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Statistical Approach in Assessing Dynamic Variations of Estuarine Water Quality of Dhamra, Bay of Bengal

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Abstract: Multivariate statistical techniques such as cluster analysis (CA), principal component analysis (PCA) and factor analysis (FA) were applied for the evaluation of dynamic variations in water quality of Dhamra estuarine region from 2009 to 2010. The concentrations of salinity, conductivity, turbidity and inorganic nutrients varied significantly in different seasons from estuarine region to deep marine region. The intensity of microbial activities and the influx of organic sewage are reflected in high BOD content. A strong positive correlation of salinity with conductance, chlorophyll-*a* with total phytoplankton, phytoplankton with inorganic phosphate and total viable count (TVC) with temperature have been established. Further, TVC was having negative correlation with salinity. Hierarchical cluster analysis, grouping 14 parameters into two significant clusters based on their similarity and their interrelationship identified phosphate as the major nutritional requirement for phytoplankton growth. The factor loading further indicates the influence of salinity gradient and nutrient availability for the distribution plankton. FA generates six latent factors explaining 82.67% of the total variance illustrating various interrelationships of biotic and abiotic factors.

Key words: Nutrient enrichment, biological characters, temporal variation, water quality, water pollutants, Multivariate statistical analysis.

Introduction

The richness of coastal Bay of Bengal of Indian Ocean is unique with marked continental influence due to the drainage by a large number of rivers. One such riverine system is Dhamra estuary (confluence of two major rivers, i.e. Brahmani and Baitarani), which carries large municipal sewage, industrial wastes and seasonal runoff from agricultural land to the Bay of Bengal. The complex dynamism in physico-chemical characteristics of coastal waters is linked to riverine flow, atmospheric deposition, vertical mixing, dredging activities of port and other anthropogenic sources (Panda et al., 2006). The Dhamra estuarine region supports a large mangrove area with large variety of unique aquatic creatures. The study of mangrove ecosystem is necessary as they are highly productive and plays important role as breeding and nursery grounds for many commercially important fishes especially shrimps (Kathiresan and Bingham, 2001). Distribution of nutrients determines the fertility potential of a water mass (Panda et al., 1989; Bragadeeswaran et al., 2007). The nutrient cycle of different coastal environments were affected by the seasonal distribution, abiotic and biotic processes (Choudhury and Panigrahy, 1991). Fertility and healthiness of mangrove environment is reflected in productivity of phytoplanktons and zooplanktons as primary and secondary producers. Influence of physical, chemical and biological variables on planktonic communities in mangrove waters are more pronounced than the near-shore coastal environment, resulting in seasonal changes of planktonic species, composition

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and densities (Kannan and Vasantha, 1992). There is evidence that the changes in nutrient ratio have altered phytoplankton species composition in coastal waters (Jickells, 1998; Brando et al., 2006). When the estuarine water is frequently exchanged with the open ocean, the estuarine ecosystem appears to be more resistant to nutrient over-enrichment.

River bank industrialisation, continuous channel dredging of open sea Dhamra Port, shipping operations and other anthropogenic activities have posed constant threat on Dhamra Estuary to loose its ecological importance in future. Hence, the objective of the current study is to evaluate and establish a baseline on pollution levels with regard to various physico-chemical and biological parameters, and further, to identify various linking factors with the help of statistical analysis.

Details of Study Area

Dhamra estuary belongs to Bay of Bengal, which is one of the northern embayment of the Indian Ocean. Dhamra estuary acts as the recipient from two major rivers, viz. the Brahmani and the Baitarani as well as from many small rivers and rivulets. Basically rivers of the Asian continent are the chief transporting agents of continental weathering products as they supply about 30% of the global sediment input to the world's ocean. The Dhamra estuary forms an important component of the Bhitara Kanika marine sanctuary on the Eastern coast of India, covered with mangroves, a kind of endemic vegetation which provides breeding and spawning grounds of varieties of marine life forms. They spend their juvenile stage in the mangrove estuarine ecosystem and migrate to the sea in the later part of their lives. Based on these favourable ecological conditions Nasi Islands in Gahirmatha has become famous for mass nesting of Olive Ridley Turtles. Numerous industries present in the catchment areas are discharging huge quantity of untreated wastes. With the present state of water and sediment discharges, our interest is to identify the possible anthropogenic influence on the water quality of Dhamra estuary.

Location Details

The study site selection for sample collection was based on their proximity to open coast and the level of anthropogenic pressure. The sampling stations were chosen along a stretch of 30 kilometres from the mouth

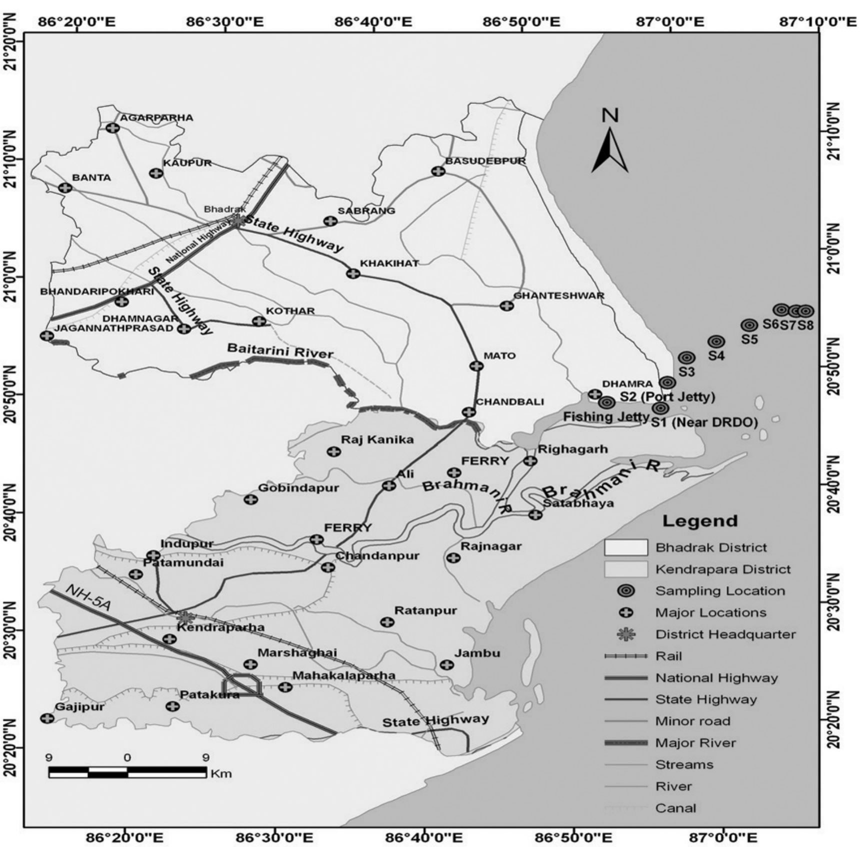


Figure 1: Map showing the study area at Dhamra Estuary.

of estuary to offshore region including dredging channel of newly constructed Dhamra port. The stations selected for sample collection were Station 1 (86°57′40.5″ E, 20°46′ 55.5″ N), Station 2 (86°58′14.3″E, 20° 49′ 05″ N), Station 3 (87°00′17.0″E, 20°51′33.5″ N), Station 4 (87°02′44.9″E, 20°52′55.8″N), Station 5 (87°05′14″E, 20°54′20.4″N), Station 6 (87°06′13.8″E, 20°54′54.3″N), Station 7 (87°07′13.6″E, 20°54′45.0″N) and Station 8 (87°07′50.4″E, 20°54′42.8″N). Water samples were collected seasonally from these eight stations of Dhamra estuary during July 2009 to June 2010.

Materials and Methods

Sample Collection and Analysis

Surface water samples were collected in acid washed clean polyethylene bottles by Niskin water sampler. Preservation, transportation and analysis of the water samples were done as per standard methods (APHA, 1998). The samples were analyzed for different physico-chemical parameters. Water temperature, pH, conductance and salinity were measured by using WTW kit (WTW model Multi 340). Dissolved oxygen was fixed immediately after water sample collection and then determined by Winkler's method, modified by Grasshoff (1983). Inorganic nutrients (NO_3^-, NH_4^+ and PO_4^{3-}) were determined by standard photometric method (Grasshoff, 1999) using Varian 50 Bio U.V visible spectrophotometer. Samples for BOD were incubated in laboratory for five days at 20°C (Trivedy and Goel, 1984) and then analyzed by same Winkler's method. Turbidity was measured by 2100P HACH Turbidimeter using 0.01, 20, 100 and 800 NTU standards.

Phytoplankton biomass (chlorophyll-*a*) of water samples were measured by filtering 1000 ml of water sample through Whatmann GF/F (25 mm diameter, nominal pore size 0.7 μm) using parallel filtration under low vacuum pressure (<250 mg Hg) or gravity. After filtration, Chlorophyll-*a* was immediately extracted by immersing the filter paper in 10 ml of 90% acetone and preserved at 4°C for overnight for digestion or extraction. Then the digest was centrifuged at 5000 rpm for 15 minutes and the supernatant was adjusted to 10 ml with 90% acetone by volume make up. Then the chl-*a* was estimated by measuring OD at a wavelength of 750 nm, 664 nm, 647 nm and 630 nm with the help of spectrophotometer (Jeffrey et al., 1975). For phytoplankton 1000 ml of sea water was preserved with 10 ml of Lugol's iodine fixative solution. Then the sample was settled overnight and further 50 ml of sample was decanted from the settled sample (Utermohl, 1958) for subsequent microscopic analysis using an inverted light microscope at 200 to 400 × magnifications. The diversity index of the phytoplankton community was estimated by using Shannon's diversity index (*H'*) equation. Water samples were collected in a 100 ml of pre-sterilized glass bottles and stored at 4°C for microbial analysis. Bacterial load in water samples were estimated by using pour plate colony count method and the TVC count was expressed in terms of CFU/ml (APHA, 1998).

Statistical Analysis

Statistical methods can be used to assess the complex processes by showing the relationship and interdependency among the variables and their relative weights. XLSTAT software was used for statistical analyses of given data. Pearson's correlation coefficient and multivariate techniques including cluster analysis (CA), and factor analysis (FA) have been applied to fourteen parameters of surface water to generate latest information about the similarities among the monitoring variables and to identify different key factors leading to spatiotemporal variations in water quality in Dhamra estuary. Cluster analysis is an unsubstantiated pattern identification method that divides a large group of cases into small groups or clusters of relatively analogous cases that are different to other groups. Principal component analysis is most powerful and common techniques are used for reducing the dimensionality of large data sets without loss of information (Huang et al., 2011).

Results and Discussion

Physico-chemical Parameters and Their Correlation Analysis

The statistical summary of distribution of all the analyzed physico-chemical and biological parameters in water samples is given in Table 1 and Figure 2 and also their correlation analysis were presented in Table 2. The surface water temperature is usually influenced by the intensity of solar radiation, evaporation, freshwater influx and cooling (Govindasamy et al., 2000). During the study period the surface water temperature has marginal variations ranging from 27.0 (min) to 28.4°C (max) in all the stations. Hydrogen ion concentration (pH) in surface waters remained alkaline with the maximum value (8.35) occurring in the winter season at off-shore Station 5 and minimum value (7.59) occurring in the monsoon season at Station 1 (Table 1). Seasonal fluctuations of pH is ascribed to the factors like dilution

Table 1: Descriptive statistics of water quality parameters at different locations in the Dhamra estuarine system during three different seasons

	Pre monsoon				*Monsoon*				*Post monsoon*			
	Max	*Min*	*Avg.*	*Std dev.*	*Max*	*Min*	*Avg.*	*Std dev.*	*Max*	*Min*	*Avg.*	*Std dev.*
Temperature (°C)	28.4	27	27.37	0.53	30.95	30.55	30.81	0.14	26.4	25.55	25.94	0.34
pH	8.15	7.98	8.06	0.06	8.03	7.59	7.89	0.17	8.35	8.03	8.18	0.14
Conductance (mS/cm)	50.85	40	47.93	4.05	43.5	15.52	33.06	11.72	37.95	31.55	35.13	2.65
Turbidity (NTU)	560	30.45	273.53	219.96	46	8.36	20.78	13.83	387	4.58	144.01	177.62
Salinity	33.35	29.15	31.91	1.59	28.4	9.25	21.03	8.16	23.8	19.6	22.1	1.8
DO (mg/l)	6.8	4.86	6.15	0.7	6.54	6.04	6.33	0.21	7.35	6.92	7.17	0.15
BOD (mg/l)	5.34	3.24	4.03	0.77	4.12	2.73	3.55	0.53	4.63	3.84	4.17	0.3
NO_3^- (mg/l)	0.86	0.16	0.43	0.27	0.5	0.06	0.25	0.18	0.38	0.26	0.35	0.05
PO_4^{3-} (mg/l)	0.06	0	0.03	0.02	0.15	0.04	0.08	0.04	0.07	0.03	0.04	0.02
NH_3 (mg/l)	0.03	0.03	0.03	0	0.06	0.01	0.03	0.02	0.05	0.02	0.03	0.01
Phytoplankton count/l	1785	820	1254	412	9985	1115	5156	3868	12117	1553	5261	4099
Chl-*a* (µg/l)	1.35	0.69	0.97	0.26	2.34	1.31	1.88	0.37	2.82	0.55	1.63	0.77
DI	2.62	1.62	2.07	0.33	2.24	1.75	2.01	0.16	1.83	1.07	1.55	0.26
TVC (CFU)	185	40	124	56.16	620	210	448	149.98	546	65	315	177.66

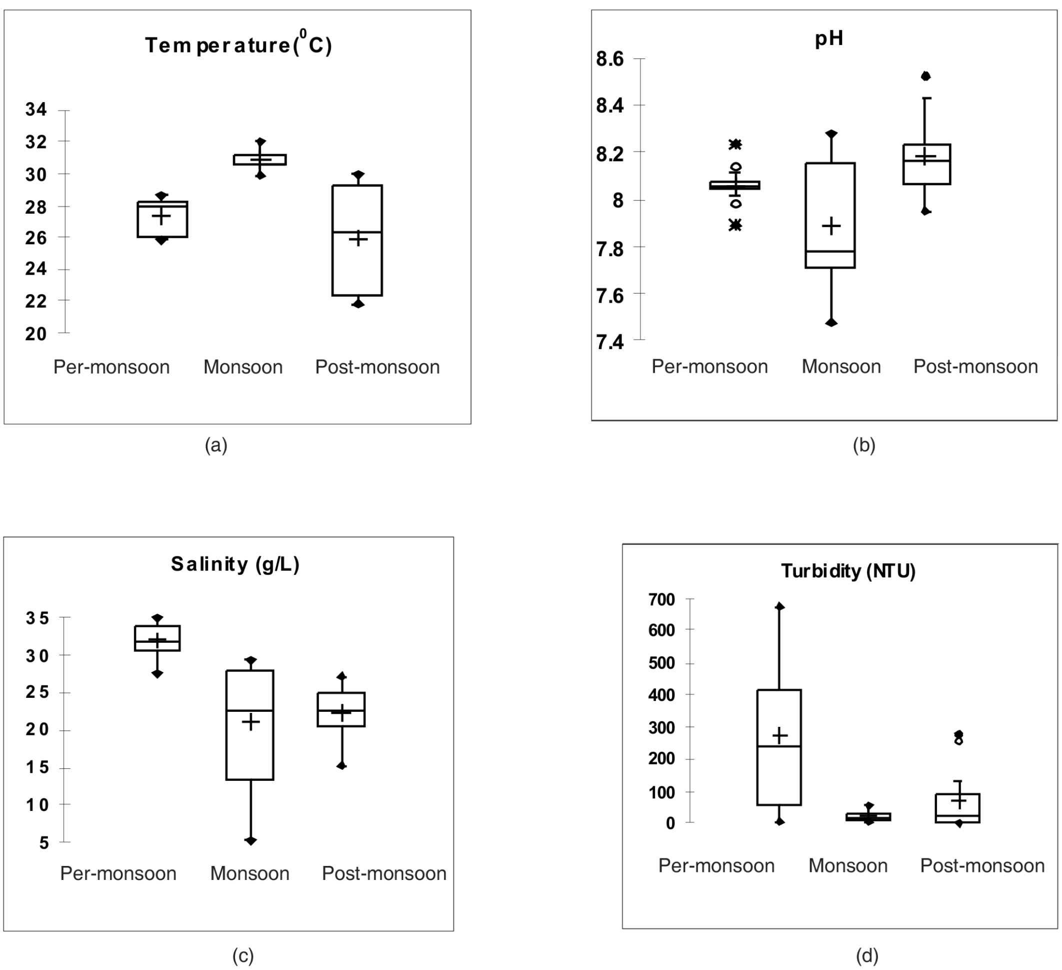


Figure 2: Box Plot of temperature, pH, salinity and turbidity value at Dhamra Estuary.

Table 2: Correlation matrix of different water quality parameters along Dhamra estuary during the study period

	Temp	*pH*	*Condu*	*Turb*	*Salinity*	*DO*	*BOD*	*NO_3*	*PO_4^{3-}*	*NH_3*	*Phyt. count*	*Chl-a*	*Diversity index*	*TVC count*
Temp	1.00													
pH	-0.26	1.00												
Condu	-0.33	0.38	1.00											
Turbidity	-0.12	-0.10	0.18	1.00										
Salinity	-0.31	0.35	0.99	0.24	1.00									
DO	-0.36	0.25	-0.29	-0.18	-0.32	1.00								
BOD	-0.04	-0.14	0.16	0.17	0.19	0.38	1.00							
NO_3	0.23	0.03	-0.16	0.19	-0.16	0.03	-0.09	1.00						
PO_4^{3-}	0.21	-0.04	-0.29	-0.25	-0.29	-0.18	-0.55	-0.06	1.00					
NH_3	0.03	-0.03	-0.42	-0.08	-0.42	0.03	-0.37	0.07	0.42	1.00				
Phyt. count	0.08	0.21	-0.28	-0.26	-0.30	0.19	-0.28	-0.04	0.59	0.10	1.00			
Chl-*a*	0.10	-0.10	-0.27	-0.32	-0.28	0.04	-0.03	-0.14	0.36	0.03	0.70	1.00		
Diversity index	-0.11	-0.33	0.13	0.08	0.23	-0.34	0.06	-0.26	0.03	-0.17	0.03	0.21	1.00	
TVC count	0.53	-0.25	-0.64	-0.08	-0.65	0.11	-0.09	0.20	0.10	-0.02	0.18	0.14	-0.14	1.00

of seawater by freshwater influx, reduction of salinity, decomposition of organic matter and removal of CO_2 by photosynthesis through carbonate degradation (Upadhyay et al., 1988; Rajasegar et al., 2003). This is further supported by the statistical analysis, which shows a strong positive correlation of pH with salinity. Similar trend in pH was reported by Thangaraj (1985), Hemalatha (1996) and Sreenivasan (1998).

Salinity acts as a limiting factor in the distribution of living organisms and its validation caused by dilution and evaporation, which is most likely to influence the fauna in the intertidal zone (Gibson, 1982). Further, the statistical analysis reveals that conductance shows highest positive correlation with salinity and salinity is also positively correlated with temperature. The minimum values of conductance (15.52 mS/cm) and salinity (9.25 g/L) were observed in the nearby estuarine region during monsoon with the obvious reason of dilution due to heavy rainfall and resultant river run-off. The maximum values of conductance (50.85 mS/cm) and salinity (33.35 g/L) were observed in offshore regions during summer. The changes in salinity of brackish water habitats such as estuaries, backwaters and mangrove are due to incursion of freshwater from land run off caused by monsoon or by tidal variations (Saravankumar et al., 2008). Turbidity is mainly due to the dispersion of suspended particles and the turbidity of Dhamra estuary surface water varied from 4.58 to 560 NTU. Abnormal values of turbidity are generally due to discharge of river water and maintenance dredging carried out by Dhamra Port (Muduli et al., 2010). As observed the turbidity was usually higher in the estuarine region, which subsequently decreases towards offshore region as a phenomenon of sea and fresh water intermixing.

In aquatic systems, oxygenation is the result of an imbalance between the process of photosynthesis, degradation of organic matter, re-aeration (Granier et al., 2000) and physicochemical properties of water (Aston, 1980). Dissolved oxygen concentration varies according to many factors such as photosynthesis and respiration of plants and animals in water. During the entire study period, dissolved oxygen was found to be varied from 4.86 to 7.35 mg/l (Table 1, Figure 3). The average concentration of DO was higher in post-monsoon due to the winter cooling, lower bacterial activity and higher photosynthetic activity. Further, the inverse correlation of DO with salinity and temperature predicted that these two parameters mainly affect dissolution of oxygen in water (Vijay Kumar et al., 2000). Biochemical oxygen demand indicates the activity of the micro organisms and their oxygen requirements to degrade biodegradable substances. It depends on temperature, level of biochemical activities, concentration of organic matter and such other related factors (Muduli et al., 2010). In Dhamra estuary due to dilution of discharged effluents the lowest BOD value (2.73 mg/l) was observed at Station 2 in monsoon and during pre-monsoon highest BOD value was recorded at Station 1 (5.34 mg/l), because of the degradation of wastes by higher bacterial load (Figure 3). Normally during pre-monsoon period, the reduced flow of riverine water and availability of huge dead decaying materials and organic sewage trigger the biological commotion at elevated temperature (Ghavzan et al., 2006), thus causing higher microbial activities in this region.

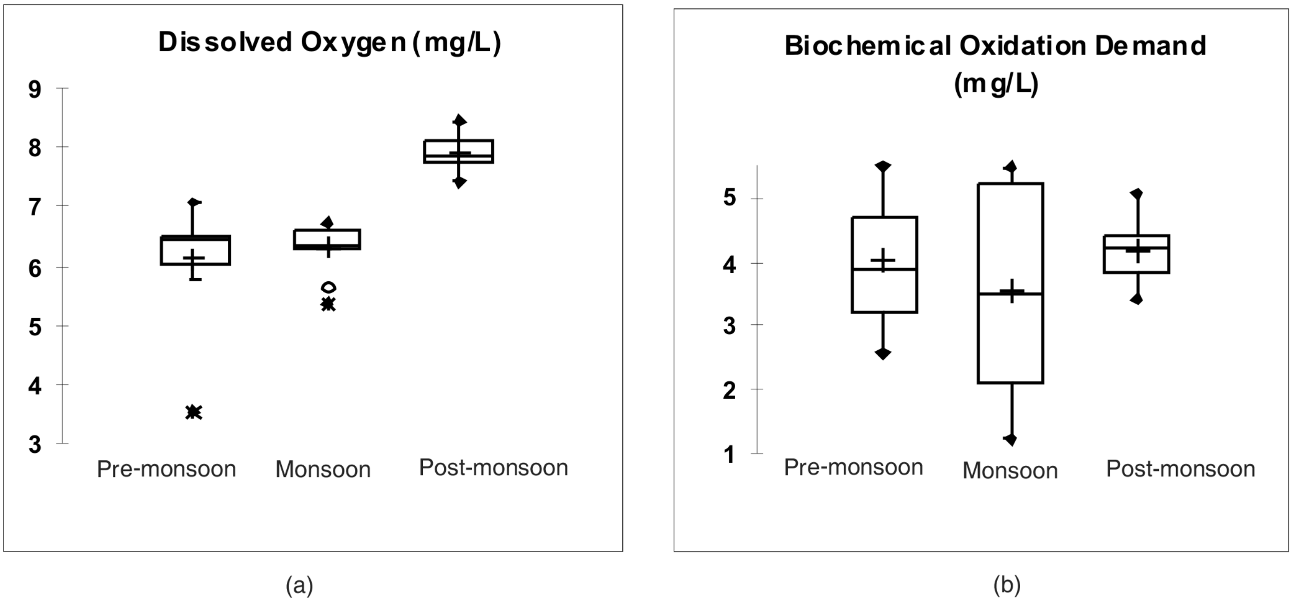
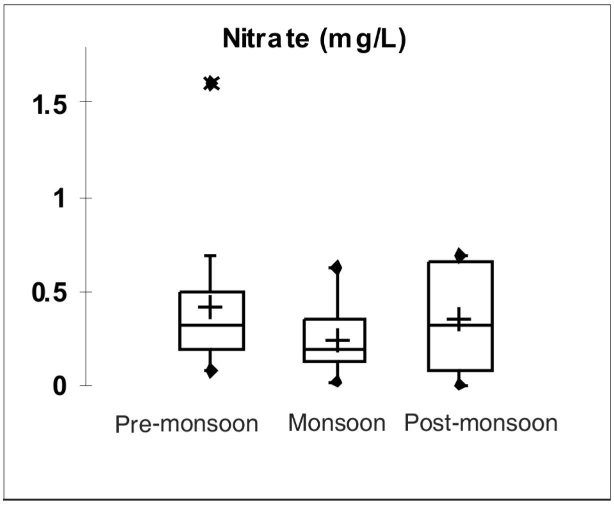


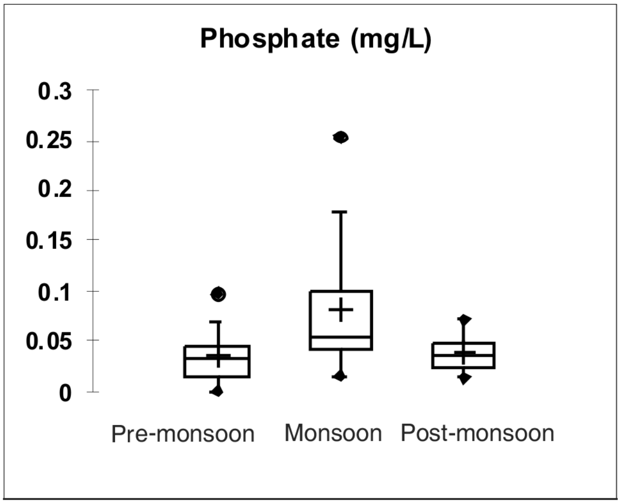
Figure 3: Box Plot of DO and BOD at Dhamra Estuary.

Out of the nine oxidation states (−3 to +5) of nitrogen, nitrate is thermodynamically the most stable form of combined inorganic nitrogen in well-oxygenated waters. As a consequence of biologically activated reactions the variations in nitrate and its reduced inorganic compounds were observed. Surface runoff and rapid uptake by phytoplanktons were the major factors influencing the large scale spatio-temporal variation of nitrate in estuarine ecosystem (Qasim, 1977; De Souza, 1983; Zepp, 1997). The nitrate value of surface water was varied from 0.1571 to 0.8564 mg/L during pre-monsoon, 0.0567 to 0.4998 mg/L in monsoon and 0.2594 to 0.3831 mg/L in the post-monsoon period (Table 1 and Figure 4). Presence of NO_3^- ion could be due to the anthropogenic sources like domestic sewage, agricultural wash offs and other waste effluents containing nitrogenous compounds. So the higher value observed during pre-monsoon period could be due to addition of domestic sewage in sea water and the lower values recorded during monsoon period may be due to dilution of sewage by precipitation and removal caused by the influx of silt-laden rainwater (Lakshmanan et al., 1987). In the present study, nitrate showed negative correlation with salinity. The negative correlation between nitrate and salinity may be due to freshwater influx, which is considered to be the main source of nutrient in coastal waters (Choudhary and Panigrahy, 1991; Satapathy, 1996). The ammonia value ranged from 0.01 to 0.0623 mg/L (Table 1), where the minimum value was recorded during post-monsoon and the maximum value in monsoon period at river mouth. The higher concentration of ammonia observed during monsoon could be partially due to death and subsequent decomposition of phytoplankton and also due to the excretion of planktonic organisms (Segar et al., 1989; Ananthan, 1994; Rajasegar et al., 2003).

The phosphate value varied from 0.0049 to 0.0620 mg/L in pre-monsoon, 0.0371 to 0.1461 mg/L in monsoon and 0.0300 to 0.0704 mg/L during post-monsoon period (Table 1 and Figure 4). The increase in phosphate concentration at estuarine region was attributed to the incursion of the nutrient-rich river water into the marine water and the resuspension of the coastal sediment due to channel dredging that releases phosphate to the water column (Chandran and Ramamurthy, 1984). The higher concentration of inorganic phosphate observed during monsoon season was due to the influx of river water into the sea, input of local sewage and industrial waste disposal which increased the level of phosphate (Sunderay et al., 2006). Weathering of rocks liberating soluble alkali metal phosphates also contributes to the increase of phosphate concentration (Das et al., 1997; Gowda et al., 2001). The limited flow of freshwater, high salinity and utilization of phosphate by phytoplankton, as evidenced by high photosynthetic activity, could be the reason behind the lower phosphate value observed during pre-monsoon period (Senthilkumar et al., 2002; Rajasegar et al., 2003). Similar observations were also reported by Sundararaj and Krishnamurthy (1975) from Pitchavaram waters and Rajasegar (2003) from Vellar estuary. Further, the PO_4^{3-} concentration is having a moderate



(a)



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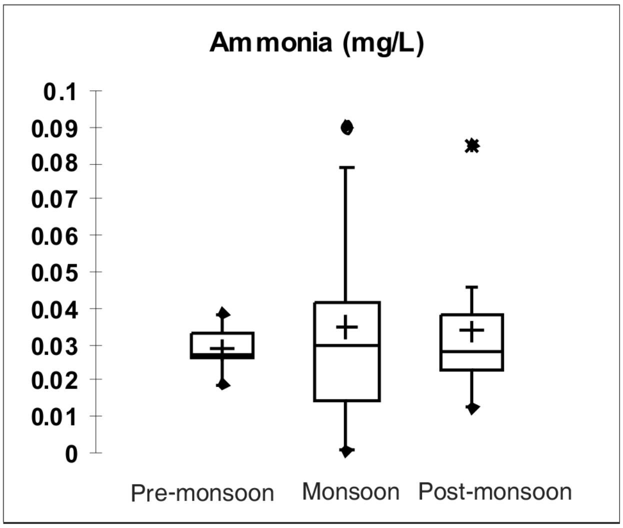

(c)

Figure 4: Box Plot of nitrate, phosphate and ammonia concentration at Dhamra Estuary.

negative correlation with DO and strong negative correlation with BOD indicating the consumption of phosphate due to utilization by phytoplankton with the release of oxygen through photosynthesis.

The biological variables such as total phytoplankton count, diversity index, chlorophyll-*a* and TVC count vary in different seasons. The total phytoplankton count ranged from 820 to 1785 cells/lt during pre-monsoon, from 1115 to 9985 cells/lt in monsoon and from 1553 to 12117 cells/lt in post-monsoon. The highest concentration was observed during post-monsoon at Station 4. Similarly, chlorophyll-*a* ranged from 0.69 to 1.35 µg/l during pre-monsoon, 1.31 to 2.34 µg/l in monsoon and 0.55 to 2.82 µg/l during post-monsoon period. The average highest value of chlorophyll-*a* was observed during post-monsoon period at Station 4 (Figure 5) was due to the availability of inorganic nutrients, favourable temperature and sunlight for photosynthesis which increased the phytoplankton population. Moreover, tidal variation has a role in the variability of chlorophyll-*a* concentration. Further, the correlation coefficient analysis shows that the total phytoplankton count and chlorophyll-*a* were showing strong positive correlation with inorganic nutrient

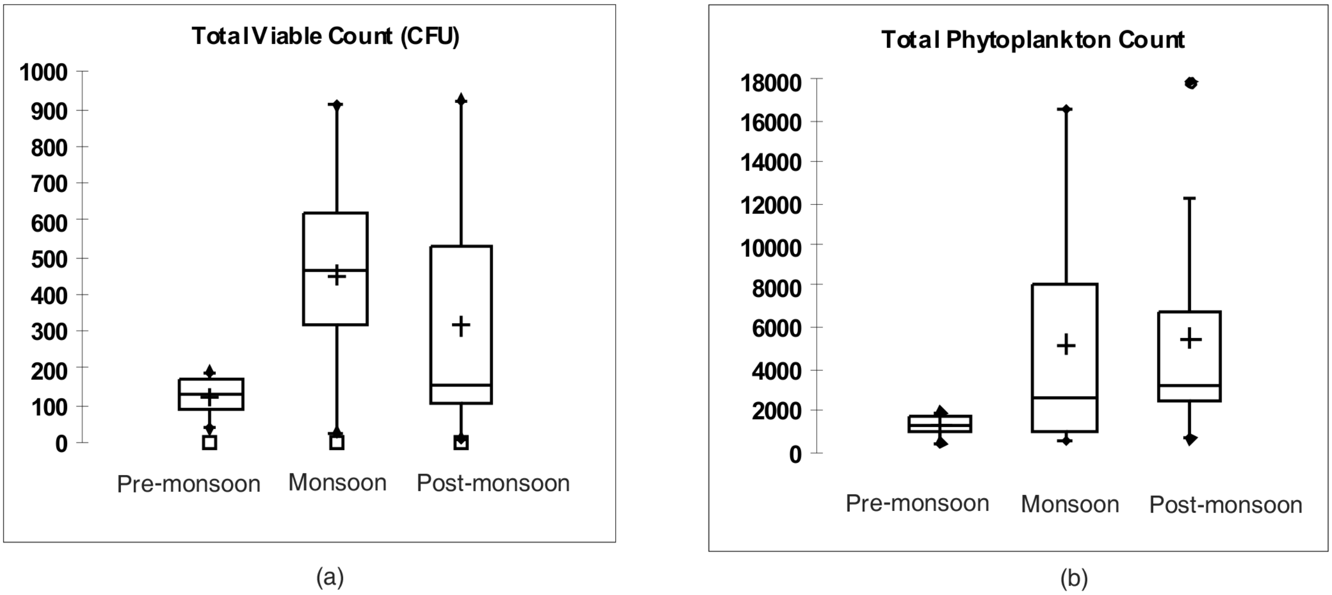

Figure 5: Box Plot of total viable count and total phytoplankton count at Dhamra Estuary.

PO_4^{3-}, indicating the dependence of phytoplankton population with phosphate. The diversity index (*H*') of phytoplankton ranged from 1.62 to 2.62 during pre-monsoon, from 1.75 to 2.24 in monsoon and from 1.07 to 1.83 in post-monsoon. The highest concentration was observed during pre-monsoon at Station 1. TVC count of water was recorded from 40 to 185 CFU/ml during pre-monsoon, from 210 to 620 CFU/ml in monsoon and from 65 to 546 CFU/ml during post-monsoon. The highest concentration of TVC observed during monsoon at Station 1 was due to the availability of plenty of inorganic carbon from dead decaying materials, favourable temperature and less salinity. Movement of fishing vessels and disposal of fecal materials to the water may be another reason of higher TVC bacterial count. TVC shows good correlation with temperature as the higher temperature inhibits the bacterial activity and strong negative correlation (0.6508) with salinity as high salinity causes ex-osmosis and hence death of the micro organisms. The maximum and minimum ranges are presented in Table 2 and the seasonal variations are given in Figure 5.

Taking standard deviation as one of the statistical aspects, temperature, turbidity, nitrate, DO, BOD and diversity index were showing maximum standard deviation during pre-monsoon period, whereas during monsoon pH, salinity, conductance, phosphate and ammonia were showing maximum standard deviation. During post-monsoon total phytoplankton count, chl-*a* and TVC bacterial count were showing maximum standard deviation.

Multivariate Analysis

In the present study different multivariate statistical techniques were used to identify different bio-physical and bio-chemical relationship among parameters of surface water of Dhamra estuary.

Cluster Analysis (Similarity and Grouping of Monitored Variables)

The agglomerative hierarchical clustering (AHC) was applied on the one year raw data to generate a dendrogram, grouping 14 variables into different clusters (Figure 6). The variable cluster analysis identified similar parameters considering the effect of temporal changes in an estuarine ecosystem. The first and the important cluster, which comprises PO_4^{3-}, phytoplankton and chlorophyll, indicates that the ortho-phosphate is the principal nutritional requirement for phytoplankton growth and plays a major role in phytoplankton population density as well as in chlorophyll concentration. The association of NH_3 with the first cluster may indicate that among other inorganic nitrogen, phytoplanktons depend upon NH_3 only as their nitrogenous source for growth in Dhamra estuary. The association of temperature and total viable count in the second cluster indicate the strong influence of temperature on bacterial growth.

Principal Component Analysis and Factor Loading of Variables

Principal component analysis (PCA) was applied to standardized data sets (14 parameters) towards examining difference or similarity between parameters

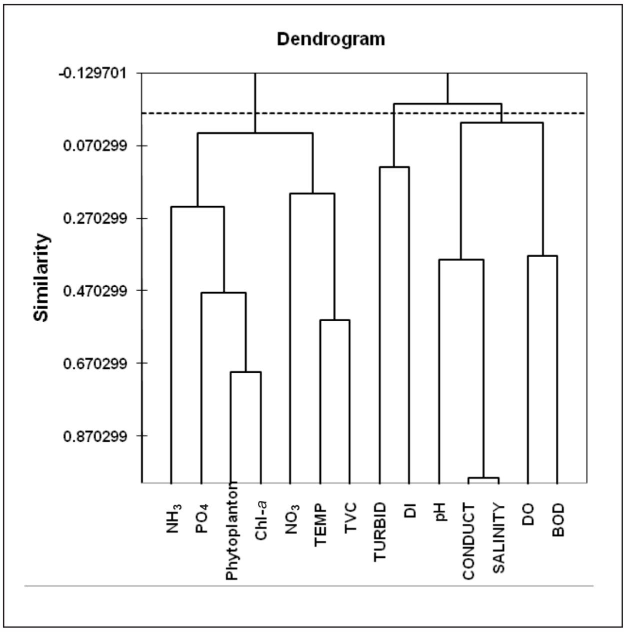

Figure 6: Dendrogram showing variable clustering at Dhamra Estuary.

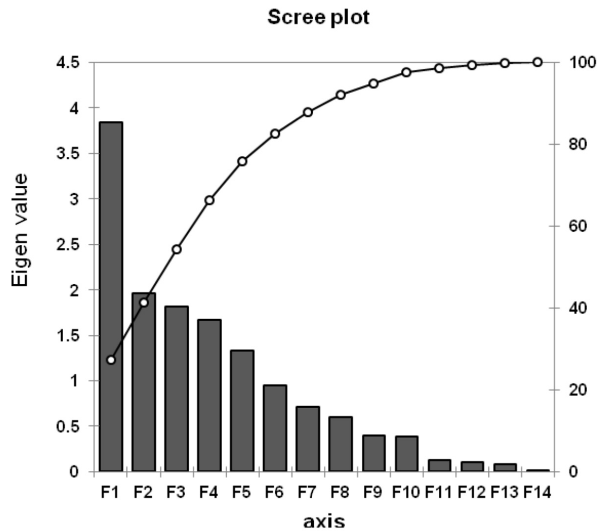

Figure 7: Scree-plot of PCA for variables at Dhamra Estuary.

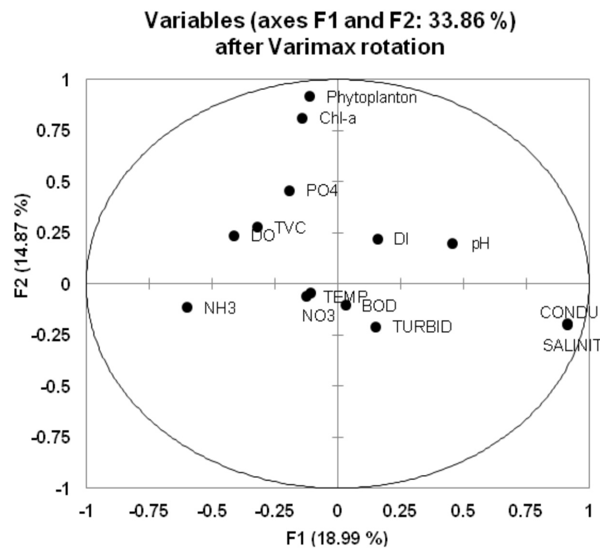

Figure 8: Principal component analysis (PCA) of the physico-chemical parameters at Dhamra Estuary.

and identify latent factors. A scree plot is the graphical representation of factors, where eigen values are plotted in the sequence of the principal factors (Figure 7). Based on scree plot the eigen values which are >1 are considered to be essential. PCA of the given data yield six factors explaining 82.67% of the total variance in the respective water quality records. The results of PCA comprising the loadings were summarized in Table 3 and Figure 8. The absolute values are more than 0.4 after varimax rotation were highlighted. Six numbers of factors were obtained to compare the compositional pattern between analyzed water parameters and identify the factors influencing each other by applying factor analysis performed on the principal components. Corresponding factors, variable loadings and their variance are presented in Table 3 and a scatter plot between factors 1 and 2 were plotted in Figure 8. According to Liu et al. (2003), the factor loadings are classified as 'strong' with absolute loading value of >0.75, moderate with loading value of 0.5-0.75 and 0.30-0.50 as weak loading.

From the six factors, F1 explaining 18.99% of the total variance had strong positive loadings of pH, conductance, salinity as well as moderate to weak negative loading on ammonia and TVC. Thus, F1 represented estuarine water quality—basically the salinity gradient—affecting the microbial growth. F2 (14.87% of the total variance) had positive loadings on PO_4^{3-}, phytoplankton and chlorophyll. This interrelationship was also observed in the cluster analysis. F3 (12.40% of the total variance) had strong positive loadings on pH with strong negative loading on phytoplankton diversity. Thus, F3 indicates the variation of ionic condition of estuary, which inversely influences the diversity of phytoplanktons. Hence, the survived species get slowly adapted to such fluctuating environment. The F4 (14.16% of total variance) was having strong negative loading on DO and BOD with positive loading of nitrate and phosphate. This factor represented nutrient depletion during biological degradation of organic contaminants. The F5 (13.70% of total variance) had strong positive

Table 3: Factor loading after Varimax rotation of 14 measured parameters of Dhamra estuary during the study period.

	F1	*F2*	*F3*	*F4*	*F5*	*F6*
TEMP	-0.123	-0.060	-0.083	0.164	**0.848**	-0.001
pH	**0.456**	0.199	**0.716**	0.103	-0.242	0.001
Conduct	**0.916**	-0.194	0.034	-0.079	-0.265	0.003
Turbid	0.153	-0.210	**-0.312**	-0.082	-0.210	**0.750**
Salinity	**0.915**	-0.198	-0.052	-0.091	-0.277	0.039
DO	-0.412	0.236	0.228	**-0.543**	**-0.338**	-0.068
BOD	0.033	-0.104	-0.120	**-0.850**	-0.102	-0.024
NO_3	-0.109	-0.042	0.281	0.048	0.270	**0.752**
NH_3	**-0.598**	-0.116	0.106	**0.599**	**-0.326**	0.025
PO_4^{3-}	-0.191	**0.458**	-0.040	**0.704**	0.103	-0.119
Phytoplankton	-0.111	**0.916**	0.144	0.206	0.077	-0.016
Chl-*a*	-0.142	**0.813**	-0.213	0.020	0.042	-0.201
DI	0.158	0.220	**-0.812**	-0.070	-0.108	-0.025
TVC	**-0.321**	0.276	0.059	-0.041	**0.784**	0.079
Variance %	18.992	14.872	12.401	14.161	13.701	8.550
Cumulative %	18.992	33.864	46.265	60.426	74.127	82.676

loadings on temperature and TVC, which represented higher bacterial growth at elevated temperature and the weak negative loading on DO and ammonia possibly representing the exhaustion of above at high temperature and increased bacterial consumption. F6 (8.55% of total variance) represents subsequent sediment upwelling, land runoff and sewage discharge, which is greatly related to the positive loading of turbidity and nitrate.

Conclusion

The present investigation revealed that the physicochemical and biological properties of the coastal waters of Dhamra estuary were considerably affected by freshwater input during monsoon. The highest concentration of all the nutrients (except nitrate), total viable count (TVC) and chlorophyll-*a* were observed during the monsoon period. On the other hand the physical parameters such as salinity, pH and conductance were at their minimum level during this period. Correspondingly, the nutrient values were higher in the estuarine region in comparison to the marine region as the estuarine region is significantly influenced by freshwater influx and agricultural runoff. The high BOD values observed near estuary is due to the higher intensity of microbial activities and the influx of organic sewage. Hence, from the overall study, conclusion may be drawn that the estuarine water is extremely influenced by the anthropogenic activities and fresh water influx as it is a transition zone between river and ocean environments.

By applying multivariate statistical techniques, the varifactors obtained from factor analysis indicate that the parameters responsible for biotic environment and water quality variations are mainly related to the salinity gradient, temperature and nutrients. The cluster analysis indicates that ammonia and phosphate are the major nutritional requirements for phytoplankton in Dhamra estuary. Further, it predicts that the salinity gradient and nutrient availability influence the plankton distribution and their diversity. The turbidity and nitrate association specified about non-point source of pollution in the estuary. So the application of multivariate statistical techniques such as cluster analysis, factor analysis and principal component analysis recognized more specifically different bio-physical and bio-chemical relationship among various parameters of Dhamra estuary and also illustrates the various linking factors of Dhamra estuary, which sustains the whole biotic environment, which is further effective for estuarine water quality management.

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