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B – data collection
C – statistical analysis
D – data interpretation
E – manuscript preparation
F – literature search

Assessment of water physico-chemical characteristics and statistical evaluation of Narmada Estuarine Region, Gujarat, India

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Abstract

Investigations on physicochemical parameters (temperature, pH, salinity, dissolved oxygen), including dissolved nutrients (PO_4-P, NO_3-N, SiO_4-Si) and chlorophyll-a were carried out in the water off the mouth of the Narmada estuary from July 2008 to June 2009. The multivariate statistics and principal component analysis applied to the datasets, indicated two factors during the whole study period influencing variability in the water to the extent of 72%. Principal axis factoring and alpha factoring have been used to observe the mode of association of parameters and their interrelationships, for evaluating water quality. The results indicated the addition of phosphates and silicates to the coastal water by the Narmada estuary from natural sources during study period. The study indicated that the Narmada estuary adds sufficiently well-oxygenated, nutrient-rich water to the coastal region.

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

INTRODUCTION

Rivers are the main inland water resources for domestic, industrial and irrigation purposes and often carry large municipal sewage, industrial wastewater discharges and seasonal run-off from agricultural land to the coastal region. It is 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 that change with time, and differences in the local channel form. Contrary to this, the coastal environments are highly economical, important and are significantly involved in the transport of terrestrial organic matter and associated nutrient elements to the sea for their biogeochemical cycling [CHAKRAPANI 2005]. The balance in the concentrations of biogenic elements in coastal water 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 is more pronounced in tropical estuaries than in temperate estuaries. Reports on some tropical estuaries include those of EDWARD and AYYAKKANU [1991] on the Kollidan estuary, southeast coast of India, JIYALALRAM [1991] on the Mahi estuary and in Coastal waters of Kalpakam, East coast of India. Physico chemical characteristics of tropical Devi Estuary in the eastern region of India was analysed by PRADHAN *et al*. [2009]. Physicochemical characteristics in relation to pollution and phytoplankton production potential of brackish water were carried out in Sundarbans of India by SHYAMALENDU *et al*. [2001]. Spatial and temporal fluctuations in water quality of Tapi estuarine system was carried out by NIRMAL KUMAR *et al*. [2009]. Physicochemical characterstics and its statistical evaluation of hydrobiological parameters of Narmada River was carried out by SHRADDHA *et al*. [2007].

The complex dynamism in physico-chemical characteristics of coastal waters is related to 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 the drainage by 16 major and minor rivers. One such riverine system is the Narmada River in Gujarat. The river originates in Madhya Pradesh state, flowing through Maharashtra it finally ends in Gulf of Cambay. Major urban settlements and industrial set ups along the banks of this river have resulted in release of a large amount of untreated domestic waste and effluents directly in to the river. Due to 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 the adjacent coastal region. Physico-chemical studies were carried out at selected locations in the coastal region off the mouth of the Narmada estuary (Fig. 1) in July 2008–June 2009 to assess the water quality of the region and to understand its input to the coastal water. The present study also aims to find out the seasonal variations in physico-chemical parameters and statistical evaluation of the coastal water off the mouth of the Narmada estuary and the anthropogenic influence.

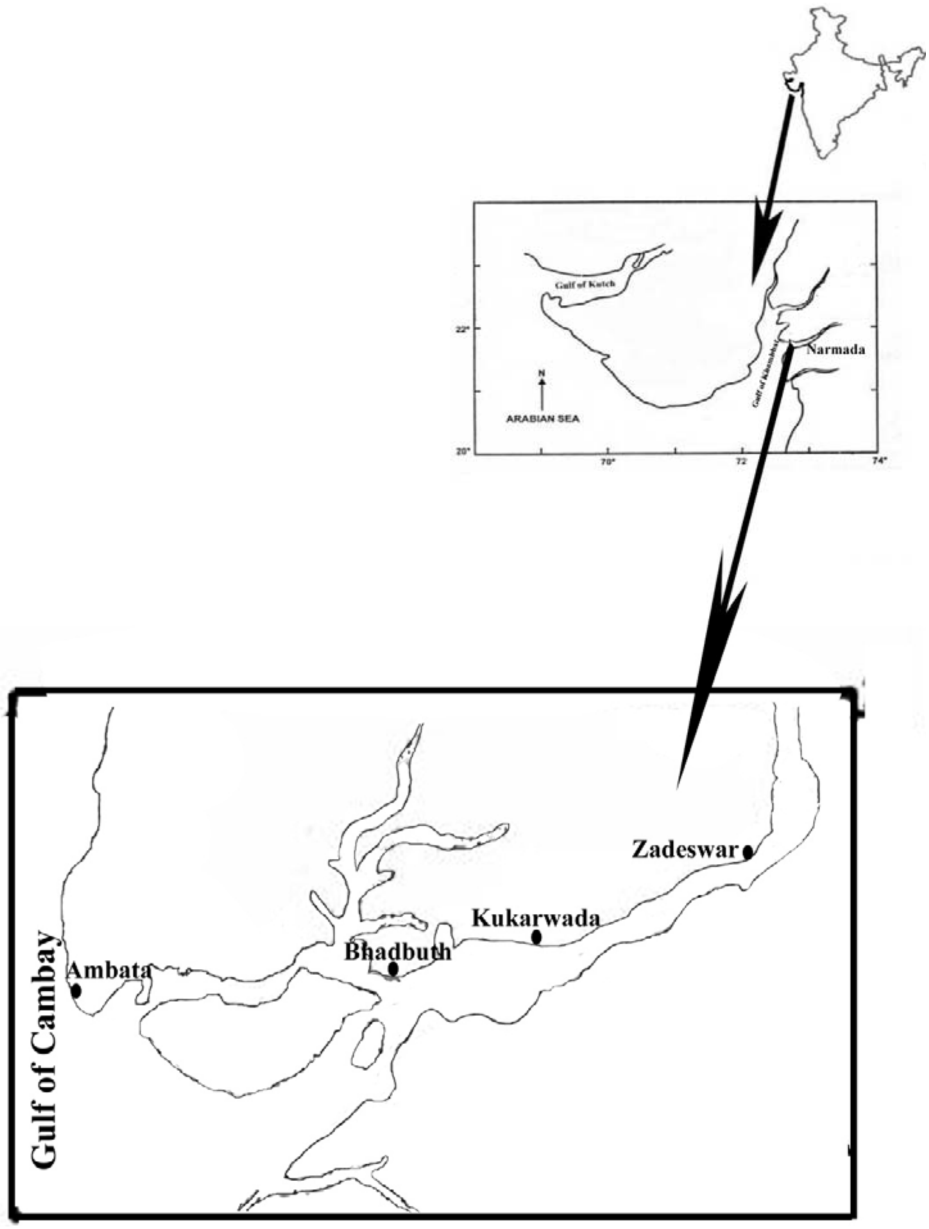

Fig. 1. Study area in Narmada estuary

MATERIALS AND METHODS

Four study sites were selected along the northern bank of the river (Fig. 1). Zadeshwar (Site-1) was 37–39 km away from the mouth of estuary which is a fresh water dominated area and tidal influence hardly affects this area. The area receives nutrients from agricultural runoff and industrial regions upstream to it. Kukarwada (Site-2) is 15 km downstream to Zadeshwar and this area mainly receives effluent released by cities like Baruch and industrial complexes in Ankleshwar area. Bhadbuth third site was selected which is 6–7 km away down to Kukarwada; area receives effluents from the industrial complexes like ONGC. Ambata which forms the fourth site was located near to the mouth region and this area forms the main mixing zone of estuary. This region receives effluents from Industrial setups like Reliance industries, Birlla Copper and many fertilizers industries in and around the region.

A total of 48 water samples from four selected stations along southern bank extending from the mouth of the river towards the offshore region (Fig. 1). The water samples were drawn in monthly intervals from the surface layers during the period from July 2008 to June 2009. The samples were collected in Polyethylene bottles and stored in ice boxes at –4°C and brought to the laboratory. The physico-chemical parameters such as pH, dissolved oxygen (DO), phosphate (PO_4-P), nitrite (NO_2-N), nitrate (NO_3-N) and silicate (SiO_4-Si) were measured according to the standard procedures [CLESCERL *et al.* 1998]. The data quality was ensured through careful standardization, procedural blank measurements, 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 done spectrophotometricaly by filtering the samples using glass fibre filter papers and extracted in 90% acetone.

Principal component analysis (PCA) is one of the best statistical techniques for extracting linear relationships among a set of variables [IYER *et al.* 2003]. Principal components are the linear combinations of original variables and are the eigenvectors [WUNDERLIN 2001]. The varimax rotation distributes the PC loadings such 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, that are uncorrelated with one another and with the common factor, and is thus excluded from our factor analysis. The reproduced and residual correlation matrix indicates that the factors indeed do capture the relationships between variables by calculating correlations between them and the correlations between factors and variables. The reliability (alpha) or alpha factor analysis (AFA) attempts to create factors which are linear combinations of the variables, to estimate the 'latent variables' or constructs which the instrument measures [JACKSON 1991]. In this study, the exploratory data analysis techniques have been applied to datasets on physico-chemical parameters collected during the study period and the results obtained on the basis of various natural and anthropogenic conditions are highlighted.

RESULTS AND DISCUSSION

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

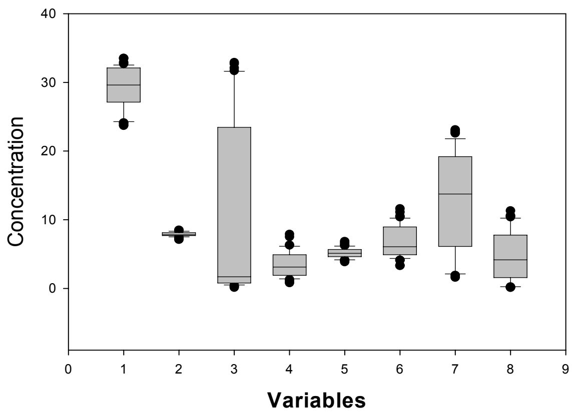

Fig. 2. Box plot showing variation of physico-chemical parameters; *1* – temperature (°C), *2* – pH, *3* – salinity (ppt), *4* – DO ($mg \cdot l^{-1}$), *5* – phosphate ($\mu mol \cdot l^{-1}$), *6* – nitrate ($\mu mol \cdot l^{-1}$), *7* – silicate ($mg \cdot l^{-1}$), *8* – chlorophyll-a ($mg \cdot l^{-1}$)

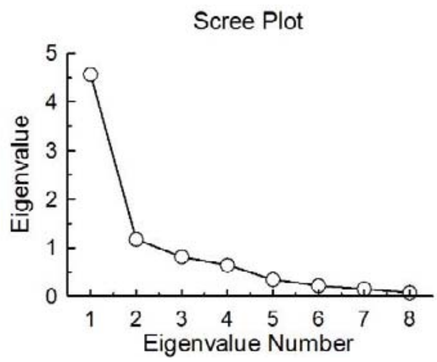

Fig. 3. Scree plot between different principal components and their eigenvectors

A data matrix of 48 observations was processed separately for both the seasons through multivariate statistical analyses. The varimax-rotated and normalized factors were extracted through various methods such as PCA and PAF. Adjusted eigenvalues greater than one was further cleaned up using this technique and in varifactors; the original variable participated more clearly.

The two factors or PCs explain 71.68% of the total variance during study period (Tab. 1). PC1 accounts for 57.02% of the total variance, which is due to strong positive load of silicates (0.999), chlorophyll-a (0.669) and nitrate (0.556) and a strong negative load of salinity (–0.891) and pH (–0.711) with significant positive correlations of pH with salinity (r = 0.72) and silicates with DO (r = 0.71) and their negative correlations with salinity (Tab. 2). Temperature was observed maximum in summer season (Fig. 4a). Besides, the significant positive correlation between phosphate and silicates (Tab. 2) indicates a common source for both, and suggests that the phosphate and silicate content increases in low-salinity water, which is a riverine-source water coming from the hinterlands. Thus, the riverine water adds phosphate and silicates to the coastal region (Fig. 4e, h) and this factor therefore suggests a riverine source.

Table 1. Rotated component matrix (RCM) with varifactors (principal components, PCs) and extracted communalities; results after varimax rotation (orthomax with weight = 1); factor pattern matrix (factor loadings)

Parameter	Factor1	Factor2	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		

PC2 explains 14.6% of the total variance with strong positive loading of NO_3-N (0.835) (Tab. 2).
There is a strong positive correlation between pH and salinity (r = 0.72). pH showed a clear variation from fresh water receiving sites to 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 (Fig. 4c, g). The possible reason for this are the anthropogenic sources, i.e. waste discharges in the coastal water, mostly from fertilizer industries present in the north of the Narmada estuary. High alkalinity was found in the summer month and it might be due to industrial discharge and low fresh water inflow. High load of phosphate and nitrate concentration was found in fresh water zone especially during the monsoon season (Fig. 4e, f).

The less saline riverine water from the Narmada estuary is enriched with DO, as can be seen from Fig. 4d, which shows a tongue of high concentration of DO of 6.3 $ml \cdot l^{-1}$, extending from the Narmada estuary into the coastal water, where the DO decreases to as low as 0.8 $ml \cdot l^{-1}$ in the mixing zone. Large amount of industrial complexes effluents and domestic sewages may contribute to the low DO observed in the mouth region. Dissolved oxygen was found to be high in freshwater receiving area during winter season and monsoon season and low in the mixing zone. Silicate concentration was found high in the fresh water receiving zone and mesohaline zone. The influence of fresh water on silicate distribution is evident from the Fig. 4g. Chlorophyll-a concentration is found to be maximum 11.3 $mg \cdot l^{-1}$ during winter season and the increase in chlorophyll-a concentration from monsoon season towards winter season is evident from Fig. 4h.

The inter-relationships among the varifactors were found from the correlation between them through component transformation matrix and plot between PC1 and PC2, wherein the scores of samples drawn and the loadings of variables have been plotted (Fig. 5). The results showed the phosphate, silicate and dissolved oxygen to be 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 seen in the third quadrant indicates the close association between these parameters, which can be interpreted as the utilization of inorganic nutrients supporting the photosynthetic process.

Table 2. Correlation matrix between physico-chemical parameters

Parameter	Temperature	pH	Salinity	DO	Phosphate	Nitrate	Silicate	Chlorophyll
Temperature	1							
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

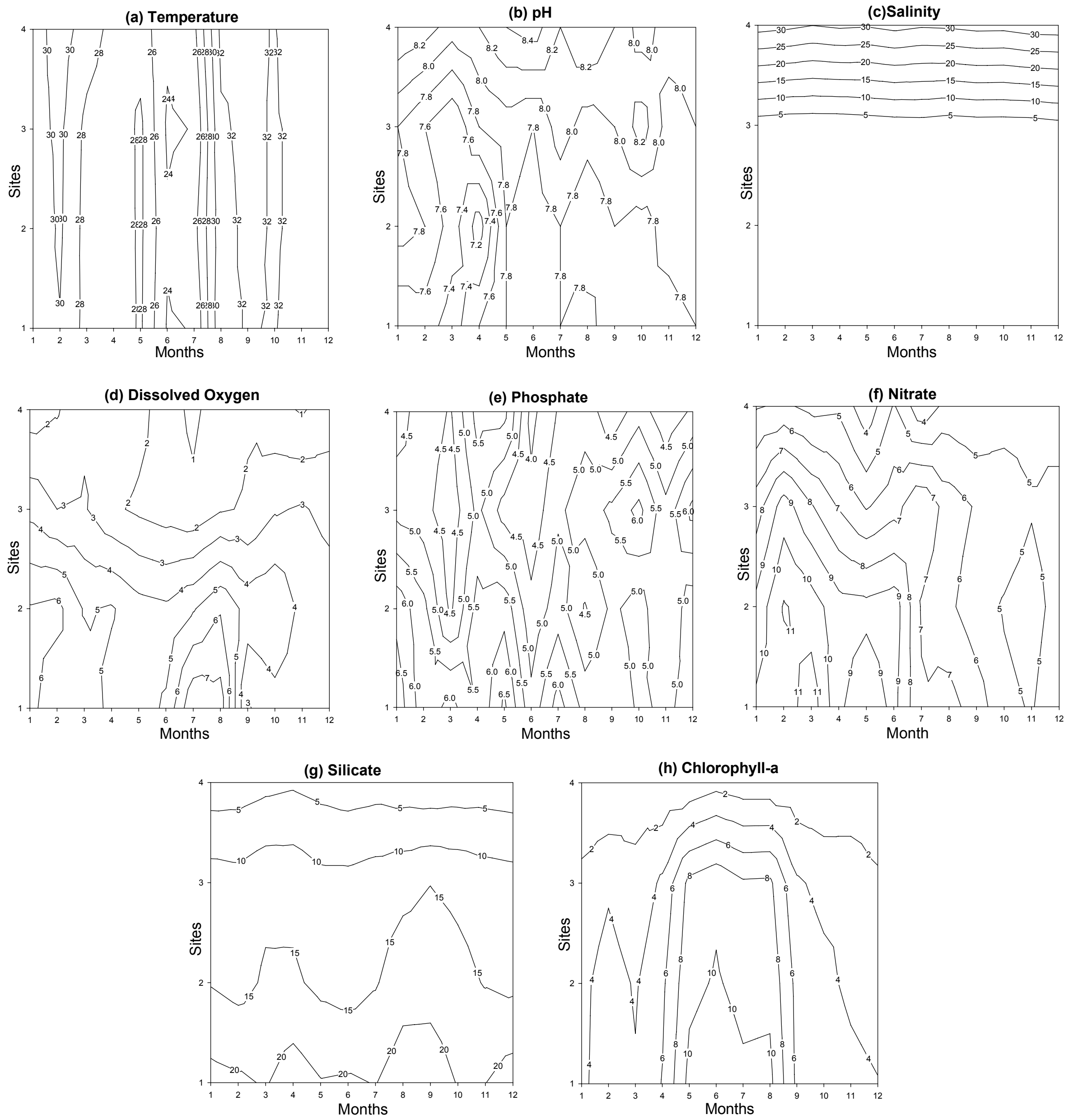

Fig. 4. Contours showing months wise variation in temperature, pH, salinity, dissolved oxygen, phosphate, nitrate, silicate and chlorophyll-a; sites: *1* – Zadeswar, *2* – Kukarwada, *3* – Bhadbuth, *4* – Ambata; months: *1* – July, *2* – August, *3* – Septmber, *4* – October, *5* – November, *6* – December,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

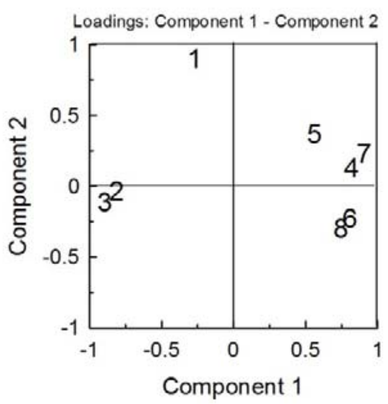

Fig. 5. Biplot showing loadings of physico-chemical variables

CONCLUSION

The present study summarizes the seasonal fluctuations in 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 mainly during the monsoon season. 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 monsoon in the water near the mouth of the Narmada estuary. The interrelationship between varifactors suggests the association of inorganic nutrients during monsoon. The high load of nutrients like phosphate, nitrate, silicate during the monsoon contribute to the growth of flora and fauna community which is evident from the high chlorophyll-a concentration found in winter season. The overall study suggests that the health of estuarine ecosystem found to be in a good state for the floral and faunal community thriving in the area.

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Analiza i statystyczne opracowanie fizyczno-chemicznych właściwości wody z estuarium Narmada, Gujarat, Indie

STRESZCZENIE

Słowa kluczowe: *analiza głównych składowych, estuarium Narmada, parametry fizyczno-chemiczne, sezonowość, statystyka wielowymiarowa*

Analizę parametrów fizyczno-chemicznych (temperatura, pH, zasolenie, tlen rozpuszczony), stężenia pierwiastków biogennych (PO_4-P, NO_3-N, SiO_4-Si) i chlorofilu prowadzono w wodach estuarium Narmada od lipca 2008 do czerwca 2009. Statystyka wielowymiarowa i analiza głównych składowych, zastosowana do zbioru wyników, wskazała dwa czynniki, które w 72% odpowiadały za zmienność składu chemicznego wody w całym okresie badań. Do oceny jakości wody zastosowano analizę czynnikową celem określenia powiązań między parametrami i ich wzajemnych zależności. Wyniki pokazały, że w okresie badawczym estuarium Narmada dostarczało do wód przybrzeżnych fosforany i krzemiany pochodzące z naturalnych źródeł. Przeprowadzone badania dowodzą, że estuarium Narmada zasila strefę brzegową w dobrze natlenione i bogate w pierwiastki biogenne wody.