AN EVALUATION OF PHYTOPLANKTON ASSEMBLAGE IN RELATION TO ENVIRONMENTAL VARIABLES OF NARMADA ESTUARINE REGION OF GULF OF KHAMBHAT, GUJARAT, INDIA

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Abstract. A study on the relationship between physicochemical parameters and phytoplankton assemblage in Narmada estuarine region (21◦40’05.19”N and 72◦34’26.90”E) of the Gulf of Khambhat, Gujarat, India was carried out from July 2009- June 2010. Principal Component Analysis with environmental variables like pH, dissolved oxygen, salinity, ammonia, phosphate, nitrate, silicate and chlorophyll-a reveled two factors influencing variability in the water nutrient composition up to 72% during the whole study period. Canonical Correlation Analysis between environmental variables and 31 dominant taxa of phytoplankton showed the freshwater influence on phytoplankton distribution in the estuarine zone. The maximum diversity in phytoplankton assemblage was observed during the post-monsoon (November, December, January, February) and pre-monsoon (March, April, May, June) period. The same period reported a high load of inorganic nutrients at the middle and upper reaches of the estuary due to anthropogenic influence and low freshwater flow in this zone.
Keywords: e*stuary; environmental variable; PCA; CC; phytoplankton*

Introduction

Estuaries are biologically dynamic zones with intensive exchange of matter and energy occurring between terrestrial and marine ecosystems (Prandle, 2009; Ahel, et al., 1996). Physicochemical properties play a major role in determining the density, diversity and occurrence of phytoplankton in marine and freshwater ecosystem. The quality and quantity of phytoplankton and their seasonal patterns have been successfully implicated in the quality of water and its capacity to sustain heterotrophic communities (White et al., 2004). Dynamic changes in; pH, trace metal speciation, concentrations of dissolved gases like oxygen, carbon dioxide, methane, inorganic nutrients (nitrate, phosphate, silicate) and organic compounds such as amino acids, organo-sulfur compounds are all closely associated with fluctuations in phytoplankton composition (George et al., 2012). Trophic linkages also exist, between phytoplankton who are primary producers and populations of consumer organisms including zooplankton, benthic invertebrates and fish. The phytoplankton communities are also useful indicators of estuarine water quality (Paerl et al., 2007).

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The variation of phytoplankton succession is strongly linked to meteorological and water stratification mixing processes in a tropical estuary (Devassy and Goes, 1988). The complex dynamism in physico-chemical characteristics of coastal waters is related to riverine flow, up welling, atmospheric deposition, vertical mixing and other anthropogenic sources. The coastal Gulf of Khambhat, Gujarat State, India, is a unique marine environment in the tropical belt with marked continental influence due to the drainage by 16 major and minor rivers in to the Gulf. In the present study involving one such riverine system, the Narmada estuarine region, hydro-chemical variables were evaluated to determine their role in phytoplankton distribution using various statistical methods.

Materials and Methods

Narmada estuarine region is located at geographical coordinates 21◦40’05.19”N, 72◦34’26.90”E. Three study sites in this region were selected Zadeshwar, Bhadbhut and Ambata (10-15 km between each sites) on the basis of upcoming industrial set ups and anthropogenic pressure at these regions (*Figure 1*).

Surface water samples were drawn at monthly intervals during the period from July 2009 to June 2010 at high tide. For nutrient analysis, water samples were collected in 1 L clean polythene bottles and kept in an ice box at 4°C and transported immediately to the laboratory. Physico-chemical parameters such as pH, dissolved oxygen (DO), phosphate (PO_4-P), nitrate (NO_3-N), ammonia (NH_4) and silicate (SiO_4-Si) were measured according to the standard procedures (APHA, 1998; Strickland and Parsons,1979). The data quality was ensured through careful standardization, procedural blank measurements, and using spike and duplicate samples. Measurements of *in situ* temperature (°C) and salinity (ppt) were made using probes, while DO was measured using Winkler’s method. The chlorophyll-a estimation was carried out in a spectrophotometer after filtering the samples using glass fiber filter papers and extraction in 90% acetone (Maiti, 2003).

Plankton samples were collected by filtering 10 liters of water through planktonic net of 20µ mesh size and were preserved in 4% formalin for future use. Plankton identification was carried out with help of literatures and books (Desikachary, 1959; Newell and Newell, 1977; Thomas, 1997). The enumerations of phytoplankton were carried out with the aid of light microscope by Lackey’s drop method (Lackey, 1938).

Results and Discussion

Principal component analysis (PCA) is one of the best statistical techniques for extracting relationships among a set of variables. Principal component analysis aims to transform the observed variables to a new set of variables of principal components (PC) which are arranged in decreasing order of importance. . Principal components are the linear combinations of original variables and are the eigenvectors (Reingner, 2008). The data obtained from the laboratory analysis were used as variable inputs for principal components analysis (PCA), for water samples described using the SPSS 17 package. Prior to the analysis, the data was standardized by transforming all data to have a zero mean and a unit standard deviation $(X_i-\mu)/\delta$, μ and δ are standard deviations of X_i’s. Rotation of data will ensure that the variability explained is more or less evenly distributed between the factors. From the standardized covariance or correlation matrix

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of the data, the initial factor solution was extracted by the multivariate principal components extraction, then a number of PC were selected only those with eigenvalues >1.0.

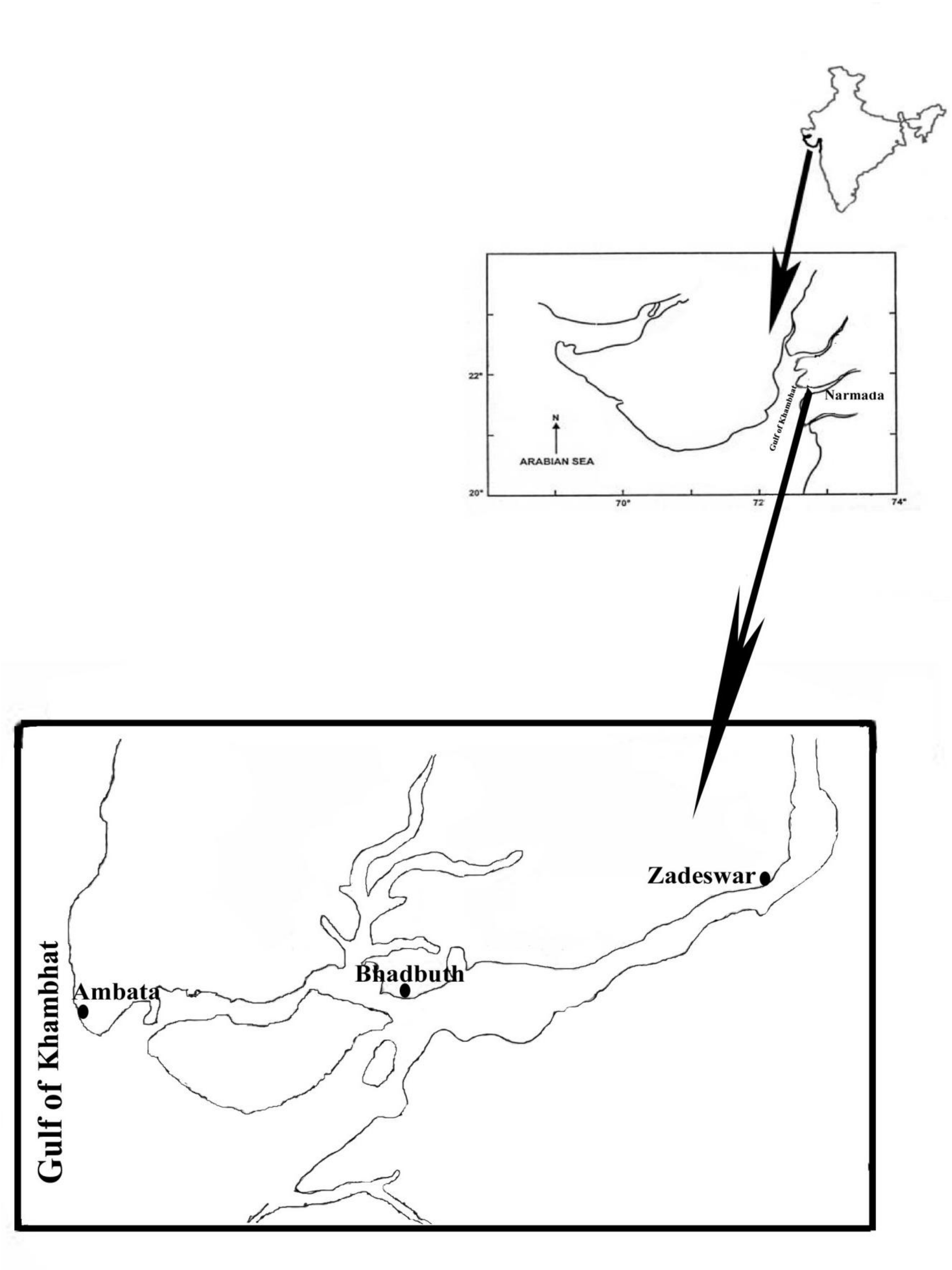

Figure 1. *Selected study sites on Narmada estuarine zone.*

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Initial eigenvalues, percentage of variance and cumulative percentage obtained through principal component analysis is represented in table 1. Eigenvalues above 1.0 account for the first two axis and represent more than 76% of the variance. Components loading, which measure the degree of closeness between the variables and the PC, the largest loading either positive or negative, suggest the meaning of the dimensions; positive loading indicates that the contribution of the variables increases with the increasing loading in dimension and negative loading indicates a decrease. Temperature variation in Narmada estuarine region followed a similar trend observed in other tropical regions (Newall et al., 2011).

Table 1.*Total Variance Explained Narmada estuary*

Component	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.582	62.021	62.021	4.658	51.754	51.754
2	1.309	14.541	76.562	2.233	24.808	76.562
3	.892	9.915	86.478			
4	.746	8.293	94.771			
5	.155	1.722	96.492			
6	.128	1.423	97.915			
7	.099	1.096	99.012			
8	.054	.595	99.607			
9	.035	.393	100.000			

PC1 accounts for 62.02% of the total variance, which is due to strong positive load of silicates (0.950), chlorophyll-*a* (0.870) and nitrate (0.794), ammonia (0.801) , dissolved oxygen (0.880) and a strong negative load of salinity (–0.842) and pH(-0.820). There is a significant positive correlation ($p \leq 0.05$) of pH with salinity (r = 0.81), where as silicates and chlorophyll showed a positive correlation with DO (r = 0.75 and 0.76 respectively). Ammonia showed a significant positive correlation with silicate (r=0.84) and chlorophyll-*a* (r=0.85) and silicate also found to be positively correlated with chlorophyll-a ((r=0.87). Silicate (r= -0.86) and chlorophyll-a (r= -0.65) showed a significant negative correlation with salinity (*Table 2*).

The highest value of ammonia is associated with freshwater inflow, and positive correlation with silicate indicates the freshwater origin of nutrients (Martin et al., 2008).The highest amount was reported in the upper reaches during the post monsoon period. In an estuarine environment, the primary productivity depends upon phytoplankton, which along with macrophytes contributes more than 90% of the total estuarine primary productivity (Bally et al., 1985). Thus, chl-*a*, which constitutes the chief photosynthetic pigment of phytoplankton, is an index that indicates the primary production potential of that system's biodiversity, biomass and carrying capacity (Nirmal, et al, 2009). Chlorophyll-*a* (3.5mg/L- 8.9 mg/L) having a significant positive correlation with DO and inorganic nutrients were observed to be high during the post monsoon period. The range of inorganic nutrient concentration during the study period is represented as box plot in *Figure 2*. The concentration of nitrate (0.489 mg/L- 1.84

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mg/L) and phosphate (0.058 mg/L – 0.377mg/L) were observed to be high at the middle reaches, mostly during the post- monsoon and pre-monsoon because of surface run off, increased pollution load, low freshwater inflow and tidal influence (Pradhan et al., 2009).

Table 2. *Correlation between physicochemical parameters of Narmada estuary* (P<0.05).

	Temp	pH	DO	Salinity	Ammonia	Phosphate	Nitrate	Silicate	Chlorophyll
Temperature	1.000								
pH	.470	1.000							
DO	-.706	-.674	1.000						
Salinity	.238	.815	-.603	1.000					
Ammonia	-.253	-.581	.729	-.687	1.000				
Phosphate	-.302	-.067	.197	-.164	.015	1.000			
Nitrate	-.620	-.696	.638	-.658	.342	.504	1.000		
Silicate	-.431	-.739	.754	-.860	.841	.325	.692	1.000	
Chlorophyll	-.409	-.519	.765	-.654	.853	.422	.536	.871	1.000

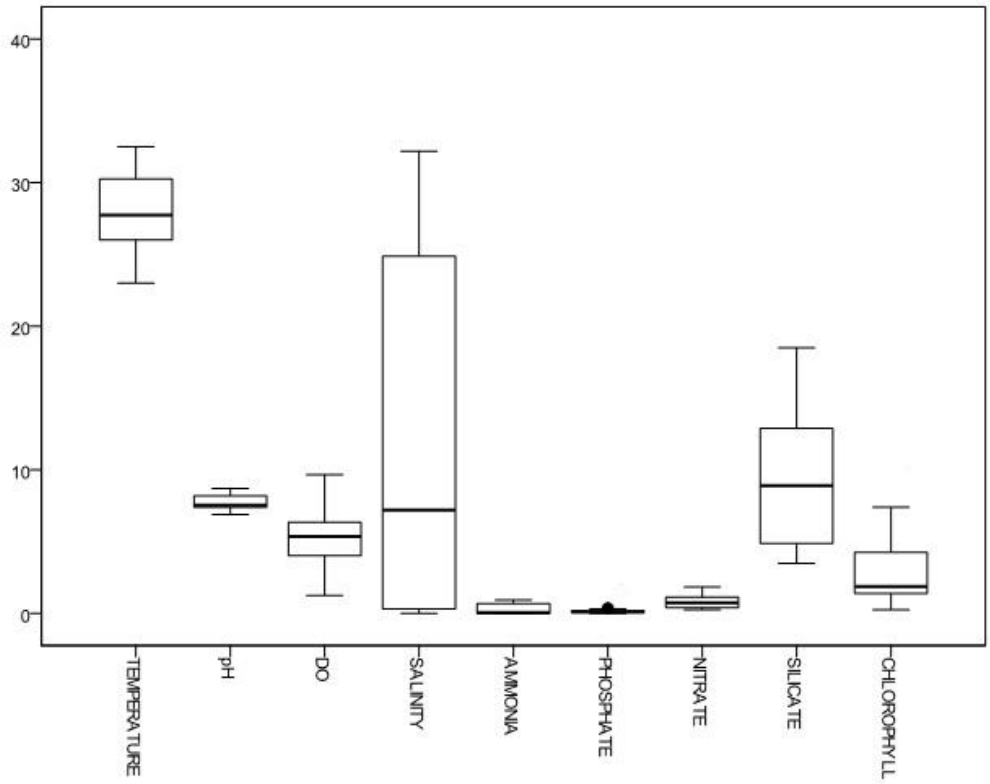

Figure 2. *Box plot showing variation of hydro-chemical parameters. All parameters are in mg/L except temperature and pH.*

PC2 explains 14.5% of the total variance with strong positive loading of NO_3-N (0.74) (*Table 3*). There is a strong positive correlation (p<0.05) of nitrate with silicate (*r*

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= 0.69) and negative correlation with temperature (*r*=0.62), pH (*r*=0.69) and salinity (*r*=0.44). pH **showed** a clear variation from fresh water receiving sites to the highly saline area. Comparatively, the strong negative correlation between salinity and NO_3-N (*r* = -0.63) indicates the addition of NO_3-N from the riverine freshwater direction. The amount of nitrates (0.489 to 1.84mg/L) was observed higher in post-monsoon season followed by pre-monsoon season in the upper and middle reaches. The high amount of inorganic nutrients observed at upper reaches may be contributed by freshwater inflow (Satpathy et al., 2009).

Table 3. *Principle component loadings in Narmada estuary*

	Component	
	1	2
Temperature	-.606	-.499
PH	-.820	.145
DO	.880	.016
Salinity	-.842	.266
Ammonia	.801	-.475
Phosphate	.357	.742
Nitrate	.794	.411
Silicate	.950	-.133
Chlorophyll a	.870	-.067

Relationships between phytoplankton species composition and environmental factors were calculated by Canonical Correlation Analysis (Ariyadej, 2004) using *Statistica 9 software (Statsoft)***.** CCA is a direct ordination that selects the combination of environmental variables that maximize the dispersion of the scores of species (Palmer, 2006). Results of environmental variables are shown by lines radiating from the center of the graph along with the points for samples. The line representing environmental variable indicates the direction of maximum change of that variable across the diagram. The position of the species point represents the environmental preference of the species.

In Zadeshwar, a total of 35 species and 16 environmental variables (which may have contributed to phytoplankton distribution) were selected for CCA analysis. Eigenvalue of axis 1 (λ= 0.2027), 2 (λ= 0.1694), 3 (λ= 0.1065) and 4 (λ= 0.087) explained 72.88% of the relation between species and environmental data. Species having significant correlation (>0.5 to <-0.5) with axis were marked in bold. The length of environmental arrows and their orientation on the biplot indicates their relative importance to each axis. Environmental arrows represent a gradient where the mean value is located at the origin and the arrow points in the direction of its increase (*Fig.3*). In CCA analysis, the first axis can be interpreted as the marine water influence and the main contributors include pH, salinity, chloride, chlorinity, alkalinity, sodium, potassium, sulphate and EC. Chlorophyll-a, phosphate, DO, temperature and silicate concentration were significantly correlated to each other in one side of axis 1 whereas silicate and nitrate shows a significant correlation with axis 1 on another side (*Table 4*).

Oscillatoria accuminata, Anabena anomala, Closterium gracile, Cladophora glomerata showed positive correlation with axis 1 which signify the effect of nitrate and silicate on its distribution. Temperature was found to have a positive relation with

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Scenedesmus quadricaudata. Cladophora glomerata. *Phacus accuminatus, Navicula amphirhynclius, Gymnodium, Merismopedium punctata, Pinnularia elongatum* showed a positive correlation with pH, salinity, chloride, chlorinity, alkalinity, sodium, potassium, sulphate and EC which indicate the significant role of these parameters in phytoplankton distribution. The effect of chemical factors, especially salinity and nutrient composition on phytoplankton distribution in Mahanadi estuary of India was studied by Naik et al. (2009**)** and they have reported higher phytoplankton count, chlorophyll-a concentration and nutrients during post-monsoon season which corroborated with our studies. Moreover, *Oscillatoria curviceps, O.subbrevis* and *Nostoc sp.* showed a positive correlation with chlorophyll-a and phosphate. While *Nitzschia plea, Merismopedium glauca, Anabena anomala, Pinnularia elongatum* and *Ankistrodesmus hantzschii* showed a positive correlation with silicate and nitrate. The values of each canonical variable of phytoplankton with the axis and the range of occurrence along with abbreviation are given in *Table 5*.

Table 4. *Correlation of environmental variables with axes in Zadeshwar*

Variables	**CV 1** (**λ= 0.** 2027**)**	**CV 2** (**λ= 0.** 1694**)**	**CV 3** (**λ= 0.** 1065**)**	**CV 4** (**λ= 0.** 087**)**
Temperature	**-0.500**	**0.741**	-0.006	0.074
pH	**-0.563**	0.309	-0.121	0.182
DO	-0.156	**-0.746**	0.095	-0.142
TS	0.175	0.378	-0.024	0.031
Salinity	**-0.612**	**0.450**	-0.365	0.154
Chloride	**-0.601**	**0.457**	-0.359	0.149
Alkalinity	**-0.703**	0.199	**-0.403**	0.231
Sodium	**-0.627**	0.295	-0.315	0.042
Potassium	**-0.651**	**0.421**	-0.247	0.229
Ammonia	-0.166	0.049	0.176	0.273
Phosphate	**-0.538**	-0.349	-0.265	0.225
Nitrate	0.011	**-0.458**	0.212	-0.256
Sulphate	**-0.583**	0.158	-0.324	0.362
Silicate	0.064	**-0.808**	0.094	0.111
Chlorophyll-a	-0.152	**-0.715**	-0.254	0.105
EC	**-0.534**	0.237	-0.124	0.226
% of Total variation	**26.13**	**21.83**	**13.73**	**11.19**

In Bhadbhut, a total of 31 species were reported and analyzed with 16 hydro-chemical parameters for CCA analysis. Eigenvalue of axis 1 (λ= 0.187), 2 (λ= 0.173), 3 (λ= 0.102) and 4 (λ= 0.064) explained 73.32% of the relation between species and environmental data (*Table 6*). Chlorophyll-*a* and silicate concentration showed a negative correlation with chloride, alkalinity, sodium, pH, potassium, sulphate and temperature. Phosphate, ammonia and nitrate showed positive correlation with axis 2. *Nitzschia obtusa, Chroococcus gigantium, Pediastrum simplex, Amphiprora alata, Oscillatoria subbrevis, Navicula amphirhynclius* and *Fragilaria crotonensis* did not

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explain much variation in distribution with change in physicochemical properties (Fig. 4). *Navicula viridis, Amphora ovalis* and *Chaetoceros tenuissimus* illustated close relationship with nitrate and phosphate. *Chlorella pyrenoidosa, Ankistrodesmus hantzschii, Ankistrodesmus flactus, Ceratium, Microcystis aeruginosa* and *Navicula amphirhynclius* found to have close relationship between DO, chlorophyll-*a* and silicate. Panigrahi et al. (2009) also reported the effect of these nutrients in phytoplankton distribution from their studies on brackish water ecosystem (Chilika Lagoon, India). *Closterium acerosum* and *Pleurosigma elongetum* found to be correlated with potassium, sulphate and temperature variation in the estuary. The correlation of phytoplankton with axis is given in the (*Table 7*) and the values having significant correlation are marked in bold.

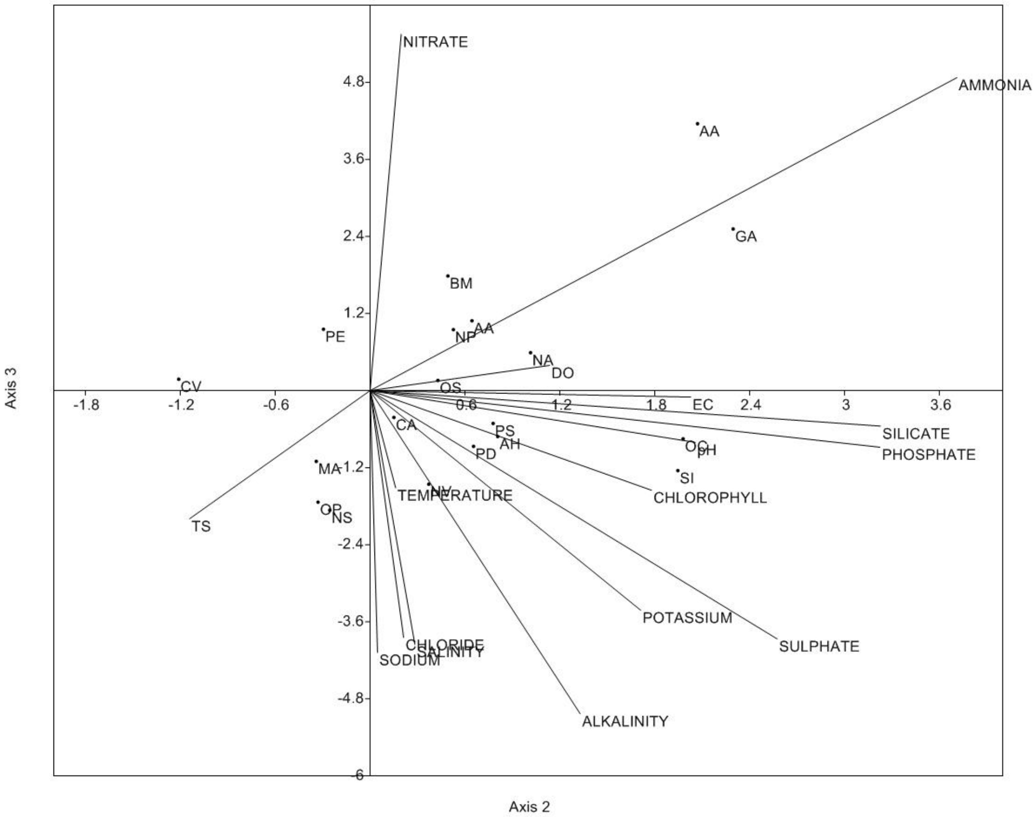

Figure 3. *CCA plot showing relationship between environmental variables and phytoplankton of Zadeshwar.*

Table 5. *List of phytoplankton taxa included in the canonical correlation analysis of Zadeshwar*

Variables	Abbreviation	CV 1	CV 2	CV 3	CV 4
Oscillatoria perornata	OP	-0.007	-0.070	**-0.559**	0.118
O. subbrevis	OS	0.217	-0.295	-0.130	0.165
O. acuminata	OA	**0.679**	-0.125	**-0.744**	0.072
O. curviceps	OC	-0.178	-0.395	-0.153	**0.549**
Spirulina subtilissima	SS	0.112	-0.307	**-0.724**	**0.519**

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Microcystis aeruginosa	MA	-0.137	0.118	-0.096	-0.065
Anaebena anomala	AA	**0.768**	-0.082	0.326	0.310
Merismopedium glauca	MG	0.100	-0.261	0.073	0.255
M. punctata	MP	0.021	-0.273	-1.211	0.443
Nostoc sp	NS	-0.061	-0.436	-0.318	-0.067
Ankistrodesmus hantzschii	AH	-0.092	-0.263	0.035	0.195
Clorella vulgaris	CV	-0.118	0.309	-0.113	-0.332
Closterium acerosum	CA	0.218	**-0.635**	-0.200	0.031
C. gracile	CG	**0.699**	0.390	**-0.572**	0.285
Cladophora glomerata	CGL	**0.662**	**0.964**	0.405	0.492
Scenedesmus quadricauda	SQ	0.477	**0.890**	0.227	0.120
Spirogyra indica	SI	-0.481	**0.774**	0.038	**0.796**
Pediastrum simplex	PS	0.014	-0.276	-0.045	0.262
P. duplex	PD	0.109	-0.286	-0.284	0.337
Amphiprora alata	AA	-0.157	-0.364	1.461	-0.193
Biddulphia mobiliensis	BM	0.192	0.008	0.528	-0.044
Coscinodiscus marginatus	CM	-0.176	**-0.800**	0.268	**-0.507**
Cymbellacistula	CC	0.039	-0.397	-0.337	0.383
C. tumida	CT	-0.226	**-0.573**	**0.862**	0.142
Gyrosigma acuminatum	GA	-0.110	**-0.481**	1.003	0.121
G. scalproides	GS	-0.187	-0.420	**0.931**	0.256
Navicula amphirhynclius	NA	-0.340	0.229	0.142	0.208
N. viridis	NV	-0.057	**-0.596**	-0.248	0.039
Pinnularia elongetum	PE	0.402	-0.331	0.041	-0.128
Nitzschia palea	NP	-0.158	-0.163	0.193	-0.044
Euglena gracilis	EG	**-0.573**	**0.534**	**-0.724**	**0.955**
E. ehrenbergii	EE	0.106	**-0.933**	-0.015	**0.539**
Phacus acuminatus	PA	**-0.521**	0.265	0.230	0.372
Peridinium	Pe	0.399	0.390	**-0.572**	0.285
Gymnodium	Gy	**-0.741**	**0.579**	0.313	-0.243

Table 6. *Correlation of environmental variables with axes of Bhadbhut*

Variables	**CV 1** (**λ= 0.** 187)	**CV 2** (**λ= 0.**173)	**CV 3** (**λ= 0.** 102)	**CV 4** (**λ= 0.** 064)
Temperature	**0.57**	**0.17**	0.23	-0.62
pH	0.40	**0.52**	0.31	-0.29
DO	-0.39	-0.23	-0.14	**0.65**
TS	-0.44	**0.58**	0.10	0.17
Salinity	0.05	**0.60**	0.31	-0.33
Chloride	0.05	**0.60**	0.31	-0.33
Alkalinity	0.14	**0.51**	**0.63**	-0.11
Sodium	0.15	0.29	0.39	-0.40
Potassium	0.44	**0.77**	0.14	-0.11

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Ammonia	0.47	**0.49**	**0.62**	0.31
Phosphate	-0.39	0.45	0.05	0.25
Nitrate	-0.23	**0.57**	0.04	0.56
Sulphate	0.44	**0.50**	0.41	-0.40
Silicate	**-0.78**	0.00	**-0.57**	-0.08
Chlorophyll-a	**-0.62**	0.22	0.14	0.42
EC	0.11	**0.58**	0.44	0.07
% Total Variation	**26.07**	**24.13**	**14.25**	**8.87**

Table 7. *List of phytoplankton taxa included in the canonical correlation analysis of Bhadbhut*

Variables	**Abbreviation**	**CV 1**	**CV 2**	**CV 3**	**CV 4**
Oscillatoria perornata	OP	**0.58**	-0.21	0.03	0.29
O. subbrevis	OS	-0.03	-0.02	0.51	**-0.66**
Microcystis aeruginosa	MA	0.17	-0.18	-0.19	-0.03
Anaebena circularis	AC	**-0.58**	-0.65	0.18	-0.42
Merismopedium glauca	MG	**-0.56**	-0.16	-0.65	-0.39
Ankistrodesmus hantzschii	AH	**-0.79**	-0.27	0.14	-0.01
A. flactus	AF	**-0.63**	0.29	**0.75**	0.36
Chlorella pyrenoidosa	CP	**-0.82**	0.18	0.02	0.25
Closterium acerosum	CA	**0.88**	0.27	-0.17	**0.82**
Pediastrum simplex	PS	-0.04	0.23	**0.69**	-0.15
Spirogyra indica	SI	0.19	-0.41	0.14	-0.32
Amphiprora alata	AA	0.02	0.23	-1.09	-0.13
Amphora ovalis	AO	-0.26	0.21	-0.01	0.45
Biddulphia mobiliensis	BM	0.13	-0.22	-0.19	-0.22
Chaetoceros tenuissimus	CT	-0.30	**0.48**	-0.35	-0.29
Chroococcus gigantium	CG	-0.09	0.18	-0.17	0.44
Coscinodiscus marginatus	CM	**-0.62**	0.21	-1.15	-0.46
Cymbella cistula	CC	0.20	0.35	**-0.70**	-0.18
Fragilaria crotonensis	FC	0.02	-0.32	0.04	-0.16
Gyrosigma acuminatum	GA	0.25	-1.02	-0.76	-0.02
G. scalproides	GS	**0.72**	-3.31	0.33	0.03
Navicula amphirhynclius	NA	-0.42	-0.22	0.02	0.22
N. sphaerophora	NS	-0.03	0.27	0.01	0.33
N. viridis	NV	-0.32	0.28	-0.07	0.10
Nitzschia amphibia	NA	0.04	-0.24	**0.57**	-0.26
N. obtusa	NO	-0.03	0.27	0.01	0.33
Surirella nervosa	SN	**-0.55**	0.18	**-0.68**	**-0.69**
Pleurosigma elongetum	PE	**0.56**	**0.42**	0.12	-0.06
Euglena gracilis	EG	**0.72**	-0.31	0.33	0.03
Ceratium	Ce	**-0.66**	0.18	-0.78	-0.31
Gymnodium	Gy	-0.37	-0.92	**0.60**	**0.53**

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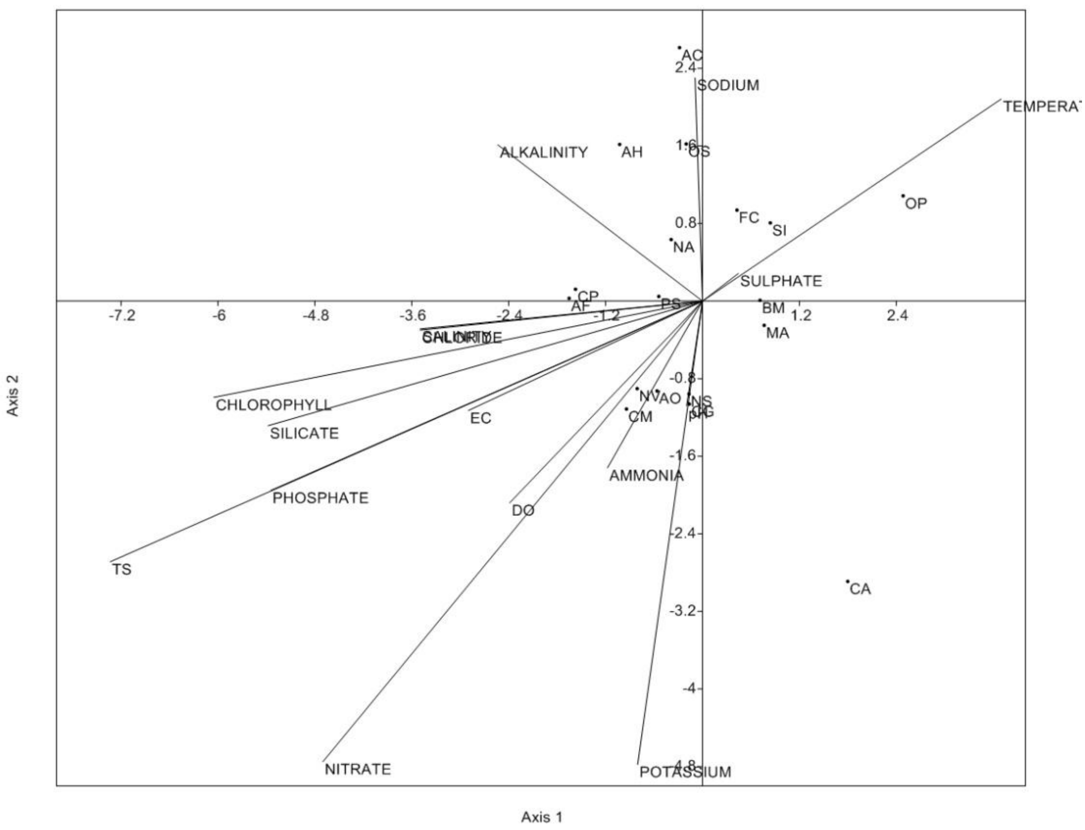

Figure 4. *CCA plot showing relationship between environmental variables and phytoplankton of Bhadbhut.*

Ambata site reported the least number of phytoplankton (26 species) dominated by Bacillariophycean members. Eigenvalue of axis 1 (λ= 0.361), 2 (λ= 0.271), 3 (λ= 0.234) and 4 (λ= 0.177) explained 70.44% of the relation between species and environmental data (*Table 8*). DO, nitrate, ammonia, chlorophyll-a, and silicate found to be correlated with each other and showed a negative correlation with potassium, temperature and salinity. These indicated the freshwater and marine water source of these nutrients in to the estuarine environment. *Peridinium, Ceratium, Amphora elliptica, Surirella nervosa* and *Gymnodium* showed a positive correlation with potassium and temperature. *Thalassionema nitzschioides, Chaetoceros tenuissimus, Merismopedium punctata, Fragilaria oceanic* and *Leptocylindrus danicus* found to be closely associated with concentration of nitrate, chlorophyll, ammonia and silicate (*Fig. 5*).Correlation of environmental variables with phytoplankton species were given in *Table 9*. Similar results were also obtained from shallow coastal station of Bay of Bengal by Choudhury and Pal, (2010) in which they observed prominent effect of temperature, pH, dissolved oxygen, salinity and nutrient contents-including nitrate, phosphate and silicate on Bacillariophycean distribution.

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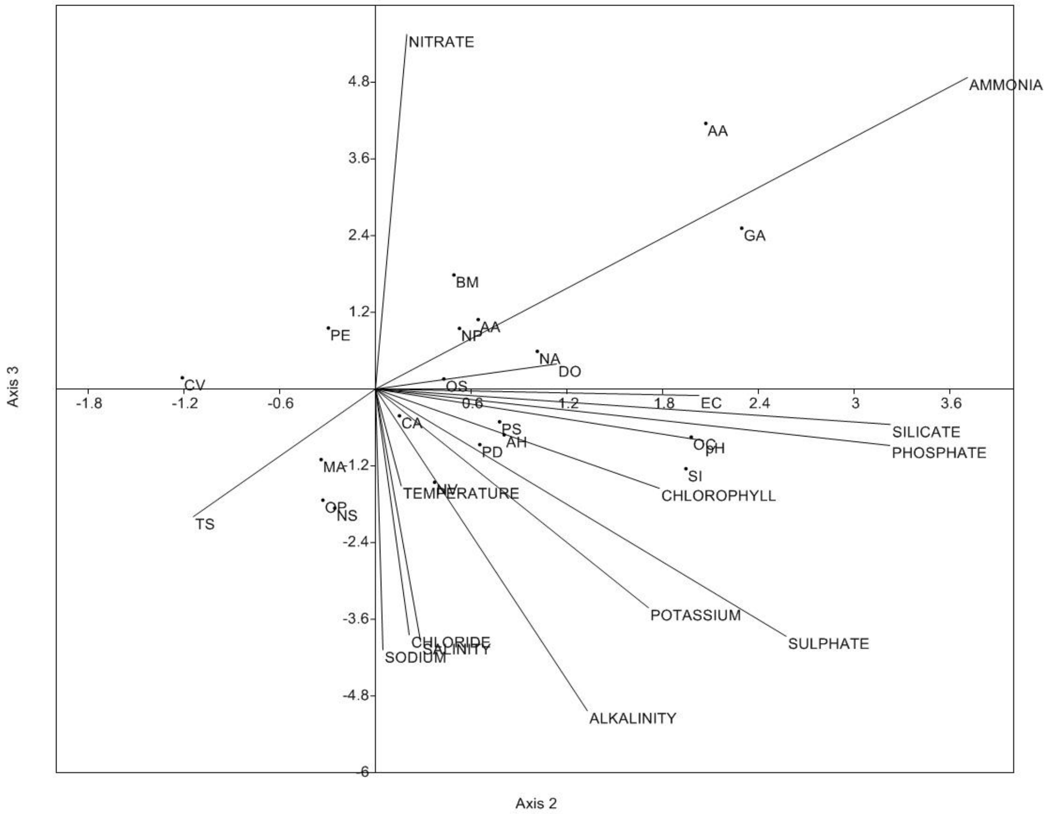

Figure 5.*CCA plot showing relationship between environmental variables and phytoplankton of Ambata.*

Table 8. *Correlation of environmental variables with axes in Ambata*

Variables	**CV 1 (λ= 0. .361)**	**CV 2 (λ= 0. 271)**	**CV 3 (λ= 0. 234)**	**CV 4 (λ= 0. 176)**
Temperature	0.11	0.42	0.18	-0.32
pH	-0.41	0.68	-0.14	-0.40
DO	-0.07	-0.49	-0.38	0.29
TS	-0.49	0.51	-0.34	0.05
Salinity	-0.16	0.57	-0.49	-0.42
Chloride	-0.16	0.57	-0.49	-0.42
Alkalinity	-0.17	0.56	-0.05	-0.25
Sodium	-0.66	0.47	-0.20	-0.36
Potassium	-0.05	0.65	-0.01	-0.38
Ammonia	-0.16	-0.62	-0.18	-0.21
Phosphate	-0.45	0.16	-0.42	-0.30
Nitrate	-0.48	-0.35	-0.13	0.24
Sulphate	-0.18	0.53	-0.32	-0.22

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Silicate	-0.06	-0.68	-0.31	-0.04
Chlorophyll-a	-0.54	-0.48	-0.15	0.16
EC	-0.34	0.20	-0.72	-0.42
% Total variation	**21.41**	**16.08**	**13.87**	**10.47**

Table 9. *List of phytoplankton taxa included in the canonical correlation analysis of Ambata*

Variables	Abbreviation	CV 1	CV 2	CV 3	CV 4
Oscillatoria perornata	OP	**-0.50**	0.41	2.38	**0.98**
Microcystis aeruginosa	MA	-0.27	0.43	-0.34	**-0.44**
Merismopedium punctata	MP	-0.32	-0.24	1.65	0.07
Ankistrodesmus flactus	AF	-0.20	**0.87**	-0.29	0.21
Closterium gracile	CG	0.08	-0.04	**0.54**	-0.20
Amphiprora alata	AA	0.43	-0.07	-0.49	0.16
Amphora elliptica	AE	0.07	**0.96**	-0.14	-0.28
A. ovalis	AO	-0.07	0.54	0.09	-0.48
Chaetoceros tenuissimus	CT	**-0.45**	-0.14	**-0.55**	0.14
Coscinodiscus marginatus	CM	-0.32	0.22	0.21	0.27
Fragilaria crotonensis	FC	0.22	-0.14	-0.07	-0.32
F. oceanica	FO	**-0.53**	**-0.89**	0.09	**-0.66**
Gyrosigma acuminatum	GA	0.10	-0.03	**0.58**	0.11
G. scalproides	GS	3.34	-1.05	-0.32	0.47
Leptocylindrus danicus	LD	-0.13	**-0.57**	**0.86**	**-0.50**
Navicula cuspidata	NC	**-0.55**	-0.49	**-0.49**	0.01
N. radiosa	NR	-0.04	0.16	0.33	-0.08
Nitzschia amphibia	NA	0.27	-0.23	-0.11	0.13
Thalassionema nitzschioides	TN	-0.26	-0.20	-0.07	0.02
Pinnularia elongetum	PE	0.20	0.07	-0.13	-0.46
Surirella nervosa	SN	0.33	**0.81**	0.12	-0.18
Peridinium	Pe	-0.64	-0.38	-0.43	0.10
Ceratium	Ce	0.10	0.11	-0.09	-0.19
Gymnodium	Gy	0.31	**0.92**	**-0.65**	-0.14

In the present study phytoplankton have shown a positive correlation with salinity value at all sampling stations because estuarine regions are subjected to considerable fluctuations and these micro floras were well adapted to such dynamic environment (Lionard et al., 2005). Phytoplankton need a wide variety of chemical elements with the critical ones being nitrogen and phosphorous (Dawes, 1981). In the present study it was registered that phytoplankton showed positive correlation with phosphate and inorganic nitrogenous nutrients but the relationship was not very significant. This could be due to lower concentration or rapid recycling of these nutrients. Similar positive correlation between phytoplankton and nitrogenous organic nutrients were observed by Steinhart et

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al. (2002) on southern Chilean lakes and Hergenrader (1980) in salt valley reservoirs (California). Dawes (1981) reported a negative relationship of phytoplankton with temperature and turbidity which supports our present observed results. Studies carried out by Ye and Cai (2011) suggested that the occurrence of Cyanophycean and Chlorophycean members were directly proportional to the concentration of dissolved inorganic nitrogen and phosphate which also corroborated with our studies.

Most of the species abundance were found to be correlated with environmental variables, and this might be due to cosmopolitan characteristic of the species indicating the species tolerance to a wide range in water quality (Bonilla et al., 2005). A negative correlation was observed for Cyanophycean members like *Oscillatoria perornata* and *Merismopedium glauca* with environmental variables like chlorophyll-*a* and silicate. Most of the species belonging to Bacillariophyceae showed a positive correlation with environmental parameters like chlorophyll-a, silicate and phosphate. Chlorophycean members like *Ankistrodesmus flactus*, *Closterium acerosum* and *Spirogyra indica* showed a positive correlation with nitrate, DO and ammonia. Similar results were also obtained by Ye and Cai (2011) for their assessment on spring phytoplankton bloom of Xiangi Bay.

Navicula amphirhynclius and *Navicula radiosa* showed a positive correlation with pH and salinity which may have a major effect on its distribution. The close association of salinity and pH revealed the effect of tidal influence in the estuarine area. Temperature was found to have a positive relation with *Clorella vulgaris* and *Merismopedium punctata*. However, the negative correlation of temperature with ammonia and silicate showed the freshwater influence on these nutrients during post-monsoon season. *Navicula cuspidate, Surirella nervosa, Thalassionema nitzschioides, Amphiprora alata, Amphora ovalis, Coscinodiscus marginatus* and *Amphora elliptica* showed a positive correlation with chloroplyll-*a*, silicate and phosphate which indicates the significant role of these parameters in phytoplankton distribution (Harnstrom et al., 2009). *Anaebena anomala, Nitzschia amphibian* and *Gymnodium sp.* showed a negative correlation with inorganic nutrients, which showed their adaptability to a wide range of variations in physicochemical properties (Varis, 1991).

Conclusion

The present study summarizes the seasonal fluctuations of various physico-chemical parameters and plankton diversity in the coastal waters of the Narmada estuary as exploratory statistical data output. Freshwater discharges through the river and rivulets include additions of nitrate, phosphate and silicate to the coastal water mainly during the monsoon season (Martin et al., 2008). The addition of nitrogenous compounds and phosphorus compounds from anthropogenic sources such as fertilizer output, as an effect of industrialization and from agricultural runoff in the northern region of the Narmada estuary, has been observed during the monsoon in the water near the upper and middle reaches. Principal component analysis extracted two components (PC1 and PC2) responsible for the 76% variation observed in the estuary. The high load of nutrients like phosphate, nitrate and silicate during the monsoon contributes to the growth of phytoplankton community which is evident from the canonical correlation analysis. Hydrology and nutrients factors were found to be the main determining factors of phytoplankton distribution among the estuary (Costa et al., 2009). In the canonical correlation analysis the maximum correlation of phytoplankton with inorganic nutrients

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is linked to the abundance of these nutrients mostly entering during the monsoon season. The present study suggests that, hydrochemical variables play an important role in determining the phytoplankton distribution along estuarine gradient.

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REFERENCE

[1] Ahel, M., Barlow, R.G., Mantoura, R.F.C. (1996): Effect of salinity gradiant on the distribution of phytoplankton pigments in a stratified estuary. –Marine Ecology Progress Series 143: 289-295.

[2] APHA (American Public Health Association), AWWA (American Water Works Association), and WEF (Water Environment Federation). (1999): Standard methods for the examination of water and wastewater (20th ed.). Washington DC, USA.

[3] Ariyadej, C., Tansakul, R., Tansakul, P., Angsupanich, S. (2004): Phytoplankton diversity and its relationships to the physico-chemical environment in the Banglang reservoir, Yala province. -Songklanakarin Journal of Science and Technology 26: 595-607.

[4] Bally, R., McQuaid, C. D., Pierce, S. M. (1985): Primary productivity of the Bot river estuary, South Africa. -Transactions of the Royal Society of South Africa 45: 333-345.

[5] George,B., Nirmal Kumar, J.I, Kumar, N.K. (2012): Study on the influence of hydro-chemical parameters on phytoplankton distribution along Tapi estuarine area of Gulf of Khambhat, India.- Egyptian Journal of Aquatic research 38: 157-170.

[6] Bonilla, S., Conde, D., Aubriot, L., Perez, M.D.C. (2005). Influence of hydrology on phytoplankton species composition and life strategies in a subtropical costal lagoon periodically connected with the Atlantic Ocean. -Estuaries 28: 884-895.

[7] Choudhury, A.K., Pal, R. (2010) Phytoplankton and nutrient dynamics dynamics of shallow coastal stations at Bay of Bengal, Eastern Indian Coast. -Aquatic Ecology 44: 55-71.

[8] Clarke, K.R., Warwick, R.M. (2001). Changes in marine communities: an approach to statistical analysis and interpretation. 2nd edition, PRIMER- E: Plymouth.

[9] Costa, L.S., Huszar, V.L.M., Ovalle, A.R. (2009). Phytoplankton Functional Groups in a Tropical Estuary: Hydrological Control and Nutrient Limitation. -Estuaries and Coasts 32: 508–521.

[10] Dawes, C.J. (1981). Marine Botany. A Wiley-Interscience publication, USA.

[11] Desikacharya. T.V.(1959). Cyanophyta. Indian Council of Agricultural Research. New Delhi.

[12] DeJong T. M. (1975). A comparison of three diversity indices based on their components of richness and evenness. -Oikos 26: 222-227.

[13] Devassy , V.P., Goes, J.I. (1988). Phytoplankton community structure and sucession in a tropical estuarine complex (central west coast of India).-Estuarine, Coastal and Shelf Science 27: 671-685.

[14] Harnstrom, K., Karunasagar,I., Godhe. A. (2009). Phytoplankton species assemblage and their relationship to hydrographic factors- a study on the old port in Mangalore, Coastal Arabian Sea. -Indian Journal of Marine science 38: 224-234.

[15] Hergenrader, G. L. (1980). Eutrophication of the salt valley reservoirs, 1968–1973 II. Changes in physical and chemical parameters of eutrophication. -Hydrobiologia. 74: 225-240.

[16] Lackey, J.B. (1938). The manipulation and counting of river plankton and changes in some organism due to formalin preservation. U.S. Public Health Reports. 63: 2080-2093.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: 10.15666/aeer/1301_115131

[17] Lionard, M., Muylaert, K., Gansbeke, D.V., Vyverman, W. (2005). Influence of changes in salinity and light intensity on growth of phytoplankton communities from the Schelde River and estuary (Belgium/The Netherlands). -Hydrobiologia 540: 105-115.

[18] Madhu, N.V., Joythibabu, R., Balachandran, K.K., Honey, U.K., Martin, G.D., Vijay, J.G., Shiyas, Guptha, G.V.M., Achuthankutty, C.T. (2007). Monsoonal impact on planktonic standing stock and abundance in a tropical estuary (Cochin backwaters-INDIA). -Estuarine, Coastal and Shelf Science 73: 54-64.

[19] Maiti, S.K. (2003). Handbook of methods in Environmental Studies, Vol: 1, Water and Wastewater Analysis. (2nd ed.) Oxford Book Company, Jaipur, India.

[20] Martin, G.D., Vijay, J.G., Laluraj, C.M., Madhu, N.V., Joseph, T., Nair, M., Gupta, G.V.M., Balachandran K.K. (2008). Freshwater influence on nutrient stoichiometry in a tropical estuary, southwest coast of India. -Applied Ecology and Environmental Research 6: 57-64.

[21] Naik, S., Acharya, B.C., Mohapatra, A. (2009). Seasonal variations of phytoplankton in Mahanadi estuary, east coast of India. -Indian Journal of Marine science 38:184-190.

[22] Newall, E.J.R., Chu, V.T., Pringault, O., Amouroux, D., Arfi, R., Bettarel, Y., Bouvier, T., Got, P., Nguyen, T.M.H., Mari, X., Navarro, P., Duong, T.N., Cao, T.T.T., Pham, T.T., Ouillon, S., Torreton, J.P. (2011). Phytoplankton diversity and productivity in a high turbid, tropical coastal system (Bach Dang Estuary, Vietnam). Biogeosciences 8: 487-525.

[23] Newell G.E. ,Newell R.C. (1977). Marine Plankton, Hutchinson of London.

[24] Nirmal Kumar J.I., George, B., Kumar, R.N., Sajish P.R., Viyol, S. (2009). Assessment of spatial and temporal fluctuations in water quality of a tropical permanent estuarine system, Tapi, West Coast of India. -Applied Ecology and Environmental Research 7(3):267-276.

[25] Paerl, H.W., Lexia M. V., Alan R. J., Valerie W. (2007). Phytoplankton indicators of ecological change in the eutrophying Pamlico sound system, North Carolina. -Ecological Applications 17: 88–101.

[26] Palmer, M. (2006). Ordination methods an overview. http://ordination.okstate.edu/overview.htm.

[27] Panigrahi, S., Wikner, J., Panigrahy, R. C. Satapathy, K. K., Acharya, B. C. (2009). Variability of nutrients and phytoplankton biomass in a shallow brackish water ecosystem (Chilika Lagoon, India). Limnology 10: 73-85.

[28] Pradhan U.K., Shirodkar, P.V., Sahu, B.K. (2009). Physico-chemical characteristics of the coastal water off Devi estuary, Orissa and evaluation of its seasonal changes using chemometric techniques. Current Sciences 96: 1203-1209.

[29] Prandle, D. (2009). Estuaries: dynamics, mixing, sedimentation and morphology. Cambridge University Press, UK.

[30] Rantajarvi, E., Gran, V., Hallfors, S., Olsonen R. (1998). Effect of environmental factors on the phytoplankton community in the Gulf of Finland- unattended high frequency measurements and multivariate analyses. -Hydrobiologia 363: 127-139.

[31] Reingner,M. (2008). What is principal component analysis? Nature Biotechnology 26: 303-304.

[32] Satpathy, K. K., Mohanty, A. K., Natesan, U., Prasad, M. V. R., Sarkar. S. K. (2009). Seasonal variation in physicochemical properties of coastal waters of Kalpakkam, east coast of India with special emphasis on nutrients. -Environmental Monitoring and Assessment 164: 153-171.

[33] Shannon, C.E., Weiner, V. (1949). A mathematical Theory of Communication. University Press, Illinois Urban.

[34] Steinhart,G. S., Likens, G.E., Soto, D. (2002) Physiological indicators of nutrient deficiency in phytoplankton in southern Chilean lakes. -Hydrobiologia 489: 21-27.

[35] Strickland, S. C., Parsons, T. R. (1979). A Practical Handbook of Seawater Analyses, Bulletin of Fisheries Board of Canada, Ottawa.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: 10.15666/aeer/1301_115131

[36] Thomas, C.R. (1997). Identifying marine phytoplankton. Academic press, California.
[37] Varis, O. (1991). Association between Lake Phytoplankton community and growth factors- a canonical correlation analysis. -Hydrobiologia 210: 209-216.
[38] White,D.L., Porter, D.E., Lewitus, A.J. (2004). Spatial and temporal analyses of water quality and phytoplankton biomass in an urbanized versus a relatively pristine salt marsh estuary. -Journal of Experimental Marine Biology and Ecology 298: 255– 273.
[39] Ye, L., Cai, Q. (2011). Spring phytoplankton blooms in Xiangxi Bay of three –gorges reservoir: spatiotemporal dynamics across sharp nutrient gradients. -Journal of Freshwater Ecology 26:11-18.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: 10.15666/aeer/1301_115131