

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 revealed 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: estuary; 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).

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 ($\text{PO}_4\text{-P}$), nitrate ($\text{NO}_3\text{-N}$), ammonia (NH_4) and silicate ($\text{SiO}_4\text{-Si}$) 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 20 μ 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

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 .

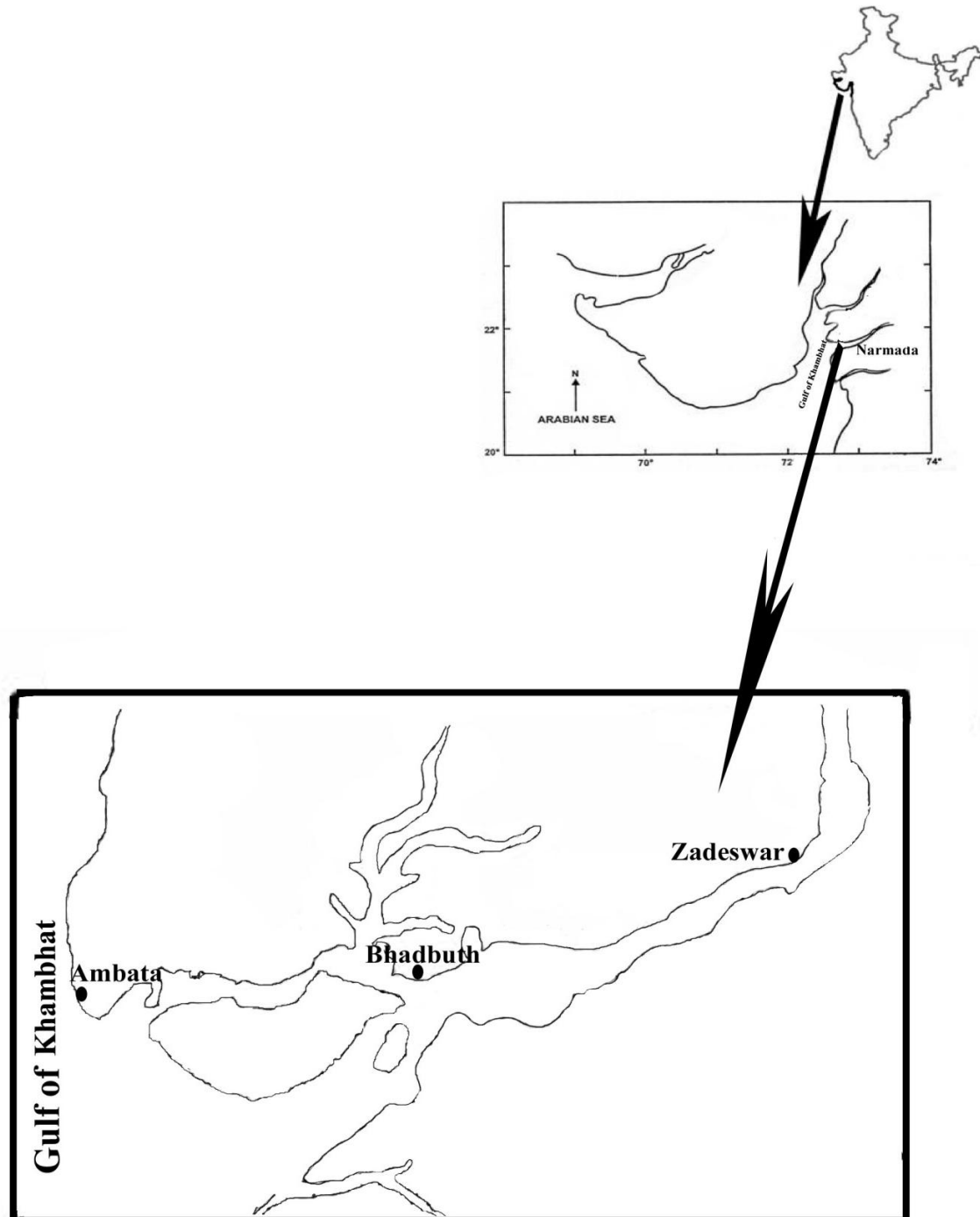


Figure 1. Selected study sites on Narmada estuarine zone.

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	Total	Initial Eigenvalues		Total	Rotation Sums of Squared Loadings	
		% of Variance	Cumulative %		% 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

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

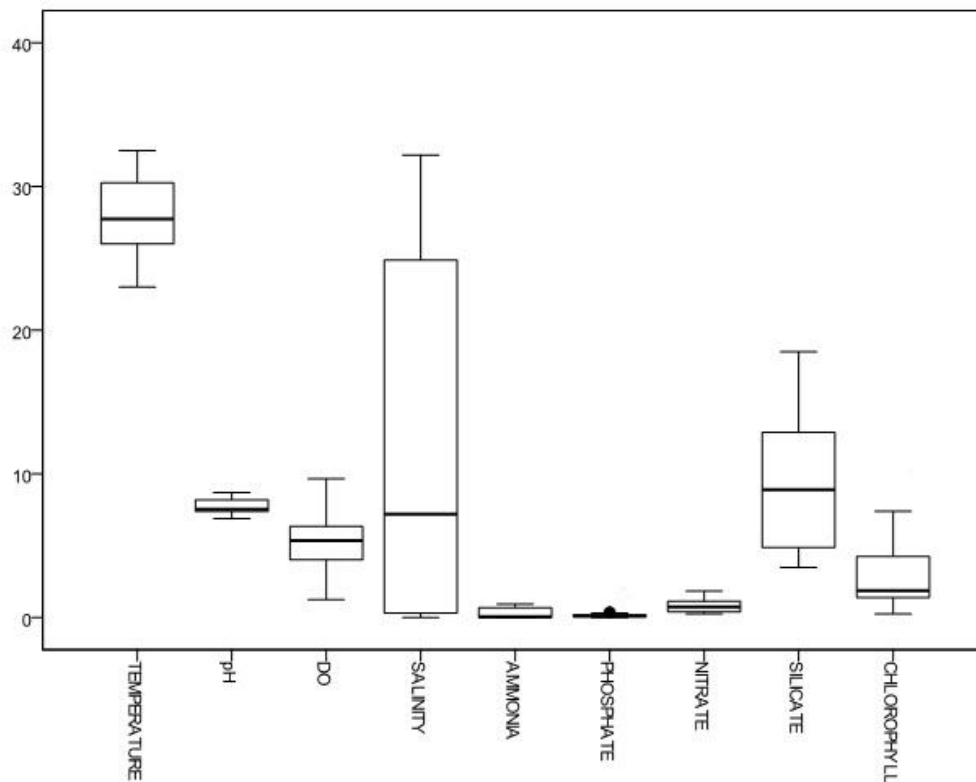


Figure 2. Box plot showing variation of hydro-chemical parameters. All parameters are in mg/L except temperature and pH.

PC2 explains 14.5% of the total variance with strong positive loading of $\text{NO}_3\text{-N}$ (0.74) (Table 3). There is a strong positive correlation ($p < 0.05$) of nitrate with silicate (r

= 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 $\text{NO}_3\text{-N}$ ($r = -0.63$) indicates the addition of $\text{NO}_3\text{-N}$ 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 ($\lambda = 0.2027$), 2 ($\lambda = 0.1694$), 3 ($\lambda = 0.1065$) and 4 ($\lambda = 0.087$) 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

Scenedesmus quadricaudata, *Cladophora glomerata*, *Phacus accuminatus*, *Navicula amphirhynchus*, *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 ($\lambda = 0.2027$)	CV 2 ($\lambda = 0.1694$)	CV 3 ($\lambda = 0.1065$)	CV 4 ($\lambda = 0.087$)
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 ($\lambda = 0.187$), 2 ($\lambda = 0.173$), 3 ($\lambda = 0.102$) and 4 ($\lambda = 0.064$) 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 amphirhynchus* and *Fragilaria crotonensis* did not

explain much variation in distribution with change in physicochemical properties (Fig. 4). *Navicula viridis*, *Amphora ovalis* and *Chaetoceros tenuissimus* illustrated close relationship with nitrate and phosphate. *Chlorella pyrenoidosa*, *Ankistrodesmus hantzschii*, *Ankistrodesmus flactus*, *Ceratium*, *Microcystis aeruginosa* and *Navicula amphirhynchus* 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 elongatum* 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.

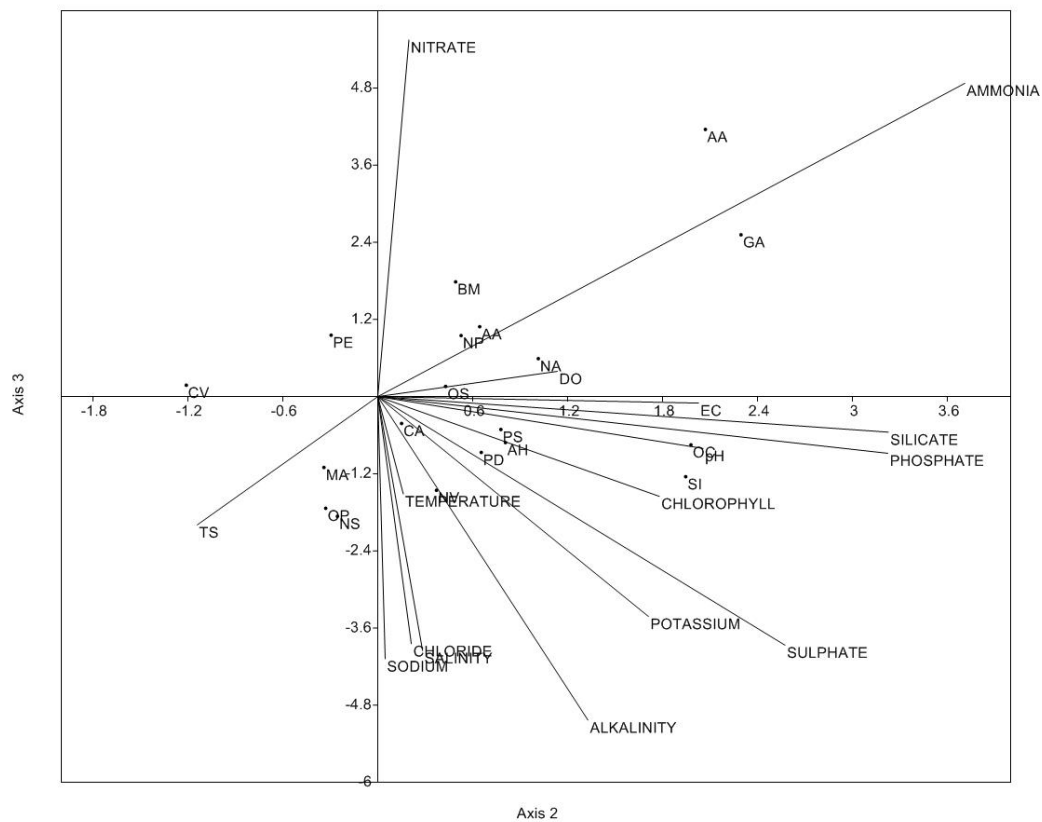


Figure 3. CCA plot showing relationship between environmental variables and phytoplankton of Zadeshwar.

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

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

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

Table 6. Correlation of environmental variables with axes of Bhadbhut

	CV 1	CV 2	CV 3	CV 4
Variables	($\lambda = 0.187$)	($\lambda = 0.173$)	($\lambda = 0.102$)	($\lambda = 0.064$)
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

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

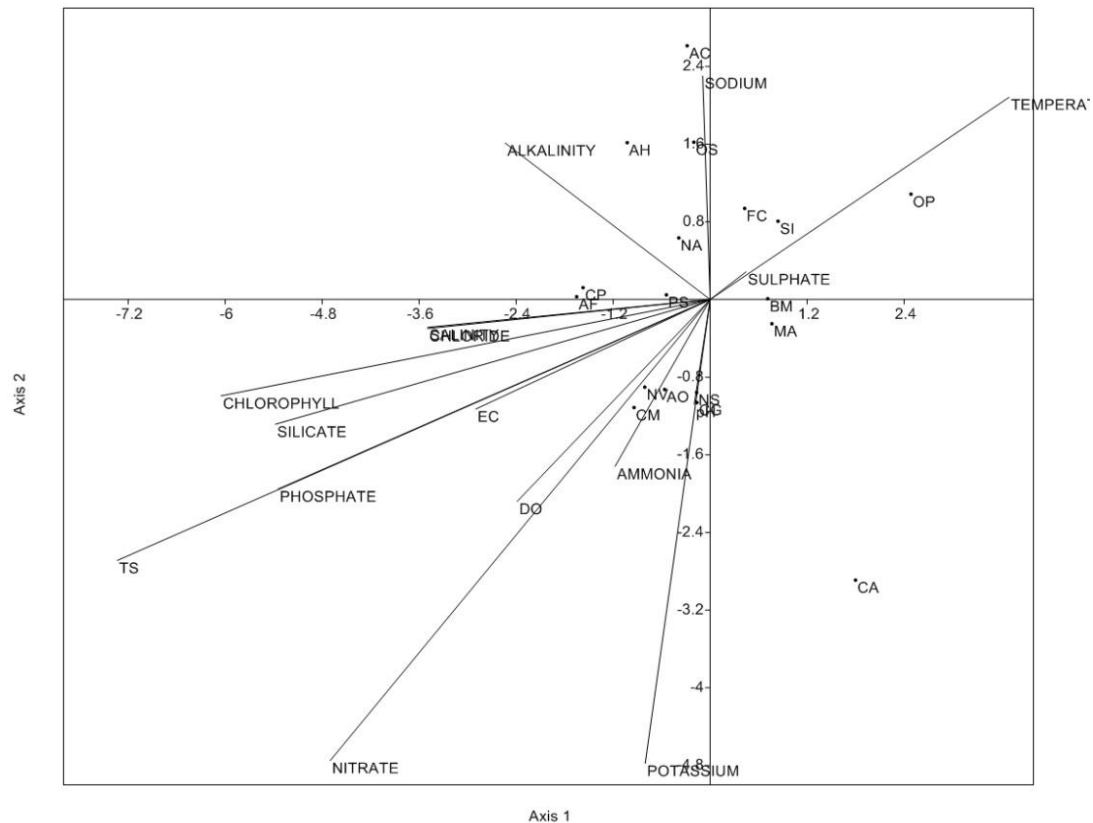


Figure 4. CCA plot showing relationship between environmental variables and phytoplankton of Bhadbhut.

Ambata site reported the least number of phytoplankton (26 species) dominated by Bacillariophycean members. Eigenvalue of axis 1 ($\lambda = 0.361$), 2 ($\lambda = 0.271$), 3 ($\lambda = 0.234$) and 4 ($\lambda = 0.177$) 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.



Ambata.

Table 8. Correlation of environmental variables with axes in Ambata

Variables	CV 1 ($\lambda = 0.361$)	CV 2 ($\lambda = 0.271$)	CV 3 ($\lambda = 0.234$)	CV 4 ($\lambda = 0.176$)
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

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

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 amphirhynchius 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 chlorophyll-*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

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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