*	-	-	+	+	-	-	-	-	-
23. *Coscinodiscus marginatus*	-	-	+	+	+	-	-	-	-
24. *Coscinodiscus radiatus*	-	-	-	+	-	-	-	-	-
25. *Cosmarium reniforme*	+	-	-	-	-	-	-	-	-
26. *Cymbella marina*	-	+	-	-	-	-	-	-	-
27. *Cyclotella striata*	-	-	-	-	+	-	-	+	-
28. *Diploneis penduliformes*	-	-	-	-	+	-	-	-	-
29. *Ditylum brightwelli*	+	+	-	+	+	-	+	-	+
30. *Ditylum sol*	-	-	-	+	-	+	-	+	+
31. *Eucampia cornuta*	+	+	-	-	-	-	+	+	+
32. *Fragileria ocenica*	-	-	-	-	+	-	+	-	-
33. *Guinardia sp.*	-	-	-	-	-	-	-	+	-
34. *Gyrosigma balticum*	-	-	-	-	+	+	-	+	+
35. *Hemidiscus sp.*	-	-	-	-	-	-	-	-	+
36. *Hyalodiscus sp.*	+	-	-	-	-	-	-	-	-
37. *Leptocylindrus danicus*	-	+	+	+	+	+	+	+	+
38. *Licmophora sp.*	-	-	-	-	-	-	-	-	+
39. *Melosira sulcata*	+	+	-	-	+	+	+	+	+
40. *Navicula clavata*	-	+	-	+	+	+	+	-	+
41. *Navicula pygmaea*	+	-	+	-	-	-	+	+	-
42. *Nitzschia pungens*	+	-	-	-	-	-	-	-	-
43. *Nitzschia closterium*	-	+	-	-	+	+	-	-	+
44. *Nitzschia seriata**	-	-	+	-	+	-	+	+	+
45. *Paralia sulcata*	+	+	-	-	+	-	-	+	-
46. *Pinnularia alpina*	+	-	-	-	-	-	-	+	-

(*Contd*)

Table 4—Seasonal variations of phytoplankton species recorded in Mahanadi estuary

Species	2004-05			2005-06			2006-07		
	PRM	POM	SUM	PRM	POM	SUM	PRM	POM	SUM
47. *Planktonella sol*	-	-	-	-	-	+	-	-	-
48. *Pleurosigma angulatum*	+	-	+	-	-	+	+	-	+
49. *Pleurosigma normanii*	-	+	+	-	-	+	-	-	-
50. *Rhizosolenia alata*	+	+	-	-	+	-	-	+	-
51. *Rhizosolenia setigera*	-	-	-	-	-	+	+	+	+
52. *Scendesmus sp.*	+	-	-	-	-	-	-	-	-
53. *Schroederella sp.*	-	-	+	-	-	-	-	-	-
54. *Skeletonema costatum*	+	+	-	+	-	+	+	+	+
55. *Stephanopyxis turris*	-	-	-	+	-	-	-	+	-
56. *Surirella fluminensis*	-	+	-	+	+	-	+	-	-
57. *Surirella eximia*	-	-	-	-	-	+	-	+	-
58. *Synedra formosa*	-	+	-	-	-	+	-	-	+
59. *Synedra ulna*	-	+	-	-	+	-	+	+	-
60. *Thalassionema nitzschioides*	-	+	-	-	-	-	+	-	-
61. *Thalassiosira gravida*	-	-	+	+	+	-	+	-	-
62. *Thalassiothrix longissima*	-	-	-	-	+	+	+	+	+
63. *Triceratium favus*	-	-	-	-	-	-	+	-	-
Dinoflagellate									
64. *Ceratium longicep*	+	-	-	-	+	+	-	+	+
65. *Ceratium pentagonum*	-	-	+	-	-	-	-	-	-
66. *Dinophysis sp**	-	+	+	-	-	-	-	-	+
67. *Gonialux minima*	-	-	-	-	-	-	+	+	+
68. *Gymnodium sp.*	-	+	-	-	-	-	-	+	-
69. *Peridinium sp.*	-	-	-	+	-	+	-	+	+
70. *Prorocentrum micans**	+	-	-	+	-	-	+	-	+
71. *Noctiluca miliaris*	-	-	-	+	+	-	-	-	-
Cyanobacteria									
72. *Anabaena sp.**	+	+	-	-	-	-	-	+	-
73. *Chlorococcus sp.**	-	+	+	-	-	-	-	-	-
74. *Mycrocystis sp.**	+	-	-	-	+	-	-	-	-
75. *Oscillatoria sp.**	+	+	+	-	-	-	+	+	+
76. *Trichodesmium sp.**	+	+	+	-	-	-	-	-	-
77. *Phaeocystis sp.**	-	+	+	-	+	-	-	-	-

PRM = Pre-monsoon; *POM = Post-monsoon; SUM = Summer; += present; - = absent; * = pollution indicating species*

mainly dominated by S*keletonema costatum* and *Nitzschia sp*. whereas in post-monsoon it was mainly dominated by *Coscinodiscus gigas* and *Thalassiothrix longissima.* Diatoms are considered as a euryhaline and eurythermal phytoplankton group, which grow quickly under estuarine conditions[21]. This is further established in the present study, as the dinoflagellate and cyanobacteria community were relatively much less in abundance than that of diatoms.

Chlorophyll-a

The chlorophyll-a concentration ranged from 1.95±0.59 to 4.09±1.89 mg/m^3, 2.28±1.22 to 6.07±1.20 mg/m^3 and 1.43±0.34 to 2.47±0.15 mg/m^3 in pre-monsoon, post-monsoon and summer seasons respectively (Table 1).

Statistical analysis

Correlation co-efficient matrix is calculated among 16 physico-chemical and biological variables (Table 5).

Table 5—Correlation matrix of various environmental parameters with phytoplankton and Chl-a

	Phyto-plankton	Chl-a	WT	pH	DO	Salinity	NO_2-N	NO_3-N	NH_4-N	PO_4-P	SiO_4-Si	TSS	DIN	Diatoms	Dino-flagellates	Cyano-bacteria
Phytoplankton	1.000															
Chl-a	0.594**	1.000														
WT	-0.225	-0.198	1.000													
pH	-0.038	-0.058	0.010	1.000												
DO	0.289*	0.665**	-0.054	0.225	1.000											
Salinity	-0.493**	-0.496**	-0.184	0.724**	-0.163	1.000										
NO_2-N	0.453**	-0.073	-0.513**	0.256*	-0.095	0.029	1.000									
NO_3-N	0.079	-0.059	-0.118	-0.302*	-0.568**	0.048	-0.325**	1.000								
NH_4-N	0.362**	0.120	-0.465**	-0.488**	-0.244	-0.519**	0.594**	-0.061	1.000							
PO_4-P	-0.018	-0.257*	-0.466**	-0.670**	-0.414**	-0.300*	0.365**	0.092	0.680**	1.000						
SiO_4-Si	-0.067	-0.058	-0.638**	0.358**	0.415**	0.562**	0.235	-0.253*	-0.133	0.046	1.000					
TSS	0.195	0.705**	0.212	0.008	0.536**	-0.188	-0.611 **	0.112	-0.375**	-0.495***	-0.078	1.000				
DIN	0.381 **	0.058	-0.493**	-0.550**	-0.533**	-0.395**	0.388**	0.493**	0.836**	0.642**	-0.233	-0.297*	1.000			
Diatoms	0.961 **	0.577**	-0.018	-0.187	0.279*	-0.657**	0.301 *	0.083	0.343**	-0.048	-0.246	0.219	0.355**	1.000		
Dinoflagellates	0.514**	0.165	-0.655**	0.516**	0.078	0.434**	0.543**	0.192	0.096	-0.117	0.564**	-0.035	0.236	0.291 *	1.000	
Cyanobacteria	0.537**	0.412**	-0.648**	-0.169	0.020	-0.278*	0.574**	0.092	0.483**	0.537**	0.079	-0.092	0.499**	0.390**	0.377**	1.000

*significant at 0.05 level ; **significant at 0.01 level
WT = Water temperature, DO = Dissolved oxygen, TSS = Total suspended Solids, DIN = Dissolved inorganic nitrogen

Phytoplankton has very strong positive correlation with diatoms and the diatoms to be the dominant phytoplankton population. There exists positive correlation of phytoplankton population with chlorophyll-a, NO_2-N, NH_4-N, DIN and Dissolved Oxygen. This proves that the phytoplankton population is generally N-limited. N-limited phytoplankton population was also been reported from coastal Atlantic Ocean and most long island estuaries[22]. Diatoms has strong positive correlation with NO_2-N, NH_4-N and DIN. This related the dependency of the former with the above nutrients. Similarly, cyanobacteria are also dependent on NO_2-N, NH_4-N, DIN and PO_4-P as indicated by strong positive correlation. Negative co-relationship of phytoplankton with salinity suggests that the phytoplankton population is dependent on the nutrient rich fresh water of the river.

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