Evaluation of Physico-Chemical Characteristics of Water off Mumbai Coast using Exploratory Data Analysis

A. S.Shirodkar[1], P.V.Shirodkar[1], S. D.Rivonkar[1] and U. K. Pradhan[2]

[1]National Institute of Oceanography, Dona Paula, Goa - 403004, INDIA

[2]State Key Laboratory of Estuarine & Coastal Research Shanghai, China

Corresponding author email : adityashirodkar7@gmail.com, ashirodkar@nio.org

Introduction

Coastal seas are among the most important areas in terms of human perspectives and are constantly threatened by sewage and effluent discharges from metropolis and industrialized zones posing significant effect on its ecology. Various studies carried out in the coastal environments of India coast suggested that Mumbai and Gujarat (west coast) and Pondicherry (east coast) have degraded coastal environments due to the discharges from industrial and domestic outfall (*S. S. Dhage et al., 2006, Govindasamy and Azariah, 1999, Panigrahy et al., 1999*). Both natural processes and anthropogenic influences together determine the fate of coastal water (*Jarvie et al., 1998*). Rapid increase in population and urbanization in the recent past have resulted in increasing loads of nutrients and toxic trace metals intrusion in the coastal belts.

Although many studies have been carried out pertaining to polluted creeks in Mumbai, limited studies on pollution of these creeks on coastal environment have been carried out and published. In view of this, a study on the physico-chemical characteristics of the in coastal waters off Mumbai was carried out to assess the present environmental condition and anthropogenic influences of various creeks and rivers on coastal water quality.

Geographic location of study area

Mumbai lies within the geographical location: 18° 96' N and 72° 81' E with an average elevation of 10 to 15 m. It is a city of 7 islands located in the 'Konkan' region along the west coast of India. There are four major rivers within its vicinity *viz.* Oshiwara, Mahim, Dahisar, and Poisar River and number of creeks (*Haldankar et al 2011*). All these rivers and the creeks receive industrial effluents from small industries which is finally discharged into the sea. Besides this, rapid urbanisation across the state is a major culprit as well. Domestic sewage is a source of nutrient enrichment in this rivers, besides industrial and other sources. (Zingde and Govindan, 2000) showed that coastal waters of Mumbai receives industrial discharges more than 230 million litres per day (MLD) and domestic wastes of more than 2200 MLD of which, 1800 MLD are untreated. This has affected the water and sediment quality, with consequent effect on aquatic communities.

Study area and its Anthropogenic setup

All the stations were demarcated (Fig. 1) to demonstrate localized polluting effects of various rivers and creeks draining Mumbai metropolises which finally discharge into the Arabian Sea.

Thane Creek begins at Bombay harbour and extends 26 km northwards joining the Ulhas River by a minor connection near Thane city. Thane-Belapur industrial complex and Navi-Mumbai residential complex are on the east bank of the creek, while the west bank has a densely populated Thane-Mumbai residential area and good number of industries. These industrial and urban complexes release their effluents and waste into the creek which finally drain into the sea causing stress and deterioration of the ecosystem (Quadros, G. *et al.*, 2003) Mahim Creek is among the worst affected areas with some Sewage Treatment Plants discharging around 160 MLD (million liters per day) of domestic waste most of which is untreated. Apart from this several industrial establishments also release 25 MLD of effluents in Mahim River which finally drain into the Arabian Sea (M. D. Zigade and B. N. Desai, *et al.*, 1980). Manori creek, is among the highly stressed creeks, which sustains mangrove formations in close vicinity of Mumbai. However, it is intensively targeted for dumping garbage and disposal of sewage as well as overexploited for salt industries, fishing, navigation, and recreational activities.(V. Kulkarni *et al.*, 2010). Malad creek, receives sewage and wastewater from various drains and partially treated effluent from Malad and Versova treatment facilities (V. K. Sardar, *et al.*, 2010). Vasai creek, located between Ulhas river and Arabian Sea receives continuous discharges of pollutants by oil and grease, chemical industries, shipping and public sewage discharges making water polluted (R.S Lokahnde and Nilima Kelkar 1999).

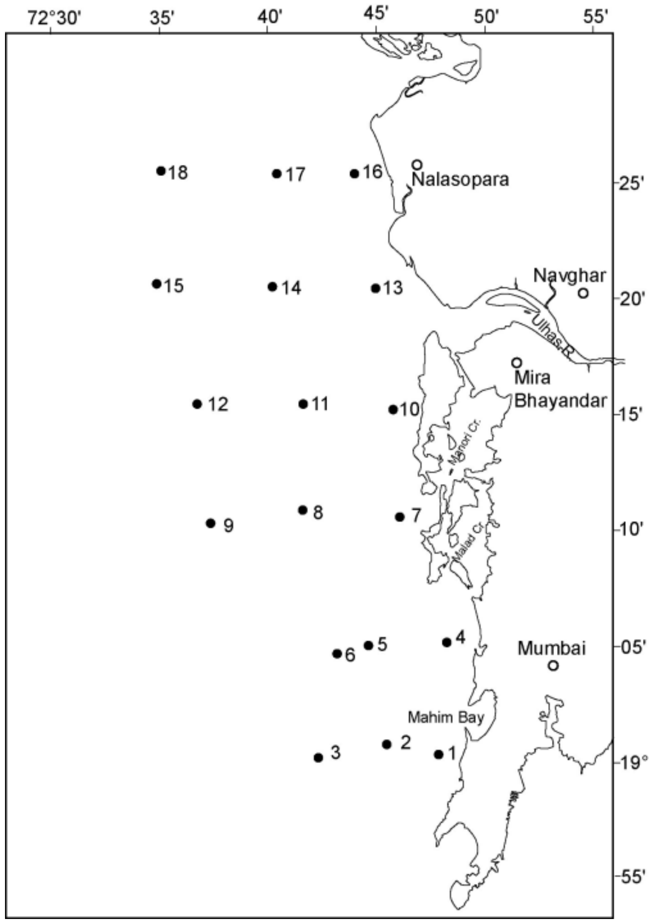


Fig. 1. Map showing various station locations of study off Mumbai coast.

Material and Methods

Sampling and analysis

The water samples were collected from 18 stations in six transects extending from off Mahim to off Virar coastal area to 5-10 kms seaward distance, during October 2009 by using 5L capacity PVC Niskin Water Sampler. The exact station location was set with the help of a Global Position System (GPS; Model Garmin). Soon after the collection, samples were preserved in ice, the water samples were fixed for dissolved oxygen on board and then measured by Winkler's method at the NIO laboratory, while the BOD was measured after 5 days of incubation at 20°C in BOD incubator. The *in situ* temperature and salinity measurements were done through a CTD profiler; pH with Eutech pH meter and the turbidity by using a Turbidimeter. The nutrients (PO_4-P,

NO_2-N, NO_3-N, NH_3-N, SiO_4-Si, Total P and Total N) were analysed using standard methods as given by Strickland and Parsons (1979), APHA (1992) and Grasshoff (1999).The data quality was ensured through careful standardization, procedural blank measurements, spike, and duplicate samples.

Multivariate statistical analysis

Principal Component analysis- Data generated were subjected to multivariate statistical analysis such as principle component analysis (PCA) / (FA) for the interpretation of the influence of various parameters on physico-chemical aspects within the study area. (*Wunderlin et al., 2001, Simeonova et al., 2003, Singh et al., 2004*). All mathematical and statistical computations have been made using Microsoft Office Excel 2003 and Statistica 10. R-mode (sorted) factor analysis resulted in eigen values, percentage of variance and cumulative percentage for all stations allowing inter-parameter relation and variations. A varimax normalized different varifactors with factor loading was calculated using eigen values greater than 1 and sorted by the results having values greater than 0.4 based on significant influence (*Sahu et al., 1998; Rath et al.,2000*). Rotation of the axis defined by factor analyses produced a new set of factors, each one involving primarily a subset of the original variables with as little overlap as possible so that original variables are divided into groups. The factor loading was classified as per (*Liu et al., 2003*) as "strong" (>0.75), "moderate" (0.5-0.75) and "weak" (0.4-0.5)

Water Quality Index- Water quality determination is a complex issue as it involves physical, chemical, hydrological and biological characteristics of water and their complex and delicate relations. It is a tool which transforms bulk data into a single digit, cumulatively derived numerical expression indicating the level of pollution.The parameters are selected as per the guidelines provided by the Inland Surface Water in India for classification of types of water, and is accepted by the Central Pollution Control Board (CPCB), which then recommended the suitability of water for specific use. The WQI is first measured individually for each parameter by using the equation obtained from the value function curve in which, the concentration of parameter is taken on Y-axis and the index value on X-axis and are plotted for each of the parameter as per (Sargaonkar and Deshpande 2003). These measured WQI values are then transformed into a single number called the Overall Index of Pollution (OIP), representing the overall quality of water at that particular station. The OIP is thus estimated as the average of all the pollution indices (Pi) for individual water quality parameters considered in this study and is given by the mathematical expression below and classified as per the (Fig 3) (Table 3).

$$OIP = \Sigma_i P_i / n,$$

Where, Pi = pollution index for i^{th} parameter; where, i = 1, 2,.n and n = number of parameters.

Results and Discussion

Water quality parameters

Datasets were obtained from seawater collected from surface and bottom layers at 18 stations (Fig 1) along 6 vertical transects in the study area extending from south off Mahim to north off-Virar were processed. The variation in significant physico-chemical parameters along these transects is shown in (Fig 2) and has been explained as below;

Temperature showed a variation from 26.60 - 30.50°C in surface and 26.00-27.9 °C, which indicated that it is lying below the threshold value of 35°C with a distinct difference between the surface and bottom water. This suggested temperature variation within the normal limits (Fig 2a). Salinity increases gradually from near shore region to offshore in surface layer, while in bottom layer, the salinity of (31.59 psu) was observed at station 1(Fig 2b) may be due to incomplete mixing of high saline seawater with contaminated Mahim bay water resulting in salinity a gradient (M.D Zingde *et al.*, 2000).Near consistent pH was observed from south to north, with an apparent increase towards north in surface and bottom water except station 7 with pH (8.42) and (8.54) in surface and bottom respectively, which showed comparatively low pH (Fig 2c). Dissolved oxygen (DO) showed a variation from 1.48 mg/l to 7.17 mg/l in surface and 0.67 to 4.67 mg/l in bottom water. Values in surface water showed increasing trend towards north whereas the bottom water showed consistent lower oxygen content indicating hypoxic condition (Fig 2d). BOD showed an average of 1.10 mg /l in surface water and 0.59 mg/l in bottom water. Though there exists anthropogenic inputs from adjoining creeks, no high values of BOD have been observed. This indicated relatively low organic pollution in the study area (Fig 2e). Surface water showed low turbidity (9.50-62.90 NTU) compared to bottom waters (10.30 -271 NTU), with highest turbidity recorded at station 13 in bottom water (Fig 2f). Surface and bottom water showed fairly consistent TSS range of > 31 - < 36.5 mg/l with abrupt decrease at station 13 (29 mg/l) although prominent high turbidity is observed at this station, it is not contributed by suspended matter but may be due to fresh water influxes in this region also evident from low saline water. Prominently high concentration of PO4-P > 2.00 mol/l was clearly evident from the dataset with exception to few stations, however higher concentration of 7.81 mol/l was observed in the bottom water (Fig 2g). NO_2-N concentration in the water column varied from 0.24-1.82 mol/l and 0.27-2.33 mol/l in surface and bottom water with an increase towards the north except at station 15 with lower concentration of (0.27 mol/l) (Fig 2h). NO_3-N showed no clear difference in its variation in surface and bottom water layer. It showed increasing concentration towards north except at station 9 with low concentration. Highest concentration (max.19.33 mol/l) off Vasai creek suggested input from Vasai creek and adjoining areas imparting high concentrations of nutrients (Fig 2i). NH_3-N ranged from 0.97-36.42 mol/l, with an average of >8.71 mol/l observed in surface water and 1.45-20.24 mol/l in bottom water. Station 1 to 6 showed high concentration of NH_3-N with a maximum concentration of 36.42 mol/l seen at station 2 (Fig 2j) indicating inputs of Worli outfall point and Mahim bay, resulting in high ammoniacal concentration. Earlier studies conducted by NEERI in 2006 suggested that the post commissioning of Worli outfall point have resulted in the enrichment of nutrients in coastal environment (*S.S.Dhage et ., al* 2006). Average Silicates concentration of 33.30 mol/l and 24.84 mol/l was seen in surface and bottom water respectively, with increasing trend observed from off Mahaim to off Virar. Maximum silicate concentration of (72.71 mol/l) was observed at station 16 and minimum concentration

Fig. 2 (a-f). Variation of Hydrographic parameters off Mumbai coast.

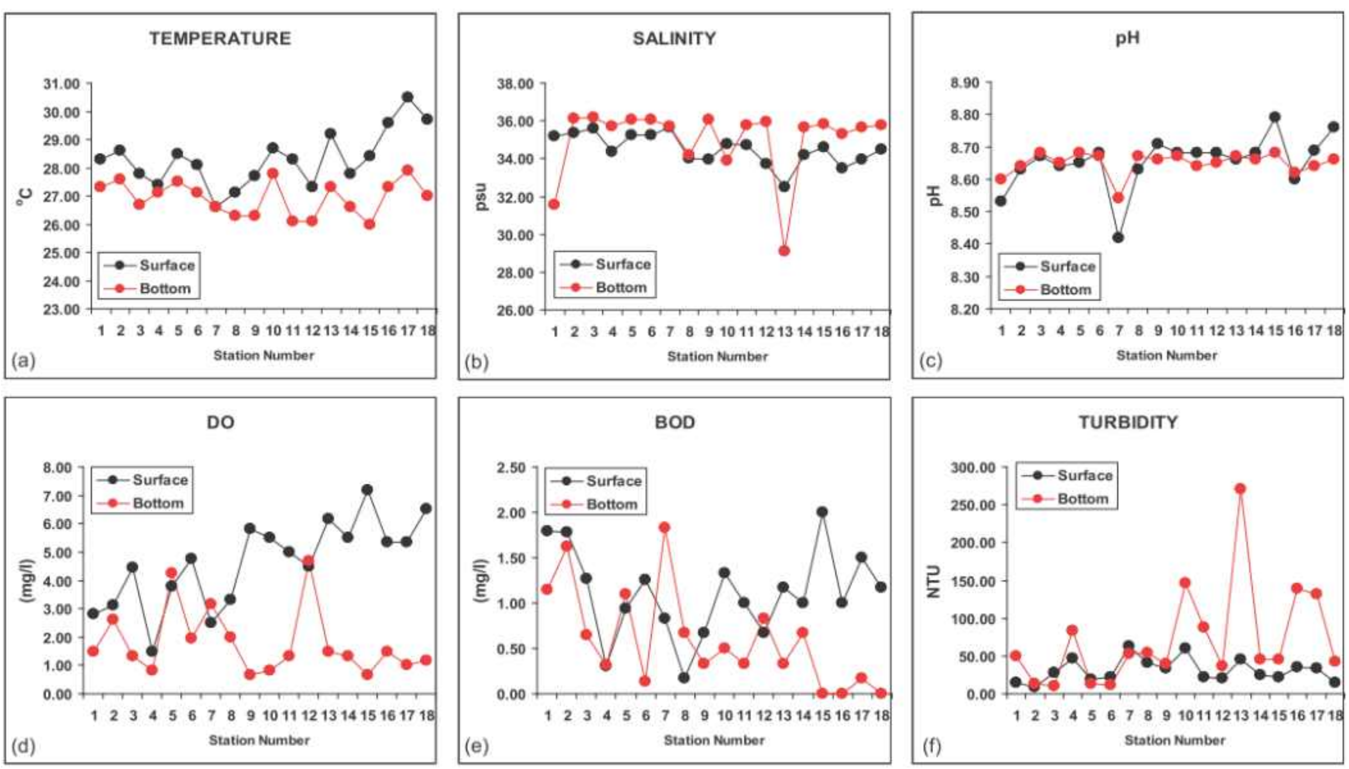
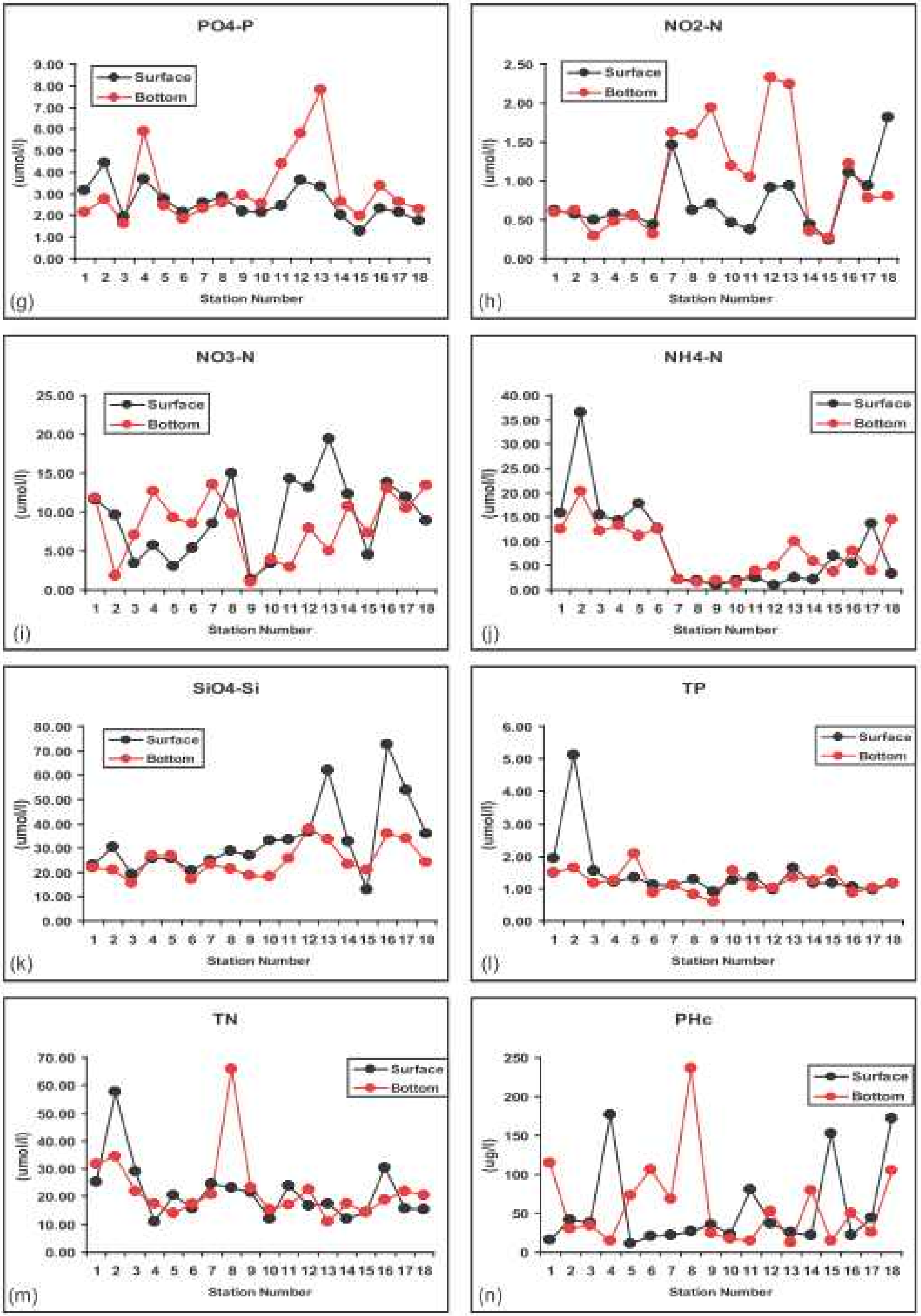


Fig. 2 (g-n) : Variation of Hydrographic parameters off Mumbai coast



(12.97 mol/l) at station 15 in surface water (Fig 2k). However, presence of values above normal range in most of the stations suggested creeks and rivers as the sources of addition of nutrients to the coastal environment. Concentration of Total Phosphorus (TP) varied from 0.92 to 5.11 mol/l in surface and 0.58-2.07 mol/l in bottom water. TP concentration lies within normal acceptable range throughout the study area except station 2 nearing off Mahim bay indicating the influence of Worli outfall point contributing enrichment of this nutrient in coastal environment (Fig 2l). Total nitrogen (TN) showed similar trend as TP with highest concentration (57.69 mol/l) in surface water station 2 and (66.00 mol/l) in bottom water station 8. High concentration of TN in stations 8 may be contributed from Malad creek contributing for high TN concentration (Fig 2m).

Principal Component Analysis (PCA) / Factor Analysis (FA)- Factor analysis performed on normalized data set (14 variables) generated four factors for explaining 77.21% total variance in surface water and 68.91% for bottom water (Table 2).The loadings were considered as strong (>0.75), moderate (0.5-0.75) and weak (0.4-0.5). The factor loadings with values greater than 0.40 are retained and are used for factor interpretation. Factor analyses suggested hydrographic parameters (Temperature and turbidity) and nutrient (PO_4-P, NH_3-N SiO_4-Si and TP) dominance throughout surface and bottom water.

Surface Water

Factor 1 explained total cumulative variance of 28.47 % with strong positive loadings of NH_4-N TP and TN, moderate lodgings of PO_4-P with Significant positive correlation observed between TP and TN with NH_3-N and PO_4-P (Table 2a) suggesting common source for this nutrient enrichment. Domestic and industrial sewage waste intrusion from localized inputs from metropolises water may be probable source of these high nutrient loadings. Factor 2 Total cumulative variance of 49.15 % was seen in this factor with strong positive loadings of Temperature, DO and BOD and weak loadings of pH. With temperature showing positive correlation (Table 1a) with DO and BOD wherein no significant correlation is seen between DO and BOD (Table 2a) showing well oxygenated water. Factor 3 is strongly loaded with SiO_4 -Si and NO_3-N and weak positive loadings of temperature and NO_2-N and strong negative lodgings of salinity with total variance of 68.72% with no significant correlation among them except for SiO_4-Si with temperature (r = 0.62) and NO_3-N and salinity (r = 0.60). Strong factor loadings of nutrient suggesting significant impact of industrial and domestic waste discharges reaching the coastal water from adjoin polluted creeks and rivers finally discharging waste into the sea. Many Factor 4. Contributed 77.21 % of total variance with weak positive loadings of turbidity and strong negative loadings of pH and PHc with no distinct correlation among them.

Table 1 (a) **Correlation between physico- chemical parameters of surface water.**

Surface	Temperature	Salinity	pH	DO	BOD	Turbidity	PO4	NO2	NO3	NH4	SiO4	TP	TN	PHc
Temperature	1.00													
Salinity	-0.32	1.00												
pH	0.39	-0.29	1.00											
DO	**0.53**	-0.42	**0.72**	1.00										
BOD	**0.51**	0.30	0.17	0.35	1.00									
Turbidity	-0.24	-0.18	-0.40	-0.17	-0.41	1.00								
PO4	-0.22	-0.08	-0.42	**-0.66**	-0.20	-0.05	1.00							
NO2	0.23	-0.19	-0.26	0.05	-0.18	0.16	-0.02	1.00						
NO3	0.20	**-0.60**	-0.21	0.03	-0.11	-0.01	0.34	0.25	1.00					
NH4	0.17	0.49	-0.11	-0.43	0.45	-0.45	0.47	-0.26	-0.22	1.00				
SiO4	**0.62**	**-0.73**	-0.05	0.28	-0.08	0.19	0.12	0.42	**0.64**	-0.20	1.00			
TP	0.07	0.29	-0.15	-0.30	0.42	-0.37	**0.62**	-0.16	0.08	**0.79**	-0.08	1.00		
TN	0.01	0.31	-0.33	-0.32	0.27	-0.32	**0.50**	-0.01	0.10	**0.67**	0.04	**0.85**	1.00	
PHc	0.11	-0.02	0.47	0.12	0.01	-0.13	-0.17	0.14	-0.18	-0.02	-0.21	-0.09	-0.27	1.00

Table 1(b) **Correlation between physico-chemical parameters of bottom water**

Bottom	Temperature	Salinity	pH	DO	BOD	Turbidity	PO4	NO2	NO3	NH4	SiO4	TP	TN	PHc
Temperature	1.00													
Salinity	-0.26	1.00												
pH	-0.04	0.04	1.00											
DO	-0.06	0.16	-0.20	1.00										
BOD	0.08	0.00	**-0.54**	**0.61**	1.00									
Turbidity	0.34	**-0.72**	-0.01	-0.32	-0.34	1.00								
PO4	-0.06	-0.47	0.06	0.11	-0.14	**0.64**	1.00							
NO2	-0.23	-0.37	-0.20	0.29	0.09	0.45	**0.58**	1.00						
NO3	0.11	0.04	-0.40	0.11	-0.01	-0.07	-0.14	-0.23	1.00					
NH4	0.43	-0.02	0.10	0.11	0.16	-0.22	0.02	-0.45	0.08	1.00				
SiO4	0.11	-0.20	-0.18	0.34	-0.15	**0.50**	**0.65**	0.46	0.28	-0.09	1.00			
TP	0.41	-0.17	0.14	0.26	0.38	-0.04	-0.06	-0.40	-0.03	0.39	-0.07	1.00		
TN	-0.16	-0.04	-0.06	0.09	0.28	-0.27	-0.23	0.15	0.05	-0.07	-0.20	-0.27	1.00	
PHc	-0.15	-0.07	-0.03	0.22	0.15	-0.33	-0.34	0.01	0.41	-0.04	-0.19	-0.20	**0.77**	1.00

Table 2 **R-mode varimax rotated factor analysis of physico-chemical parameters (N=18)**

	Surface				Bottom			
	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Temperature		0.77	0.45				0.78	
Salinity			-0.85		0.74			
pH		0.44		-0.83		-0.53		
DO		0.76				0.89		
BOD	0.42	0.76				0.83		
Turbidity	-0.53			0.46	-0.90			
PO4	0.66	-0.61			-0.79			
NO2			0.45		-0.64		-0.60	
NO3			0.82					-0.56
NH4	0.88						0.72	
SiO4			0.91		-0.72			
TP	0.94						0.75	
TN	0.84							-0.76
PHc				-0.72				-0.89
Expl.Var	3.60	2.49	2.91	1.80	3.13	2.19	2.30	2.03
Prp.Totl	0.26	0.18	0.21	0.13	0.22	0.16	0.16	0.14
Eigenvalue	3.99	2.90	2.74	1.19	3.33	2.49	2.26	1.56
% Total variance	28.47	20.68	19.56	8.50	23.82	17.79	16.13	11.16
Cumulative Eigenvalue	3.99	6.88	9.62	10.81	3.33	5.83	8.08	9.65
Cumulative %	28.47	49.15	68.72	77.21	23.82	41.61	57.75	68.91

Table 3 **Classification of Water Quality Index.**

OIP (Score)	Classification
0 - 1.0	Excellent
1.0-2.0	Acceptable
2.0-4.0	Slightly Polluted
4.0-8.0	Polluted
8.0-16.0	Heavily Polluted

Bottom Water

Factor 1 Contributed 23.82% variance with strong positive loadings salinity and negative lodgings turbidity PO4-P and SiO4-Si (Table 2a) with significant correlation between turbidity and nutrients (PO4-P and SiO4-Si) (Table 1b) suggesting increase in these nutrients with high turbid water due to benthic resuspension or domestic and industrial waste water influx in coastal regions. Factor 2 suggested strong loadings of DO and BOD with total variance of 31.61% with significant positive correlation (Table 1b) suggesting well oxygenated water with some BOD load. Factor 3 explained cumulative variance of 57.95% with strong positive loadings of temperature NH4-N and TP. With no distinct correlation among them. This factor suggested ammonical and phosphate dominance. Factor 4 contributed 68.91% of total variance with strong negative loadings of TN and PHc and moderate loads of nitrate.

Water quality Index

Water Quality Index of data sets from various important physico-chemical parameters were evaluated to understand the changes in the water quality parameters using overall index of pollution (OIP) values (Fig. 3.) It was prominent that all the stations suggested

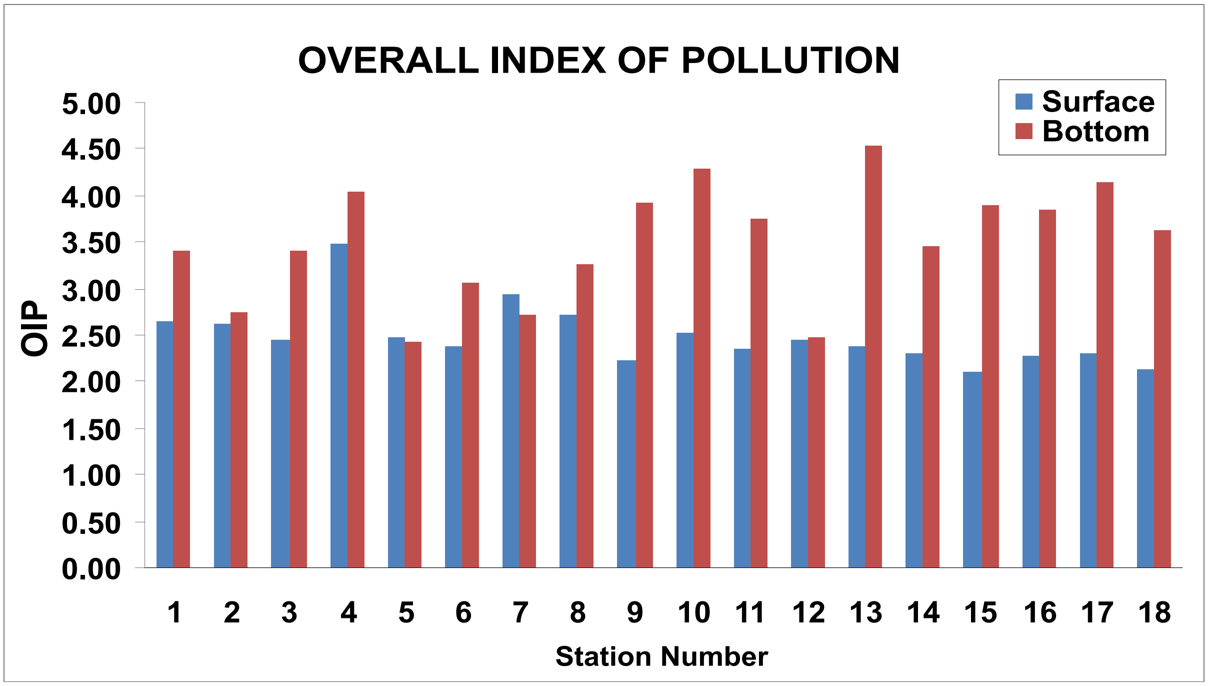


Fig. 3. Overall Index of Pollution along off Mumbai coast.

slightly polluted to polluted water (OIP=2.11-3.43) in surface and (OIP=2.42-4.53 in bottom water off - Mumbai coastal water. However stations 4,10 and 13 showed OIP > 4.0 with station 13 showing most polluted water (OIP=4.53) among them. The relatively higher OIP values at these stations indicate effect of localized inputs of sewage form drainage channels and other anthropogenic contributions such industrial discharges through creeks and rivers and sewage outfall points.

Conclusion

Mumbai, a metropolitan city, on the west coast of India is surrounded by coastal marine environment comprising of the Arabian Sea to the west and a number of tidal inlets round it such as the Thane creek, Mahim creek, Vasai creek, Ulhas estuary, Malad creek, Manori creek in its vicinity moving from south Mahim to north Vasai creek. Due to unprecedented population growth nearing about 20.5 million and rapid industrialization in recent past resulted tremendous stress on rivers and coastal waters in these regions.

Multivariate technique, such as factor analyses used in this study, provided important information for better understanding the distribution and concentrations of pollutants that enter and get deposited in the complex, dynamic coastal environment rendering variation in physico-chemical properties of coastal environment. FA revealed high influx of nutrients mostly contributed due to domestic, industrial sewage drains and outfall points.

Water quality index values revealed slightly polluted state throughout study region with some stations reaching threshold limit of OIP (2-4) for slightly polluted water rendering polluted state. In order to preserve and protect the coastal environment from any further degradation caused due to population explosion, increasing human settlements along riverine and coastal belts continuous monitoring and scientific studies are of prime importance.

Acknowledgment

The authors express their sincere gratitude to the Director NIO, Goa. They thank all participants who were involved in sample collection.

References

1. APHA, 1992. Standard Methods of Seawater Analyses. American Public Health Association, New York
2. Govindasamy, C., Azariah, J., (1999). Seasonal variation of heavy metals in the coastal waters of Koromandal coast, Bay of Bengal. Indian Journal of Marine Science, 249-256.
3. Grasshoff, K., (1999). Methods of Seawater Analyses. Verlag Chemie, Weinheim.
4. Haldankar Sonali R., Shirodkar P.V., and Fernandes Dearlyn., 2011. Water quality and Trophic levels as indicators of anthropogenic influences on aquatic environments along the central west coast of India. IEEE
5. Jarvie HP, Whitton BA, Neal C. (1998). Nitrogen and phospourus in east coast British rivers: speciation ,sources and biological significance. Sci Toal Enviorn 210/211, 79-109.
6. Liu, C.W., Lin, K.H., Kuo, Y.M., (2003). Application of factor analysis in the assessment of ground water quality in a black foot disease area in Taiwan. Science of the Total Environment 313, 77-89.
7. M.D Zingde and B.N Desai. Waste water discharge and its effect on quality of water of mahim creek and bay. (1980) Mhasagar - bulletine of National Institute of Oceanography 13 (3) 205-213.
8. Panigrahy PK, Das J, Das SN and Sahoo RK (1999). Evaluation of the influence of various physico-chemical parameters on coastal water quality, around Orissa, by factor analysis. Ind.J. Mar. Sci. 28, 360-364.
9. Quadros, G.; Athalye, R.P.; Mishra, V.; Ullal, V.; Mukherjee, M.; Pejaver, M.K.; Tandel, S.S.; Borkar, M.; Somani, V.; Gokhale, K.S. (2003). Deterioration of Thane Creek ecosystem near Thane City over the past 20 years Seshaiyana: 11(2); 6-7
10. Rath, P., Bhatta, D., Sahoo, B.N., Panda, U.C., 2000. Multivariate statistical approach to study physico-chemical characteristics in Nandira-Brahmani river. Pollution Research 4, 201-210.
11. R.S Lokahnde and Nilima Kelkar (1999). Studies on heavy metals in water of Vasai creek, Maharashtra IJEP 20(6); 441-446.
12. Sahu, K.C., Panda, U.C., Mohapatra, D.M., (1998). Geo-chemistry and mineralogy of sediments in Rushikulya estuary, east coast of India. Chemical and Environmental Research 7, 77-92.
13. Sargaonkar, A., Deshpande, V., (2003). Development of an overall Index of Pollution for surface water based on a general classification Scheme in Indian Context. Environmental Monitoring and Assessment 89, 43-67.
14. Simenova, P., Simenova, V., Andrew, G., 2003. Environmetric analysis of the struma river water quality. Central European Journal of Chemistry 2, 121-126.
15. Singh, K.P., Malik, A., Mohan, D., Sinha, S., (2004). Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomti River (India)- A case study. Water Research 38, 3980-3992.
16. Strikland, S.C., Parsons, T.R., (1979). A Practical Handbook of Seawater Analysis. Bulletin of Fisheries Research Board of Canada, Ottawa.
17. S.S Dhage, A.A. Chandorkar, Rakesh Kumar, A. Srivastava, I.Gupta (2006). Marine water quality assasment at Mumbai west coast Enviornmantal international 32 149-158
18. Vikrant A. Kulkarni ,Tanaji G. Jagtap · Namrata M. Mhalsekar · Anuradha N. Naik (2010). Biological and environmental characteristics of mangrove habitats from Manori creek, West Coast, India Environ Monit Assess 168:587-596.
19. V K Sardar, R Vijay, R A Sohony (2010). Water quality assessment of Malad Creek, Mumbai, India: an impact of sewage and tidal water. Water Sci Technol.;62(9);2037-43.
20. Wunderlin, D.A., Diaz, M.P., Ame, M.V., Pesce, S.F., Hued, A.C., Bistoni, M.A., 2001. Pattern recognition techniques for the evaluation of spatial and temporal variation in water quality. A case study: Suquia River Basin (Cordoba-Argentina). Water Research 35, 2881-2894.
21. Zingde, M.D., Govindan, K., (2000). Health status of Coastal waters of Mumbai and regions around. In: Sharma, V.K. (Ed.), Environmental Problems of Coastal Areas in India. Bookwell Publ., New Delhi, India, pp. 119-132.