Journal Home page : www.jeb.co.in ★ E-mail : editor@jeb.co.in

JEB
Journal of Environmental Biology

ISSN: 0254-8704
CODEN: JEBIDP

Impact of water quality on phytoplankton community and biomass in Dhamara estuary east coast of India

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Publication Info

Paper received:
28 August 2012

Revised received:
18 January 2013

Accepted:
03 June 2013

Abstract

Distribution of phytoplankton, productivity and chlorophyll-a concentration in relation to physico-chemical parameters viz. water temperature, pH, total suspended solid, turbidity, dissolved oxygen, biochemical oxygen demand, salinity and nutrients (NO_2-N, NO_3-N, PO_4-P and SiO_4-Si) were studied for pre-monsoon, monsoon and post-monsoon during the year 2005. The major groups of phytoplankton species were diatoms followed by dinoflagellates and other algae. A total of 43 species of phytoplankton comprising 32 diatoms, 6 dinoflagellates and 5 other algae were recorded during the entire study period. The species *Nitzschia*, *Chaetoceros* and *Coscinodiscus* were identified as dominant diatoms group. Higher values of phytoplankton (28612 nos l^{-1}) with high rate of photosynthesis were observed during post-monsoon season, which was responsible for increasing DO (8.72 mg l^{-1}) and pH(8.24) of the water column. R-mode factor analysis revealed that there were two factors or PCs that explained 93.0%, 95.2% and 94.4% of the total variance for pre-monsoon, monsoon and post-monsoon respectively. Generally, the trend distribution of phytoplankton closely followed the distribution of salinity, pH and DO of estuarine water.

Key words

Chlorophyll-*a*, Dhamara estuary, Phytoplankton abundance, Water quality

Introduction.

Phytoplankton diversity and biomass in marine ecosystem account for major contribution of annual production and are responsible for the availability of organic matter and control of energy flow in food web dynamics (Turley *et al*., 2000). Rapid industrialization and human settlement for livelihood along the coasts causes voluminous disposal of the anthropogenic waste into nearby coastal environment. This is a major threat to the ecosystem, and results in alteration of the coastal phytoplankton and Chl-*a* dynamics (Pedersen and Borum, 1996). The study of seasonal distribution of phytoplankton , Chl-*a* pigment and the respective environmental variables help us to understand the dynamics of the ecosystem and provide information on secondary and tertiary population. Phytoplankton composition is affected by different environmental factors such as pH, light and temperature (Buzzi, 2002). A few study of seasonal variation of phytoplankton pigments are available only at the mouth of Mahanadi river estuary (Mishra *et al*., 2009; Naik *et al*., 2009). However, survey of literature suggests that very less attention has been paid on the phytoplankton dynamics in Dhamara estuary. Hence, the present study was carried out to understand the functioning of Dhamara estuarine ecosystem on phytoplankton density, diversity and biomass and to record the changes against the different kinds of stresses forced by environmental and anthropogenic factors.

Materials and Methods

Brahmani and Baitarani rivers combine together to form Dhamara river before meeting the Bay of Bengal. Brahmani receives effluents from most of the major industries of Rourkela, Angul and Talcher industrial areas of the Orissa state. As a result, Brahmani water does not represent a healthy aquatic ecosystem. The river Baitarani receives mostly agricultural runoff and domestic effluents. The Dhamara estuary is one of the sensitive ecosystem due to the association of Bhitarakanika marine sanctuary, crocodile breeding center and an important olive ridley (sea turtle) nesting beach. Around Dhamara river mouth area luxuriant mangroves vegetation is present.

Water samples were collected from an estuarine point of Dhamara river mouth (20º 46' 52" N latitude and 86º 57' 21" E longitude) during three different seasons viz. pre-monsoon, monsoon and post-monsoon (Fig.1). This work was carried out before the dredging of Dhamara port. The samples were collected in triplicate, 4 times a day, with 3hrs duration in order to examine the tidal variation. The onboard measurements of pH, water temperature, salinity and turbidity were carried out immediately after the collection of the sample, using a battery operated Water Quality Checker (Model No - WQC 22A). The DO and BOD_5 were measured by using Winkler's method and the BOD was calculated from the difference of DO concentration after 5 days of incubation at 20ºC and was analyzed following standard guidelines and procedures (APHA, 2005).

Nutrients such as nitrite (NO_2-N), nitrate (NO_3-N), phosphate (PO_4-P) and silicate (SiO_4-Si) were analyzed following standard guidelines and procedures (Grassholf *et al.*, 1999). Each analysis was done in triplicate and the mean value was taken for consideration. Cellulose nitrate membrane filters of pore size 0.45 μ were used for determination of TSS.

One litre of surface water samples were collected in pre-cleaned polythene bottle and fixed with Lugol's iodine solution and subsequently preserved in 3% neutralized formaldehyde for qualitative and quantitative estimates of phytoplankton. Each sample was allowed to stand for 48 hrs for sedimentation. The supernatant solution was siphoned out to concentrate the volume to exactly 100 ml. From this concentrated aliquot, 1 ml was taken

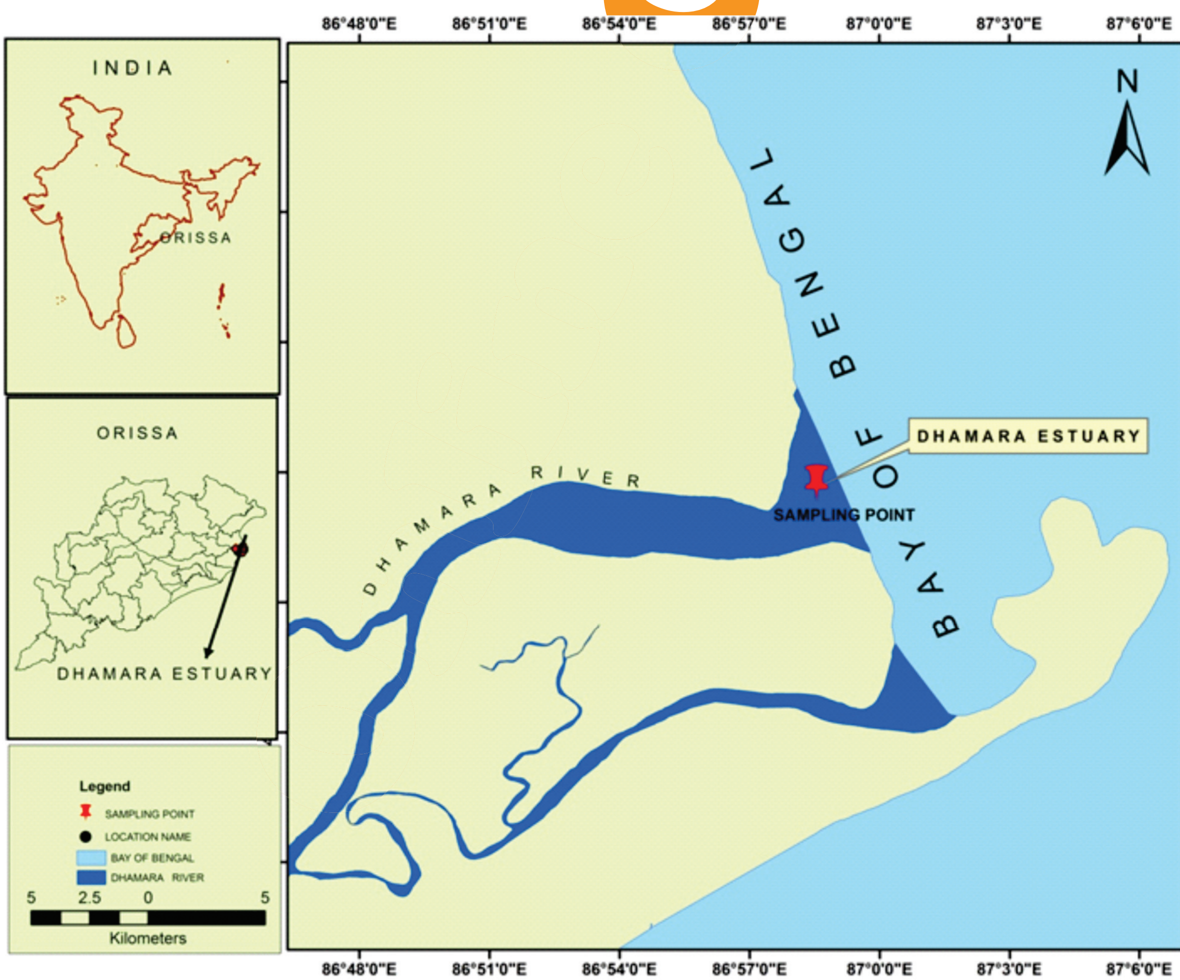

Fig. 1 : Map showing the sampling point in Dhamara estuary

on a Sedgwick Rafter cell and screened under a binocular research microscope (Leitz ME/MM/38) and organisms were counted, species wise. The population density is presented as Cells l^{-1} Identification of phytoplankton was made by using standard phytoplankton identification manuals (Desikachary 1987; Tomas 1996).

Light and dark bottle method was adopted for the estimation of primary productivity. The Chl-*a* was estimated by a doubled beam UV-visible spectrophotometer (Perkin Elmer 35) following standard procedure of Parson *et al*. (1984). Statistical analyses like correlation matrix and R-mode factor analysis were carried out for 14 parameters in three seasonal data sets using SPSS 10.0 statistical packages.

Results and Discussion

The tidal variation of water quality parameters during three different seasons was observed (Table.1). The water temperature varied from 27.6 to 33.8º C, 24.1 to 27.9º C and 20.4 to 22.5º C during pre-monsoon, monsoon and post-monsoon respectively. The trend of variation of water temperature with respect to tide almost followed the time of collection and a significant seasonal change was marked.

The pH varied from 7.45 to 8.42, 7.82 to 8.35 and 8.12 to 8.54 for pre monsoon, monsoon and post monsoon, respectively. The highest value was always associated with high tide condition during all three seasons. There was no remarkable seasonal difference in pH of Dhamara estuarine water. However, a slightly higher value was observed during post- monsoon period. This was due to high rate of photosynthesis during winter season. Higher alkaline condition was due to uptake of CO_2 from the water column (Subba Rao *et al*., 1981; Panda *et al*., 1989; Nayak *et al*., 2004).

Photosynthesis activity, river runoff, tidal variation as well as waves due to wind control the dissolved oxygen concentration in an estuarine ecosystem. Dissolved oxygen also indicated the health of the ecosystem. Dissolved oxygen of Dhamara estuary ranged from 6.14 to 7.92 mg l^{-1} , 7.46 to 8.12 mg l^{-1} and 7.96 to 8.72 mg l^{-1} for three different seasons respectively. Slightly lower values were associated with pre-monsoon and higher values with post-monsoon. The higher DO values during post-monsoon may be related to the high rate of photosynthesis. The highest and lowest peak DO values were associated with flood and ebb tide respectively during pre-monsoon and monsoon periods.

The BOD varied from 1.01 to 3.10 mg l^{-1}, 1.48 to 2.10 mg l^{-1} and 1.45 to 2.05 mg l^{-1} for three different seasons, respectively. The highest value (3.10 mg l^{-1}) was associated with low tide condition of pre-monsoon season, which might cause environmental stress to aquatic lives. The decomposition of organic wastes at fishing jetty present in the upstream of Dhamara estuary was mainly responsible for increasing BOD at the study area.

Salinity is considered as the most important factor in estuarine ecosystem. The salinity value ranged from 16.8 to 28.46 PSU, 2.3 to 7.94 PSU and 8.5 to 18.7 PSU in pre-monsoon, monsoon and post-monsoon respectively. From the salinity variation, it was observed that the fresh water or river influx was dominated during all the seasons, especially the monsoon period. The highest and the lowest values of salinity followed the same trend of dissolved oxygen.

The nutrients like NO_2, NO_3, PO_4 and SiO_4 varied from 0.48 to 5.68 mmol l^{-1}, 1.45 to 7.31 mmol l^{-1}, 0.68 to 3.26 mmol l^{-1}, and 1.25 to 12.8 mmol l^{-1}, respectively. The NO_2, NO_3 and PO_4 showed a similar trend of variation, where much higher and lower concentrations were associated with monsoon and post-

Table 1 : Seasonal and tidal variation of phytoplankton population, chlorophyll-*a*, primary productivity along with water quality parameters in Dhamara estuary

	Date	Time hrs	Tide	WT (ºC)	pH	TSS ($mg\ l^{-1}$)	Turbidity (NTU)	DO ($mg\ l^{-1}$)	BOD ($mg\ l^{-1}$)	Salinity (PSU)	NO_2 ($\mu mol\ l^{-1}$)	NO_3 ($\mu mol\ l^{-1}$)	PO_4 ($\mu mol\ l^{-1}$)	SiO_4 ($\mu mol\ l^{-1}$)	Phytp. (Cells l^{-1})	Chl.a $mg\ m^{-3}$	PP (mg C $m^{-3}hr^{-1}$)
Pre-monsoon	26.05.05	7.00	Low	27.6	7.45	279.2	54	6.14	3.1	16.82	3.21	3.47	2.56	2.85	11540	0.54	27.42
		10.00	Mid	29.1	7.82	146.8	33	6.75	1.58	20.4	1.58	2.12	2.24	2.16	13230	0.92	23.26
		13.00	High	33.8	8.42	68.32	14	7.92	1.12	28.46	1.12	1.98	1.02	1.25	16450	1.78	30.14
		16.00	Mid	32.5	8.11	245.3	41	7.01	2.05	24.1	2.05	2.62	1.68	1.86	12360	0.82	26.36
Monsoon	08.07.05	6.30	Low	24.1	7.82	714	456	7.46	2.1	2.3	5.68	7.31	3.26	12.8	15620	1.12	30.42
		9.30	Mid	26.7	7.96	464	382	7.68	1.57	5.7	4.58	6.57	2.78	10.2	18240	1.68	24.56
		12.30	High	27.9	8.35	198	244	8.12	1.6	7.94	4.12	3.84	2.21	8.57	21346	2.24	34.84
		15.30	Mid	26.1	8.11	364	287	7.72	1.48	6.7	4.62	4.87	2.12	9.48	16860	1.56	27.14
Post-monsoon	07.10.05	7.30	Low	20.4	7.12	312	186	8.1	1.78	8.5	1.14	2.98	1.16	4.24	21462	2.29	14.45
		10.30	Mid	22.5	7.86	256	112	8.35	2.05	12.5	1.23	2.62	1.01	3.75	23246	2.42	16.71
		13.30	High	25.4	8.24	92.12	76	8.72	1.68	18.7	0.48	1.45	0.68	2.64	28612	2.76	27.82
		16.30	Mid	25.1	8.12	138	92	7.96	1.45	16.2	1.26	2.24	0.84	2.72	24568	2.31	21.32

monsoon seasons respectively. The higher concentrations during the monsoon seasons were related to agricultural run-off through flood water (Panda *et al*., 1989), land drainage and precipitation (Upadhyay 1988; Das *et al*., 1997; Sundaray *et al*., 2006). Uptake of nutrients by phytoplankton, as well as high primary productivity and Chl-*a* content were responsible for lowering nutrient concentration during post-monsoon season. The silicate concentration showed remarkable higher values during monsoon, probably on account of the input of more siliceous sediments gathered from its upstream catchments (Pai and Reddy, 1981; Sharma and Ghose, 1987; Gouda and Panigrahy, 1992; Bhattacharya *et al*., 2002). The lower values of silicate during pre-monsoon might be related to high biological productivity uptake by diatoms and biological removal of dissolved silicates by adsorption onto suspended solids at higher salinity values (Desouza *et al*., 1981; Sundaray *et al*., 2006). Besides the seasonal variation of nutrients a well-defined tidal variation was marked.

Turbidity and TSS showed a similar pattern of variation, where monsoon showed much higher values. The turbidity and TSS ranged from 14 to 456 NTU and 68.3 to 714 mg l^{-1} respectively for all three seasons. The higher values of TSS during monsoon reflected high rate of catchments erosion in the upstream of Dhamara river.

The phytoplankton population varied from 11540 to 16450 cells l^{-1}, 15620 to 21346 cells l^{-1} and 21462 to 28612 cells l^{-1} during pre-monsoon, monsoon and post- monsoon periods respectively. The primary productivity varied from 23.26 to 30.14 mgC m^{-3} hr^{-1}, 24.56 to 34.84 mgC m^{-3} hr^{-1} and 24.45 to 37.82 mgC m^{-3} hr^{-1} during pre-monsoon, monsoon and post-monsoon periods respectively. The Chl-*a* concentration revealed wide seasonal as well as tidal variation. It varied from 0.54 to 1.78 mg m^{-3}, 1.12 to 2.24 mg m^{-3} and 2.29 to 2.76 mg m^{-3} for pre-monsoon, monsoon and post-monsoon respectively. Always the higher values were associated with high tide condition. Relatively higher values were also observed during post-monsoon reflects the higher phytoplankton productivity. The tidal variation of Chl-*a* content during post-monsoon was insignificant and a reverse condition was marked during pre-monsoon. The phytoplankton population showed a positive correlation with the Chl-*a* concentration (Fig.2). The total number of species encountered during the study period were 43. The diatoms were found to be dominant phytoplankton group through out the study period and have prime importance as primary producers since they are able to thrive successfully in the oligotrophic waters.

A total of 43 species of phytoplankton were recorded from the area of which 32 belonged to diatoms, 6 to dinoflagellates and 5 to other algae (Table 2). *Nitzschia, Chaetoceros* and *Coscino-discus* were identified as dominant diatoms genera. The diatoms species *Planktonell sol, Thalassionema nitzschioides, Chaetoceros compressus, Leptocylindrus danicus, Skeletonema costatum* and the dinoflagellate species *Prorocentrum micans* and *Ceratium furca* are typical members of warm water phytoplankton.

In order to establish the relationships between phytoplankton population and other physico-chemical and

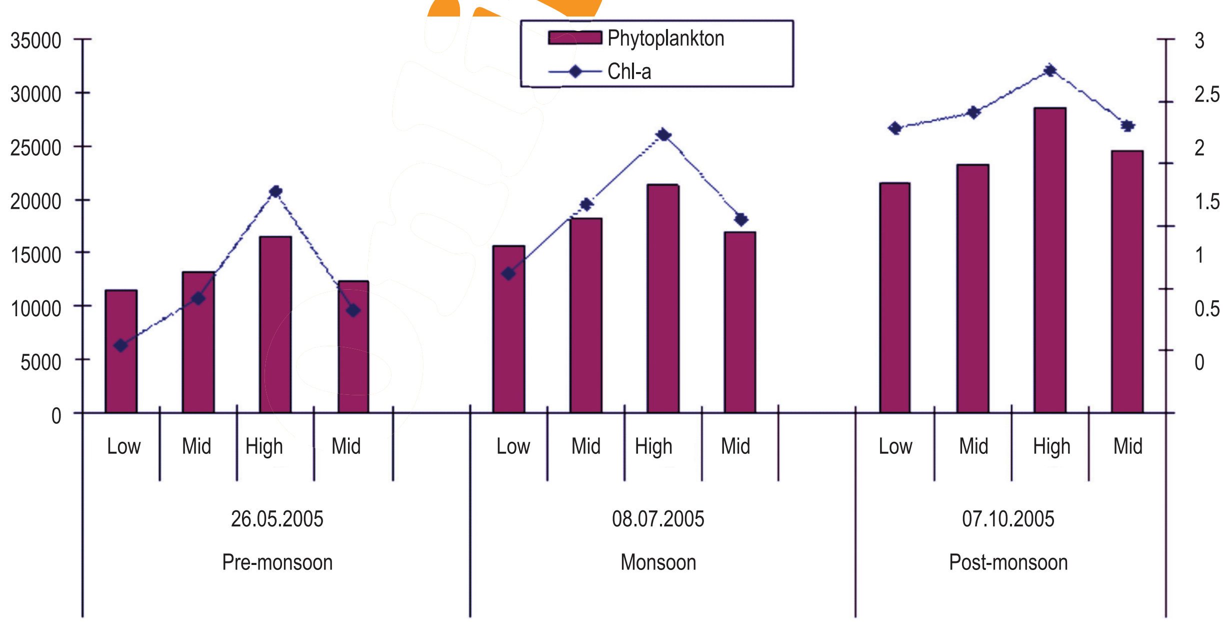

Fig. 2 : Seasonal variation of phytoplankton and chlorophyll-*a* concentration in the Dhamara estuary

biological parameters in an estuarine environment, R-mode varimax rotated factor analyses are calculated for three seasonal data were set separately. The varimax rotated factor analyses were calculated using cumulative variance greater than 80% and sorted by results having values greater than 0.6 being considered significant influences towards the bio-geochemical processes (Sahu *et al*., 1998; Panda *et al*., 2006).

Correlation coefficient measures the strength of relationship between variables. During pre-monsoon, phytoplankton population was positively correlated with DO, Chl-*a*, pH, salinity, water temperature and primary productivity and negative relationships with BOD, all nutrients parameters as well as turbidity and TSS (Table 3). Similar trend of variation was also observed during the other two seasons. Positive correlation of DO with both phytoplankton population and Chl-*a* concentration gives a clear picture that the DO, pH, salinity and temperature in the estuary played a major role on the photosynthetic activity of the phytoplankton (Smyda 1990; Buzzi 2002).

Due to complexity of the relationship, it was difficult to draw clearer conclusion directly. However, the use of factor analysis was able to explain the structure of correlations in more detail.

Table 2 : Correlation matrix of phytoplankton population, chlorophyll-a, primary productivity and water quality parameters

	WT	pH	TSS	Turbidity	DO	BOD	Salinity	NO_2	NO_3	PO_4	SiO_4	Phyp.	Chl a	PP
WT	1.00													
pH	.978*	1.00												
TSS	-0.58	-0.73	1.00											
Turbidity	-0.76	-0.87	.971*	1.00										
DO	0.93	.977*	-0.84	-0.94	1.00									
BOD	-0.73	-0.86	0.92	.953*	-0.88	1.00								
Salinity	.979*	.996**	-0.73	-0.87	.984*	-0.83	1.00							
NO_2	-0.74	-0.86	0.91	0.95	-0.88	1.000**	-0.83	1.00						
NO_3	-0.65	-0.79	0.90	0.91	-0.81	.990**	-0.75	.992**	1.00					
PO_4	-.97*	-.981*	0.71	0.86	-.98*	0.78	-.994**	0.78	0.69	1.00				
SiO_4	-.95*	-.95**	0.80	0.92	-.99*	0.90	-.989*	0.90	0.84	.971*	1.00			
Phyp.	0.73	0.83	-0.95	-.975*	0.93	-0.86	0.85	-0.85	-0.79	-0.86	-0.87	1.00		
Chl-a	0.79	0.87	-0.92	-.971*	.956*	-0.86	0.89	-0.85	-0.78	-0.90	-0.91	.996**	1.00	
PP	0.54	0.47	-0.27	-0.38	0.54	-0.11	0.54	-0.10	0.03	-0.63	-0.44	0.55	0.59	1.00

*Correlation is significant at the 0.05 level; **Correlation is significant at the 0.01 level.

Table 3 : R-mode factor analysis in different seasons with rotated component matrix

Pre-monsoon variables	F1	F2	Monsoon variables	F1	F2	Post-monsoon variables	F1	F2
No_3	0.993		BOD	0.977		SiO_4	0.972	
No_2	0.993		SiO_4	0.969		WT	-0.957	
Turbidity	0.901		Salinity	-0.967		TSS	0.929	
SiO_4	0.880		No2	0.953		Salinity	-0.896	
BOD	0.870		TSS	0.918		PO_4	0.866	
TSS	0.862		PO_4	0.914		pH	-0.865	
pH	-0.840		WT	-0.888		Turbidity	0.842	
DO	-0.837		Turbiity	0.882		PP (mgC m-3 hr-1)	-0.790	
Salinity	-0.802		NO_3	0.803		BOD	0.762	
Phytoplankton	-0.781		Chl-a	-0.797		NO_3	0.759	
Chl-a	0.780		pH	-0.792		Phytoplankton	-0.717	-0.645
PO_4	-0.741	-0.648	DO	-0.754	0.651	DO		0.693
WT	-0.720		Phytoplankton	-0.672	0.641	Chl-a		0.937
PP (mgC m^{-3} hr^{-1})		0.968	PP (mgC m^{-3} hr^{-1})		0.982	NO_2		-0.878
Eigen values	11.685	1.335	Eigen values	11.710	1.611	Eigen values	8.240	4.980
% of variance	83.465	9.537	% of variance	83.646	11.505	% of variance	58.859	35.570
Cum % var	83.465	93.001	Cum % var	83.646	95.151	Cum % var	58.859	94.429

So far as the factor analysis had been discussed two factors explain 93.0%, 95.2% and 94.4% of the total variance for pre-monsoon, monsoon and post- monsoon seasons respectively, which was sufficient to give a good idea of the data structure (Table.4). Factor-1 of pre-monsoon accounts for 83.5% of the total variance, which is positively loaded with NO_3, NO_2, turbidity, silicate, BOD, TSS and PO_4 with negative loading of pH, DO, salinity, phytoplankton population, Chl-*a* and water temperature. In the second factor an inverse relationship between PO_4 and primary productivity is observed.

The Factor-1 of monsoon explained 83.6% of the total variance where BOD, silicate, NO_2, TSS, PO_4, NO_3 loaded positively against salinity, Chl-*a*, pH, DO and phytoplankton population. The agricultural run-off through flood water was mainly responsible for this factor distribution. In Factor-2, DO, phytoplankton, primary productivity loaded positively. This factor demonstrates only 11.5% of the total variance.

During post-monsoon season, Factor-1 explained only 58.9% of the total variance, which was positively loaded with silicate, TSS, PO_4, turbidity, BOD, NO_3 against negative loading of salinity, pH, primary productivity and phytoplankton population. In the second factor DO, Chl-*a* and phytoplankton population stands against NO_3, NO_2. The uptake of these two nutrients by the high productivity and high phytoplankton population was clearly reflected in this factor. The information of correlating environmental variables can be reduced by factor analysis. For the Dhamara estuary, two common factors were extracted for each seasonal data. This factors signifies negative loading with salinity, pH,DO and phytoplankton; positive loading with nutrients (except PO_4) and TSS due to terrigenous. The high turbid estuarine water restrict sunlight passage into the water column and ceases the photosynthesis activities. The two factors were able to explain 93-95% of the total variance of the input variables. Such a high amount indicates that there is a common structure of variables, and that the factor solution explains most of it. The correlation analysis was also used to study if the variability of phytoplankton was related to the patterns of these season types. Although the observation patterns of phytoplankton variables were an outcome of environmental conditions, yet high correlation between physico-chemical and biological variables does not necessarily indicate causality.

Acknowledgment

We would like to thank Head of the Department of Marine Sciences, Berhampur University for his invaluable help and kindly acknowledged for providing the laboratory facilities.

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