Coastal water characteristics along Tamil Nadu, east coast of India during pre-northeast monsoon period

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A study was carried out to characterize the coastal waters along Tamil Nadu during the pre-northeast monsoon period. A significant spatial variation in coastal water characteristics with respect to physico-chemical parameters was observed, indicating the different level of anthropogenic influence at different study sites. Sampling locations near to the mega city Chennai (Ennore and Pattinapakkam) showed relatively high concentrations of almost all the nutrients due to significant anthropogenic inputs in terms of house hold wastes and industrial effluents through the Adyar and Cooum rivers. A clear decreasing trend in nitrate and phosphate was observed from the northern to southern region of the study area, typifying the signature of pollution in the northern regions. Positive correlations among all the nutrients indicated their common source of origin through external input by the river estuaries and backwaters. Cluster analysis clearly established the presence of a polluted zone (near to Chennai), a buffering zone (Kovalam and Kalpakkam) and a least effected environment in the southern region (Marakanam, Poombukar, Pondicherry and Parangipettai) of the study area.

[Keywords: Physico-chemical properties, coastal waters, pollution, Tamil Nadu coast, Bay of Bengal]

Introduction

Deterioration of surface water quality including coastal areas all over the world has been attributed to both natural processes and anthropogenic activities. Phenomena such as precipitation, weathering of rocks, climate change, land use etc significantly shape the coastal ecosystem. Thus, studies pertaining to physico-chemical properties have become an imperative part of environmental monitoring of late. Physico-chemical properties significantly influence the productivity potential of coastal ecosystems[1]. Salinity and temperature together play an important role in shaping the coastal water mass[2]. Nutrient content in an aquatic environment is a measure of the productivity of the system[3] and therefore, it is important to gather information about their distribution and behaviour in different coastal ecosystems. Although, the life supporting processes in marine coastal ecosystems require many inorganic substances, nitrogen, phosphorous and silicon are considered to be more important than the others, as they play a key role in phytoplankton abundance, growth and metabolism[4]. Therefore, studies pertaining to the source of origin, distribution pattern and rate of utilization of these inorganic components have become an imperative scientific research in coastal areas in the last few decades. The distribution and behaviour of nutrients in the coastal environment, particularly in the nearshore waters and estuaries, exhibit considerable

variations depending upon the local conditions such as rainfall, quantum of fresh water inflow, tidal incursion and also biological activities like uptake by phytoplankton and regeneration. Many studies have shown the existence of a regular seasonal cycle of nutrients with high concentrations (in surface waters) in winter and low in spring and summer. The low levels in summer months have been attributed to the outburst of phytoplankton populations which utilize nutrients for their growth and multiplication.

In the tropical waters the amount of published work on the subject of nutrients is relatively small as compared to the temperate region. The earliest published work is from the waters off North-east Australian coast. Subsequently, reports from Java sea[5], Singapore straits[6], and tropical areas of the Pacific Ocean have appeared. The earliest published data on nutrients from the Indian subcontinent is that of Malabar Coast[7]. The first attempt to study and understand the distribution and seasonal cycle of nutrients from the Bay of Bengal was reported by Jayaraman[8], which was followed by several other studies form Indian coasts[9-12]. More recent additions to these data from various coastal waters in the Bay of Bengal have also been made[13-18]. A cursory glance of all the available literature from Bay of Bengal, particularly from the Tamil Nadu coast showed that, previous studies were mainly confined to particular locations with regional importance. In this backdrop, the present study was undertaken in order to find out the behavior of physico-chemical properties of coastal waters in a larger stretch (~ 300km) along the Tamil Nadu coast and was restricted to the pre-northeast monsoon period of 2014.

Study area

The study area covered a stretch of approximately 300km from Ennore to Poombukar along the Tamil Nadu coast, comprising of eight sampling locations viz. Ennore, Pattinapakkam, Kovalam, Kalpakkam, Marakkanam, Pondicherry, Parangipettai and Poombukar. Ennore is situated on a peninsula and Korttalaiyar River running into it (Figure 1). Ennore creek is a highly polluted area[19-20]. The treated effluents of the Madras Refinery Ltd, through the Buckingham canal and the Madras Fertilizers Ltd, through the Red Hills surplus channel, reach the Ennore backwater[21]. Pattinapakkam is located on the marina beech

which is situated between Chennai harbor and Adyar river estuary. Adyar River receives sizable amount of untreated sewage from Chennai city which has witnessed rapid industrialization and urbanization leading to severe contamination of this river[22]. Kovalam beach, a recreation area, entice people from across the globe, is situated 40km south of Chennai and it is located very near (3.3 km) to the Muttukadu backwaters, which serves as a boating destination for tourists. The Muttukadu backwaters also receives huge amount of urban waste which is ultimately discharged to the coastal waters. Kalpakkam is a well known location for a number of nuclear industrial activities viz., Madras Atomic Power Station (MAPS), Nuclear Desalination Demonstration Plant, Prototype Fast Breeder Reactor (under construction), PRP, Waste Immobilization Plant (WIP) and Indira Gandhi Centre for Atomic Research (IGCAR). In addition, all these activities have brought in associated small scale industrial activities leading to increased anthropogenic impact in and around the coast. Marakkanam is a small coastal town and it is having coastal lagoon (Kaliveli Lagoon) which lies approximately 16 kilometres north of Pondicherry city. Pondicherry is a popular tourist destination in South India. Parangipettai is located on the north bank of the Vellar estuary which is near the world's second largest mangrove forest (Pichavaram mangroves). Poombukar is a tourist's town in the Nagapattinam district and it's located near the Kaveri River estuary. An important feature of the study area is the presence of 796 km long Buckingham canal (part of the National Waterway 4 (NW-4)), which originates in Godavari district of Andhra Pradesh and runs parallel to the coastline up to Villipuram District of Tamil Nadu. In this segment, of the study area, the canal opens into the coastal waters at various locations such as, Ennore creek, Cooum river estuary (Chennai), Adyar river estuary (Chennai), Muttukadu backwaters, Edaiyur Backwaters, Sadras Backwaters, Palar River estuary, Marakanam and Pondicherry. The canal receives untreated sewage and industrial discharge from the Chennai and the nearby industrial establishments.

The Tamil Nadu coast represents a true tropical climate without much variation in the climatology. Seasonal monsoon reversal of wind is a unique feature of Indian Ocean, which is

experienced prominently along this coast[23-24]. Due to this, the coastal regions of this part of the Indian peninsula experiences two monsoon seasons: the prominent northeast (NE) monsoon and the relatively weak southwest (SW) monsoon. The pole-ward current during SW monsoon changes to equator-ward during the NE monsoon season[25-27]. Subsequent to the change in the current pattern, the alterations in coastal water quality have also been reported[16, 28-31]. As the present study was carried out during the pre-NE monsoon, riverine discharge and land runoff were minimum except the anthropogenic inputs in terms of untreated sewage and industrial effluents.
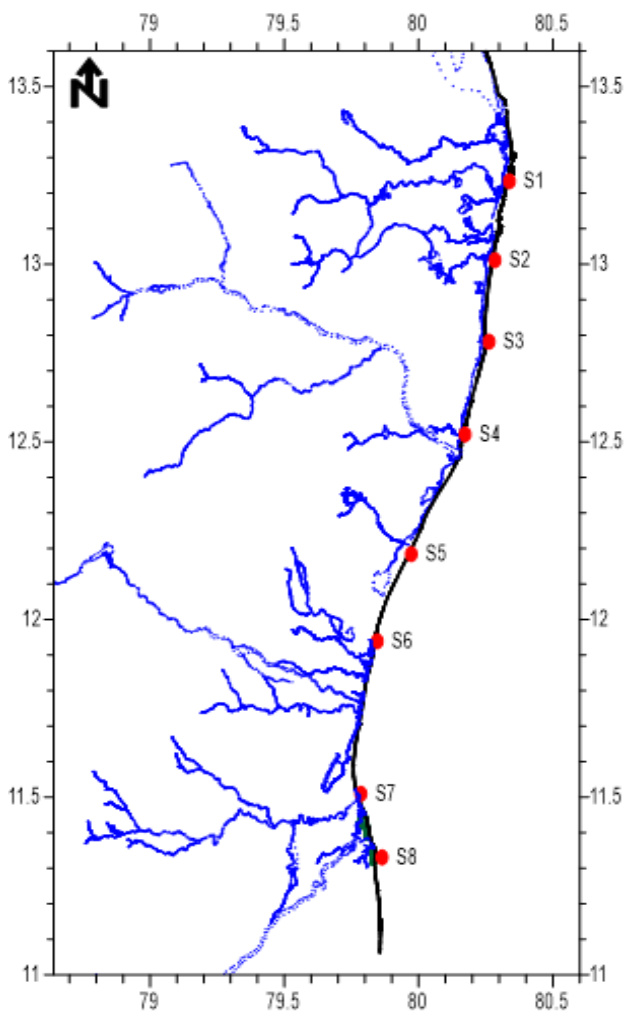

Figure 1: Map of study area showing sampling locations (S1-Ennore, S2-Pattinapakkam, S3- Kovalam, S4- Kalpakkam, S5-Marakkanam, S6- Pondicherry, S7- Parangipettai and S8-Poombukar)

Material and Methods

Surface and bottom water sample were collected in duplicate, about 2 km inside the sea, from all the eight locations viz. Ennore, Pattinapakkam, Muttukadu, Kalpakkam, Marakkanam, Pondicherry, Parangipettai and Poombukar during pre-NE monsoon period (September-October, 2014). Bottom samples (10-12m depth) were drawn by using a Niskin water sampler and acid clean polyethylene bottles were used to store the samples for transportation to laboratory. Physical parameters such as pH, temperature and dissolved oxygen (DO) were measured on board by using multi-parameter probe (Model: Hydrolab Quanta). Salinity estimations were carried out by Knudsen's method[36]. Samples were stored at -20°C until analysis. Samples were filtered by using 0.45 μm Millipore filter paper prior to analysis. Suspended particulate matter (SPM) was calculated as the difference between initial and final weight of the filter paper after drying. Dissolved micronutrients such as, nitrite, nitrate, ammonia, silicate, phosphate along with total nitrogen (TN) and total phosphorus (TP) were estimated using standard methods[32-33]. For all the spectrophotometric analyses, a double beam UV–Visible Spectrophotometer (Thermo Spectrascan UV 2600) was used. Correlation analysis and cluster analysis was carried out by using XLStat Pro 2008.

Results and discussion
Temperature

Borrego and Borrego[34] opined that, temperature conditions in estuarine and coastal environment fluctuate depending upon their bathymetry, stratification, insolation, local atmospheric variation and water exchange between the estuary and the sea. Temperature in the present study ranged from 27.27 ^{o}C to 30.18 ^{o}C in surface and 25.87 ^{o}C to 29.09 ^{o}C in bottom waters. The highest temperature was recorded from Poombukar surface and lowest was recorded from Kalpakkam bottom waters (Figure 2a). A clear temperature stratification was observed at all the locations except Kovalam, Which could be attributed to the fact that samples from Kovalam were collected towards the end of the sampling period which coincided with early phase of NE monsoon season.

Thus the excessive surface runoff and backwater discharge could have disrupted stratification due to churning action. A visible spatial decrease in water temperature from south to north of the study site could be attributed to the fact that sampling was carried out from south to north during the onset of the NE monsoon when the temperature gradually decreases to the minimum in an annual cycle. Observation of ΔT of about 3 ^{o}C for surface and 4 ^{o}C fro bottom waters indicated a wide variation in annual temperature might be existing along this coast[17].

pH

pH values were recorded between 7.40 to 8.33 in surface water and 7.80 to 8.20 in bottom water samples. The highest and the lowest values for surface water were observed from Marakkanam and Kovalam respectively. Bottom water pH was the highest at Pondicherry and the lowest at Kovalam (Figure 2b). pH did not show any significant correlation with any other parameters. The lowest pH value for surface and bottom waters observed at Kovalam could be attributed to the freshwater discharge form Muttukadu backwaters due to influence of NE monsoon period as

described earlier. Apart from the Muttukadu coastal waters, the observed insignificant variation in pH could be attributed to the negligible terrestrial runoff and precipitation during the pre-NE monsoon period coupled with the extensive buffering capacity of the seawater that causes pH change within a very narrow limit[35].

Salinity

Salinity stands as the key factor controlling almost all other environmental characterstics of coastal water and their inhabitant flora and fauna. The salinity fluctuations in coastal environment mainly depend upon the local precipitations and influx of surface runoff. The observed surface and bottom salinity values ranged 31.36 to 35.65 psu and 31.46 to 35.78 psu respectively (Figure 2c). Apart from Kovalam, where the minimum values were observed for surface and bottom samples, salinity at all other locations remained almost same. Salinity showed a strong positive correlation (r= 0.668; p≤0.01) with pH (Table 1) indicating the decrease in pH with decreasing salinity as was observed at Kovalam coastal waters., which corroborated similar observations from other coastal waters[13].
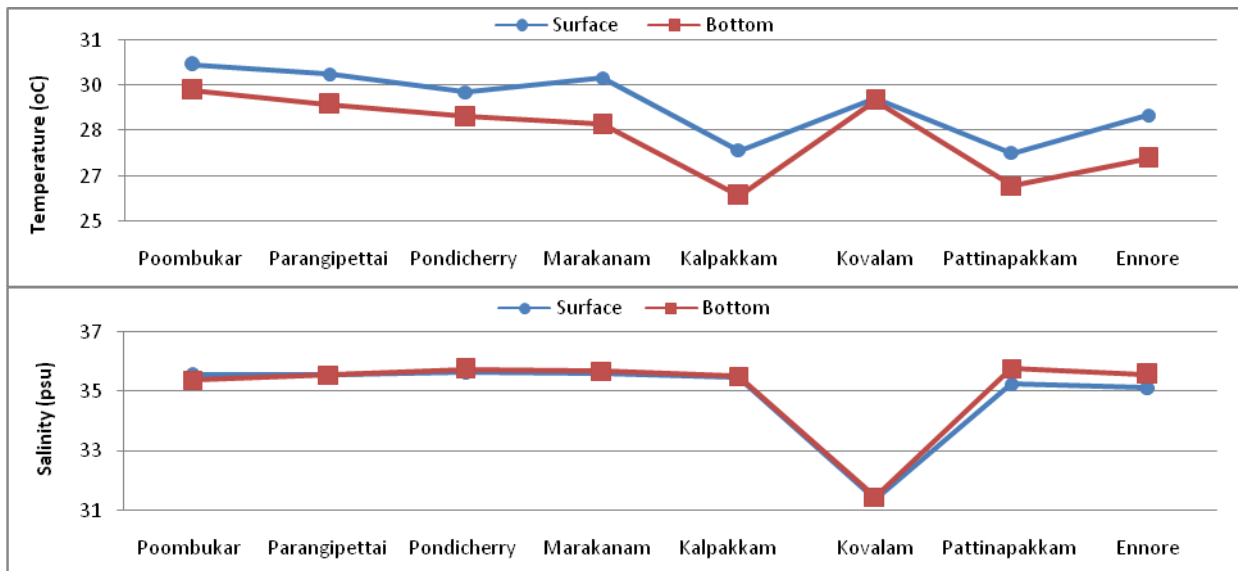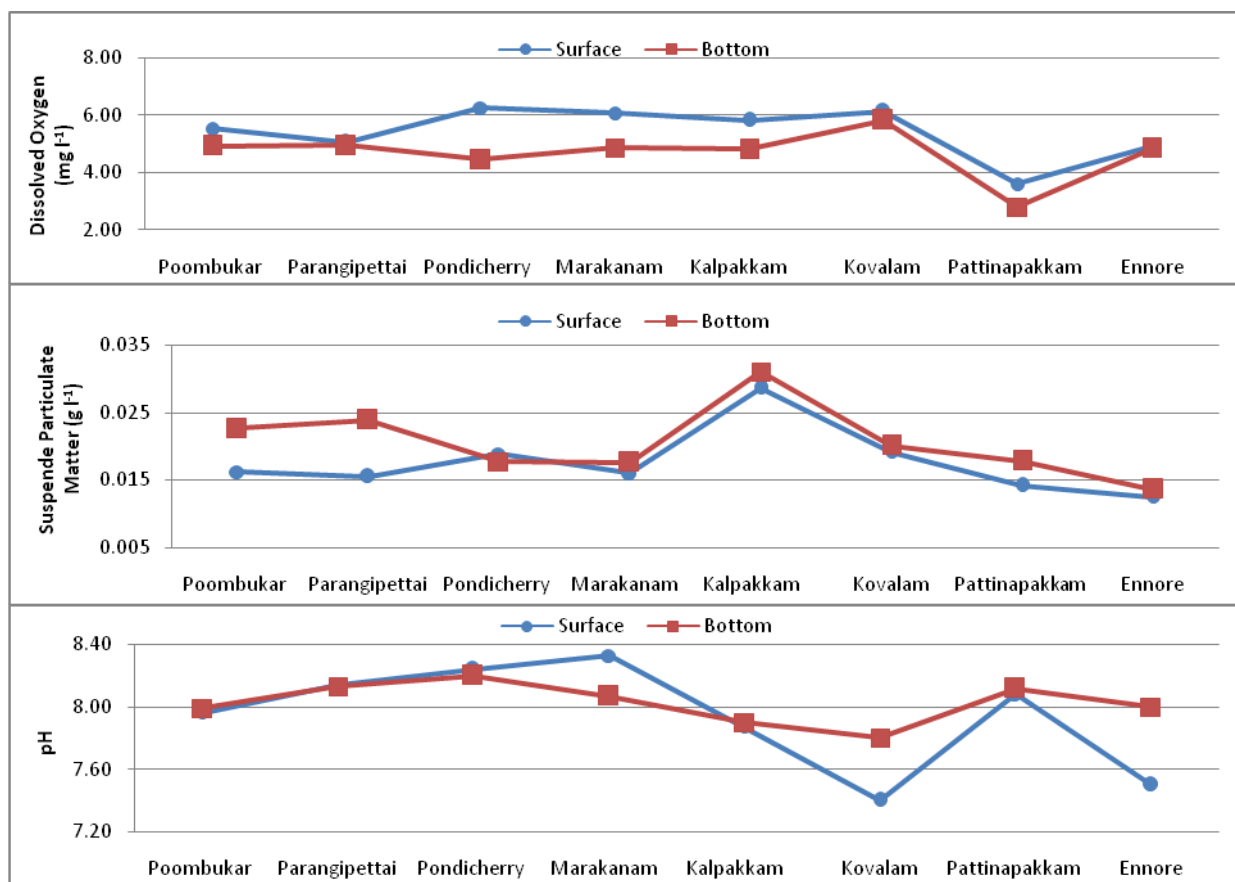
Figure 2a-e: Variations in Temperature, pH, Salinity dissolved oxygen (DO) and suspended particulate matter (SPM) in the coastal waters of Tamil Nadu during pre-northeast monsoon period

Table 1: Correlation matrix (Pearson) of environmental variables

Variables	Temp.	pH	Salinity	DO	SPM	Nitrite	Nitrate	Ammonia	TN	Phosphate	TP	Silicate
Temp.	1											
pH	0.130	1										
Salinity	-0.194	**0.737**	1									
DO	0.569	-0.315	-0.439	1								
SPM	-0.261	-0.105	-0.035	0.317	1							
Nitrite	0.560	-0.126	-0.260	0.083	0.101	1						
Nitrate	-0.537	-0.058	-0.127	-0.408	-0.137	-0.394	1					
Ammonia	0.208	0.071	0.291	0.080	**-0.645**	-0.336	0.028	1				
TN	-0.594	**-0.744**	**-0.627**	-0.133	0.133	-0.152	0.592	-0.227	1			
Phosphate	**-0.658**	0.089	0.258	**-0.792**	-0.518	-0.534	**0.700**	0.276	0.368	1		
TP	**-0.754**	-0.053	0.308	**-0.791**	-0.176	-0.271	**0.681**	0.142	0.472	**0.847**	1	
Silicate	-0.100	0.180	0.085	-0.499	-0.107	0.284	**0.638**	-0.184	0.119	0.373	0.528	1

Values in bold are significantly different from 0 with a significance level alpha=0.05

Dissolved oxygen

DO values varied from 3.60 to 6.56 mg l^{-1} in surface waters and in bottom samples it varied from 2.80 to 5.83 mg l^{-1}. Most of the sampling locations showed relatively higher DO in surface water when compare to bottom water (Figure 2d).

Significantly low values of DO were recorded at Pattinapakkam location. Pattinapakkam is located near the Adayar river estuary, which receives copious amount of untreated sewage from Chennai city. Thus, the decomposition of organic matter

discharged into the coastal waters at this location might have resulted in rapid utilization of DO. Both the surface and bottom DO values at Pattinapakkam were below the minimum O_2 content (4 mg l^{-1}) required for growth and survival of aquatic organisms. In aquatic systems, oxygenation is the result of an imbalance between the process of photosynthesis, degradation of organic matter and re-aeration[36]. The surface replenishment by atmospheric exchange and photosynthetic activity and the bottom consumption of oxygen for the oxidation of organic matter coupled with respiration make the dissolved oxygen content of surface waters slightly higher than that of bottom water.

Suspended particulate matter

SPM content plays an important role in marine environment, which decides the depth of euphotic zone and thus indirectly acts as one of the key factors for productivity potential of coastal waters. The influx of silt born surface runoff, resuspension of surficial sediments by stirring action and high density of phytoplankters are the key factors that determines the SPM content in the coastal waters. SPM values were recorded between 13 to 29 mg l^{-1} in surface water and 14 to 31 mg l^{-1} in bottom (Figure 2e). Relatively high SPM content was observed at Kalpakkam coastal waters which could be attributed to the shallow bathymetry of the region that causes the resuspension of bottom sediment easily[16]. The above SPM values can be considered as low and indicates the quick settlement of suspended matter by coagulation and precipitation.

Nutrients

Nitrite

Nitrite concentration varied from BDL to 0.45 μmol $^{-1}$ in surface water samples and BDL to 0.72 μmol $^{-1}$ in bottom water samples. The highest values were recorded at Poombukar and Parangipettai area surface samples whereas, BDL was observed for surface and bottom samples from Kalpakkam, Marakkanam and Pondicherry samples (Figure 3a). Nitrite is the intermediate oxidation state between ammonia and nitrate, and as such it can appear as a transient species by the oxidation of ammonia or by the reduction of nitrate. Nitrite is

also often released into the water as an extracellular product of the planktonic organisms[37]. Thus, being the most unstable form of inorganic nitrogen in seawater and due to its extracellular production, nitrite distribution depicts irregular picture and wide variations in the studied coastal milieu.

Nitrate

The concentration of nitrate ranged from 0.39 to 7.43 μmol $^{-1}$ for the surface and 0.77– 6.95 μmol $^{-1}$ for the bottom water samples. The highest values for surface and bottom were observed from Pattinapakkam coastal waters (Figure 3b), whereas, much lower values were observed at Poombukar, Parangipettai and Pondicherry stations. A clear demarcation with respect to nitrate concentration was observed with relatively high values from Marakanam to Ennore. It is worthwhile to mention here that, the Buckingham canal which runs parallel to the coast and debouches into the coastal waters at several locations, as described earlier, could be the reason for the above observations. Though the canal ran up to Pondicherry in early years, it has now been obstructed at many places and the flow has been diminished significantly. Thus, due to absence of any strong point source as well as lack of dispersion mechanism, like via bucking canal for northern locations, the southern locations showed relatively low nitrate concentrations. Out of the nine oxidation states (-3 to +5) of nitrogen, nitrate is thermodynamically the most stable form of combined inorganic nitrogen in well-oxygenated waters. Variations in nitrate and its reduced inorganic compounds are predominantly the results of biologically activated reactions. Quick assimilation by phytoplankton and enhancement by surface runoff results in large-scale spatio-temporal variation of nitrate in the coastal milieu[38]. Nitrate showed strong positive correlation (p≤0.05) with phosphate and silicate, which showed that, all the nutrients originated from the same source and most probably through the external input by the estuaries and backwaters[16].

Ammonia

The ammonia level varied from BDL to 20.28 μmol $^{-1}$ for surface sample and BDL to 4.52 μmol $^{-1}$ for bottom samples. Relatively high values were observed at Marakkanam and Ennore.
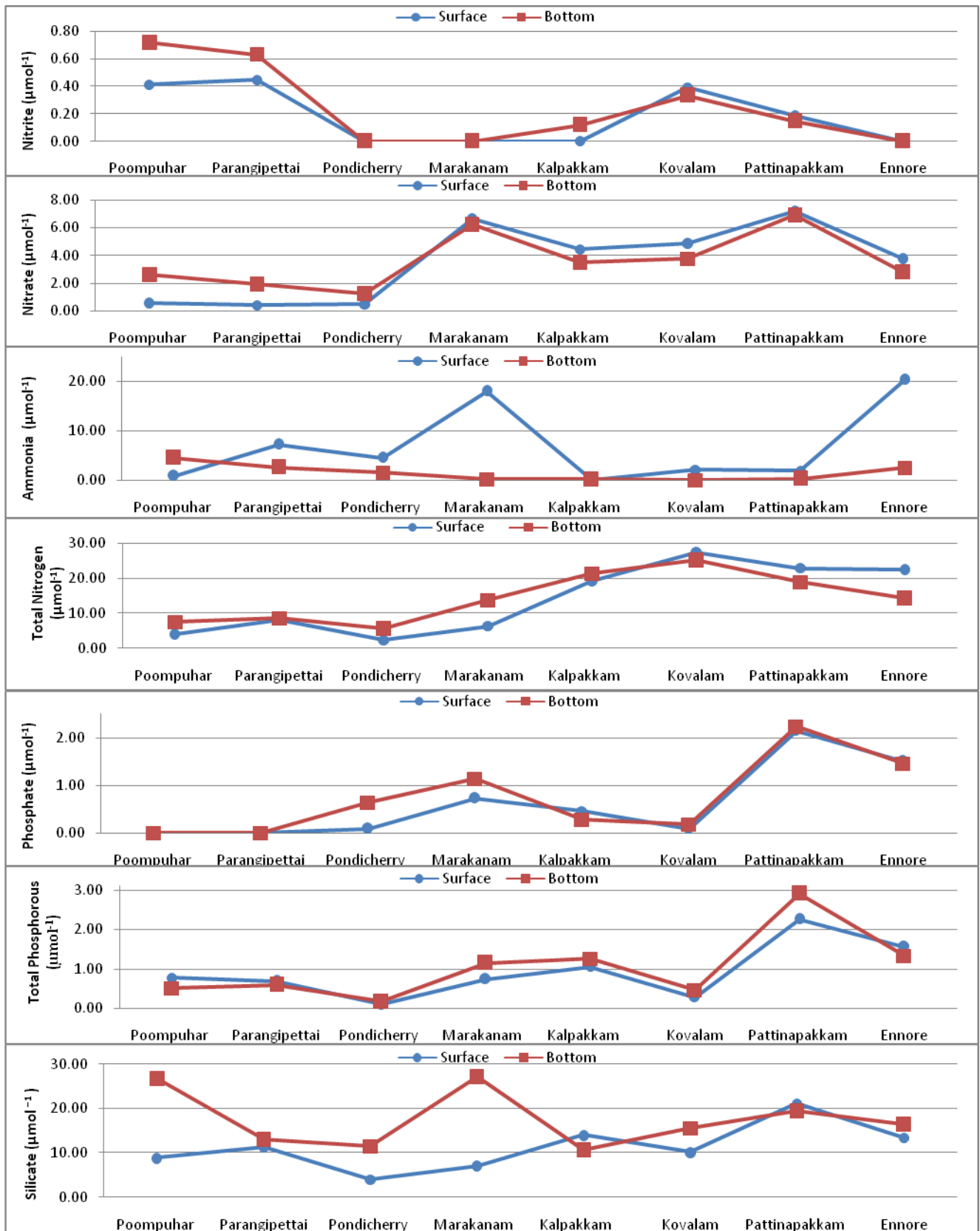
Figure 3a-g: Variations in nitrite, nitrate, ammonia, total nitrogen, phosphate, total phosphorus and silicate concentrations in the coastal waters of Tamil Nadu during pre-northeast monsoon period

BDL values for ammonia were observed at two stations in both surface (Kalpakkam) and bottom (Kovalam) water samples (Figure 3c). Out of the eight sampling locations, the two locations alone recorded higher ammonia content in the surface water than the bottom water. Ammonia, the chief excretory product of the marine invertebrates, is also well known as a nutrient, which is preferred over nitrate by the phytoplankton community in certain environmental conditions. The above two factors i.e. excretory release and utilization by phytoplankton significantly affects the concentration of ammonia[39] in the marine environment. The highest concentration observed at Ennore could be due to the presence of benthic invertebrate communities thriving on the marine structures of harbor, fishing ports and jetties along with the elevated pollution level in that locality. A clear trend in ammonia distribution was not observed, which could be due to its oxidation to other forms or reduction of nitrate to lower forms in coastal waters[16].

Total nitrogen

Values of TN ranged from 2.28 to 27.39 and 5.60 to 25.32 μmol $^{-1}$ for surface and bottom samples, respectively. Highest concentrations of TN were observed at Kovalam coastal waters. The lowest TN content was recorded in both surface and bottom waters of Pondicherry (Figure 3d). It showed almost similar trend as that of nitrate. The highest concentrations observed at Muttukadu could be attributed to the fact that, Muttukadu is the largest backwater system in this stretch of the study area with luxuriant growth of green and blue-green algae that enhances the organic nitrogen production. Thus the contribution of organic nitrogen through primary production along with the domestic and industrial effluents might have elevated the TN concentrations in the nearby coastal waters.

Phosphate and total phosphorous

Concentration of phosphate ranged from BDL to 2.15 μmol $^{-1}$ and 0.05–2.24 μmol $^{-1}$ for surface and bottom waters respectively. TP concentrations ranged from 0.09 to 2.25 and 0.16 to 2.92 μmol $^{-1}$ for the surface and bottom water respectively. The highest concentration of phosphate and TP for both surface and bottom waters was recorded at Pattinapakkam (Figure 3e-f), which could be attributed to the discharge of effluents from the Chennai city. Phosphate concentration in coastal waters depends upon its concentration in the fresh water that mixed with the seawater within the land-sea interaction zone, phytoplankton uptake, addition through localized upwelling and replenishment as a result of microbial decomposition of organic matter[48]. Usually seawater serves as the main source of phosphate in estuarine and coastal waters except those receives fresh water contaminated with domestic wastes containing detergent and wastes from agro field rich with phosphate-phosphorous fertilizer. Interestingly, though concentrations of nitrogenous nutrients were relatively high at Kovalam, phosphate and TP contents were relatively low at this location. This could be attributed to the fact that, phosphate often acts as the limiting nutrient in estuarine and coastal environment due to its low availability and it is rapidly utilized by the phytoplankton community[40]. Thus, the thriving phytoplankton biomass in the Muttukadu backwaters and the adjoining coastal waters might have played a significant role in reduction of phosphate concentration in that locality.

Silicate

Silicate contents ranged from 4.05 to 21.08 μmol $^{-1}$ in surface and 6.45 to 27.23 μmol $^{-1}$ in bottom water samples. Poombukar and Marakkanam samples showed relatively high concentrations of silicate in the surface samples (Figure 3g). The spatio-temporal variation of silicate in coastal water is influenced by several factors, more importantly the proportional physical mixing of sea water with fresh water and adsorption of reactive silicate into suspended sedimentary particles[41]. Biological removal by phytoplankton, especially by diatoms and silicoflagellates[42] has also been reported as one of the important factors of silicate distribution. Moreover, chemical interaction with clay minerals[43-44] and co-precipitation with humic compounds and iron also play a significant role. In the present study, silicate concentrations did not show any spatial trends as that of nitrate and phosphate.

Cluster analysis

Cluster analysis (CA) is an important tool to find out the spatio-temporal patterns in water quality[45-46]. In the present study, CA was carried out in order to find out a clear picture of water mass characteristics spatially. Agglomerative hierarchical

clustering for similarity among the sampling locations developed 4 clusters (Figure 4). Cluster-1 comprised of 4 locations such as Marakanam, Poombukar, Pondicherry and Parangipettai. All these locations showed relatively low concentrations of almost all the nutrients with similar physical properties (Figure 2 & 3). It indicated that, these four locations are least influenced by anthropogenic impacts. Two locations i.e. Kalpakkam and Kovalam combined together formed the 2nd cluster. These two locations showed an intermediate type of water mass characteristics with moderately high concentrations of nutrients as compared to the four southern locations in the 1st cluster. Pattinapakkam which is relatively polluted as compared to Kalpakkam and Kovalam, formed the 3rd cluster. Ennore which is a highly polluted area, alone formed the 4th cluster. In broader sense, the cluster analysis indicated that Kovalam and Kalpakkam coastal waters behaved as the buffer zone between the least influenced environments of southern locations (Marakanam, Poombukar, Pondicherry and Parangipettai) and the highly polluted northern locations (Ennore and Pattinapakkam) near the metropolitan city Chennai.
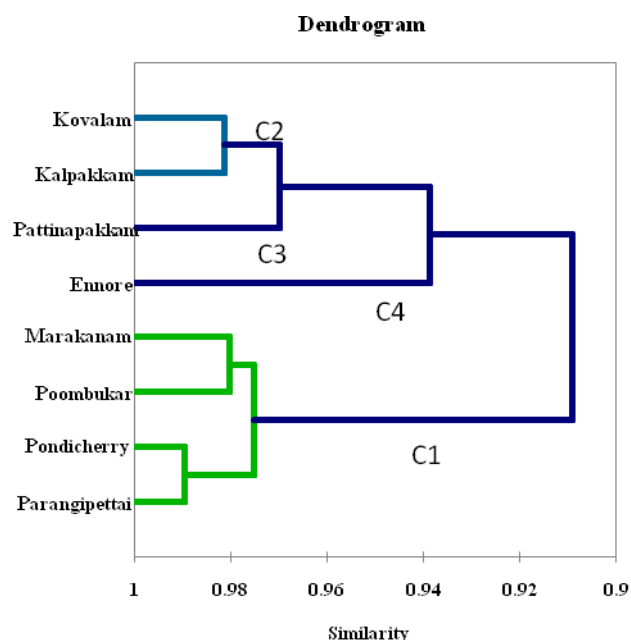
Conclusion

A significant spatial variation in physico-chemical properties of the coastal waters was observed along the Tamil Nadu coast. Sampling locations near to the mega city Chennai showed relatively high concentrations of almost all the nutrients. Similarly, northern locations (near to Chennai) also exhibited fluctuations in physical parameters as compared to the southern locations. A clear decreasing trend in nitrate and phosphate was observed from the northern to southern locations. Correlation analysis showed positive correlations among all the nutrients indicating their common source of origin through external input by the estuaries and backwaters. Cluster analysis clearly indicated the presence of a polluted zone (near to Chennai), a buffering zone (kovalam and Kalpakkam coastal waters) and a least effected environment in the southern region (Marakanam, Poombukar, Pondicherry and Parangipettai) of the study area.

Figure 4: Dendrogram showing the similarty clusters developed among the eight coastal sampling locations along Tamil Nadu coast

References

1. Satpathy, K.K., Seasonal distribution of nutrients in the coastal waters of Kalpakkam, East Coast of India, *Indian J Mar Sci*., 25 (1996) 221–224.
2. Satpathy, K.K., Eswaran, M.S., Nair, K.V.K., Distribution of temperature in the vicinity of a condenser outfall in Kalpakkam coastal waters. J Mar. Biol. Ass. India, 28 (1986) 151-158.
3. Harvey, H. W., The chemistry and fertility of seawater, *London: Cambridge University Press*, (1960).
4. Grant, G. M., Gross, E., Oceanography-A View of the Earth, *Prentice-Hall, USA*, (1966) 472.
5. Delsman, H.C., Preliminary plankton investigations in the Java Sea, *Treubia*, 17 (1939) 139.
6. Kow, T. Ah., A preliminary study of the physica l, chemica l and biological characteristics of Singapore Straits, *Fish- Publn., Lond*., 1(4) (1953) 123.
7. Chidambaram, K ., Menon, M.D., The correlation of the West coast (Malabar and South Kanara) fisheries with plankton and certain oceanographical factors, *Proc. Ind. Acad. Sci*., 27 (1945) 355-367.
8. Jayaraman, R., Observations on the chemistry of the waters of the Bay of Bengal off Madras city during 1948-49, *Proc. Indian Acad. Sci*., 33 (1951) 92-99.
9. Ramamurthy, S., Hydrobiological studies in Madras coastal waters, *J. Madras Univ*., 23 (1953) 143-163.
10. Jayaraman, R., Seasonal variations in salinity, dissolved oxygen and nutrient salts in the inshore waters of the Gulf of Mannar and Palk Bay near Mandapam (S. India), *Indian J. Fish*., 1 (1954) 345-64.
11. George, P. C., The marine plankton of the coastalwaters of Calicut with observations on the hydrologi-cal conditions. *Journal of Zoological Society of India*, 5 (1953) 76–103.

12. Seshappa, G., Phosphate content of mudbanks along the Malabar coast, *Nature*, 171 (1953) 526.

13. Gouda, R., Panigrahy, R. C., Ecology of phytoplankton in coastal waters off Gopalpur, east coast of India. *Indian J. Mar. Sci*., 25(2) (1996) 81-84.

14. Panigrahy, R.C., Mishra, S., Sahu, G., Mohanty, A.K., Seasonal distribution of phytoplankton in the surf water off Gopalpur, east coast of India, *J. Mar. Biol. Ass*., 48 (2006) 156-160.

15. Satpathy, K.K., Mohanty, A.K., Prasad, M.V.R., Natesan, U., Sarkar, S. K., Rajan, M., Post-tsunami changes in water quality of Kalpakkam coastal waters, east coast of India with specialreferences to nutrients, *Asian J. Water Env. Poll*., 5 (2008) 15–3.

16. Satpathy, K.K., Mohanty, A.K, Prasad , M.V.R., Natesan, U., Sarkar, S.K., Seasonal variation in physicochemical properties of coastal waters of Kalpakkam, east coast of India with special emphasis on nutrients, *Environ Mon Ass*., 164 (2010) 153–171.

17. Sahu, G., Satpathy, K.K., Mohanty, A.K. and Sarkar, S.K.. Variations in community structure of phytoplankton in relation to physicochemical properties of coastal waters, southeast coast of India, *Indian Journal of Geo-Marine Sciences,* 41(2012.) 223-241.

18. Achary M.S, Panigrahi, S., Satpathy, K.K., Sahu, G., Mohanty, A.K., Panigrahy, R.C. Nutrient dynamics and seasonal variation of phytoplankton assemblages in the coastal waters of southwest Bay of Bengal, *Environmental Monitoring and Assessment*, 186 (2014) 5681-5695.

19. Chitrarasu, P., Jawahar Ali , A., Babuthangadurai, T., Manickam, N., Studies on the heavy metal analysis of sediment at Ennore Estuary in Southeast coast of India, *Current Biotica* 7(1&2) (2013) 1-7.

20. Jayaprakash, M., Srinivasalu, S., Jonathan, M.P., Mohan, V.R ., A baseline study of physico-chemical parameters and trace metals in waters of Ennore Creek, Chennai, India, *Marine pollution bulletin*, 50 (5) (2005) 583-589.

21. Shanthi, V., Gajendran, N., The impact of water pollution on the socio-economic status of the stakeholders of Ennore Creek, Bay of Bengal (India): Part I, *Indian Journal of Science and Technology*, 2(3) (2009) 66-79.

22. Venugopal, T., Giridharan, L., Jayaprakash, M., Velmurugan, P.M., A comprehensive geochemical evaluation of the water quality of River Adyar, India. *Bulletin of Environmental Contamination and Toxicology*, 82(2) (2009) 211-7

23. Wyrtki, K., Physical oceanography of the Indian Ocean. In B. Zeitzshel (Ed.), Biology of the Indian Ocean, (1973).

24. Satpathy, K.K., Mohanty, A.K., Sahu, G., Natesan, U., Sarkar, S.K., Venkatesan, R., Prasad, M.V.R., Variation of physio-chemical properties in Kalpakkam coastal waters East Coast of India during South-West to North-East monsoon transition period. J Environmental Monitoring Assessment, 171 (2010) 411-424.

25. Vinayachandran, P. N., Masumoto, Y., Mikawa, T., Yamagata, T., Intrusion of the Southwest Monsoon Current into the Bay of Bengal, *Journal of Geophysical Research*, 104 (1999) 11077–11085.

26. Hugen, V.E., Vinayachandran, P.N., Yamagata, T. J., Comment on Indian Ocean: validation of the Miami Isopycnic coordinate Ocean Model and ENSO events during 1958-1998, *Geophys. Res*., 108 (2003) 3179.

27. Satpathy, K.K., Sahu, G., Mohanty, A.K., Prasad, M.V.R., Panigrahy, R.C., Phytoplankton community structure and its variability during SW to NE monsoon transition in the coastal waters of Kalpakkam, East coast of India. J Oceans & Oceanography, 30 (2009) 43-74.

28. Ramaraju, V.S., Sarma, V.V., Rao, P.B., Rao, V.S., Water masses of Visakhapatnam shelf, Physical processes in Indian seas (Proceedings of First Convention, ISPSO), (1992) 75-78.

29. Babu, M.T., In Proceedings Symposium on Physical Processes in the Indian Seas, *Proceedings of First Convention ISPSO*, (1992) 57-62.

30. Saravanane, N., Nandakumar, K., Durairaj, G., Nair, K. V. K., Plankton as indicators of coastal water bodies during southwest to northeast monsoon transition at Kalpakkam, *Current Science*, 78 (2000) 173–176.

31. Satpathy, K.K., Mohanty, A.K., Sahu, G., Sarguru, S., Sarkar, S.K., Natesan, U., Spatio temporal variation in physico- chemical properties of coastal waters off Kalpakkam, southeast coast of India, during summer, pre-monsoon and post-monsoon period. J Environmental Monitoring & Assessment, 180 (2011) 41-62.

32. Grasshoff, K., Ehrhardt, M., Kremling, K., Methods of seawater analysis, *Wiley-VCH, New York*, (1983) 419.

33. Parsons, T.R., Maita, Y., Lalli, C.M., A manual of chemical and biological methods for Seawater analysis, *Pergamon Press, New York*, (1984) 1-173.

34. Borrego, M.H., Borrego, S. A., Temporal and spatial variability of temperature and in two coastal lagoons, *Cal. Coti. Rep*., 23 (1982) 185-197.

35. Riley, J.P., Chester, R., An introduction to Marine Chemistry, *Academic Press, London*, (1971).

36. Granier, J., Billen, G., Palfner, L., Understanding the oxygen budget and related ecological processes in the river Mosel: the RIVERSTRAHLER approach, *Hydrobiol*, 410 (2000) 151-166.

37. Santschi, P., Honener, P., Benoit G., Brink, M.B., Chemical process at the sediment – water interfaces, *Mar. Chem*., 30 (1990) 269-315.

38. Zepp, R.G., Interactions of marine biogeochemical cycle and photodegradation of dissolved organic carbon and dissolved organic nitrogen In: Gianguzza, A.; Pelizzetti, E.; Sammarkano, S.; Ed.; *Marine chemistry, Kluwer Academic Plublication, London*, (1997) 329-352.

39. Gilbert, P. M., Biggs, D. C., McCarthy, J. J., Utilization of ammonium and nitrate during austral summer in the Scotia Sea, *Deep Sea Res*., 29 (1982) 837-850.

40. Cole, C.V.; Sanford, R.L. Proceedings of Symposium on Phosphorous Requirements Sustainable Agriculture in Asia and Oceania, SCOPE/UNEP (1989) 6-10.

41. Lal, D., Transfer of Chemical species through estuaries to oceans, Bio-geochemistry of estuarine sediments (Proc. of UNESCO/SCOR workshop, Melreus, Belgium), (1978). 166-170.

42. Aston, S.R., Nutrients dissolved gasses and general biochemistry in estuaries, Chemistry and biogeochemistry of estuaries, E. Olausson and I. Cato eds., *Jhon Wiley & sons: New York*, (1980) 233-262

43. Liss, P.S., Spencer, C.P., A biological processes in the removal of silicate from seawater, *Geochim. Cosmochim. Acta*., 34 (1970) 1073-1088.

44. Gouda, R., Panigrahy, R.C., Seasonal distribution and behaviour of silicate in the Rushikulya estuary, east coast of India, *Indian J. Mar. Sci.*, 21(2) (1992) 111 - 115.

45. Simeonov V, Simeonova P & Tsitouridou R, Chemometric quality assessment of surface waters two case studies. Chemical and Engineering Ecology, 11 (2004) 449–469.

46. Mohanty, A.K. Sahu G., Bramha, S.N., Samantara, M.K. and Satpathy, K.K.. Assessment of temporal variation in coastal water characteristics through multivariate statistics- A case study at southwestern Bay of Bengal, India, *Indian Journal of Geo-Marine Sciences* 43 (9) (2014) 1718 – 1731.