Indian Journal of Geo-Marine Sciences
Vol. 42 (7), November 2013, pp. 915-923

Water quality assessment of Alibaug mangrove forest using multivariate statistical technique, Maharashtra, India

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Received 31 May 2012; revised 20 December 2012

Physicochemical properties of surface water from Alibaug mangrove forest and Akshi coastal area were examined using multivariate statistical techniques viz. cluster analysis and factor analysis during October to December 2010. Water quality assessment was done by estimating pH, temperature, EC, TDS, DO, COD, salinity, hardness, SAR, TPH, TOG, Na^+, Ca^{2+}, Mg^{2+},Cl^-, NO^{3-} and PO_4^{3-}. Water in general showed high values of Hardness, salinity, TDS, EC, COD, TOG, calcium, magnesium, chloride, nitrate and phosphate. Dominant cation and anion were Na+ and Cl^- respectively. Cluster analysis grouped sampling sites into three clusters of similar hydrochemical features and classified mangrove forest to low, moderate and high pollution zones. Factor analysis revealed that the most significant parameters contributing to water quality variation are: EC, Na^+, PO_4^{3-}, SAR, Ca^{2+}, temperature, salinity and Cl^-. According to factor analysis different natural and anthropogenic sources affect the water quality of study area viz. weathering and seasonal variation, agriculture runoff, domestic and industrial sewage disposal and oil from spill.

[**Keywords:** Alibaug Mangrove forest, Surface water, Physicochemical properties, Correlation analysis, Cluster analysis, Factor analysis].

Introduction

Mangroves in India are under pressure of urbanization industrialization and oil from spills, transport and refineries along the coast lines further augument this adverse impacts[1]. Oil contamination of mangrove habitat has significant hydrocarbon levels after a spill event[2,3]. These impacts are likely to continue and worsen, as human populations and other activities expand further. Recognition of these impacts on mangrove forest and coastal ecosystem are likely to develop sustainable approaches. Furthermore, due to temporal and spatial variations in water qualities, monitoring programs help to understand water and soil quality .[4] Quality of water is identified in terms of its physical, chemical and biological parameters.[5] Results are usually compiled into a large data matrix with the use of data interpretations.[6] Multivariate statistical methods including cluster analysis and factor analysis are useful methods to make some management measures for water quality protection.[7]Alibaug mangrove forest in the south west of India is One of the areas threatened due to proximity to the Arabian Sea and the increase of population and human activities around and within the area. Drainage water entering urban and rural areas including domestic and industrial sewage as well as runoff from agricultural lands besides oil from spill due to the August 2010 incident in the water of the Arabian Sea may have certain adverse impact on mangrove ecosystem. Since extensive studies on physicochemical parameters and pollution sources and any environmental impact assessment have not been carried out yet, the present study is undertaken to assess the pollution load if any, through the estimation of physicochemical parameters of water as well as chemical indicators of petroleum pollution using multivariate statistical methods.

Materials and Methods

Alibaug is situated between Latitudes 18º 56' N to 18º 29' N and Longitudes 72 º 50' E to 73 º o4' E. This area is surrounded by Arabian Sea coast on its North East, North, and Southern part. Maximum temperature is 38°C and minimum 8.4°C, and atmosphere is humid. Average relative humidity is over 80% during the South West monsoon season

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and in rest of the year the relative humidity is between 65% and 75%. Average annual rainfall is between 2000 to 2200 mm.

Water samples were collected forenoon using wide mouth sterile transparent plastic jar of five-liter capacity and usually from 10-15 cm depth from the water surface during October to December of the year 2010 from eighteen sampling sites, which are shown in Fig.1.

The sites were selected based on location, natural or human caused sources of pollution such as Alibaug city, agricultural field, rural settlement and several small industries, which are in this area.

Water temperature was measured on the sites using standard mercury Celsius thermometer. For the analysis of dissolved oxygen, manganese sulphate, alkali iodide–azide agent and sulphuric acid were added immediately to water samples after collecting from the sampling sites to fix the samples. Further measurement was carried out in the laboratory. Conductivity and pH of the samples were measured with the help of a digital laboratory conductivity meter (Elico model CM 180) and digital pH meter (Global-DPH540). For the study of total dissolved solid, oil and grease, chloride, calcium, hardness, magnesium the samples were analyzed according to Standard Methods of American Public Health Association.[8] Sodium (Na^+) concentrations were determined by flame photometric method while, COD, PO_4^{3-}, and NO_3^- were analyzed using UV-VIS spectrophotometer. Total petroleum hydrocarbon (TPH) was determined according to U. S. EPA Method, 8015. Typically, a relationship of salinity = (1.805*(ppt) chloride) + 0.03) was used to calculate salinity. Sodium adsorption ratio (SAR) was also calculated in terms of sodium and calcium ion concentration which was expressed in milliequivalents. All the determinations were replicated thrice and the mean value was used to obtain representation of each station.

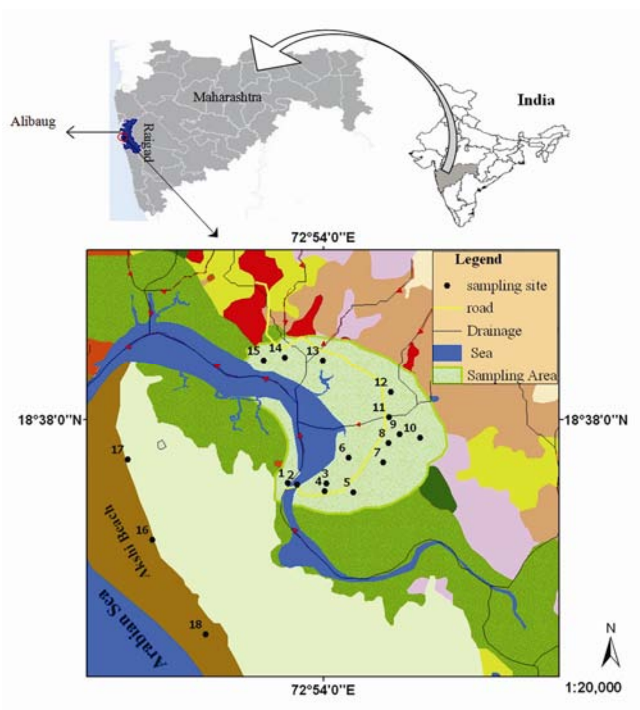

Fig. 1—Alibaug mangrove forest,Akshi coastal area and location of sampling sites

Factor analysis, Cluster analysis and Correlation matrix were performed using Minitab professional 16 software while descriptive statistics of the data was performed using Biodiversity pro statistical and ecological software. To assess of the pollution load, physicochemical parameters were compared with the water quality standard of Bureau of Indian Standard (BIS), Central Pollution Control Board (PCB) of India, seawater standard reported by Summerhayes and Thorpe(1996)[9] as well as Asian standard of marine life.

Results and Discussion

Physicochemical properties of surface water from Alibaug mangrove forest and Akshi coastal area of Arabian Sea during the October to December 2010 are presented in Table.1. Temperature of water samples ranged from a low of 23.3 to a high of 38 °C. Mean value of temperature of water samples (29.44°C) revealed mesophilic to thermophilic temperature range during the time of sampling. In general water temperature is closely related to atmospheric conditions. The standard deviation indicated high variability in the temperature of water samples during the time of sampling. Mean of pH value (7.87) revealed that the water in all the study area was alkaline between the range of 7.24 to 8.65which indicates no pH variation against BIS and PCB standards (6.5-8.5). Standard deviation showed marginal variation of pH in all the different sampling sites which may be due to oil spill incident in August leading to chemical and biological processes besides high concentration of alkaline metals, Na+ which interacted with carbonate and bicarbonate and changed the pH of water to alkaline.

Mean of electrical conductivity of water was found to be 135.43 µs/cm between the range of

Table 1—Physicochemical parameters of surface water collected from Alibaug mangrove forest and Akshi coastal area during October to December 2010

site	Sample Location	Temp (°C)	PH	EC (µs/cm)	DO (mg/l)	COD (mg/l)	TDS (g/l)	O&G (mg/l)	Cl (ppt)[a]	salinity (ppt)	Na (mg/l)	Hardness (mg/l)	SAR	Ca (mg/l)	Mg (mg/l)	NO3- (mg/l)	PO4- (mg/l)	TPH (mg/l)
site 1	forest	24.0	7.30	131.68	6.36	10235.19	39.00	0.84	23.57	42.58	5857.20	5700	21.38	881.76	2876.85	1.54	0.00	<0.5
site 2	forest	25.0	7.72	120.67	6.32	**12056.90**	41.50	0.04	**36.64**	**66.16**	5782.74	5800	20.91	1603.20	2506.40	1.92	0.00	<0.5
site 3	forest	28.0	7.81	134.64	5.54	10954.29	45.80	0.05	31.10	56.16	6495.80	6900	21.55	1122.24	3449.80	**9.08**	0.02	<0.5
site 4	forest	34.0	7.80	133.62	5.23	10546.80	43.00	0.24	29.54	53.34	5702.30	5500	21.18	1042.08	2661.87	9.00	0.02	<0.5
site 5	forest	31.0	7.90	**160.14**	6.08	4266.66	42.40	1.29	27.12	48.99	6426.30	6300	22.31	1202.40	3043.84	1.95	0.01	<0.5
site 6	forest	25.0	**7.24**	121.38	4.18	9923.58	40.80	0.14	22.86	41.30	5943.63	**4900**	23.39	1202.40	2208.12	2.09	0.01	<0.5
site 7	forest	26.0	7.72	137.70	5.96	10091.37	40.60	0.23	24.57	44.37	6104.52	5100	**23.54**	2004.00	**1849.57**	1.75	0.01	<0.5
site 8	forest	27.0	7.50	108.53	4.00	2181.27	39.00	**1.66**	**22.15**	**40.01**	5460.96	6000	19.43	881.76	3055.93	1.60	0.01	<0.5
site 9	forest	34.5	8.14	150.96	5.27	4626.21	41.80	0.38	27.55	49.75	6184.97	7400	19.81	961.92	**3843.86**	4.60	0.02	<0.5
site10	forest	28.0	7.84	125.97	5.39	8125.83	40.80	0.16	23.15	41.81	5863.19	5800	21.22	**721.44**	3032.13	2.03	0.00	<0.5
site 11	forest	**36.0**	8.00	149.94	**4.05**	**2085.39**	**36.00**	**0.36**	27.26	49.24	6184.97	7000	20.37	985.97	3590.74	1.83	0.01	<0.5
site 12	forest	30.0	7.79	159.94	6.49	7262.91	47.80	0.07	28.54	51.55	6426.30	6800	21.47	1442.88	3198.93	2.25	0.01	<0.5
site 13	forest	33.0	**8.65**	157.59	5.68	9156.54	**47.80**	1.61	29.68	53.60	**6753.88**	**8500**	20.18	**2484.00**	3592.99	**1.18**	**0.02**	<0.5
site 14	forest	28.0	7.88	132.40	6.32	7478.64	42.80	0.75	26.55	47.96	5863.19	5700	21.39	1603.20	2446.71	1.23	0.01	<0.5
site 15	forest	**23.5**	7.86	140.25	6.49	8892.87	43.40	0.05	29.11	52.57	5702.30	6200	19.95	1523.04	2792.97	1.56	0.01	<0.5
site 16	Akshi coastal area	33.0	8.10	131.58	5.27	5800.74	41.00	0.04	27.69	50.01	5058.74	5900	18.14	1282.56	2757.27	1.57	0.00	<0.5
site 17	Akshi coastal area	32.0	8.21	132.09	5.80	5513.10	39.90	0.04	27.55	49.75	**5058.74**	5900	**18.14**	1923.84	2374.92	1.81	**0.00**	<0.5
site 18	Akshi coastal area	32.0	8.19	**108.63**	**7.54**	8605.23	39.70	0.28	23.00	41.55	5541.41	6000	19.71	1202.40	2864.76	1.63	0.00	<0.5
Mean	**29.44**	**7.87**	**135.43**	**5.67**	**7655.75**	**41.84**	**0.46**	**27.09**	**48.93**	**5912**	**6189**	**20.78**	**1337**	**2897**	**2.70**	**0.01**	**ND b)**	
SD	**3.90**	**0.33**	**15.68**	**0.93**	**2981.54**	**3.02**	**0.55**	**3.60**	**6.50**	**465**	**864**	**1.49**	**456**	**5201**	**2.42**	**0.01**	**ND**	

***:Maximum & Minimum of data are given in bold.**

a): ppt = part per thousand b): Not Detected (Detection limit of GC-FID instrument for TPH was 0.5 ppm.)

108.63 µs/ cm in site-18 to 160.14 µs/ cm in site-5. Standard deviation showed a significant variation between the different sampling sites which positively related to high temperature, high quantity of dissolved salts, low water flow and high concentration of anions, cations and organic matter during the time of sampling. As high temperature favors degradation of organic pollutants. It also increases the conductivity value in water bodies[10].

Total dissolved solids in water were with mean level of 41.839 g/l, between the range of 36.00 (g/l) to 47.800(g/l). Results show TDS had direct correlation with EC in most of the sampling sites. Dissolved solids are an important part of water mass which influence the ecology and quality of water.[11] Mean value of hardness was found to be 6189 mg/l. Standard deviation also showed the high variation of hardness (4900 to 8500 mg/l) in study area against permissible limit of BIS and seawater standard which is mainly caused by agricultural runoff and high concentration of Ca^{+2} and Mg^{+2} ions in the surface water. Hardness in water is almost due to the natural accumulation of salts from contact with the soil and geological formations or it may enter from the direct pollution by human activities and agricultural runoff.

Mean of salinity was found to be 48.93 ppt and the lowest and highest concentrations were 40.01 and 66.16 ppt respectively. The result showed high variation of salinity in some sampling sites against mangrove and seawater standard (35-50 ppt). The standard deviation (6.50) showed high variation in concentration of salinity in the study area. All the sites showed an increased level of salinity during the time of sampling because of decreased water flow in the winter season (November and December). The high concentration of Na^{+}, Ca^{+2}, Mg^{+2} and Cl^{-} ions were due to the influx of sea water and basaltic host rock weathering. Industrial/ domestic sewage can affect water salinity. The water in Alibaug mangrove forest was detected hyperhaline.

Chloride content in different water samples was between 22.15-36.64 ppt and mean of that was 27.09 ppt. Standard deviation showed moderate variation of chloride in different sampling sites. Increase in concentration of chloride against seawater standard may be attributed to intrusion of brine water or pollution from industrial or domestic wastes. High chloride content is attributed to sources such as industrial and domestic effluent besides fertilizers. Similar results were also reported by More *et al*.[12]

Nitrate levels were between 1.18-9.08 mg/L. Nitrate concentration was detected highest in the surface water of sampling sites 3 and 4 respectively. This increase against seawater standard (0.005-0.009 mg/L) and Asian standard of marine life (0.006 mg/L) may be due to application of nitrogenous fertilizers. Since the type of soil in the study area is mostly lateritic soil which is poor in nutrients such as nitrogen and phosphorous, it can be cultivated with the use of fertilizers. Natural sources of nitrate are igneous rock, plant decay, and animal debris. Nitrate levels over 5 mg/L in natural waters normally indicate man made pollution. Man made sources include fertilizers, livestock, urban and agriculture runoff, and wastewater discharges.[13,14,15]

Phosphate concentration was in the range of 0.00-0.02 mg/L with the mean value of 0.01 mg/L. The highest phosphate content was detected in sites 3, 4, 9 and 13 which shows increase against seawater standard (0.003-0.006 mg/L) and Asian standard of marine life (0.045 mg/L). It can be due to runoff of phosphate containing fertilizers and pesticides in the agricultural fields. Dissolved oxygen is essential to all forms of aquatic life. It was found to be in the range of 4.0-7.54 mg/L. Standard deviation showed slight variation in DO, which was influenced by temperature, salinity, turbulence, biotic activity and contamination from fertilizers, suspended material, or petroleum waste. This is due to consumption of oxygen by microorganisms and algae. It must be noted that some of the sites show higher dissolved oxygen values than the permissible limit of PCB (5 mg/L) and seawater standard.

COD concentration in the water samples at different sampling sites was detected between the range of 2085 -12056 mg/L. This indicates higher concentration of organic matter than the seawater standard (300-500 mg/L) indicating huge amount of organic matter which can be caused by industrial wastewater and oil spillage. Mean value of sodium was found to be 5912 mg/L between the range of 5059 to 6754 mg/L. The standard deviation (465) showed moderate variation in concentration of sodium in the study area. These results show no sodium variation was detected in the study area against seawater standard (11000mg/L).

Calcium salts and calcium ions are among the most commonly occurring salts in nature. They can come from natural or man-made sources. Concentration of calcium in water was detected between the range of 721.44-2484 mg/L with mean level of 1337 mg/L. It can be attributed to hydrochemical processes like basaltic host rock weathering containing calcium and anthropogenic sources like domestic waste. Standard deviation also shows high variation in concentration of calcium in water samples. Mean value of magnesium was found to be 2897 between the range of 1849.57 to 3843.86 mg/L. The high concentration of magnesium against seawater standard (1300 mg/L) may be attributed to basaltic flows due to natural process in study area, seawater influx, industrial waste waters and fertilizers application.

Sodium Adsorption Ratio (SAR) is used to assess the relative concentrations of sodium, calcium, and magnesium in irrigation water and provide a useful indicator of its potential effects on soil structure and permeability. If water with excess sodium and low calcium and magnesium is applied frequently to clay soils, the sodium will tend to displace calcium and magnesium on clay particles, resulting in breakdown of the structure, precipitation of organic matter, and reduced permeability. SAR in different water samples was detected in the range of 18.14-23.54 with the mean level of 20.75 which is found to be less than the BIS permissible limit (26). Slight variation of SAR between different sampling sites can be attributed to variation of concentration in Na^+, Mg^{+2} and Ca^{+2} ion in water samples. Mean value of Oil & Grease was found to be 0.46 mg/L between the range of 0.04-1.66 mg/L. Standard deviation shows significant variation in the concentration of Oil &Grease in all the different sampling sites and is found to be higher than the permissible limit prescribed by PCB (0.1 mg/L) and this is mainly due to oil spill in the month of August.

The concentration of total petroleum hydrocarbon as gasoline range organic (GRO-TPH) and diesel range organic (DRO-TPH) in all the water samples was found to be lower than the detection limit of GC/FID instrument (0.5 ppm). Fig. 2 shows pie diagram of mean concentration (milliequivalentthe) of major cations and anions in water samples whose concentrations exceeded 50% of the total of measured anions and cations. Order of present cations in the surface water of study area were $Na^+ > Mg^{2+} > Ca^{2+}$ while anion were $Cl^- > No_3^- > Po_4^{3-}$.These observations indicate that the mangrove forest of study area is occupied by brackish to brine water. As can be seen from Fig. 3 the salinity of water from upstream toward downstream has been increased. To assess

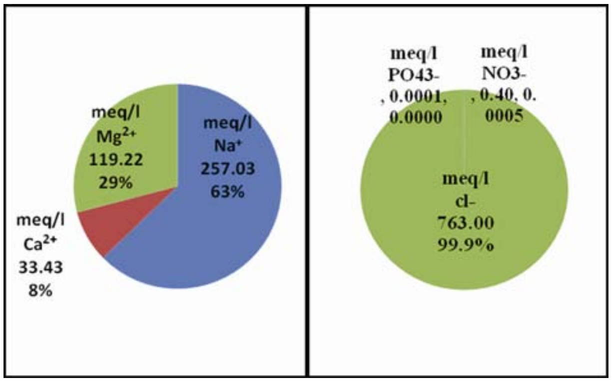

Fig.2—Pie diagram of mean value of major cations and anions in water of study area

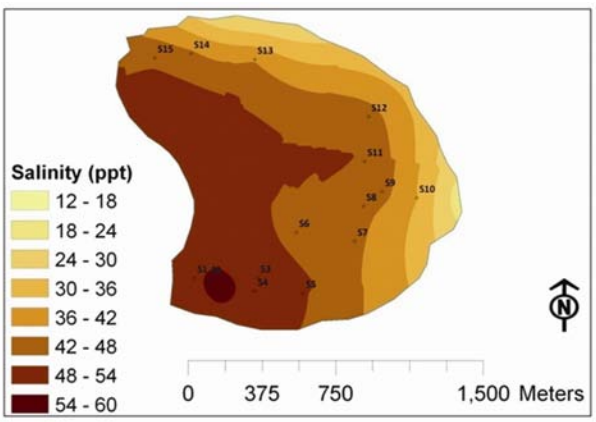

Fig.3—The Salinity variation map of Alibaug mangrove forest

water quality and recognize the factors or origins responsible for water quality variations, multivariate statistical technique such as principal component factor analysis and cluster analysis were used.

Cluster analysis is a collection of statistical methods which identifies groups of samples that behave similarly or show similar characteristics. Typically in clustering methods, all the samples within a cluster are considered to be equally belonging to the cluster. Clusters are characterized by high similarity within the cluster and high dissimilarity between the clusters. In this study cluster ward's linkage method was used and output is given in the form of dendrogram. To examine the similarity among the observations (sampling sites) Euclidean distance measure was carried out. Cluster observation with two major clusters, cluster 1 and cluster 2 is presented in Fig. 4, in which cluster 2 have two subdivisions, cluster 2a and 2b.It is observed that each cluster represents similar hydrochemical features. Samples belong to cluster 2b have the highest mean

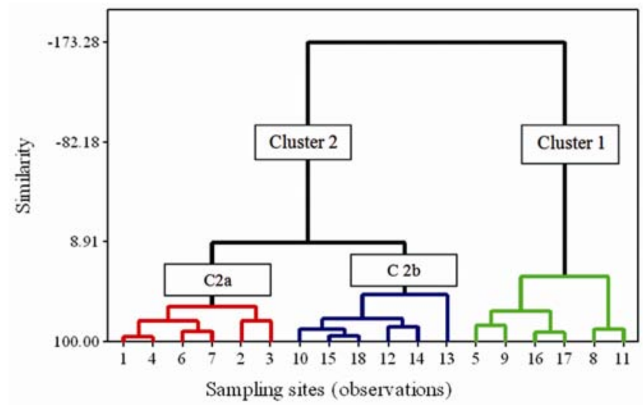

Fig.4—Dendrogram showing of cluster analyzes of sampling sites (observation)

value of each parameter followed by the cluster 1 and cluster 2a respectively. highest similarity between the extracted clusters is observed in the order of C2a;C2b> C1;C2b> C2a;C1.These observations show cluster analysis grouped eighteen sampling sites into three clusters of similar hydrochemical features and accordingly mangrove forest can be classified into three zones of low, moderate and high pollution.

Factor analysis usually proceeds in three steps which are, 1) computing of correlation matrix for all the variables(parameters), 2) extraction and rotation of factors, 3)interpretation of data. In order to examine more closely relationship between the physicochemical parameters and the factors which affect them, computing of correlation matrix between parameters as a first step of factor analysis was done. Correlation between physicochemical parameters of water were carried out using spearman correlation matrix which uses median values for description of non-normal distribution of parameters instead of mean values (Table. 2). Correlation matrix is a statistical method which measures the degree of linear relationship between two variables. The correlation coefficient assumes a value between -1 and +1. A high correlation coefficient means a good relationship between to variables, its value near zero means weak relationship, and zero means no relationship between them at significant level of 0.05. If one variable tends to increase as the other decreases, the correlation coefficient is negative. Conversely, if the two variables tend to increase together the correlation coefficient is positive. Variables showing $r > 0.7$ have strong correlation and between 0.5 and 0.7 have moderate correlation whereas $r < 0.5$ shows weak correlation.

An examination of Table. 2 reveals that there is a good correlation between pH and temperature. The energy at high temperature helps molecules of ions break apart. In the case of acids this produces more H^+ and in the case of bases this produces more OH^-. This results in acids becoming more acidic (lower pH) and bases becoming more basic (higher pH). Thus the results show positive relationship between temperature and pH. The matrix shows positive correlation between hardness and pH which is due to carbonate and bicarbonate ions present in alkaline water. A good correlation between EC with TDS, Na^+, hardness and PO_4^{3-} was observed which indicates EC is a measure of the dissolved solids in the water .Sodium is also one of the most important ions in electrical conductivity of water besides PO_4^{3-} and hardness creator ions such as Mg^{2+} and Ca^{2+}. TDS also shows good relationship with Cl^- and salinity, which indicates saline water, has more TDS than the fresh water. Salinity shows strong relationship with Cl^- and fairly good with Sodium absorption Ratio (SAR). The good correlation between Na^+ and SAR was observed as salinity occurs because of Cl^- and Na^+ ions. Sodium also shows relationship with PO_4^{3-}, it can be concluded that Na^+ and PO_4^{3-} originated from common source. A very strong relationship between hardness and Mg^{2+} was observed. A moderate relationship between SAR and TPH was also observed from which it can be deduced that organic matter is capable of changing the ratio of sodium absorption.

Since environmental data are highly complex and depend on unpredictable factors, which are usually characterized by their high variability[16] hence factor analysis was carried out to compare the compositional patterns between the water samples and respective loading factors of each variable along with the percentage of variance are presented in Table 3. Strong loading values are given in bold. The criterion to extraction factors to figure out source of variation in data set is eigenvalue which are the variances of extracted factors. Eigenvalues of 1 or greater are considered significant and the factors with the highest eigenvalues are the most significant. The sum of the eigenvalues is equal to the number of variables. Classification of factor loading (correlation between each factor and variable) is thus strong, moderate and weak, corresponding to absolute loading values of > 0.75, 0.75-0.50 and 0.50-0.30, respectively.

Table 2—Linear correlation of different physicochemical parameters of water samples collected from Alibaug mangrove forest and Akshi coastal area

Parameter	Temp	PH	EC	DO	COD	TDS	O&G	cl⁻	salinity	Na^+	Hardness	SAR	Ca^{2+}	Mg^{2+}	NO_3^-	TPH	PO_4^{3-}
Temp	1.																
PH	**0.7203**	1.															
EC	0.3653	0.3328	1.														
DO	-0.3653	0.082	0.1357	1.													
COD	-0.4696	-0.4298	-0.2095	0.2853	1.												
TDS	0.0733	0.1486	**0.5537**	0.2564	0.2998	1.											
O&G(TOG)	0.1558	0.0361	0.1873	-0.1419	-0.308	-0.1455	1.										
Cl^-	0.226	0.2559	0.4422	0.1491	0.3596	**0.6935**	-0.4252	1.									
salinity	0.226	0.2559	0.4422	0.1491	0.3596	**0.6935**	-0.4252	**1.**	1.								
Na^+	0.1352	0.0196	**0.7064**	0.0077	0.0697	0.4685	0.3111	0.2384	0.2384	1.							
Hardness	0.4959	**0.5862**	**0.5552**	-0.001	-0.4376	0.3065	0.2049	0.3829	0.3829	0.4608	1.						
SAR	-0.3865	-0.5552	0.2946	0.1367	0.403	0.2487	0.0918	-0.0841	-0.0841	**0.6316**	-0.3277	1.					
Ca^{2+}	-0.0609	0.2807	0.2436	0.4278	0.2116	0.3896	-0.3019	0.4123	0.4123	0.0588	-0.032	0.0439	1.				
Mg^{2+}	0.4376	0.3173	0.4489	-0.1646	-0.3622	0.2018	0.436	0.1925	0.1925	0.533	0.872	-0.178	-0.4211	1.			
NO_3^-	0.2239	-0.21	0.1517	-0.3019	0.1063	0.2049	-0.2998	0.1945	0.1945	0.3019	0.0526	0.3338	-0.3612	0.1517	1.		
TPH	0.0955	0.0547	0.2028	0.3344	**0.5186**	0.1858	0.4097	0.129	0.129	0.354	0.1027	**0.5377**	0.2152	0.2214	0.3142	1.	
PO_4^{3-}	0.2337	0.0691	**0.6971**	-0.1811	0.0604	**0.6821**	0.2714	0.3674	0.3674	**0.6388**	0.404	0.3313	-0.0134	0.436	0.3338	0.3075	1.

*** Good correlation is presented in bold.**

Table 3—Multivariate factor analysis score for physicochemical parameter of study area

Variable	Factor1	Factor2	Factor3	Factor4	Communalities
temperature (T)	0.213	**-0.775**	-0.017	-0.249	0.709
PH	0.248	**-0.810**	-0.049	0.376	0.861
DO(mg/l)	-0.063	0.057	-0.187	0.679	0.504
EC	**0.756**	-0.240	-0.003	0.158	0.654
COD(mg/l)	0.031	0.605	-0.558	0.371	0.816
TDS(g/l)	0.659	0.028	-0.367	0.400	0.729
O&G(mg/l)	0.405	-0.098	0.644	0.026	0.589
cl(ppt)	0.236	-0.247	**-0.765**	0.319	0.804
salinity(ppt)	0.236	-0.247	**-0.765**	0.319	0.804
Na(mg/l)	**0.924**	0.180	0.012	0.058	0.889
hardness	0.714	-0.607	0.032	0.082	0.885
SAR	0.358	**0.821**	0.005	-0.005	0.802
Ca(mg/l)	0.191	-0.118	-0.034	**0.846**	0.767
Mg (mg/l)	0.607	-0.539	0.049	-0.360	0.792
TPH(mg/l)	0.068	-0.695	-0.262	0.194	0.593
N03(mg/l)	0.288	0.049	-0.708	-0.507	0.843
po4-(mg/l)	**0.815**	-0.015	-0.309	-0.213	0.805
Percentage of variance	23.8	21.6	16.1	14.0	
commutative % of variance	23.8	45.4	61.5	75.5	
Parameters with strong positive factor loadings			Parameters with strong negative factor loadings		
EC, Na, PO_4, SAR, Ca			T, pH, Salinity, Cl		

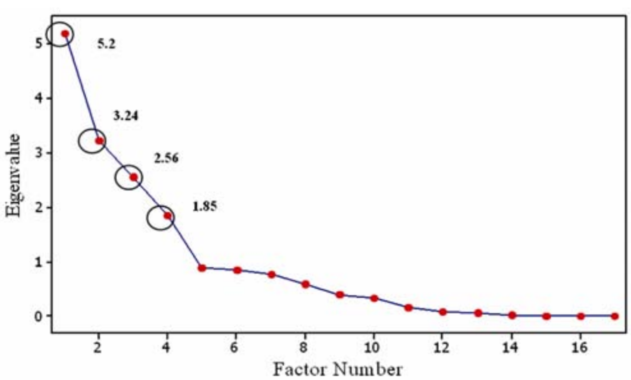

Fig.5—Scree plot of factor analysis after varimax rotation

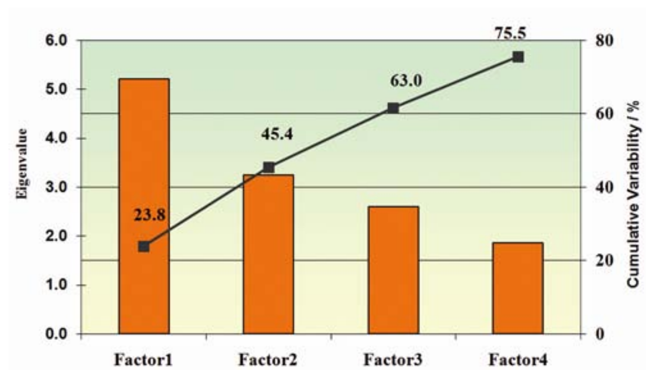

Fig.6—Relationship between Eigenvalue and cumulative variability of the extracted factors

Each water quality parameter with a strong correlation coefficient value (r > 0.75) was considered to be a significant parameter contributing to variations of the water quality in mangrove forest of Alibaug. The Scree plot, as shown in Fig. 5 has worked out to clarify the method of extraction of different factors. The examination of the Scree plot provides a visual of the total variance associated with each factor. The steep slope shows the first four factors have eigenvalue greater than 1 and rest of the factors have lower than an Eigenvalue of 1.

According to this method, only the factors with eigenvalues greater than 1 can be retained. Factor analysis was actually performed between the different seventeen parameters following Varimax rotation and the same has been used to examine their inter relationship. Varimax rotation attempts to minimize the number of variables that have high loadings on a factor. This enhances the interpretability of the factors. Relationship between eigenvalue and cumulative variability of the extracted factors are shown in Fig.6. In this figure four factors were identified with 75.5% of total variance, which was sufficient to describe the data structure.

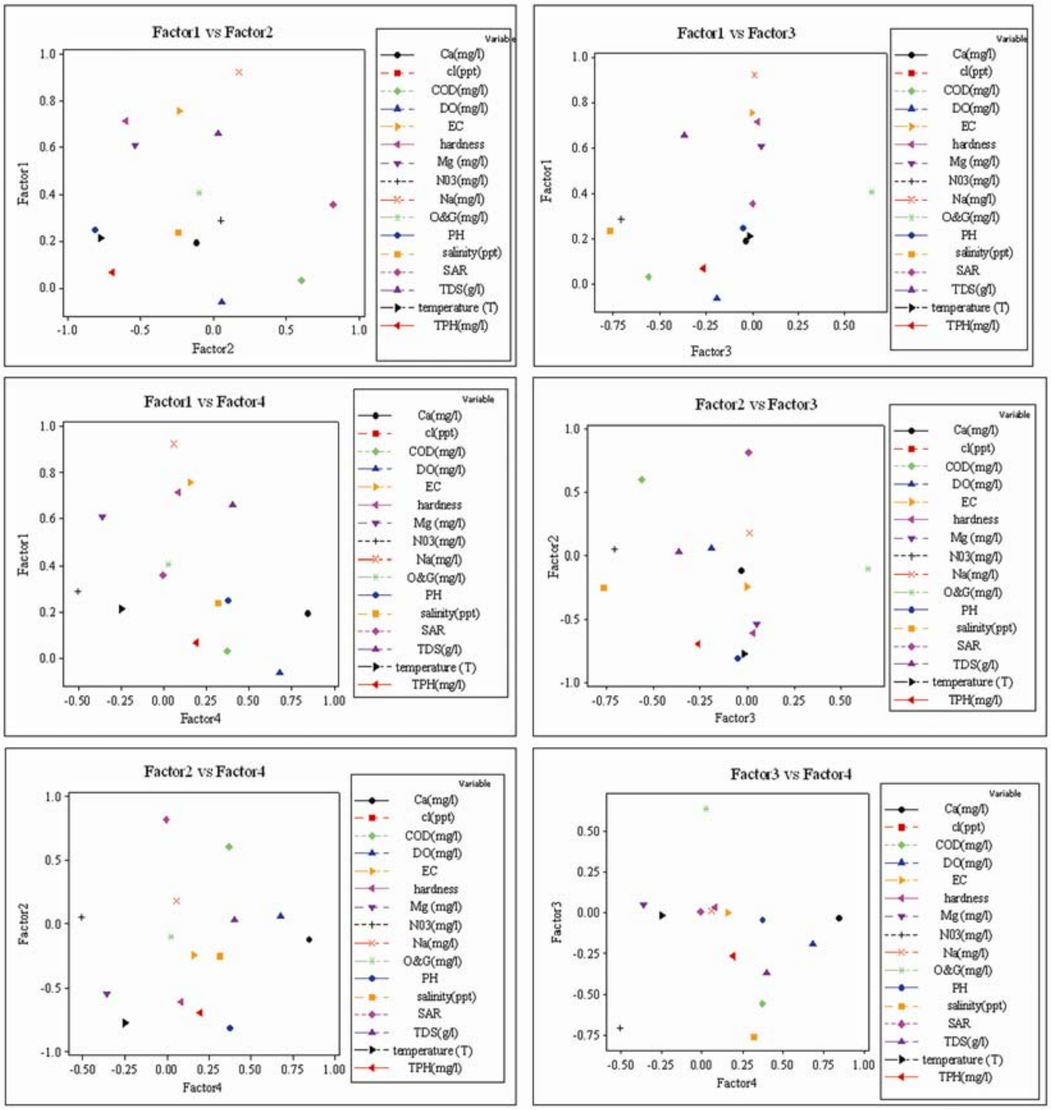

Fig.7—Scatter plot of parameters and extracted factors

Interpretation of Data

According to factor analysis the most significant parameters contributing to water quality variation are: EC, Na^+, PO_4^{3-} , SAR, Ca^{2+}, temperature, salinity and Cl^-. Factor 1 accounts 23.8% of total variance with the high loading for EC, Na^+ and PO_4^{3-} it means that considerable amount of inorganic nutrients due to anthropogenic sources like runoff from agricultural fields as well as seawater influx. Factor 2 with strong and negative factor loadings for pH and temperature and positive for SAR besides moderately for COD accounts 21.6% of total variance which may be attributed to huge amount of organic matter due to industrial wastewater and oil spillage. Factor 3 accounts 16.1% variance in the data with variable like Cl^- and salinity. This factor can be ascribed to decreased freshwater flow rate and seasonal rainfall. Factor 4 accounts for 14.0% of variance in the data that shows strong positive loading for Ca^{2+} and, moderate and negative for DO can be ascribed to domestic sewage and basaltic host rock weathering. The scatter plot of parameters and extracted factors are given in Fig. 7.

Conclusions

Hydrochemical study of Alibaug mangrove forest indicated the surface water of study area is brackish to brine water. Order of abundance of major cations in surface water of the study area is

$Na^{+}>Mg^{2+}>Ca^{2+}$ while that of anions is $Cl^{-}>NO_3^{-}>PO_4^{3-}$. Correlation analysis of physicochemical parameters of surface water showed good correlation between temperature and pH, EC with TDS, Na+, hardness and PO_4^{3-}. TDS showed good relationship with Cl^{-} and salinity which shows saline water has more TDS than fresh water. Salinity showed strong relationship with chloride and SAR, beside SAR with sodium which indicates the high salinity in the study area is due to high concentration of Na^{+} and Cl^{-} ions. Good relationship between Na^{+} and PO_4^{3-}indicates that they are originated from common source. Cluster analysis grouped eighteen sampling sites into three clusters of similar hydrochemical features and classified mangrove forest to low(eastern part), moderate(southern part) and high(northern part) pollution zones. Factor analysis revealed that the most significant parameters contributing to water quality variation are: EC, Na^{+}, PO_4^{3-}, SAR, Ca^{2+}, temperature, salinity and Cl^{-}. According to factor analysis different natural and anthropogenic sources affect the water quality of study area viz. weathering and seasonal variation, agriculture runoff, domestic and industrial sewage disposal and oil from spill.

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