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Spatio-temporal variation in physico-chemical properties of coastal waters of Kalpakkam, southeast coast of India

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Abstract

A study carried out to monitor the seasonal variations in physicochemical properties of the Kalpakkam coastal waters for a period of one year (February 2006 to January 2007) showed that the coastal water was influenced by freshwater input during northeast (NE) monsoon and post-monsoon periods. Concentration of all the nutrients and dissolved oxygen (DO) was relatively higher, whereas, salinity and chlorophyll-*a* (chl-*a*) concentration were low during monsoon. Phytoplankton production peak was observed in summer. nitrate, phosphate, silicate and turbidity were significantly high (1.5-8 times), but DO and chl-*a* were relatively low when compared to studies carried out 15 years ago along this coast. A notable indication from this study is that though nutrient concentration in the coastal waters had increased significantly, the increase in turbidity has affected the phytoplankton production adversely. Significant changes in water quality could be due to increased anthropogenic activities along the coast in the recent past, which has a potential to alter the chemical properties and biological community in the nearshore waters.

Keywords: Physicochemical properties, seasonal variations, coastal waters, southeast coast of India

Introduction

The physicochemical properties, particularly the micro-nutrient contents in any coastal water determine its potential fertility (Harvey, 1960). Therefore, it is important to gather information about their distribution and behavior in different coastal ecosystems. Although life supporting processes in marine coastal ecosystems require many inorganic substances, nitrogen, phosphorous and silicon are considered to be more important than the others, as they play a key role in phytoplankton abundance, growth and metabolism (Raymont, 1980; Grant and Gross, 1996). Therefore, the origin, distribution pattern and rate of utilization of these inorganic components have become an important area of scientific research in coastal areas in the last few decades. The distribution and behavior of nutrients in the coastal environment, particularly in the nearshore waters and estuaries, exhibit considerable variations depending upon the local conditions such as rainfall, quantum of freshwater inflow, tidal incursion and biological activities like phytoplankton uptake and regeneration. Furthermore, anthropogenic activities due to economic growth, urban development, industrialization and intensive agricultural activities exert excessive stress to the coastal environment and its inhabitants.

Kalpakkam coast (12^{o} 33' N Lat. and 80^{o} 11' E Long.) is situated about 80 km south of Chennai. At present a nuclear power plant (Madras Atomic Power Station, MAPS) and a desalination plant are located near the coast. MAPS uses seawater at a rate of 35 m^3sec^{-1} for condenser cooling. The seawater is drawn through an intake structure located inside the sea at about 500m away from the shore. After extracting the heat, the heated seawater is released into the sea. Edaiyur and Sadras backwater systems are two important features of this coast. These two backwaters are connected to the Buckingham canal, which runs parallel to the coast. Buckingham canal carries urban runoff from Chennai and adjacent coastal inhabitants. During the period of northeast (NE) monsoon and seldom during southwest (SW) monsoon, these two backwaters open up to the coast discharging considerable amount of freshwater for 2 to 3 months. This part of peninsular India receives bulk of its rainfall (~ 70%) from NE monsoon. When the monsoon stops, a sand bar is formed between the backwaters and sea due to the littoral drift, which is a prominent phenomenon in the east coast of India, resulting in a situation wherein the inflow of low saline water from the backwaters to sea is stopped. The Sadras backwaters receives the domestic discharge of the Kalpakkam Township, whereas, the Edaiyur backwater receives the urban runoff and pollutants from the Buckingham Canal and ultimately discharges to the coastal waters. The township has a population of about 50,000. Two villages inhabited by fishermen are located adjoining both sides of the township with a sizable population. Therefore, anthropogenic activities affect the coastal environment of Kalpakkam and the measurement of hydrochemical variables in the region may lead to better understanding of its impact.

This coast was severely devastated by tsunami during December 2004. During the present study the Sadras backwater was disconnected from the sea for 8 months (March to October 2006). The Edaiyur backwater remained open throughout the study period due to dredging activities. According to the climatic conditions of this area the whole year can be divided into three seasons *viz*, post-monsoon/ summer (February - May), pre-monsoon or SW monsoon (June- September) and NE monsoon (October - January).

Although information on general hydrography and biology from Kalpakkam coastal waters are available (Nair and Ganapathy, 1983; Nair, 1985; Satpathy *et al*., 1987; Satpathy and Nair, 1990; Satpathy and Nair, 1996), data on nutrients are scarce (Satpathy, 1996a, b). In view of this, a study was undertaken to estimate the nutrient (nitrite, nitrate, ammonia, total nitrogen, phosphate, total phosphorous and silicate) contents in the coastal waters of Kalpakkam for one year (February, 2006 to January, 2007) with the following objectives: i) to study the seasonal variation in nutrient contents, ii) to find out major changes, if any, over the years due to anthropogenic impacts, iii) to create baseline data for future impact studies, and iv) to assess any change in physico-chemical properties of the coastal waters during post-tsunami period. In addition to nutrient estimation, hydrographical parameters such as salinity, pH, DO and turbidity along with chl-*a* concentration were estimated, to correlate them with nutrient levels.

Material and Methods

Surface water samples were collected during February 2006 - January 2007 from five locations of different environmental stresses. The stations were fixed with the help of Global Positioning System (GPS) and were in a transect parallel to the shoreline, about ~500 m away (Fig. 1). The average depth at the sampling locations was about 7 to 8m. The 1st

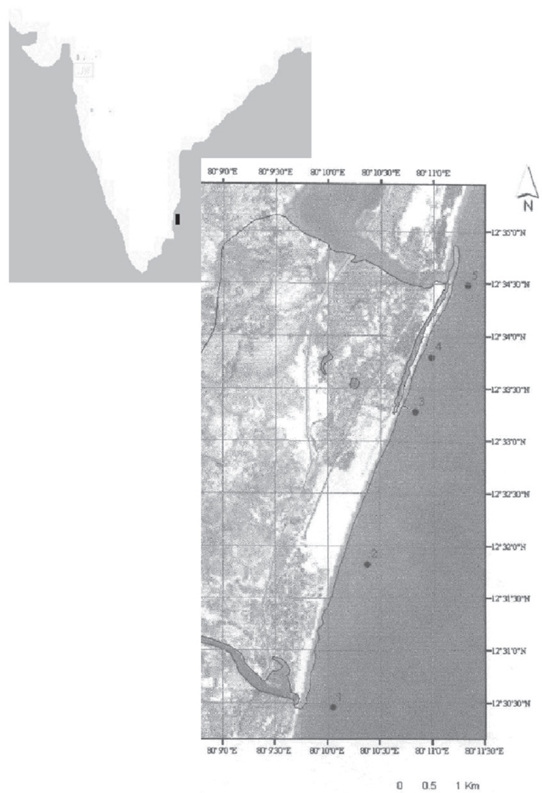

Fig. 1. Kalpakkam coast showing the sampling locations

and 5th stations are situated opposite to the opening of the Sadras backwaters and Edaiyur backwaters respectively. The 3rd and 4th locations are near the intake and the discharge points of MAPS, respectively. The 2nd location is opposite to the Sadras fishing village.

Water samples were collected fortnightly in pre-cleaned polythene bottles. Winkler's titrimetric method (Grasshoff *et al*., 1983) was followed for estimation of DO. Salinity measurements were carried out by Knudsen's method (Grasshoff *et al*., 1983). Turbidity of water samples was measured by turbidity meter (CyberScan IR TB 100) having 0.01 NTU accuracy. pH measurement was carried out by a pH meter (CyberScan PCD 5500) with an accuracy of 0.01. Dissolved micronutrients such as, nitrite, nitrate, ammonia, silicate, phosphate along with total nitrogen (TN) and total phosphorus (TP) were estimated by following standard methods (Grasshoff *et al*., 1983; Parsons *et al*., 1984), after filtering the water samples through 0.45 µm millipore filter paper. Chl-*a* concentration was estimated by spectrophotometry following the method of Parsons *et al*. (1984). For all the spectrophotometric analyses, a double beam UV–Visible Spectrophotometer (Chemito Spectrascan UV 2600) was used. Monthly average values were calculated and plotted. Monthly average represents the average of 10 samples collected from 5 locations in the respective months. Average values of parameters of different stations did not show any significant variation and hence, are not presented here. The statistical analyses were carried out by using the software XLstat Pro® provided by Addinsoft.

Results and Discussion

Hydrographic parameters: The rainfall at Kalpakkam during February 2006 - January 2007 was 1090 mm. The monthly rainfall is given in Fig. 2. The pH ranged from 7.7 to 8.4. The highest and lowest monthly average values were observed during February and May respectively (Fig. 3a). Due to absence of freshwater discharge from any perennial rivers, the land drainage and terrestrial runoff were low. Salinity ranged from 23.38 to 35.97 psu. It increased from February to May (Fig. 3b). which was due to very low quantity of freshwater influx during these months. Salinity remained almost

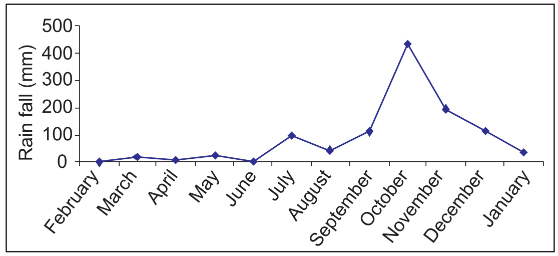

Fig. 2. Monthly rainfall at Kalpakkam during February 2006 to January 2007

constant during summer showing a typical oceanic salinity till the arrival of SW monsoon. It started decreasing from the month of August reaching a minimum in November. The significant decrease in salinity values during October - November is not only contributed by the local precipitation during NE monsoon period but also coupled with the low saline riverine water which comes from northern part of the Bay of Bengal during this period (Varkey *et al*., 1996). The current at this location changes biannually from north to south (October) and south to north (February/ March), thus bringing low saline and oceanic water respectively. In the northern part of the Bay of Bengal (BOB), a large number of rivers discharge massive amount of freshwater throughout the year into the bay leading to significant decline in salinity. This low saline water moves towards the south and is further diluted during November to January as a result of precipitation during NE monsoon. Similar trend in salinity in the coastal waters from other regions has been reported by Varma and Reddy (1959) and Subramanyan and Sen Gupta (1965). The present salinity values are almost similar to the earlier reported values (25.45-35.18 psu) from the same locality (Satpathy, 1996a) (Table 1).

Table 1. Comparison of water quality parameters between the present study and past

Parameter	Satpathy (1996a, b)	Present study
Salinity (psu)	32.21	32.79
Dissolved oxygen (mg l^{-1})	6.13	5.49
Nitrite (µ mol l^{-1})	0.53	0.58
Nitrate (µ mol l^{-1})	1.43	11.49
Phosphate (µ mol l^{-1})	0.26	0.39
Silicate (µ mol l^{-1})	7.69	10.68
Chlorophyll-*a* (mg m^{-3})	5.89	3.76

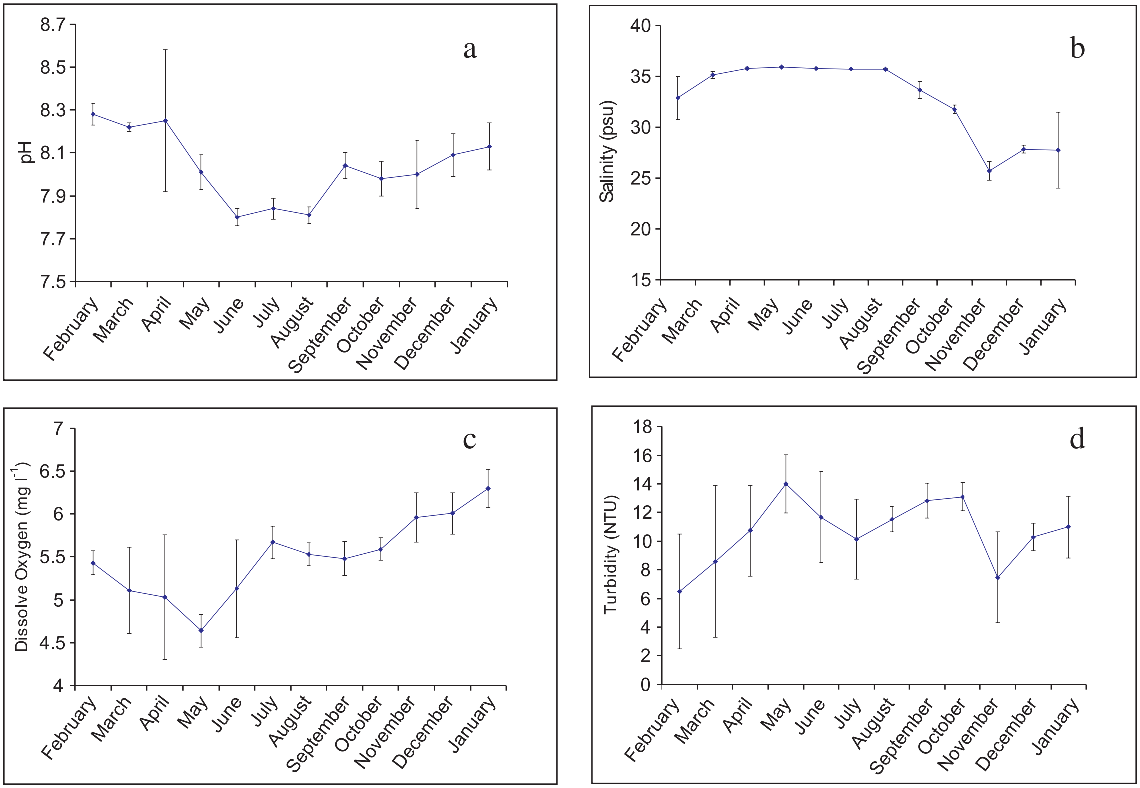

Fig. 3a - d. Monthly variations of pH, salinity, DO and turbidity in the coastal waters of Kalpakkam during February 2006 to January 2007

Dissolved oxygen content varied between 3.3 and 6.6 mg l^{-1}. The monthly average values showed decrease in concentration of DO from February to May after which it increased gradually up to January (Fig. 3c). The noticeable increase in DO observed from October to January could be attributed to the input of DO rich freshwater during the NE monsoon. During the present study, salinity was found to be

Table 2. Correlation matrix of various parameters

Variables	pH	Salinity	Turbidity	DO	Nitrite	Nitrate	Ammonia	T N	Silicate	Phosphate	T P	Chl-*a*
pH	1											
Salinity	-0.172[b]	1										
Turbidity	-0.005	0.162[b]	1									
DO	-0.039	-0.541[a]	-0.155[b]	1								
Nitrite	-0.178[a]	-0.187[a]	0.020	0.181[a]	1							
Nitrate	-0.248[a]	-0.394[a]	0.025	0.104	0.294[a]	1						
Ammonia	-0.073	-0.233[a]	-0.041	0.046	-0.091	0.221[a]	1					
T N	-0.248[a]	-0.412[a]	-0.003	0.122[c]	0.210[a]	0.846[a]	0.258[a]	1				
Silicate	-0.016	-0.303[a]	-0.004	0.235[a]	0.103	-0.064	-0.109	-0.031	1			
Phosphate	-0.030	-0.172[b]	0.122[c]	0.161[b]	0.524[a]	0.122[c]	0.106	0.074	0.080	1		
T P	-0.080	0.007	0.157[b]	0.075	0.461[a]	0.060	0.103	0.018	0.010	0.920[a]	1	
Chl-*a*	-0.029	0.610[a]	0.545[a]	-0.382[a]	-0.080	-0.238[a]	-0.045	-0.242[a]	-0.306[a]	-0.056	0.090	1

a – p≥0.000, b – p≥0.005, c – p≥0.01

the most important factor that controlled the level of DO in coastal waters as evident from its strong negative correlation ($p \geq 0.001$) with DO (Table 2). The concentration of DO in the present study is marginally lower (5.5 mg l^{-1}) as compared to the earlier reported values (6.1 mg l^{-1}) from this coast (Satpathy, 1996a). Although it is not possible to discern any plausible reason for the above observation, the general increase in anthropogenic pressure and in hindsight, the impact of tsunami which devastated the south Indian coast on 26th December 2004 could be the factors.

Turbidity values ranged from 1.69 to 17.76 NTU during the present study. Monthly values showed higher water turbidity during summer (Fig. 3d). It has been reported that wave action increases during summer due to northerly wind and northward current, prior to the onset of SW monsoon (McCreary *et al*., 1996; Varkey *et al*., 1996; Hugen *et al*., 2003) resulting in turbulent condition in the coastal waters. This favours the resuspension of the bottom sediment due to stirring action and causes low water transparency (Qasim *et al*., 1968; Nixon, 1988). Moreover, the role of phytoplankters for the increased turbidity values (Kalimurthy, 1973) during April and May cannot be overlooked, as phytoplankton production during summer is generally high as compared to the remaining periods of the year (Ganapati and Rao, 1958; Prasannakumar *et al*., 2002) in the coastal waters of BOB. A positive correlation between chl-*a* and turbidity indicated that the phytoplankton density was one of the factors that contributed to the turbidity of the water column. Resuspension of surficial sediments by stirring action is reported to be another factor for increased turbidity at this location.

Nutrients: Nitrite concentration varied from below detection limit (BDL) to 5.23 μ mol l^{-1}. Its monthly average values gradually increased from February to August after which a sharp decrease in

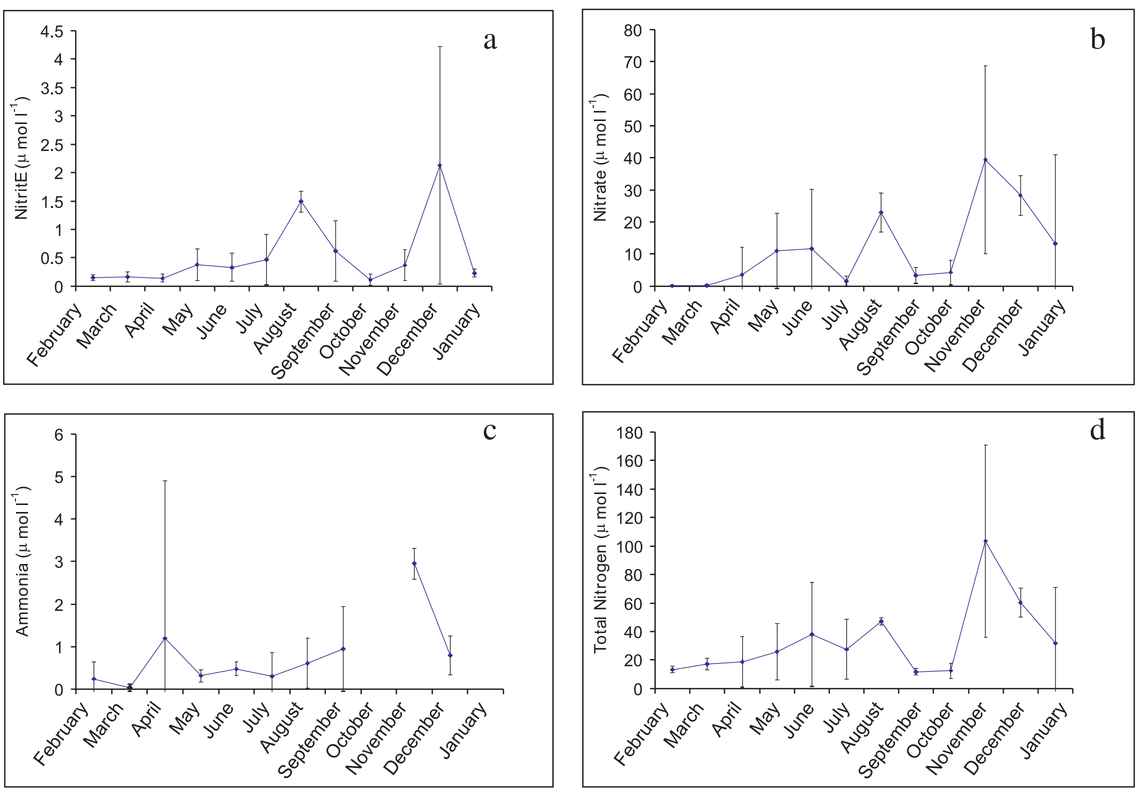

Fig. 4 a - d Monthly variations of nitrite, nitrate, ammonia and total nitrogen in the coastal waters of Kalpakkam during February 2006 to January 2007

October (Fig. 4a) was noticed. Abrupt increase in nitrite concentration during December coincided with the NE monsoon period. Nitrite, the most unstable form of dissolved inorganic nitrogen in seawater, is the intermediate one between ammonia and nitrate. According to and Chandran and Ramamurthy (1984) and Santschi *et al.* (1990) nitrite is often released into the water as an extracellular product of planktonic organisms. These processes result in irregular and wide variations in nitrite distribution in coastal milieu. Concentration of nitrate ranged from BDL to 69.18 µ mol l^{-1}. 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. Variations in nitrate and its reduced inorganic compounds are predominantly the results of biologically activated reactions. Quick assimilation by phytoplankton and enhancement by surface runoff results in large-scale spatio-temporal variation of nitrate in the coastal milieu (Qasim, 1977; De Souza, 1983; Zepp, 1997). The BDL values were encountered in the month of March and April. A period of relatively high phytoplankton production was reflected from the relatively high concentration of chl-*a* observed during the same period. Similar reduction in nitrate content and concomitant increased phytoplankton production during the post-monsoon and summer from southeast coast of India has been observed earlier (Ganapati and Rao, 1958; Prasannakumar *et al.*, 2002).

Relatively high concentration of nitrite and nitrate (Fig. 4b) was observed during November and December, the period of NE monsoon, which could be due to surface runoff and nutrient rich backwater discharge into the coastal waters. Both nitrite and nitrate showed strong negative correlations ($p \geq 0.001$) with pH and salinity and strong positive correlations ($p \geq 0.001$) with TN (Table 2). The negative correlation between nitrate and salinity as reported by others (Choudhury and Panigrahy, 1991; Satpathy, 1996a) showed that freshwater influx, which is considered to be the main source of these nutrients in coastal waters, is also true for the Kalpakkam coast. The strong positive correlation among all nitrogenous nutrients showed that they have common source of origin and in fact all of them showed strong negative correlation with salinity indicating their allchthonous origin. A comparison of the present nitrite values with that reported from this coast earlier (Satpathy, 1996a) dose not indicate any change (Table 1). On the other hand, the nitrate concentration was found to be much higher than the earlier reported values from this coast. Similar increase in nitrate concentrations (up to 8 times) in the post-tsunami period was reported by Reddy *et al.* (2005) from Dakshina Kannada coast, southwest coast of India.

Ammonia did not show any typical trend throughout the study period and BDL values were observed on many occasions. The monthly average values remained almost below 1 µ mol l^{-1} from February to August and an increase was noticed during September and November, when the average value exceeded 2.5-3 µ mol l^{-1} (Fig. 4c). Ammonia, the chief excretory product of the marine invertebrates, is also well known as a nutrient. This is preferred to nitrate by the phytoplankton community in certain environmental conditions. The above two factors i.e. excretory release and utilization by phytoplankton, significantly affect the concentration of ammonia (Olson, 1980; Gilbert *et al.*, 1982) in the marine environment. Peak ammonia concentration was observed during April, which coincided with high chl-*a* concentration. This suggests that the phytoplankton or zooplankton community might have proliferated during this period and released ammonia as the excretory product. TN concentration ranged from 3.74 to 267.68 µ mol l^{-1}. The highest and lowest values were observed during November and July respectively. The seasonal trend in TN was similar to that of nitrite and nitrate and the peak values coincided with the NE monsoon period (Fig. 4d). Strong negative correlation of TN with chl-*a* indicated that nitrogen was rapidly utilized by the phytoplankton community. The graduall increase of TN from April to August could be attributed to the process of upwelling, which is a common phenomenon along the east coast of India during the pre-monsoon (summer) and SW monsoon (La Fond, 1957; Murty and Varadachari, 1968; Shetye *et al.*, 1991).

Concentration of phosphate ranged from BDL to 4.29 µ mol l^{-1}. Monthly average values showed two peaks, one during September and the other during

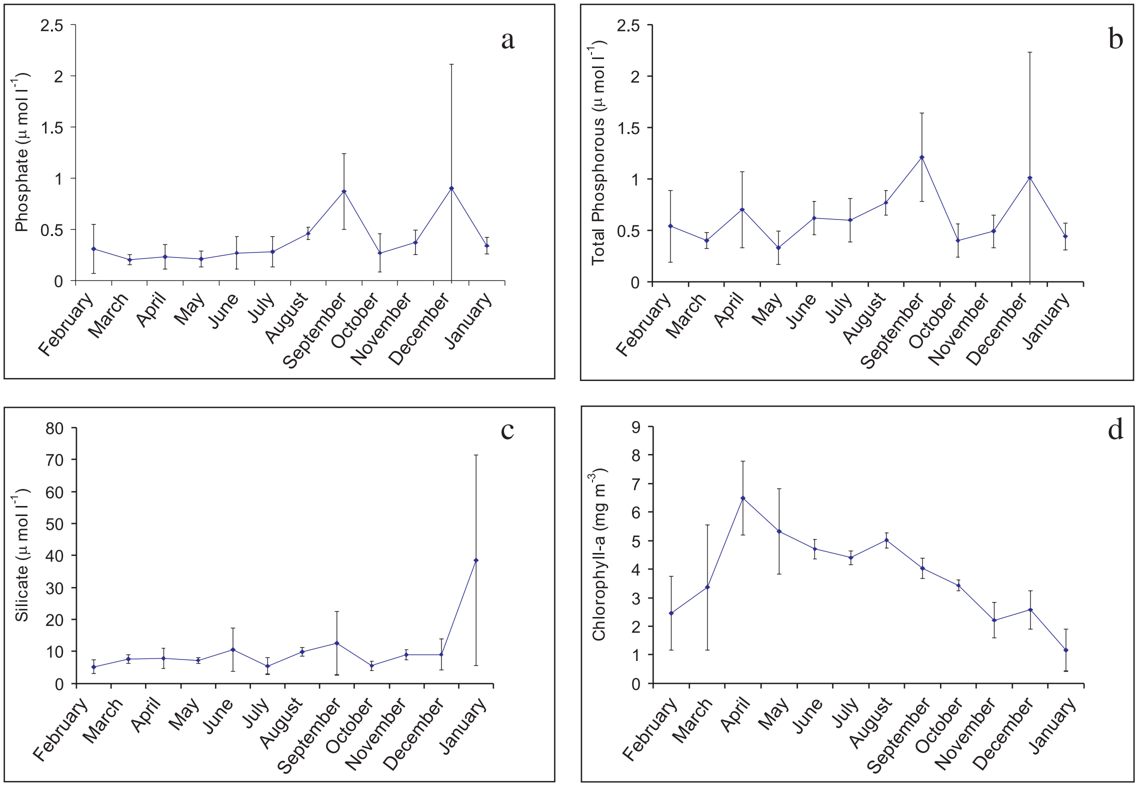

Fig. 5a - d. Monthly variations of phosphate, total phosphorous, silicate and chlorophyll-a in the coastal waters of Kalpakkam during February 2006 to January 2007

December (Fig. 5.a). TP concentrations ranged from 0.14 to 4.44 µ mol l^{-1}. The highest and lowest values were observed during December and May, respectively. Phosphate constitutes the most important inorganic nutrient that can limit phytoplankton production in tropical coastal ecosystems (Cole and Sanford, 1989) and thereby affect the overall ecological processes. The monthly average trend of TP (Fig. 5b) was almost similar to that of phosphate, which is supported by strong positive correlation between them. Phosphate showed negative correlation with salinity and positive correlation with nitrite and nitrate. This showed that the nitrogen-rich surface runoff which diluted the coastal water also acted as the external source of phosphate in this coastal milieu. Agricultural runoff from adjoining land brings a large amount of phosphate into the coastal waters during NE monsoon through the Buckingham canal. The present values of phosphate were higher than that of the earlier reported values from this coast (Table 1). Phosphate concentration in the western coastal waters of India also increased by 15 to 20 times (Reddy *et al*., 2005) during post-tsunami period as compared to pre-tsunami period. This post-tsunami increase in phosphate concentration could be due to the incursion of nutrient rich deeper waters into the coastal waters and the resuspension of the coastal sediment that releases phosphate to the water column (Chandran and Ramamurthy, 1984). The observed variation might have also been caused by various processes like adsorption and desorption of phosphate and buffering action of sediments under varying environmental conditions (Pomeroy *et al*., 1965).

Concentration of silicate during the present study ranged from 2.33- 76.13 µ mol l^{-1}. The monthly average values of silicate remained almost similar except during January when the highest value was observed (Fig. 5c). Silicate showed strong negative correlation with salinity and strong positive correlation with DO. This shows that freshwater may be the main source of silicate, as entry of

Table 3. Principal component analysis

Parameters	F1	F2	F3	F4	F5	F6
Eigenvalue	3.047	2.271	1.781	1.199	1.111	1.024
Variability (%)	23.435	17.471	13.699	9.223	8.549	7.877
Cumulative %	23.435	40.906	54.605	63.829	72.378	80.255
Factor loadings:						
	F1	F2	F3	F4	F5	F6
pH	0.187	-0.161	-0.380	-0.352	0.512	0.437
Salinity	0.748	0.372	0.199	-0.022	-0.241	-0.254
Turbidity	0.186	0.506	0.237	0.359	0.123	0.638
DO	-0.550	-0.166	-0.432	0.426	0.098	-0.072
Nitrite	-0.542	0.469	-0.067	-0.116	-0.368	0.012
Nitrate	-0.675	-0.089	0.623	0.015	-0.085	0.143
Ammonia	-0.285	-0.042	0.322	-0.034	0.673	-0.234
T N	-0.662	-0.155	0.622	0.053	-0.044	0.135
Silicate	-0.267	-0.149	-0.478	0.089	-0.322	0.415
Phosphate	-0.519	0.731	-0.240	-0.244	0.115	-0.048
T P	-0.386	0.817	-0.179	-0.215	0.112	-0.118
Chl-a	0.592	0.538	0.321	0.160	0.087	0.170

silicate into a coastal milieu mainly takes place through land drainage rich with weathered silicate material (Lal, 1978). A comparison of silicate concentration observed in the present study with that of the earlier reported values from this coast (Satpathy, 1996a) showed that the present values are much higher, indicating the possible role of tsunami. However, Reddy *et al*. (2005) did not observe elevated levels of silicate in the southwestern coast in the post-tsunami period, in spite of the fact that levels of nitrate and phosphate increase observed by them during post-tsunami were substantial, which corroborated our observation.

Chl-*a* values ranged from 0.28 to 8.29 mg m^{-3}. The highest value (8.29 mg m^{-3}) was observed during April, whereas, the lowest value was in January. Monthly average values showed that, it gradually increased from February to April and declined till the end of the study period (Fig. 5d). Relatively higher chl-*a* values observed during March to May showed that the phytoplankton productivity was high during early summer and summer. Similar observations have been made from the southeast coast of India (Ganapati and Rao, 1958; Prasannakumar *et al*., 2002) and also from other coastal waters of India (Prasannakumar *et al*., 2000; Madhupratap *et al*., 2001; Sarma *et al*., 2006). High phytoplankton production during this period could be attributed to upwelling that brings the nutrient rich deeper water to the surface, which is a regular phenomenon in this area (La Fond, 1957; Murty and Varadachari, 1968; Shetye *et al*., 1991). A sharp decline in the chl-*a* values from October to January could be attributed to the NE monsoon during which the coastal water becomes unfavorable for phytoplankton growth due to precipitation and land drainage. This is further supported by the strong positive correlation ($p \geq 0.001$) between chl-*a* and salinity. Chl-*a* also showed strong negative correlation with nitrate, TN and silicate, which further supported the observation of low phytoplankton production during monsoon. On the other hand, it showed that phytoplankton production in coastal waters of Kalpakkam was mainly dependent on nitrogen and silicate. Chl-*a* concentration observed during the present study was found to be lower than that of the previously recorded values (Table 1). Increased turbidity due to resuspension of sediment as mentioned earlier could be responsible for decrease in chl-*a* content.

Principal Component Analysis (PCA): PCA of water quality data developed six principal components (PC) as seen from the eigenvalues (Table 3), explaining 80.26% of the total variability. PC-1 accounted for 23.44% of the total variance wherein negative factor loadings of all the parameters except pH, salinity, turbidity and chl-*a* were observed. In PC-2, negative loading of pH, DO, nitrate, ammonia, TN and silicate was observed, which accounted for 17.47% of the total variability. Turbidity and chl-*a* were the only two parameters found positively loaded in all the PCs.

In conclusion, the present investigation shows that the physicochemical properties of the coastal waters of Kalpakkam were significantly affected by freshwater input from two backwaters during NE monsoon. The highest concentration of all the nutrients and DO was observed during the NE monsoon. On the other hand, salinity and chl-*a* were at their minimum during the same period. A significant increase in nitrate, phosphate, silicate and turbidity, but decrease in DO and chl-*a* concentration were noticed. The reduction in DO and chl-*a* contents in the coastal waters is of concern. Perhaps increase in pollution levels in recent years have considerably affected the coastal water quality.

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