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AN ASSESSMENT OF PHYSICO-CHEMICAL CHARACTERISTICS OF THE COASTAL WATER OF NARMADA ESTUARY, GUJARAT AND STATISTICAL EVALUATION OF ITS SEASONAL CHANGES

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Abstract

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Narmada estuary is one of the major riverine systems in Western India. Modernization and industrialization in its neighbourhood in the north have greatly influenced many tributaries of the Narmada and adjacent coastal environments in the recent past. To trace the influence of this modernization activity further south of the Narmada estuary and to understand the quality of Narmada estuarine water reaching the coastal region, investigations on physicochemical parameters were carried out from July 2008 to June 2009. These consisted of the temperature, pH, salinity, dissolved oxygen,, the dissolved PO_4-P, NO_3-N and SiO4-Si nutrients and also chlorophyll-a present in the water off the mouth of the Narmada estuary. Multivariate statistics and principal component analysis applied to the datasets during the whole study period indicated two factors which influenced water variability to an extent of 72%. Principal axis factoring and alpha factoring were used to observe the mode of association of parameters and their interrelationships in evaluating the water quality. The results indicated the addition of phosphates and silicates to the coastal water by the Narmada estuary from natural sources during this study period. The study indicated that the Narmada estuary adds sufficiently well-oxygenated, nutrient-rich water to the coastal region.

Key words: Narmada estuary, physico-chemical parameters, multivariate statistics, principal component analysis, seasonality

Introduction

Rivers are the main inland water resources for domestic, industrial and irrigation purposes and they often carry large municipal sewage, industrial wastewater discharges and seasonal run-off from agricultural land to the coastal region. It is mainly for this reason that the river water is mostly enriched in nutrients compared to other environments (Panda et al., 2006). The spatial heterogeneity within the river, however, is due to existing local environmental conditions such as light, temperature, water discharge and flow velocity, which change over time and also differences in the local channel form. Contrary to this, the coastal environments are highly economical and important and they are significantly involved in the transport of terrestrial organic matter and associated nutrient elements to the sea for their bio-geochemical cycling (Chakrapani, 2005). The balance in concentrations of bio-eugenic elements in coastal waters reflects the healthy status of water, while their excess supply as observed in the continental shelf and upwelling areas has been found to trigger high primary productivity (Pradhan et al., 2009).

Tidal variation and nutrient dynamics are more pronounced in tropical estuaries than in temperate estuaries. Reports concerning some tropical estuaries include those of Edward, Ayyakkanu (1991) on the Kollidan estuary on the southeast coast of India, Jiyalalram (1991) on the Mahi estuary and in Coastal waters of Kalpakam on the East coast of India (Satpathy et al., 2009). The physico-chemical characteristics of the tropical Devi estuary in the eastern region of India was analyzed by Pradhan et al. (2009), and physico-chemical characteristics in relation to pollution and phytoplankton production potential of brackish water were carried out in Sundarbans of India by Shah et al. (2001). Spatial and temporal fluctuations in the Tapi estuarine system's water quality were investigated by Nirmal Kumar et al. (2009). Physico-chemical characteristics and statistical evaluation of the hydro-biological parameters of the Narmada River was carried out by Shraddha et al. (2007).

The complex dynamism in the physico-chemical characteristics of coastal waters is related to the riverine flow, upwelling, atmospheric deposition, vertical mixing and other anthropogenic sources. The coastal Gulf of Cambay is a unique marine environment in the tropical belt with marked continental influence due to its drainage by 16 major and minor rivers. One such riverine system is the Narmada river in Gujarat. This river originates in Madhya Pradesh state, and it then flows through Maharashtra before finally ending in the Gulf of Cambay. Major urban settlements and industrial set-ups along the banks of this river have caused the release of large amounts of untreated domestic waste and effluents directly into the river. Due to the various anthropogenic influences in the Narmada river basin, large amounts of contaminants arising from nutrients and other parameters have been observed in many of its tributaries and also in the adjacent coastal region. Hydro-chemical studies were carried out from July 2008 to June 2009 at selected locations in the coastal region off the mouth of the Narmada estuary (Fig. 1), in order to assess the water quality in this region and to understand its input into the coastal waters.

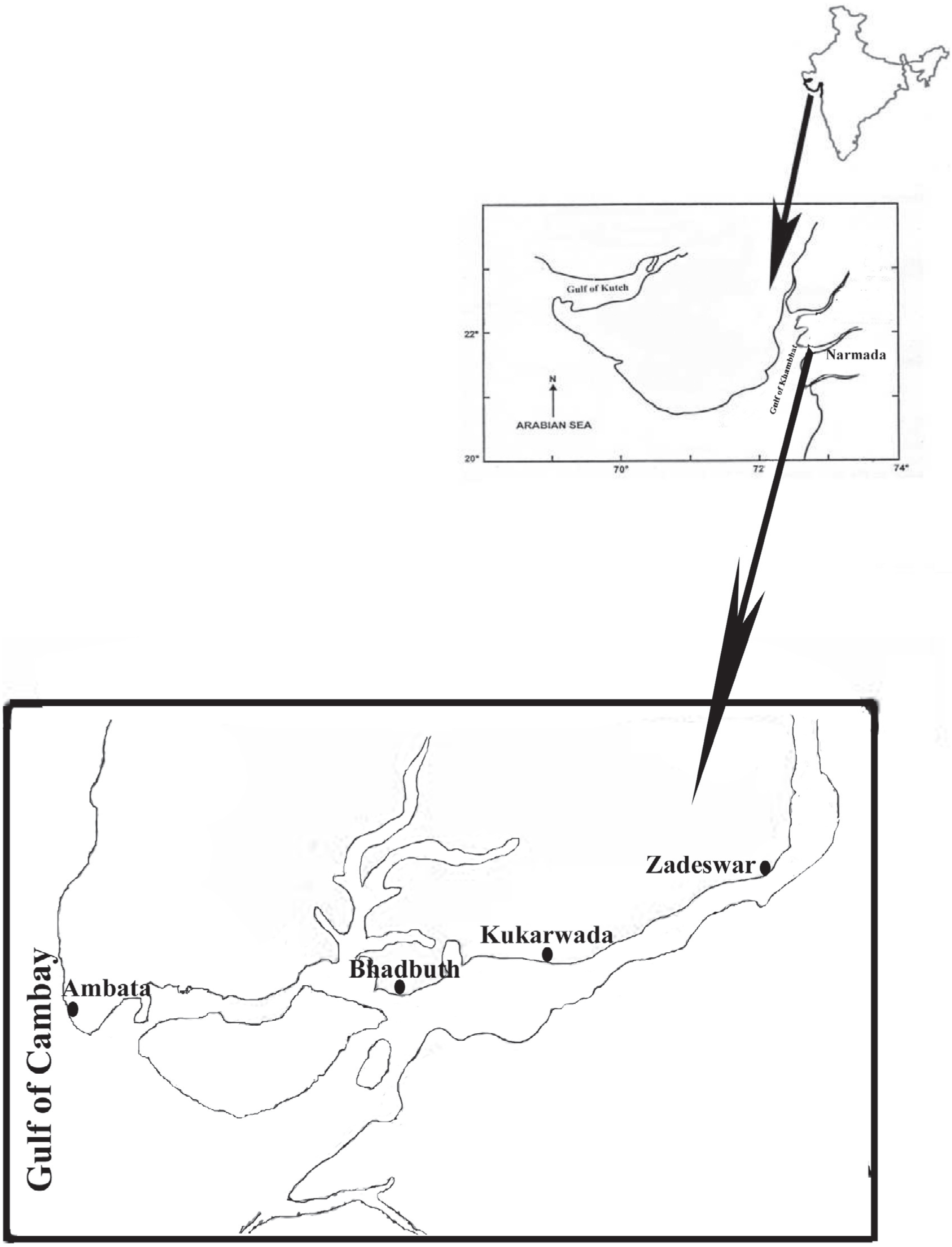


Fig. 1. Study area in Narmada estuary.

Material and methods

Four study sites were selected along the northern bank of the river (Fig. 1). Zadeshwar (site 1) is 37–39 km from the mouth of the estuary which is a fresh water dominated area hardly affected by tidal influence. This area receives nutrients from up-stream agricultural runoff and industrial regions. Kukarwada (site 2) is 15 km downstream from Zadeshwar and this area mainly receives effluent released by cities such as Baruch and also industrial complexes in the Ankleshwar area. Bhadbuth (site 3) is 6–7 km downstream from Kukarwada and its area receives effluent from industrial complexes including ONGC. Ambata (site 4) is located near the mouth of this region and it forms the main mixing-zone of the estuary. It receives effluents from industrial sites including Reliance industries, Birla Copper and many fertilizer industries in and around this region.

A total of 48 water samples were collected from the four selected stations along the southern bank which extended from the mouth of the river to the offshore region (Fig. 1). The water samples were collected at monthly intervals from the surface layers from July 2008 to June 2009. These samples were collected in Polyethylene bottles and stored in ice boxes at –4 °C for laboratory analysis.. The physico-chemical parameters of pH, dissolved oxygen (DO), phosphate (PO_4-P), nitrite (NO_2- N), nitrate (NO_3-N) and silicate (SiO_4-Si) were measured by standard procedures (APHA, 1998). The data quality was ensured by careful standardization, procedural blank measurements and 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 (Strickland, Parsons, 1979).The chlorophyll-a estimation was carried out spectrophotometrically by filtering samples using glass fibre filter papers and then extracted in 90% acetone.

Principal component analysis (PCA) is one of the best statistical techniques for extracting the linear relationships between sets of variables (Iyer et al., 2003). Principal components are linear combinations of original variables and are the eigenvectors (Wunderlin et al., 2001). The Varimax rotation distributes the PC loadings in such a way that their dispersion is maximized by minimizing the number of large and small coefficients (Richman, 1986). The normalized promax-rotated principal axis factoring (PFA) eliminates the variance due to unique factors which are uncorrelated with each other, and with the common factor, and it is therefore excluded from factor analysis. The reproduced and residual correlation matrix indicates that the factors indeed capture the relationships between variables by calculating the correlations between them and the correlations between factors and variables. The reliability of this alpha factor analysis (AFA) is based on attempts to create factors which are linear combinations of the variables, to estimate the "latent variables" or constructs which the instrument measures (Jackson, 1991). Exploratory data analysis techniques have been applied in this study to the datasets of the physico-chemical parameters collected during the study period, and results obtained for the various natural and anthropogenic conditions are highlighted.

Results and discussion

The ranges in variation, mean and standard deviation, and the variation in parameters with their standard error are shown by the box plots in Fig. 2. The datasets were collected and the scree plot for both the seasons shows the amplitude of different eigenvectors against their principal components (Fig. 3).

A data matrix of 48 observations was processed separately for both seasons using multivariate statistical analysis. The varimax-rotated and normalized factors were extracted using various methods such as PCA and PAF. Adjusted eigenvalues greater than one were further manipulated using this technique and varifactors, and the original variable was seen to participate more clearly. Liu et al. (2003) classified the factor loading as being strong at greater than 0.75 or moderate from 0.5 to 0.75–0. or weak from 0.40 to 0.50. The residual correlation between the parameters was determined from the descriptive and reproduced correla-

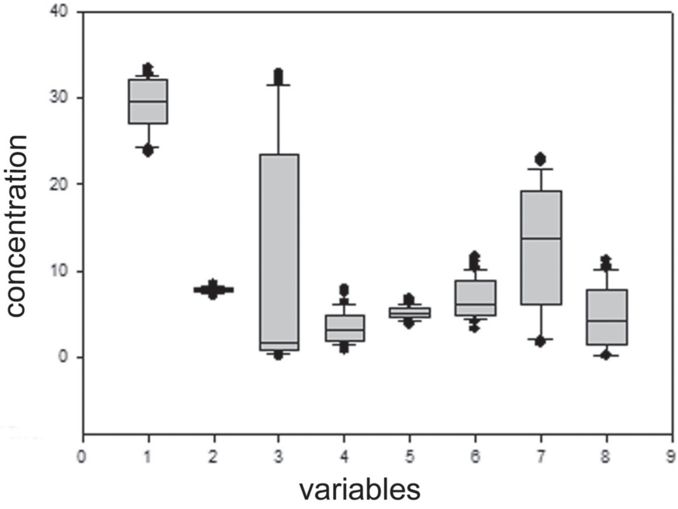


Fig. 2. Box plot showing variation of physico-chemical parameters.
Notes: 1 – temperature(°C), 2 – pH, 3 – salinity(ppt), 4 – DO(mg/L), 5 – phosphate(μmol/L), 6 – nitrate(μmol/L), 7 – silicate(mg/L), 8 – chlorophyll-a(mg/L).

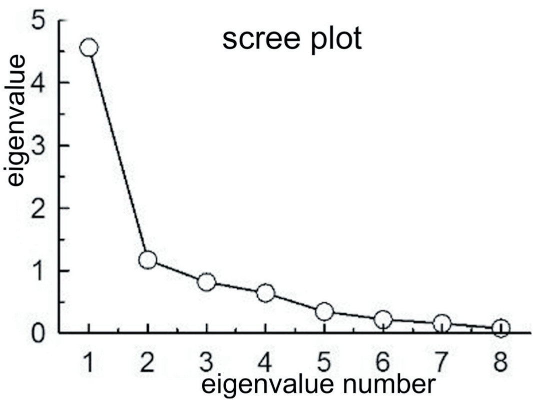


Fig. 3. Scree plot between different Principal components and their eigenvectors.

tion matrix. This resulted in a low percentage of the non-reductant residuals in the dataset. (Chakrapani, 2005).

The two factors or PCs explain 71.68% of the total variance during this study period (Table 1). PC1 accounts for 57.02% of the total variance, which is due to the following; (1) a strong positive load of silicates (0.999), chlorophyll-a (0.669) and nitrate (0.556), (2) a strong negative load of salinity (-0.891) and pH (-0.711) (3) significant positive correla-

T a b l e 1. Rotated component matrix (RCM) with varifactors (principal components, PCs) and extracted communalities. Results after varimax rotation (orthomax with weight = 1).

	Factor 1	Factor 2	Uniqueness	Communality
Temperature	-0.019	-0.460	0.788	0.212
pH	-0.711	-0.383	0.347	0.653
Salinity	-0.891	-0.165	0.178	0.822
DO	0.698	0.302	0.422	0.578
Phosphate	0.491	0.158	0.734	0.266
Nitrate	0.550	0.835	0.000	1.000
Silicate	0.999	0.032	0.000	1.000
Chlorophyll-a	0.669	0.131	0.536	0.464
Eigenvalues	4.560	1.170		
Variance %	57.020	14.600		
Cumulative %	57.020	71.680		

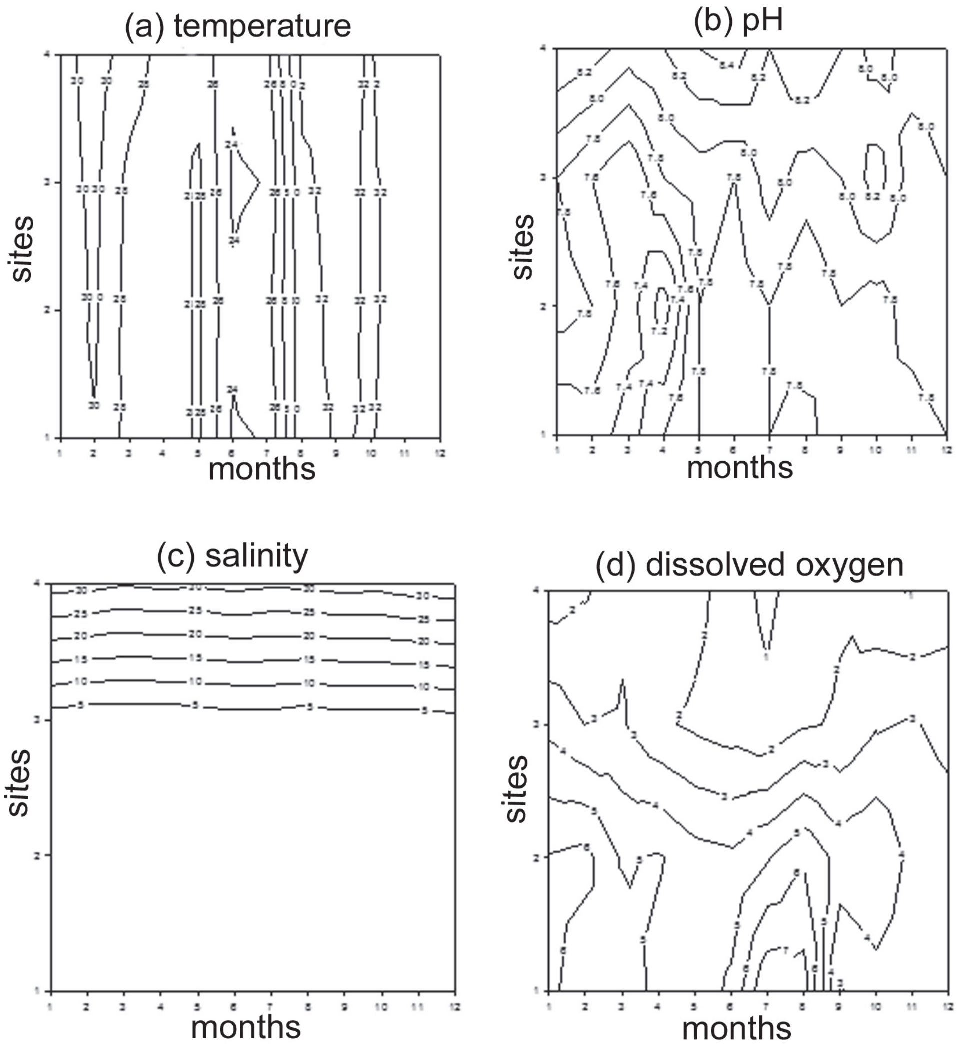
T a b l e 2. Correlation matrix between physico-chemical parameters.

	Temperature	pH	Salinity	DO	Phosphate	Nitrate	Silicate	Chlorophyll-a
Temperature	1.000							
pH	0.136	1.000						
Salinity	0.099	0.719	1.000					
DO	-0.147	-0.602	-0.610	1.000				
Phosphate	-0.016	-0.274	-0.412	0.549	1.000			
Nitrate	-0.395	-0.711	-0.628	0.636	0.402	1.000		
Silicate	-0.034	-0.723	-0.896	0.707	0.496	0.577	1.000	
Chlorophyll-a	-0.384	-0.454	-0.708	0.519	0.238	0.477	0.673	1.000

tions of pH with salinity ($r = 0.72$) and silicates with DO ($r = 0.71$) and (4) negative correlations with salinity (Table 2). The temperature was observed to be maximal in the summer season (Fig. 4a). In addition, the significant positive correlation between phosphate and silicates shown in Table 2 indicates a common source for both, and this suggests that the phosphate and silicate content increases in these low-salinity waters in this riverine-source water emanating from the hinterlands. Since this water adds phosphate and silicates to the coastal region, this factor suggests a riverine source (Figs 4e and h) .

PC2 explains 14.6% of the total variance with a strong positive loading of NO_3-N (0.835) (Table 2). In addition, there is a strong positive correlation between pH and salinity ($r = 0.72$) where the pH showed a clear variation from fresh water sites to that observed in a highly saline area (Fig. 4b). 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 (Figs 4c and g). The most likely cause of this is anthropogenic sources of waste discharge into the coastal water, mainly from fertilizer industries to the north of the Narmada estuary. High alkalinity was noted in the summer months and this may have been caused by industrial discharge and low fresh water inflow. A high load of phosphate and nitrate concentration was found in the fresh water zone, especially during the monsoon season (Figs 4e and f).

The less saline riverine water from the Narmada estuary is enriched with DO, as can be seen in Fig. 4d, which shows a high 6.3 ml/l, concentration spike of DO. It extended from the Narmada estuary into the coastal water where the DO concentration decreased to the low level of 0.8 ml/l in the mixing zone. Large amounts of industrial effluents and domestic



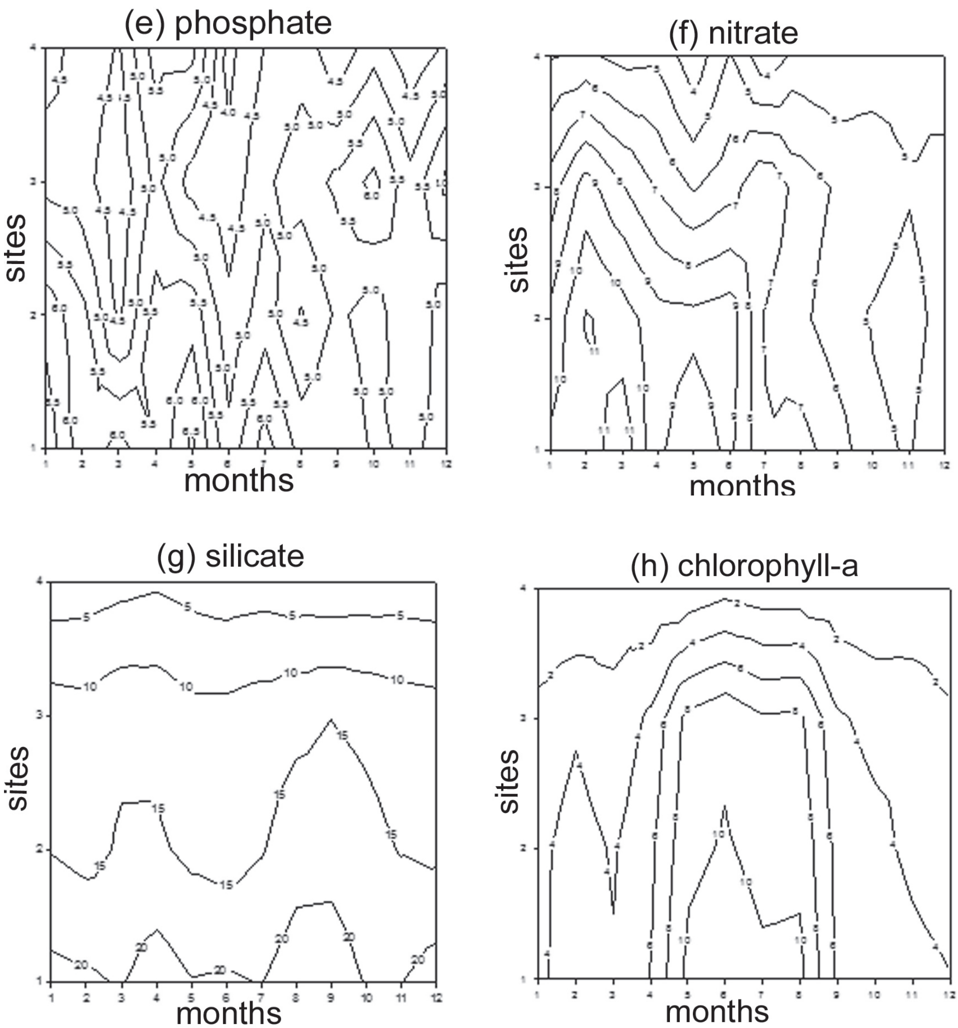


Fig. 4.(a–h) Contours showing month wise variation in temperature, pH, salinity, dissolved oxygen, phosphate, nitrate, silicate and chlorophyll-a.
Sites: 1– Zadeswar, 2 – Kukarwada, 3 – Bhadbuth, 4 – Ambata.
Months: 1 – July, 2 – August, 3 – September, 4 – October, 5 – November, 6 – December, 7 – January, 8 – February, 9 – March, 10 – April, 11 – May, 12 – June.

sewage may have contributed to the low DO observed in the mouth region. Dissolved oxygen was high in the freshwater-receiving area during the winter and monsoon seasons, and low in the mixing zone. Silicate concentration was high in the fresh water-receiving zone and in

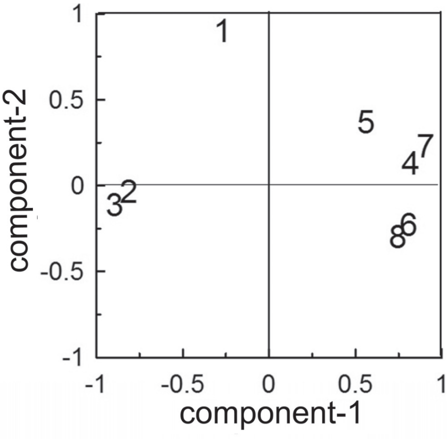


Fig. 5. Biplot showing loadings of physico-chemical variables.

the mesohaline zone, and this influence of fresh water on silicate distribution is evident in Fig. 4g. Chlorophyll-a concentration was maximal at 11.3 mg/L during the winter season, and the increase in chlorophyll-a concentration from the monsoon to winter season is aptly depicted in Fig. 4h.

The inter-relationships between the varifactors were established from the correlation between them via component transformation matrix and plots between PC1 and PC2. Here, the scores of samples drawn and the loadings of variables were plotted as in Figure 5 The results showed that the phosphate, silicate and dissolved oxygen were present in the second quadrant, indicating the close relationship between these factors. The occurrence of pH and salinity in quadrant 4 indicates the close association between these two parameters. Other parameter such as chlorophyll and nitrate were observed in the third quadrant. This indicates the close association between these parameters, which can be interpreted as the utilization of inorganic nutrients supporting photosynthetic processes.

Conclusion

This study summarizes seasonal fluctuations in the various physico-chemical parameters in the coastal waters off the Narmada estuary as exploratory statistical data output. Freshwater discharge through the river and rivulets includes additions of nitrate, phosphate and silicate to the coastal water occurring mainly during the monsoon season. The addition of nitrogenous and phosphorus compounds from the anthropogenic sources of fertilization, industrial output, and agricultural runoff in the northern region of the Narmada estuary was observed during monsoon in waters near the mouth of the Narmada estuary. The interrelationship between these varifactors suggests association of inorganic nutrients during monsoon. The high load of nutrients, such as phosphate, nitrate and silicate during monsoon contributes to the growth of the flora and fauna community, which is evident from the high chlorophyll-a concentration in the winter season. The overall results of this study suggest that the health of this estuarine ecosystem is beneficial for the floral and faunal communities thriving in this area.

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