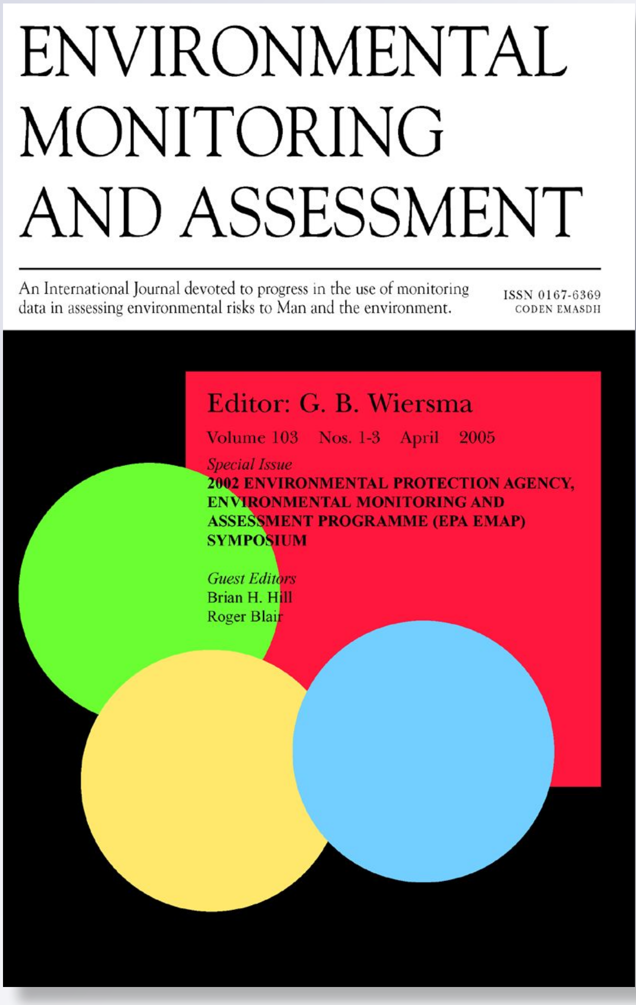
Identification of mangrove water quality by multivariate statistical analysis methods in Pondicherry coast, India

P. Satheeshkumar & Anisa B. Khan

Environmental Monitoring and Assessment
An International Journal Devoted to Progress in the Use of Monitoring Data in Assessing Environmental Risks to Man and the Environment

ISSN 0167-6369

Environ Monit Assess
DOI 10.1007/s10661-011-2222-4



Springer

Environ Monit Assess
DOI 10.1007/s10661-011-2222-4

Identification of mangrove water quality by multivariate statistical analysis methods in Pondicherry coast, India

P. Satheeshkumar · Anisa B. Khan

Received: 15 November 2010 / Accepted: 30 June 2011

Abstract Different multivariate statistical analysis such as, cluster analysis, principal component analysis, and multidimensional scale plot were employed to evaluate the trophic status of water quality for four monitoring stations. The present study was carried out to determine the physicochemical parameters of water and sediment characteristics of Pondicherry mangroves—southeast coast of India, during September 2008–December 2010. Seasonal variations of different parameters investigated were as follows: salinity (10.26–35.20 psu), dissolved oxygen (3.71–5.33 mg/L), pH (7.05–8.36), electrical conductivity (26.41–41.33 ms^{-1}), sulfide (1.98–40.43 mg/L), sediment texture sand (39.54–87.31%), silt (9.89–32.97%), clay (3.06–31.20%), and organic matter (0.94–4.64%). pH, temperature, salinity, sand, silt, clay, and organic matter indicated a correlation at $P<0.01$. CA grouped the four seasons in to four groups (pre-monsoon, monsoon, post-monsoon, summer) and the sampling sites in to three groups. PCA identified the spatial and temporal characteristics of trophic stations and showed that the water quality was worse in stations 3 and 4 in the Pondicherry mangroves.

Keywords Mangrove · Sediment · Water · Multivariate analysis · Physicochemical parameters · Pondicherry

P. Satheeshkumar · A. B. Khan
Department of Ecology and Environmental Sciences,
Pondicherry University,
Puducherry 605014, India

P. Satheeshkumar (✉)
Central Marine Fisheries Research Institute,
Kochi, Kerala 682018, India
e-mail: indianscientsathish@gmail.com

Introduction

Coastal water has become a major concern because of its values for socioeconomic development and human health. With the growth of human populations and commercial industries, marine water has received large amounts of pollution from a variety of sources such as recreation, fish culture, toilet flushing, and the assimilation and transport of pollution effluents (Zhou et al. 2007). Human activities have already negatively influenced water quality and aquatic ecosystem functions. This situation has generated great pressure on these ecosystems, resulting in a decrease of water quality and biodiversity, loss of critical habitats, and an overall decrease in the quality of life of local inhabitants (Herrera-Silveira and Morales-Ojeda 2009). It is therefore essential to prevent and control marine water pollution and to implement regular monitoring programs, which help us to understand the temporal and spatial variations in marine water quality (Simeonov et al. 2003; Singh et al. 2004) and diagnose the present condition of coastal water quality. Good quality of water resources depends on a large number of physicochemical parameters and the magnitude and source of any

Published online: 15 July 2011

pollution load and to assess that monitoring of these parameters is essential (Rajasegar 2003). Assessment of water resource quality of any region is an important aspect of developmental activities of the region because rivers, lakes, and manmade reservoirs are used for water supply to domestic, industrial, agricultural, and fish culture (Saravanakumar et al. 2008). Coastal water quality changes with time and space, and continuous water quality measurements and analyses are necessary for effective water quality management along the Pondicherry Coast.

Mangrove forests are one among the world's most productive tropical ecosystems. Mangrove ecosystem in Pondicherry is dynamic, fragile with the plant, and environmental factors interconnect the process of energy fixation, accumulation of biomass, decomposition of dead organic matter, and nutrient cycling. Mangrove ecosystem provides an ideal nursery and breeding ground to most of the marine and brachish-water fish and shell fish (Saravanakumar et al. 2008). These productive marine ecosystems are important habitats for many fish and other marine organisms that are not only a significant source of food for human consumption, but are also vital components of marine ecosystems (Bierman et al. 2009). Environmental conditions such as salinity, oxygen, temperature, and nutrients influence the composition, distribution, and growth of its biota (Ajithkumar et al. 2006).The regular and periodic changes in the climate synchronized with season are ultimately reflected in the environmental parameters also, which in turn have a direct or indirect influence over the planktonic population. The seasonal distribution, abiotic, and biotic processes affect the nutrient cycle of different coastal environments (Ananthan et al. 2005; Ajithkumar et al. 2006; Saravanakumar et al. 2008). Hydrogen sulfide is a major pollutant of the water bodies; the blackening of sediment in the polluted area was due to the local chemical reaction where sulfates get converted to sulfides (Hynes 1966). Total organic carbon of sediment has a major role in keeping fertility of soil and thereby flourishing the biological activity (Sunil Kumar 1996).

Sediments are indicators of quality of overlying water and its study is a useful tool in the assessment of environmental pollution status (Anilakumary et al. 2007). Pondicherry coastal area is polluted due to the discharge of industrial, domestic, and agricultural wastes through small tributaries and channels in to the Bay of Bengal. There are several major and small industries located in the vicinity of the study area, discharging their effluents continuously into these estuaries and coastal environments.

In recent years, multivariate statistical techniques are the appropriate tool for a meaningful data reduction and interpretation. The multivariate statistical techniques such as cluster analysis (CA), non-multidimensional scale plot (MDS) and principal component analysis (PCA) have widely been used as unbiased methods in analysis of water quality data for drawing meaningful conclusions (Simeonov et al. 2003; Singh et al. 2004; Sundaray et al. 2006; Wang et al. 2006). The multivariate analysis is widely used to characterize and evaluate the river water quality and it is useful for evidencing variations caused by natural and anthropogenic processes (Quadir et al. 2007). CA is an unsupervised pattern recognition method that groups objects into classes (clusters) such that objects within a class are similar to each other but different from those in other classes (Wang et al. 2006). PCA and CA find groups and sets of variables with similar properties, thus potentially allowing us to simplify our description of observations by finding the structure or patterns in the presence of chaotic or confusing data (Ragno et al. 2007). In this study, statistical analysis methods (CA, PCA, and MDS) were employed to evaluate the trophic status of water quality on Pondicherry mangroves, southeast coast of India. Cluster analysis was used to identify similar groups of temporal and spatial variations of water quality; the temporal and spatial patterns of trophic status were also determined by principal component analysis.

Materials and methods

Study site

The mangrove forest at Pondicherry (latitude, 11°46′03″ to 11°53′40″ N; longitude 79°49′45″ to 79°48′00″ E) is located along the southeast coast of India (Fig. 1). It is one of the typical mangrove swamps of Ariyankuppam estuarine complex, covering an area of 168 ha distributed along the sides of Ariankuppam estuary, which is seasonally bar-built and semidiurnal type that flows eastwards and empties into the Bay of Bengal at Veerampatinam on southeast coast of India. Along its exposed banks and on its upper reaches, it is fringed with mangrove trees covering an area of approximately

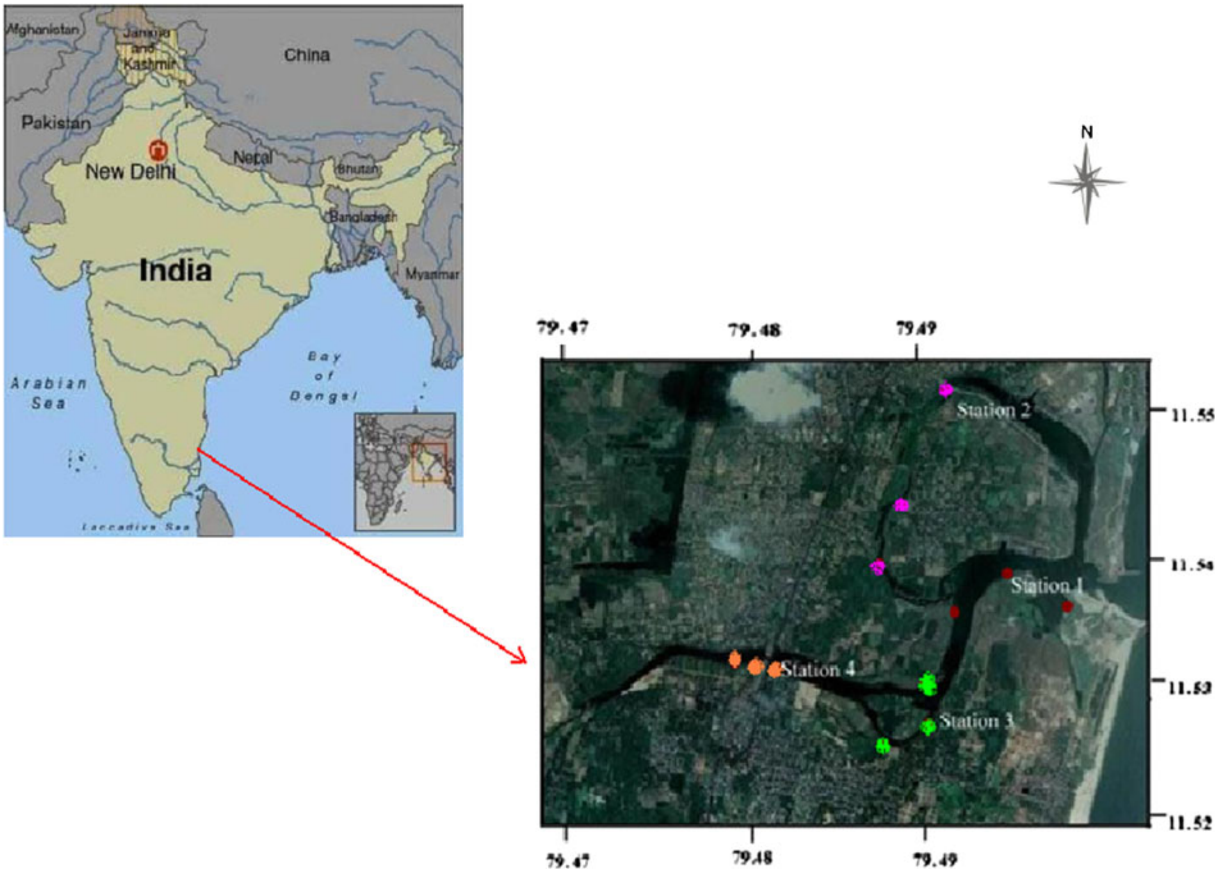


Fig. 1 Monitoring stations in Pondicherry mangroves, India

30 ha. The channels in the mangroves are lined by a luxuriant vegetation of small salt marsh plants, trees, shrubs, and thickets totaling about seven true mangrove species and 16 associate plants belonging to 12 floral families. Four different sampling sites were chosen with 2-km distance between the two stations: station 1, receive neritic waters from the adjacent Bay of Bengal at the mouth of Veerampattinam; station 2, Thengaithittu is located in the interior area and characterized by brackish water; station 3, Ariyankuppam is located 4 km south of Pondicherry harbor that receives water carrying wastes from adjacent agriculture lands and industries in addition to domestic municipal and distillery effluents; station 4, Murungapakkam is located in the interior area; banks of the waterway in this area are lined by dense mangrove vegetation. The details on GPS coordinates, zone, and soil substratum are presented in Table 1. The tides are semidiurnal and vary in amplitude from 15 to 100 cm in different regions during different seasons, reaching a maximum during monsoon and post-monsoon and a minimum during summer. The rise and fall of the tidal waters are through a direct connection with the sea at Veerampattinam mouth and also through the adjacent estuaries.

Table 1 Details on GPS coordinates, mangrove zone, and soil substratum

Study area	Mangrove zone	Latitude	Longitude	Substratum
Station 1	*Avicennia* zone	11°0.90′450″ N	79°0.82′563″ E	Sand
Station 2	*Rhizophora zone*	11°0.90′703″ N	79°0.81′851″ E	Sandy and silt
Station 3	*Acanthus* zone	11°0.90′107″ N	79°0.80′547″ E	Silt and clay
Station 4	*Rhizophora* and *Acicennia* zone	11°0.90′154″ N	79°0.80′571″ E	Clay

Sampling and analytical methods

Annual rainfall, temperature, and relative humidity data was obtained from Regional Meteorological Department at Chennai. Water and sediment samples from the surface and bottom levels were collected from four stations in Pondoicherry mangrove region (Fig. 1). Samples were collected every month for 2 years during September 2008–December 2010. Triplicate water samples at each station were collected in a plastic container, sediments by the Vanveen grab. The surface water temperature was measured using a standard mercury-filled thermometer. Salinity by hand-held refractometer (Erma), water pH (hand held pH meter, pH scan-2), electrical conductivity (EC) was measured using EC instruments. Dissolved oxygen (DO) was estimated by Winkler's method and sulfide estimated by Strickland and Parsons (1972), sediment texture was determined by pipette analysis method (Krumbein and Pettijohn 1983) and total organic matter of sediment was determined by wet oxidation method (El Wakeel and Riley 1957).

Statistical analysis

Coefficient of correlation (*r*) was worked out to understand the relationship between the various parameters and to test the significance of the models. It was considered to be not significant when the value of the probability of significance (*p*) was greater than 0.05. Means and standard deviations were calculated for each parameter. All these statistical analyses were performed using SPSS statistical (Version 13 for Windows XP, SPSS, and Chicago, IL, USA).

Multivariate statistical methods

Several analytical techniques are available to extract spatial and temporal patterns and trends in order to provide enhanced understanding and resolve the full information hidden within water quality data. These techniques can be used to identify regions or periods of time with different water quality characteristics, determine whether significant differences in water quality occur between different regions, and also to indicate the variables responsible for water quality variations (Bierman et al. 2009). Various multivariate statistical methods including PCA, MDS, and CA was analyzed using PAST (statistical Version 1.93 for Windows XP).

Cluster analysis

CA is a group of multivariate techniques whose primary purpose is to assemble objects based on the characteristics they possess. CA classifies objects, so that each object is similar to the others in the cluster with respect to a predetermined selection criterion (Iscen et al. 2008; Shrestha and Kazama 2007). Hierarchical agglomerative clustering is the most common approach, which provides intuitive similarity relationships between any one sample and the entire data set, and is typically illustrated by a dendrogram (tree diagram). Cluster analysis is to make objectives into groups based on the similarities inside of the group and dissimilarities of different groups. The groups are divided by their unique characteristics, and often, it helps interpreting the data (Vega et al. 1998). Many studies have shown that CA reliably classifies surface water quality and can guide future sampling strategies (Simeonov et al. 2003; Singh et al. 2004; Wunderlin et al. 2001). In this study, hierarchial agglomerative CA was performed on the normalized data set by means of the wards method, using squared Euclidean distances as a measure similarity (Simeonov et al. 2003; Shrestha and Kazama 2007).

Principal component analysis

PCA is a powerful pattern recognition tool that attempts to explain the variance of a large dataset of intercorrelated variables with a smaller set of independent variables (Simeonov et al. 2003). PCA technique extracts the eigenvalues and eigenvectors from the covariance matrix of original variables. PCA is designed to transform the original variables into new, uncorrelated variables (axes), called the principal components, which are linear combinations of the original variables. The new axes lie along the directions of maximum variance (Shrestha and Kazama 2007). It reduces the dimensionality of the data set by explaining the correlation amongst a large number of variables in terms of a smaller number of underlying factors, without losing much information (Vega et al. 1998; Alberto et al. 2001). The PCA can be expressed as

$$Z_{ij} = \mathrm{pc}_{i1}x_{1j} + \mathrm{pc}_{i2}x_{2j} + \ldots \mathrm{pc}_{im}x_{mj}$$

Where z is the component score, pc is the component loading, x is the measured value of the variable, i is the component number, j is the sample number, and m is the total number of variables.

Non-multidimensional scale plot

MDS is a set of related statistical techniques often used in information visualization for exploring similarities or dissimilarities in data. Ordination plots produced by MDS analyses were used to classify cases into categorical dependent values. One of its objectives is to determine the significance of different variables, which can allow the separation of two or more naturally occurring groups. Non-multidimensional scale plot is proposed for assessing environmental water quality in aquatic ecosystems (Michael Karydis 1992).

Data treatment

Most of the multivariate statistical methods require variables to confirm the normal distribution, thus, the normality of the distribution of each variable was checked by analyzing kurtosis and skewness statistical tests before multivariate statistical analysis is conducted (Lattin et al. 2003). The original data demonstrated values of kurtosis ranging from −1.33 to 11.75 and skewness values ranging −1.62 to 3.10, indicating that the data were far from normal distribution. Since most of values of kurtosis and skewness were >0, the raw data of all variables were transformed in the form $x'=\log 10(x)$. After transformation, the kurtosis and skewness values ranged from −2.084 to 3.12 and – 2.01 to 1.76, respectively, indicating that all the data were in normal distribution or close to normal distribution. In the case of CA, PCA, and MDS, all log-transformed variables were also z-scale standardized to minimize the effects of difference units and variance of variables and to render the data dimensionless (Singh et al. 2004).

Results and discussion

Physicochemical parameters of water

Monthly rainfall ranged between 0.0 and 808 mm in November 2008 due to Nisha storm. Rainfall being the important cyclic phenomenon in tropical countries brings vital changes in the hydrological characteristics of coastal marine environments. In India, the rainfall is largely influenced by two monsoons, viz the southwest monsoon on the west coast, northern, and northeastern India; and the northeast monsoon on the southeast coast (Paramasivam and Kannan 2005). Relative humidity of atmosphere varied from 37% to 100%, with monsoon season (Oct–Dec) with high relative humidity and summer season had lower range. Atmospheric temperatures ranged between 17.9°C and 41.7°C and surface water temperatures in the study area varied from 19.56 to 35.85°C, respectively, with maximum during summer and minimum during monsoon (Fig. 2). Water temperature during November was low because of strong land breeze and precipitation but the high temperatures during summer could be attributed to high solar radiation (Ashok Prabu et al. 2008).

In all the study stations, a bimodal pattern in salinity with maximum in summer (35.20 psu) at station 1 and minimum in early pre-monsoon and post-monsoon (21.33–29.95 psu) has been found that is consistent with the seasonal rainfall distribution (Fig. 3). The lowest salinity values were observed in the entire basin in the monsoon season (10.26–17.13 psu), where the high variability, especially towards lower values, was related to strong rainfall events that enhanced towards the estuary mouth entrance, instead, the mixing with the open sea leading to an evident salinity increases (33.3–

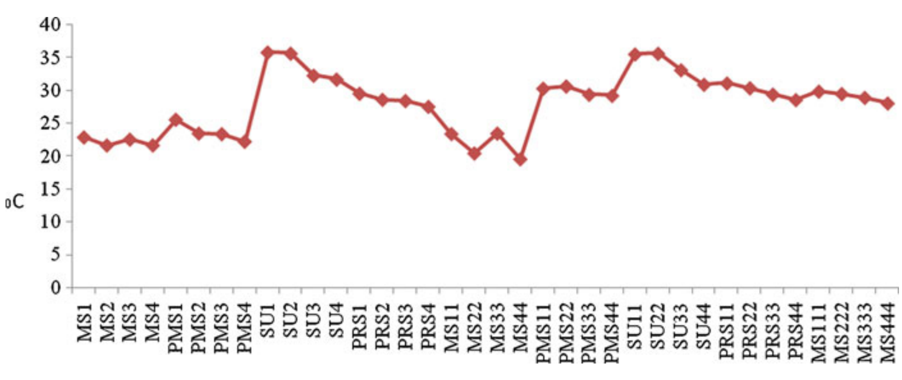


Fig. 2 Seasonal variation of water temperature at four stations

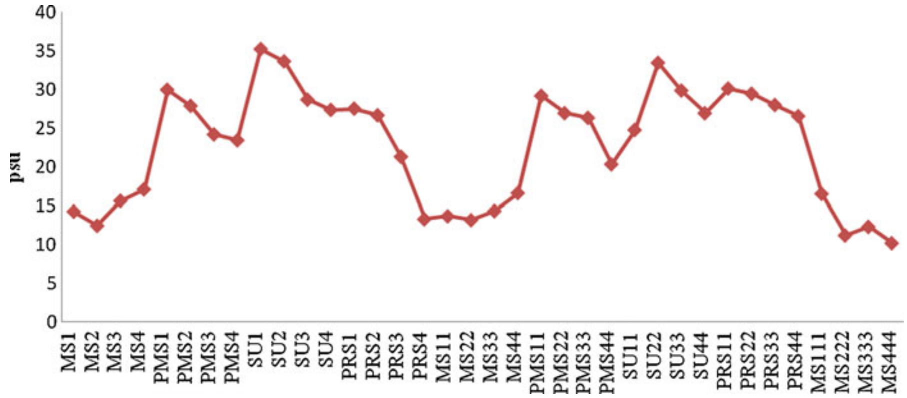


Fig. 3 Seasonal variation of salinity at four stations

35.20 psu) and decrease in variability. Table 2 shows the correlation matrix between the physicochemical parameters of water and sediment characteristics. The significant positive correlation obtained between salinity and air temperature indicates that salinity is largely influenced by the temperature. The salinity is a limiting factor in the distribution of living organisms and its changes because the dilution and evaporation act most likely on the fauna in the coastal ecosystem (Paramasivam and Kannan 2005). Thus the variations in salinity in the study sites were mainly influenced by the rainfall and entry of freshwater as reported earlier for Gulf of Kachchh by Saravanakumar et al. (2008) and for Godavari estuary by Raut et al. (2005).

The pH varied from 7.05 to 8.36 (Fig. 4), pH in surface waters remained alkaline throughout the study period at all four stations with maximum during summer and minimum during monsoon. The low pH observed during the monsoon season is attributable to some factors such as the removal of CO_2 by photosynthesis through bicarbonate degradation, the dilution of seawater by the freshwater influx, the decrease of the salinity and temperature, and the decomposition of organic material (Rajasegar 2003). The high pH values recorded during summer might be due to the influence of seawater penetration and high biological activity (Saravanakumar et al. 2008).

Dissolved oxygen concentrations ranged from 3.71 to 5.33 mg/L, the higher values were reached in monsoon (5.16 mg/L) in station 1 and lowest values were observed in the inner most station 3 (3.71 mg/L) during summer Fig. 5. The negative correlation between sulfide and salinity evidences that rainfall triggers the supply of discharge sewage rich in organic matter and poor in oxygen content into the mangrove stations. There was a slightly decrease of

Table 2 Correlation coefficient between the physicochemical characteristics of water and sediment characteristics of Pondicherry mangroves

	Salinity	pH	DO	Temperature	EC	Sulfide	OM	Sand	Silt	Clay
Salinity	1									
pH	0.796**	1								
DO	−0.411*	−0.148	1							
Temperature	0.636**	0.601**	−0.372*	1						
EC	0.622**	0.344*	−0.336	0.32	1					
Sulfide	−0.039	−0.39	−0.665**	−0.02	0.15	1				
OM	−0.071	−0.38	−0.277	−0.02	0.19	0.525**	1			
Sand	0.180	0.236	0.461**	0.187	−0.06	−0.42**	−0.198	1		
Silt	−0.268	−0.322	−0.148	−0.26	−0.04	0.419*	0.0988	−0.767**	1	
Clay	−0.079	−0.11	−0.436**	−0.07	0.092	0.218	0.1457	−0.756**	0.165	1

DO dissolved oxygen, *EC* electrical conductivity *OM* organic matter

**P=0.01, **P=0.05, level of significant of correlation (two tailed)

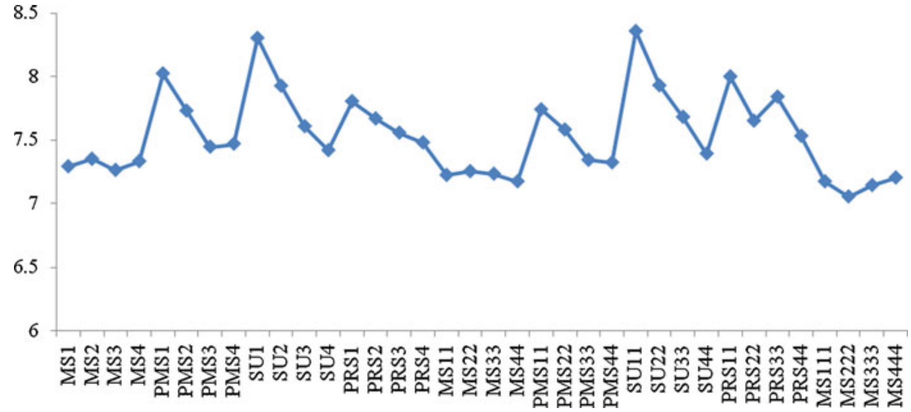


Fig. 4 Seasonal variation of pH at four stations

DO from station 3 and 4; they have cited limited mixing, high organic production, sinking and decomposition of large amount of OM as the reason for the oxygen depletion. The inverse relationship between temperature and DO is a natural process because warm water easily becomes saturated with oxygen and thus can hold less DO (Wu et al. 2009).

EC at the four stations varied from 29.41 to 41.33 ms^{-1}. The highest EC values were observed during post-monsoon (41.33 ms^{-1}) at station 1 Fig. 6. Relatively lower values were observed in monsoon season (30.60 ms^{-1}) at station 2. Electrical conductivity (EC of the saturation extract) was considerably higher at disturbed sites in Andaman mangroves (33.8–41.5 dS m^{-1}), indicating accumulation of salts (Ghoshal Chaudhuri et al. 2009). Seasonal mean fluctuations of sulfide concentrations varied from 4.03 to 40.43 mg/L, respectively, sulfide level were high (40.43 mg/l) during pre-monsoon at station 4 and relatively low values were in summer (4.03 mg/L) at station 1 Fig. 7. Significant negative correlation ($r=-0.665$; $P<0.01$) obtained between sulfide and DO indicates that the DO is largely influenced by the sulfide at this station. In this present study, higher sulfide level occur at station 3 and 4 because there are several major and small industries discharging their effluents continuously into these stations. Moreover, the piercing smell of H_2S from deeper sediments was precisely observed during field study. The sulfide biome in the retting zone is quite extensive from the surface waters down to the bottom and deeper into the sediment layers. Although the surface water becomes enriched with oxygen during monsoon, the deeper layers continue to be of anoxic sulfide biome. In Kayamkulam estuary, Cochin, a peak value of 0.92 µg H_2S g^{-1} in soil was reported at the presence of large quantities of hydrogen sulfide (Gopakumar and Kuttyamma 1999).

Mangrove sediment characteristics

The substratum was mainly composed of sand with an admixture of silt and clay. The sand fraction ranged between (39.54–87.31%) silt (9.89–32.97%), clay (3.06–31.20%), and organic matter (0.94–4.64%), Fig. 8. Seasonally, station 1 recorded higher fractions

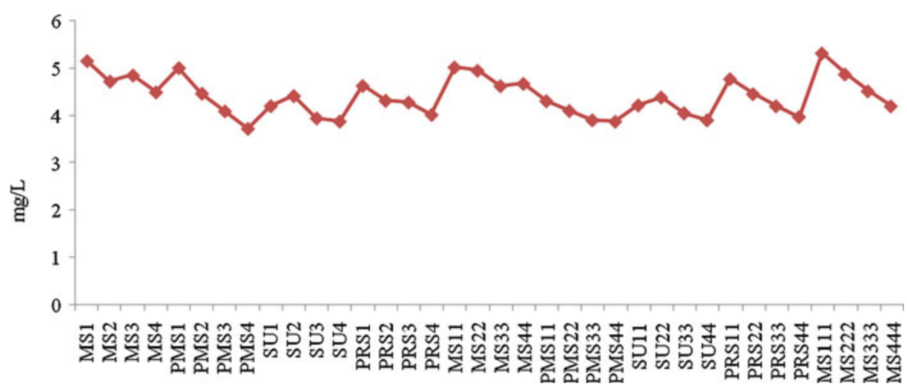


Fig. 5 Seasonal variation of dissolved oxygen at four stations

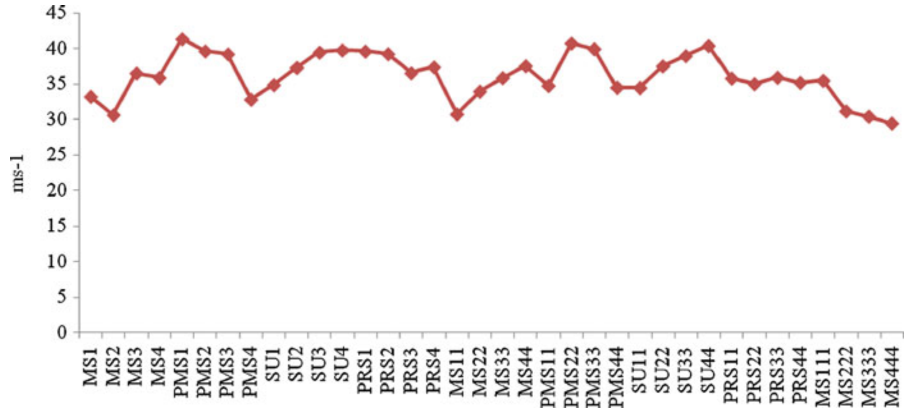


Fig. 6 Seasonal variation of electrical conductivity at four stations

of sand during monsoon and summer, silt content during post-monsoon and pre-monsoon period and clay during summer season. Such differed combinations of sediment observed are mainly due to the transport of sediments from one place to another and back associated with the tidal currents. Soil texture sand, silt, and clay was showed significant negative correlations at $P<0.01$. In general, sand is dominating in the upper estuarine region, i.e., at station 1; whereas silt, clay, and OM are mostly enriched in the lower part of the estuary. OM shows the strong positive correlation with sulfide ($r=0.525$; $P<0.01$), organic matter distribution is associated with estuary and hydrodynamic factors, and its levels explain the black color and H_2S odor of the sediments. This observation on sediment layers is corroborating with that observed at estuarine mangrove biotope of Cochin (Kumar 1997). It is well known that macrobenthic communities in marine environment are influenced by the texture of the sediment in which they establish themselves and live (Manjappa et al. 2003). High concentration of pollutants in river water resulting from municipal sewage and industrial effluents represent a major threat to the aquatic environment (Singh et al. 2005).

Multivariate statistical analysis

CA was used to detect similar groups between the sampling sites in four seasons. CA calculated the physicochemical parameters of water and sediment characteristics for all the four stations and the result were depicted (Fig. 9). CA generated a dendrogram grouping of the sampling sites in to three groups. Group A included MS1–MS4, MS11–MS44, MS111–MS444 (most of the sampling sites in monsoon from 2008 ro 2010). Group B further separated as two groups such as group B1 and group B2. Group B1 included SU22, SU44, SU4, PRS1, PRS2, PRS22, PRS44, PMS3, PMS22 (most of the sampling sites in pre-monsoon) and Group B2 included PRS11, PRS33, SU1, SU11, SU2, SU3, SU33, PMS1, PMS11, PMS2 (most of the sampling sites in summer). Group C included PMS33, PMS4, PMS44,

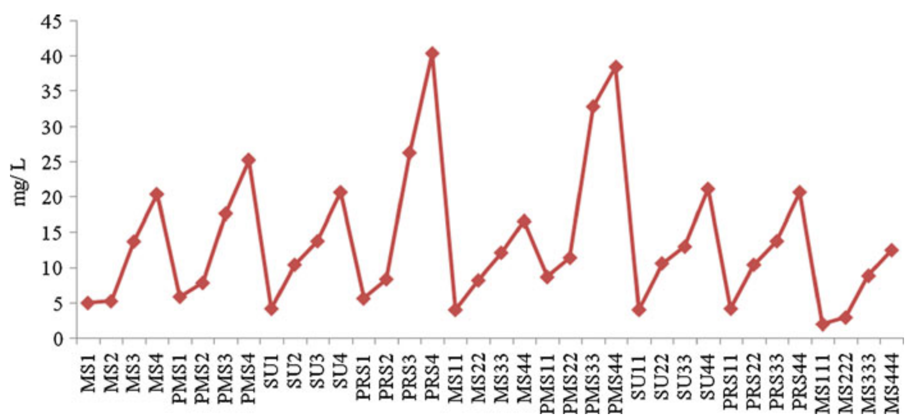


Fig. 7 Seasonal variation of sulfide at four stations

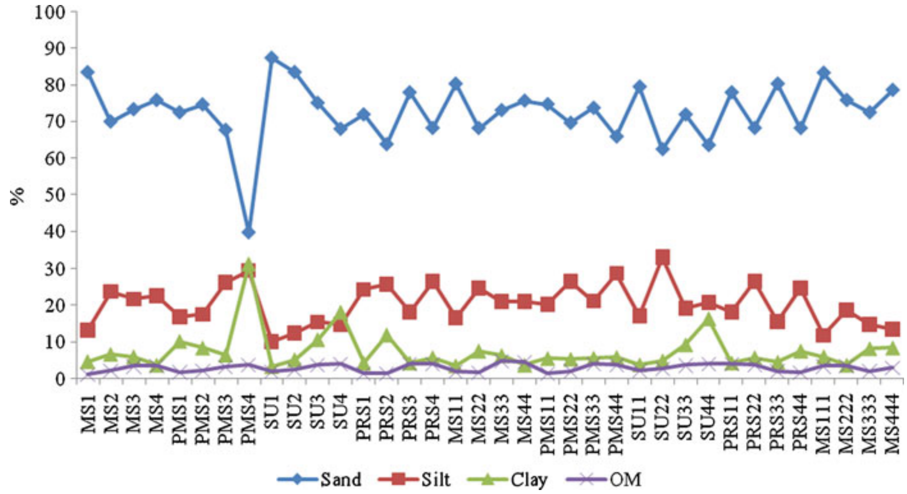


Fig. 8 Seasonal variation of sediment characteristics at four stations

PRS4, PRS3 (most of the sampling sites in post-monsoon). The concentrations of sulfide and OM in group C (pre-monsoon) were higher than those in other groups (other seasons), which correspond to a

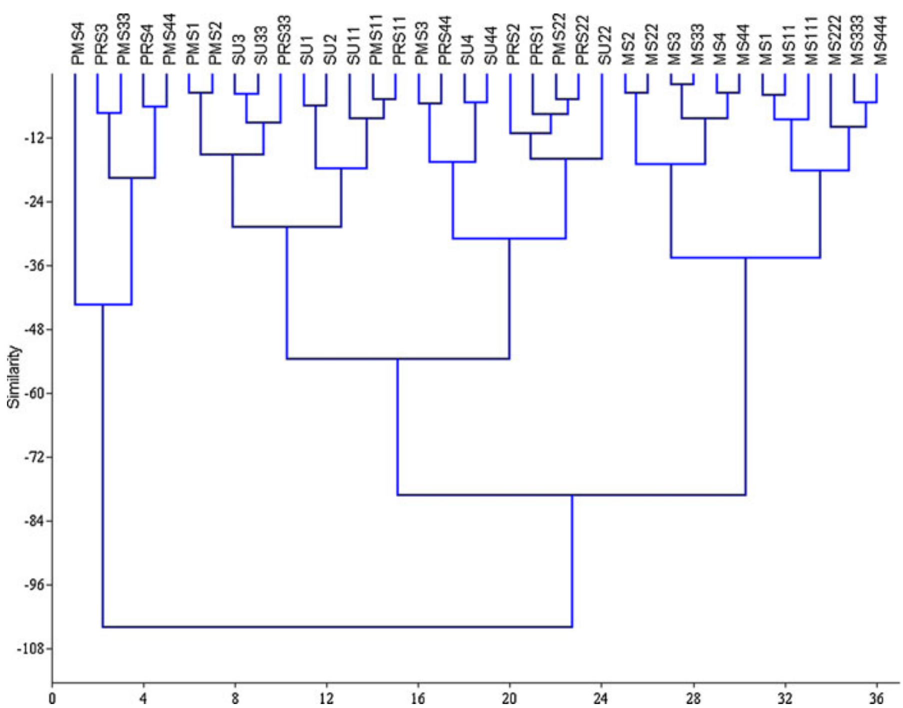


Fig. 9 Dendrogram based on ward's method clustering for four stations in different seasons in Pondicherry mangroves. *MS1* monsoon station 1, *MS2* monsoon station 2, *MS3* monsoon station 3, *MS4* monsoon station 4, *PMS1* post-monsoon station 1, *PMS2* post-monsoon station 2, *PMS3* post-monsoon station 3, *PMS4* post-monsoon station 4, *SU1* summer station 1, *SU2* summer station 2, *SU3* summer station 3, *SU4* summer station 4, *PRS1* pre-monsoon station 1, *PRS2* pre-monsoon station 2, *PRS3* pre-monsoon station 3, *PRS4* pre-monsoon station 4, *MS11* monsoon station 11, *MS22* monsoon station 22, *MS33* monsoon station 33, *MS44* monsoon station 44, *PMS11* post-monsoon station 11, *PMS22* post-monsoon station 22, *PMS33* post-monsoon station 33, *PMS44* post-monsoon station 44, *SU11* summer station 11, *SU22* summer station 22, *SU33* summer station 33, *SU44* summer station 44, *PRS11* pre-monsoon station 1, *PRS22* pre-monsoon station 2, *PRS33* pre-monsoon station 3, *PRS43* pre-monsoon station 4, *MS111* monsoon station 1, *MS222* monsoon station 2, *MS333* monsoon station 3, *MS444* monsoon station 4

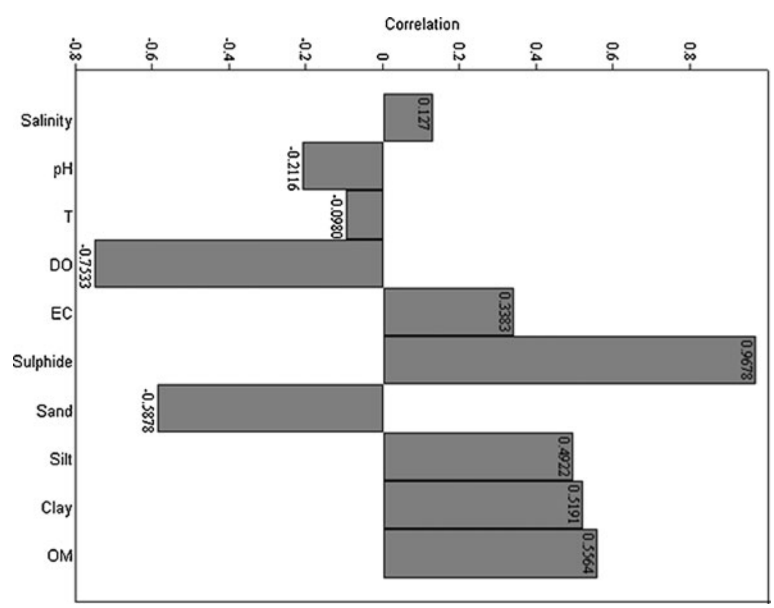
relatively low pollution, moderate pollution, polluted, and very highly polluted regions respectively.

The stations in Group A were located in the monsoon season, water quality was found to be strongly influenced by season, with the monsoon season being associated with much higher levels of nutrients and sediments than the dry season. Cluster B were placed mostly in summer, pre- and post-monsoon seasons, station 1 and 2 lay in the shrimp culture area of Veerampattinam and near the Pondicherry harbor, respectively. Station 3 was close to textile and tributary industry area in Murungapakkam bay; station 4 was primarily impacted by the industrial waste water, agricultural runoff, and municipal sewage from Pondicherry Corporation. The concentration of some water parameters remained high, such as sulfide (40.43 mg/L), OM (4.64 mg/L), and EC (41.3 ms^{-1}). It can be said that hierarchical CA provides a reliable tool to classify surface water in the study region and make it possible to optimize a future monitoring strategy which can reduce sharply the number of monitoring periods and sites and associated costs. There are other reports (Simeonov et al. 2003; Singh et al. 2004; Wang et al. 2006) where similar approach has successfully been applied in water quality programs.

PCA were applied to standardized log-transformed data set to identify the latent factors. The objective of this analysis was primarily to create an entirely new set of factors much smaller in number when compared to the original data set in subsequent analysis. Before applying PCA, correlation analysis was carried out. This was utilized to find an internal structure and assist in the identification of pollution sources not accessible at first glance. The highest correlation existed between DO and sulfide, OM and sulfide (Table 2) and Fig. 10.

The results of PCA are given in (Fig. 11). Four principal components accounting for 93% of the total variation are retained on the basis of the eigenvalue-greater-than-one rule. The first two principal components explain 52.62% and 17.95% of the variance, respectively. The third and fourth principal components are considerably less important, explaining only 12.34% and 10.06% of the variance, respectively. Therefore, we consider only the first two components, which account for a large proportion of the variation in the data (70.57% of the variance). In Fig. 11, the temporal and spatial characteristics of trophic status in Pondicherry mangroves can be observed clearly. Cluster A was characterized by high content of DO, cluster B was characterized by EC, and cluster C was characterized by sulfide and OM. The data were distributed in a limited region of space spanned by the two principal components well-defined axes. The scores of stations PRS3, PRS4, MS4, PMS3, PMS33, PMS44 and MS22, MS3, MS44, MS444 in Cluster C had positive and negative values in principal components, respectively; stations 3 and 4 are located in the southern and eastern parts of Bay of

Fig. 10 Linear correlation coefficient of ten parameters. *T* temperature, *DO* dissolved oxygen, *EC* electrical conductivity, *OM* organic matter



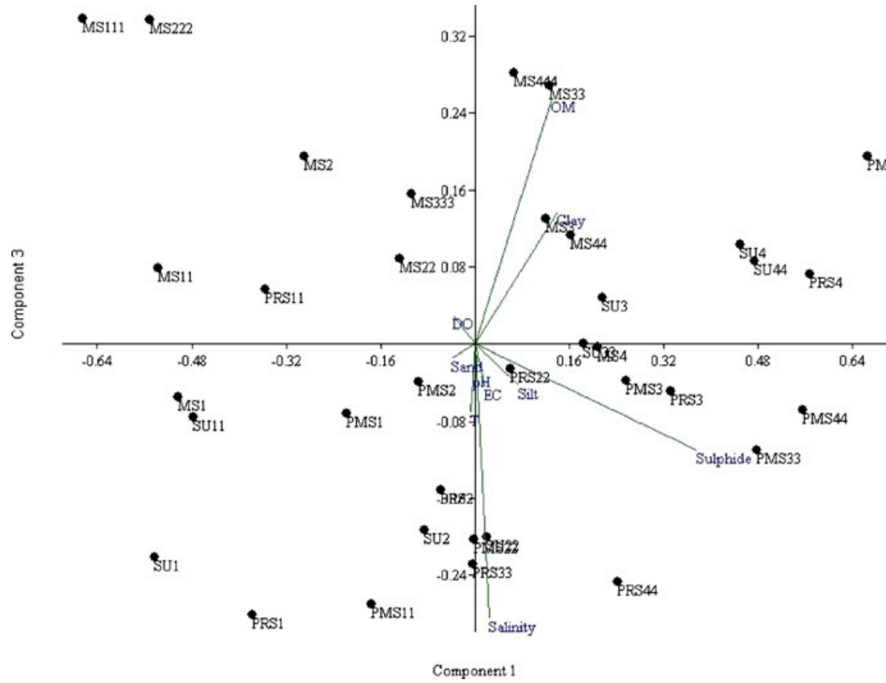


Fig. 11 Principle component analysis method for four stations in different seasons in Pondicherry mangroves. *MS1* monsoon station 1, *MS2* monsoon station 2, *MS3* monsoon station 3, *MS4* monsoon station 4, *PMS1* post-monsoon station 1, *PMS2* post-monsoon station 2, *PMS3* post-monsoon station 3, *PMS4* post-monsoon station 4, *SU1* Summer station 1, *SU2* Summer station 2, *SU3* Summer station 3, *SU4* Summer station 4, *PRS1* pre-monsoon station 1, *PRS2* pre-monsoon station 2, *PRS3* pre-monsoon station 3, *PRS4* pre-monsoon station 4, *MS11* monsoon station 11, *MS22* monsoon station 22, *MS33* monsoon station 33, *MS44* monsoon station 44, *PMS11* post-monsoon station 11, *PMS22* post-monsoon station 22, *PMS33* post-monsoon station 33, *PMS44* post-monsoon station 44, *SU11* Summer station 11, *SU22* Summer station 22, *SU33* Summer station 33, *SU44* Summer station 44. *PRS11* pre-monsoon station 1, *PRS22* pre-monsoon station 2, *PRS33* pre-monsoon station 3, *PRS43* pre-monsoon station 4, *MS111* monsoon station 1, *MS222* monsoon station 2; *MS333* monsoon station 3; *MS444* monsoon station 4

Bengal. However, from the PCA results, it may convincingly be presumed that in all the four regions under study, pollution is mainly from agricultural runoff, leaching from solid waste disposal sites, domestic, and industrial wastewater disposal. These findings are also supported by the catchments source/activity inventory. Similar approach based on PCA for evaluation of temporal and spatial variations in water quality has earlier been used (Sundaray et al. 2006; Ragno et al. 2007).

Mangrove water quality parameters, evaluated by using MDS, were used to identify which sampling stations were more influenced by the parameters which described each coordinate, as well as to visualize similarities or differences between samples. The similarities among the four monitoring stations were found according to coordinate 1 and coordinate 2. Figure 12 illustrates that cluster A included MS1, MS2, MS11, MS22, MS 111, MS222, PRS1, PRS11, PRS2, PMS1, PMS2, SU1, and SU11 (most of the sampling sites from monsoon season and stations 1 and 2 only) and characterize the negative values in multidimensional plot. Group B included MS3, MS4, MS33, MS44, PMS22, PMS3, PMS33, PMS4, PMS44, PRS22, PRS3, PRS33, PRS4, PRS44, SU2-SU4, SU22–SU44 (most of the sampling sites from summer and post-monsoon and stations 3 and only) and characterize the positive values in multidimensional plot. Seasonality has an important influence on trophic status of water, the parameters causing dissimilarity between stations 1 and 2, stations 3 and 4 can be seen from Figs. 2, 3, 4, 5, 6, 7, and 8. It is clear from the figure that DO, salinity, EC, sulfide, OM, and clay are the most important parameters causing these dissimilarities. These parameters represent from the domestic sewage and industrial organic pollution. Human activities have strong influence on the aquatic environment in the southeast coast of Bay

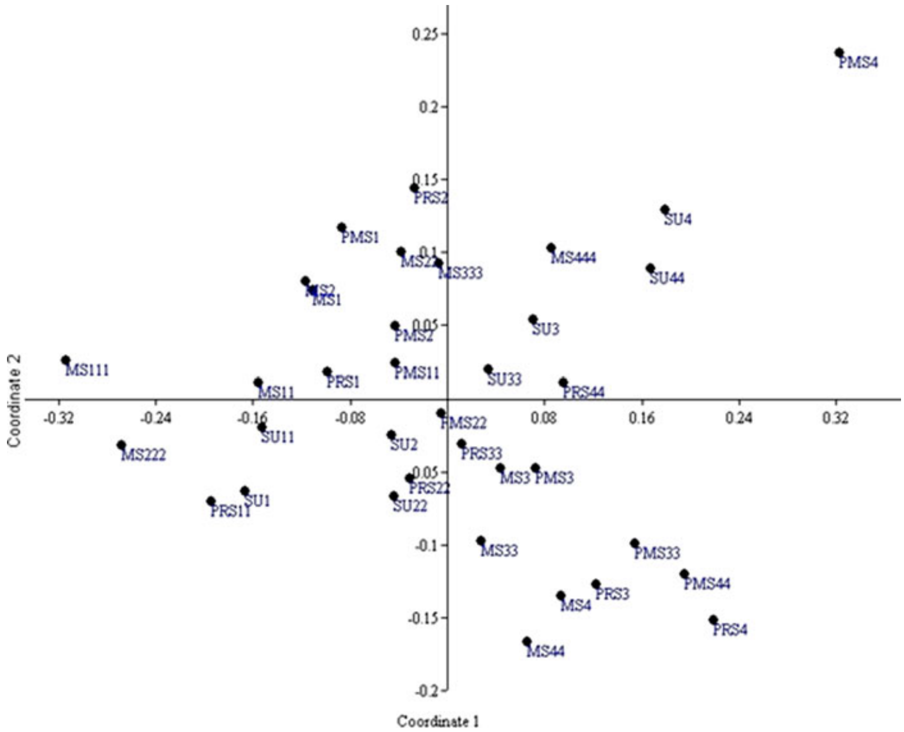


Fig. 12 Non-multidimensional scale plot analysis for four stations in different seasons in Pondicherry mangroves. *MS1* monsoon station 1, *MS2* monsoon station 2, *MS3* monsoon station 3, *MS4* monsoon station 4, *PMS1* post-monsoon station 1, *PMS2* post-monsoon station 2, *PMS3* post-monsoon station 3, *PMS4* post-monsoon station 4, *SU1* Summer station 1, *SU2* Summer station 2, *SU3* Summer station 3, *SU4* Summer station 4, *PRS1* pre-monsoon station 1, *PRS2* pre-monsoon station 2, *PRS3* pre-monsoon station 3, *PRS4* pre-monsoon station 4, *MS11* monsoon station 11, *MS22* monsoon station 22, *MS33* monsoon station 33, *MS44* monsoon station 44, *PMS11* post-monsoon station 11, *PMS22* post-monsoon station 22, *PMS33* post-monsoon station 33, *PMS44* post-monsoon station 44, *SU11* Summer station 11, *SU22* Summer station 22, *SU33* Summer station 33, *SU44* Summer station 44. *PRS11* pre-monsoon station 1, *PRS22* pre-monsoon station 2, *PRS33* pre-monsoon station 3, *PRS43* pre-monsoon station 4, *MS111* monsoon station 1, *MS222* monsoon station 2; *MS333* monsoon station 3; *MS444* monsoon station 4

of Bengal (Ananthan et al. 2005). As was stated above, DO, salinity, EC, sulfide, clay, and OM are the most important surface water quality parameters causing differences among the monitoring stations in the southeast region of Pondicherry mangroves, India.

Multivariate techniques (CA, PCA, and MDS) were used to differentiate the trophic status of water quality in the monitoring sites. Nutrients are introduced into the bay by rivers and sewage discharges in post-monsoon and summer and can be released into water under certain environmental conditions. The mean concentration of sulfide in post-monsoon and summer was higher than monsoon, suggesting a high load of dissolved organic matter added from land-based resources, such as domestic wastewater, agricultural-related activities and industrial effluents (Wu et al. 2009). Therefore the water quality in summer and post-monsoon was worse than that in the other seasons (Fig. 9). The results indicate that the CA techniques are useful in offering a reliable classification of the trophic state. PCA can support more information about trophic status of water quality and corresponding factors. MDS approach can further identify the differences among the trophic status of water quality in different sites and can distinguish the corresponding driving factor. Based on the MDS plot, DO, sulfide, and OM may be major driving factors for deteriorating trophic status of water quality. From the above discussion, we can say that CA, MDS, and PCA are a useful tool to analyze the pollution source and monitoring sites. It can offer information to identify polluted sites and help in the decision making on controlling of water pollution.

Conclusion

In this case study, different multivariate statistical techniques were successfully applied to evaluate variations in the water quality of the Pondicherry mangroves. CA, PCA, and MDS obtained similar results regarding spatial and temporal patterns of water quality. In spatial characteristics, the water quality in Pondicherry mangroves divided in two groups by chemometrics. Stations 1, 2, 3, and 4 were near the bar mouth and lagoon region, Pondicherry harbor, and northeastern part of mangroves exposed to sewage waste water from industries, urban waste water, and agricultural runoff, all contributing to the current condition of the sources contaminating the mangrove. In addition, H_2S pollution from both agricultural and industrial inputs deteriorates the water quality of mangrove ecosystem at station 3 and 4. PCA identified latent factors and explained 93% of the total variance, standing for low, moderate, and highly polluted regions, respectively. Stations 3 and 4 were greatly affected by municipal sewage and tributary industrial pollution; DO, salinity, EC, sulfide, OM, and clay are the most important parameters represent from the domestic sewage and industrial organic pollution. The immediate need is to maintain existing sewage treatment plants so that effluent discharge has a minimum of suspended solids. As a result, it is essential that Pondicherry mangrove health in coastal environment monitoring is urgently required. Thus, this study illustrated the usefulness of multivariate statistical techniques for the analysis and interpretation of complex data set, water assessment, and identification of pollution sources.

Acknowledgments Authors thank the University Grants Commission, Government of India for the financial support and Pondicherry University administration for providing necessary facilities.

References

Ajithkumar, T. T., Thangaradjou, T., & Kannan, L. (2006). Physico-chemical and biological properties of the Muthupettai mangrove in Tamil Nadu. *Journal of Marine Biological Association of India, 48*, 131–138.

Alberto, W. D., Del Pilar, D. M., Valeria, A. M., Fabiana, P. S., Cecilia, H. A., & De Los Angeles, B. M. (2001). Pattern recognition techniques for the evaluation of spatial and temporal variations in water quality. A case study: Suquia River basin (Cordoba—Argentina). *Water Research, 35*, 2881–2894.

Ananthan, G. A., Sampathkumar, P., Soundarapandian, P., & Kannan, L. (2005). Observation on environmental characteristics of Ariyankuppam estuary and Veerampattinam coast of Pondicherry, India. *Journal of Aquatic Biology, 19*, 67–72.

Anilakumary, K. S., Abdul Aziz, P. K., & Natrajan, P. (2007). Water quality of the Adimalathma estuary, southwest coast of India. *Journal of Marine Biological Association of India, 49*, 1–6.

Ashok Prabu, V., Rajkumar, M., & Perumal, P. (2008). Seasonal variations in physico-chemical parameters in Uppanar estuary, Cuddalore Southeast coast of India. *Journal of Marine Biological Association of India, 50*, 161–165.

Bierman, P., Lewis, M., Ostendrof, B., & Tanner, J. (2009). A review of methods for analysing spatial and temporal patterns in coastal water quality. *Ecological Indicators*. doi:10.1016/j.ecolind.2009.11.001.

El Wakeel, S. K., & Riley, J. P. (1957). The determinations of organic carbon in marine muds. Conseil Permanent International pour. *Exploration de Mer Journal, 22*, 180–183.

Ghoshal Chaudhuri, S., Dinesh, R., Sheeja, T. E., Rajal, R., Jeykumar, V., & Srivastava, R. C. (2009). Physico-chemical, biochemical and microbial characteristics of soils of mangroves of the Andamans: a post-tsunami analysis. *Current Science, 97*, 98–102.

Gopakumar, G., & Kuttyamma, V. J. (1999). Effect of hydrogen sulphide on benthic fauna of a tropical estuary. *Fishery Technology, 36*, 43–47.

Herrera-Silveira, J. A., & Morales-Ojeda, S. M. (2009). Evaluation of the health status of a coastal ecosystem in southeast Mexico: assessment of water quality, phytoplankton and submerged aquatic vegetation. *Marine Pollution Bulletin, 59*, 72–86.

Hynes, H. B. N. (1966). *The biology of polluted waters*. Liverpool: Liverpool University Press. 202 pages.

Iscen, C. F., Emiroglu, O., Ilhan, S., Arslan, N., Yilmaz, V., & Ahiska, S. (2008). Application of multivariate statistical techniques in the assessment of surface water quality in Uluabat Lake, Turkey. *Environmental Monitoring and Assessment, 144*, 269–276.

Karydis, M. (1992). Scaling methods in assessing environmental quality: A methodological approach to eutrophication. *Environmental Monitoring and Assessment, 22*(2), 123–136.

Krumbein, W. C., & Pettijohn, F. J. (1983). *Manual of sedimentary petrography.* New York: Appleton Century Crafts Inc.. 549 pages.

Kumar, S. R. (1997). Vertical distribution and abundance of sediment dwelling macro invertebrates in an estuarine mangrove biotope-south west coast of India. *Indian Journal of Marine Sciences, 22*, 235–240.

Lattin, J., Carroll, D., & Green, P. (2003). *Analyzing multivariate data*. New York: Duxbury press.

Manjappa, H., Gowda, G., Rajesh, K. M., & Miridula. (2003). Sediment characteristics of mangrove areas of brackish-water impoundments. *Indian Journal of Fisheries, 50*(3), 349–354.

Paramasivam, S., & Kannan, L. (2005). Physico chemical characteristics of Muthupettai Mangrove environment

South east coast of India. *International Journal of Ecology and Environmental Science, 31*, 273–278.

Quadir, A., Malik, R. N., & Husain, S. Z. (2007). Spatio-temporal variations in water quality of Nullah Aik–tributary of the river Chenab, Pakistan. *Environmental Monitoring and Assessment, 140*, 1–3.

Ragno, G., De Luca, M., & Ioele, G. (2007). An application of cluster analysis and multivariate classification methods to spring water monitoring data. *Micro chemical Journal, 87*, 119–127.

Rajasegar, M. (2003). Physico-chemical characteristics of the Vellar estuary in relation to shrimp farming. *Journal of Environmental Biology, 24*, 95–101.

Raut, Ganesh, T., Murty, N. V. S. S., & Raman, A. V. (2005). Macro benthos of Kakinada Bay in the Godavari delta, East coast of India: comparing decadal changes. *Estuarine, Coastal and Shelf Science, 62*, 609–620.

Saravanakumar, A., Rajkumar, M., Sesh Serebiah, J., & Thivakaran, G. A. (2008). Seasonal variations in physico-chemical characteristics of water, sediment and soil texture in arid zone mangroves of Kachchh-Gujarat. *Journal of Environmental Biology, 29*, 725–732.

Shrestha, S., & Kazama, F. (2007). Assessment of surface water quality using multivariate statistical techniques: a case study of the Fuji river basin, Japan. *Environmental Modeling and Software, 22*, 464–475.

Simeonov, V., Stratis, J. A., Samara, C., Zachariadis, G., Voutsa, D., Anthemidis, A., et al. (2003). Assessment of the surface water quality in Northern Greece. *Water Research, 37*, 4119–4124.

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.

Singh, K. P., Malik, A., & Sinha, S. (2005). Water quality assessment and apportionment of pollution sources of Gomti River (India) using multivariate statistical techniques—a case study. *Analytica Chimica Acta, 538*, 355–374.

Strickland, J. D. H., & Parsons, T. R. (1972). *A Practical hand book of seawater analysis*. Bulletin Fisheries Research Board Canada, pp. 310.

Sundaray, S. K., Panda, U. C., Nayak, B. B., & Bhatta, D. (2006). Multivariate statistical techniques for the evaluation of spatial and temporal variation in water quality of Mahanadi River–estuarine system (India)—a case study. *Environmental Geochemistry and Health, 28*, 317–330.

Sunil Kumar, R. (1996). Distribution of organic carbon in the sediments of Cochin mangroves, south west coast of India. *Indian Journal of Marine Science, 25*, 56–61.

Vega, M., Pardo, R., Barrato, E., & Deban, L. (1998). Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. *Water Research, 32*, 3581–3592.

Wang, Y. S., Lou, Z. P., Sun, C. C., Wu, M. L., & Han, S. H. (2006). Multivariate statistical analysis of water quality and phytoplankton characteristics in Daya Bay, China, from 1999 to 2002. *Oceanologia, 48*, 193–211.

Wu, M. L., Wang, Y. S., Sun, C. C., Wang, H. L., & Dong, J. D. (2009). Using chemometrics to identify water quality in Day Bay, China. *Oceanologia, 52*, 217–232.

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 variations in water quality. A case study: Suquira river basin (Cordoba— Argentina). *Water Research, 35*, 1894–2881.

Zhou, F., Guo, H. C., Liu, Y., & Jiang, Y. M. (2007). Chemometrics data analysis of marine water quality and source identification in Southern Hong Kong. *Marine Pollution Bulletin, 54*, 745–756.