

**Factors controlling physico-chemical characteristics in the coastal waters off Mangalore –
A multivariate approach**

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Abstract

Water quality parameters (Temperature, pH, salinity, DO, BOD, suspended solids, nutrients, PHc, phenols, trace metals - Pb, Cd and Hg, Chl.a and phaeopigments) and the sediment quality parameters (Total phosphorous, total nitrogen, organic carbon and trace metals) were analysed from samples collected at 15 stations along 3 transects off Karnataka coast (Mangalore harbor in the south to Suratkal in the north), west coast of India during 2007. The analyses showed high ammonia off Suratkal, high nitrite (NO₂-N) and nitrate (NO₃-N) in the nearshore waters off Kulai and high nitrite (NO₂-N) and ammonia (NH₃-N) in the Harbour area. Similarly, high PHc (Petroleum hydrocarbon) values were observed near the harbour, while phenols remained high in the nearshore waters of Kulai and Suratkal. Significantly, high concentrations of cadmium and mercury with respect to the earlier studies were observed off Kulai and Harbor region respectively.

R-mode varimax factor analyses were applied separately to surface and bottom water data sets due to existing stratification in the water column caused by riverine inflow and to sediment data. This helped to understand the interrelationships between the variables and to identify probable source components for explaining the environmental status of the area. Six factors (each for surface and bottom waters) were found responsible for variance (86.9% in surface and 82.4% in bottom) in the coastal waters between Mangalore and Suratkal. In sediments, 4 factors explained 86.8% of the observed total variance.

The variances indicated addition of nutrients and suspended solids to the coastal waters due to weathering and riverine transport and are categorized as natural sources. The observed contamination of coastal waters indicated anthropogenic inputs of Cd and phenol from industrial effluent sources at Kulai and Suratkal, ammonia from wastewater discharges off Kulai and harbour, PHc and Hg from boat traffic and harbour activities of New Mangalore Harbour. However, the strong seasonal currents and the seasonal winds keep the coastal waters well mixed and aerated, which help to disperse the contaminants, without significantly affecting Chlorophyll a concentrations. The inter-relationship between the stations as shown by cluster analyses and depicted in dendograms, categorize the contamination levels sector-wise.

Keywords: Physico-chemical characteristics, chlorophyll a, coastal water, Mangalore –Suratkal coast, R- mode factor analysis, cluster analysis.

1.0 Introduction

Human settlement and the developmental activities along the coastal regions have greatly accelerated environmental pressure on downstream estuarine and coastal ecosystems. Anthropogenic nutrient loads from coastal watersheds to the nearshore waters are dramatically altering aquatic habitats (GESAMP 1990). In estuarine and coastal marine waters, increased nitrogen loads stimulate eutrophication (Galloway et al. 1995), and as a consequence, the assemblage of primary producers found in these waters often changes.

A few coastal regions in India are constantly threatened by sewage and effluent discharges from the metropolis and industrialized areas. Various studies carried out so far in the Indian coastal environment indicate that the coastal environments of Mumbai and Gujarat (Zingde and Govindan, 2000; Zingde and Desai, 1987) along the west coast and Pondicherry along the east coast (Govindasamy and Azariah, 1999; Panigrahy et al., 1999) of India are degraded due to discharges from industrial and domestic outfalls. Since the past one and half decade, the Kulai, a developing industrial town north of Mangalore along the central west coast of India, has been subject to environmental degradation. The industrial wastes from this area are discharged into the coastal water through pipelines, while, the municipal wastes of Mangalore city are discharged into a nulla adjoining the Gurpur River, which empties into the coastal sea off Mangalore. Such discharges may give rise to aquatic pollution, resulting in severe ecosystem modifications, including depletion of fishery resources.

The studies carried out by the National Institute of Oceanography (NIO), Goa (India) during 1997 - 98 in the coastal region from Mangalore to Padubidri revealed significant pollution of the coastal waters off Kulai (Verlecar, 2005), due to industrialization (Table 1). The present systematic study on physical, chemical and biological aspects of seawater and sediments of the coastal belt from New Mangalore harbor to Suratkal, was carried out to assess the existing environmental status, trace the natural and anthropogenic sources and understand their effects on water and sediment quality and biological properties of the area.

2.0 Material and methods

2.1 Environmental setting of the study area

The coastal stretch from Mangalore to Mulki (Fig.1) is low lying and trends in NNW– SSE direction. The coast is generally sandy, fringed with coconut and cassuarina plantations. The bathymetry contours are parallel to the shoreline with beach width varying from 100 to 125 m with respect to high water line. The

shore is even and smoothly carved by sea waves. The continental shelf in this region extends upto 75 km from the coast. The bottom sediments are in general, silty and clayey, except in the nearshore areas, where they are mainly sandy. Rock formations extend out into the sea north of this region.

Netravati is one of the largest rivers in this region, which originates in the Western Ghat and joins the Gurpur River to form a common estuary before entering the Arabian Sea, south of New Mangalore harbour. These two rivers are the main sources of sediments and flood water discharges into the coastal sea. Winds in this region are stronger (of the order of 10 m/s) and westerlies during SW monsoon months (June-September). The current direction is from south to north during November-January, and it reverses in February with strong north to south currents from May to October (Mandal, 1996).

The coastal belt between Mangalore and Suratkal is an industrialised zone and Kulai is a major industrial town between Suratkal and New Mangalore harbour (Fig.1). Various types of small, medium and large size industries are located in this area (Table 1), and they discharge their effluents into the coastal waters off Kulai. The available information indicates that Mangalore Refineries and Petrochemical Ltd (MRPL) discharges 7,200 m³/d, BASF India Ltd., discharges 3,600 m³/d, Mangalore Chemicals and Fertilizers (MCF) discharges 13,000 m³/d, south of Mangalore harbor. All these wastes are likely to impinge on the coastal environment.

2.2. Sampling and analyses

Surface and bottom water samples were collected from 15 locations along the coastal stretch between Mangalore harbor and Suratkal (Fig. 1) using a Niskin water sampler. Soon after collection, the water samples were fixed for dissolved oxygen and DO was measured by Winkler's method, while the collected samples for BOD were measured after 5 days of incubation at 20°C in BOD incubator at the shore laboratory. The nutrients and other parameters were analysed using standard methods as given by Strickland and Parsons (1979), APHA (1992) and Grasshoff (1999), and are given in Table 2.

The trace metals, Lead (Pb) and Cadmium (Cd) in seawater were analysed by taking precaution to avoid contamination from all possible sources. The samples were vacuum filtered with 0.45 µm Millipore membrane filter and the filtrate was adjusted to pH < 3 using ultra pure HNO₃. The pre-concentration of Pb and Cd metals was done by chelating them with ammonium pyrrolidine dithiocarbamate (APDC), followed by extraction in methyl isobutyl ketone (MIBK). The organic extract was back extracted in ultra pure HNO₃. The Pb and Cd were then measured in an inorganic extract using a graphite furnace AAS. Blanks and standards were run in a similar manner for calibration.

Seawater samples were acidified to pH < 2.0 with 9 N H₂SO₄ for Mercury (Hg) analyses. Acidified samples were extracted in dithiozone and the organic extract was back extracted in 5M HCl. The acid extract was treated with NaNO₂ to decompose dithiozone and revert Hg to the aqueous phase. The inorganic mercury compounds were reduced to elemental mercury by treating with stannous chloride and measured by cold vapour AAS.

Sediments collected using van-Veen grab were sealed in plastic bags and kept frozen till analyses. For the determination of Pb and Cd in sediments, the sediments were first oven dried at 110 °C, powdered and homogenized. The metals in sediment were brought into solution phase by wet digesting a known aliquot of sediment sample with HF in pre-cleaned, acid washed Teflon beakers, followed by treatment with HNO₃ and HClO₄ to remove organic matter on a hot plate. After evaporation of acid, the residue was dissolved in dilute HCl and the Pb and Cd concentrations were measured by flame AAS.

The sediment samples oven dried at 40°C were crushed to fine powder. About 0.5 g aliquots of each sample was transferred into 300 ml BOD bottles (in duplicates) containing 5 ml Milli Q water and 5 ml aqua regia and the mixture was heated in a water bath at 90°C for 2 min. The samples were then allowed to cool and treated with 20 ml Milli Q water and 15 ml KMnO₄. After thorough mixing, the samples were heated again in a water bath at 90°C for 30 min. On cooling to room temperature, a mixture of sodium chloride-hydroxyl amine hydrochloride reagent was added to each bottle to reduce excess permanganate and the final volume was made up to 750 ml. Blanks and standards were also digested in a similar manner. Total Mercury in the final solution was reduced to elemental mercury by treating with 5ml of 20% stannous chloride. The resultant elemental Hg was measured by cold vapour AAS at 253.7 nm.

Total phosphorous and total nitrogen were analysed from sediments oven dried at 40°C and then finely powdered. The powdered sediment samples were digested in an autoclave with 5% alkaline potassium persulfate solution to decompose the organic matter. The liberated phosphate and nitrates were then analysed as per the spectrophotometric method used for the analyses of dissolved inorganic phosphate and nitrate in water (Grasshoff, 1999).

2.3. Hydrodynamics

In order to get the flow pattern of the region, 2 moorings were deployed at 2 locations (one in the north and other in the south; Fig.1) using the RCM – 9 MK II current meters, manufactured by Aanderaa Co., Norway. The two locations (13 m and 15 m water depths respectively) were separated by a distance of approximately 10km. Current measurements were carried out for one month (12 April 2007 to 11 May

2007) at 10 min sampling interval. As the depth contours are parallel to the coast, and flow pattern is nearly the same, it is sufficient to have 2 current measurement locations. The vertical profiles of temperature and salinity were obtained from different locations using a portable SBE 19 SEACAT Profiler, manufactured by Sea-Bird Electronic, Inc., USA. Vertical profiles were continued for the period 14 -19 April 2007.

2.4. Multivariate statistical analysis

a) Principle Component Analysis

The data collected was subject to multivariate statistical analysis to understand the influence of various parameters on biological component of the system. Multivariate statistical approaches such as Principle Component Analysis (PCA), also called the Factor analysis, Multiple Regression Analysis (MRA) and the Cluster Analysis (CA) have been used by several researchers for deriving the significance of specific parameters among the data generated (Vega et al., 1998; Helena et al., 2000; Simenova et al., 2003; Singh et al., 2004, Wunderlin et al, 2001 and Richman,1986).

R-mode (sorted) factor analysis resulted in Eigen values, percentage of variance and cumulative percentage for total stations in the system, allowing inter parameter relation and variation at surface and bottom water layers. Factor analyses of the present data set of the coastal water from Mangalore to Suratkal were further sorted by contribution of less significant variables (<0.4 factor score). A varimax rotation of different varifactors with factor loading was calculated using eigen value greater than 1 and sorted by the results having values greater than 0.4, based on significant influence (Sahu et al., 1998, Panigraphy et al., 1999 and Rath et al., 2000). Rotation of the axis defined by factor analyses produced a new set of factors, each one involving primarily a sub set of the original variables with a little overlap as possible so that original variables are divided into groups. The factor loading was classified as per Liu et al (2003), who categorized the factor loadings as “strong”, “moderate” and “weak” corresponding to absolute loading values of >0.75 as “strong”, of 0.75-0.5 as “moderate” and of 0.50 – 0.40 as “weak”.

b) Multiple Regression Analysis

Linear multiple regression analysis was performed by enter method using SPSS 10.0 in order to find out the impact of predictor variable (Independent) on criterion variable (Dependent). Here, the influence of hydrologic parameters on phytoplankton biomass could be analysed, hence Chl.a is chosen as the criterion variable in the present study. The co-linearity diagnostics with descriptive statistics is also

studied in order to investigate the correlation among the predictor variable that results insignificant (Tolerance level > 0.01 and Adjusted R² = 0.470).

c) Cluster Analysis

Interrelationship among the stations during the study period has been characterized by cluster analysis using Ward's method (Linkage between groups) and similarity measurements (Table 10) by Euclidian distance as demonstrated in horizontal dendograms. The dendograms are shown separately for the surface and bottom water and the sediment system in two sets among the variables to understand the association of stations having similar parameters. The dendograms separate the stations getting influenced from different sources.

3.0 Results

3.1. Physical aspects: *Temperature, Salinity, Density and Current Pattern*

Vertical profiles of temperature measured along 5 transects (Fig.1), show that the sea surface temperature (SST) varies from 30.73°C to 30.97°C off Mangalore, with a slight increase of 30.83°C to 31.32 °C off Suratkal. The profiles show a temperature inversion within 5 to 15 m depth. This is due to advection of cold, less saline riverine water over the warm saline coastal water. The horizontal temperature variation between Mangalore and Mulki is 0.2°C and the vertical temperature gradient is around 1.1°C. Vertical profiles of salinity along the 5 transects show wide variation in surface salinity (34.92 to 36.42 psu), with lowest salinity of 34.92 psu near the Mangalore coast. Off Suratkal, the surface salinity varies from 34.78 to 35.96 psu (35.96 psu near the coast), decreasing towards offshore. An average salinity gradient of 0.2 psu was found towards the coast from offshore.

Stratification of water column is evident towards the coast. The horizontal distribution of density structure off Mangalore show less dense waters near the coast (minimum density of 21.28 kg/m³) and denser water offshore (maximum density of 23.12 kg/m³). The stratification along the coast extends from Mangalore harbour to Mulki. The currents off Mangalore indicate southerly currents off Suratkal and Mulki with a maximum speed of 0.40 m/s. Frequent spells of current reversal with weak northerly currents were also observed during April to May 2007 (Fig. 2 a,b).

3.2. Chemical Aspects:

i) Water Quality

The variation in hydrographic parameters and their averages are given in Table 3. Surface water shows higher temperature relative to bottom water and increases away from the shore, which is more prominent off Harbour and Kulai (Fig. 3a). pH in surface water shows increasing values away from the shore, with a virtual reverse trend in bottom water layer (Fig. 3b). Well aerated waters with higher DO in surface (av. 5.29 mg/l) and lower in bottom water (av. 4.67 mg/l) are evident at all the stations (Fig. 3d). Biochemical oxygen demand (BOD) shows nearly similar values in surface and bottom waters (av. 1.52 mg/l). In the offshore at Kulai and near the Harbour region, higher BOD was noticed in the range of 3.58 to 4.57 mg/l, both in surface and bottom layers (Fig. 3e), while a high of 3.76 mg/l was observed off Suratkal. Total suspended solids (TSS) increase shoreward from Mangalore harbour to Suratkal, indicating addition of TSS, either from external sources or due to turbulence (Table 3f).

Nutrients show wide variation, with phosphate increasing from Harbor to Kulai with a decrease further off Suratkal, with higher values in bottom water (av. 1.03 $\mu\text{mol/l}$) relative to surface (av. 0.96 $\mu\text{mol/l}$; Fig. 4a). Nitrate and nitrite also follow the phosphate distribution pattern and remain high at bottom relative to surface at most of the stations from Harbor to Suratkal, and indicate an increase towards the shore. Near Suratkal, the surface nitrate shows wider variation (0.59 – 3.74 $\mu\text{mol/l}$), while at Harbour, the variation is narrow (1.74 – 2.91 $\mu\text{mol/l}$). Off Kulai, its range is from 1.38 to 3.07 $\mu\text{mol/l}$. Similarly, the nitrite is more prominent near Suratkal and off Mangalore harbour (Fig. 4b), indicating its input from external sources (Fig. 4c). Ammonia remains high in Harbour area, decreases in Kulai and increases further at bottom in the offshore at Suratkal (Fig. 4d). The high values are observed in the surface water near Harbour and also to some extent in Kulai. Silicates increase from Harbor to Suratkal with bottom water showing higher values (Fig. 4e).

Petroleum hydrocarbons (PHc) and phenolic compounds show higher values towards the shore. Harbor area (66.36 -275.63 $\mu\text{g/l}$; av. 148.77 $\mu\text{g/l}$) and off Kulai (11 – 246 $\mu\text{g/l}$; av. 132.8 $\mu\text{g/l}$), show higher values of PHc, decreasing further in the north off Suratkal (3.74 – 27.3 $\mu\text{g/l}$; av. 13.6 $\mu\text{g/l}$) (Fig. 5a & b). Vertical distribution shows higher values in surface relative to bottom. Phenols show a different trend as compared to PHc and remain high away from the shore off Suratkal (2.32 – 17.4 $\mu\text{g/l}$; av. 5.7 $\mu\text{g/l}$), which gradually decrease off Kulai (0.46 – 9.03 $\mu\text{g/l}$; av. 3.5 $\mu\text{g/l}$) and increase slightly in Harbour area (1.39 – 9.96 $\mu\text{g/l}$; av. 4.98 $\mu\text{g/l}$). Phenols show high values in bottom relative to surface in Harbor and Suratkal area and show an opposite trend in Kulai.

Trace metals show wide ranges of variation. Lead concentration varies marginally in Harbour (0.09 – 0.35 µg/l) and Kulai region (0.09 to 0.42 µg/l), while in Suratkal, Pb ranges widely from 0.13 to 1.45 µg/l, with average high value of 0.60 µg/l. Vertical distribution of Pb shows higher surface values relative to bottom off Kulai and Suratkal, with a uniform distribution in surface and bottom water in Harbour area (Fig. 5d). Significantly, high Cd values are observed in Kulai area (0.42 – 26.56 µg/l; av. 9.5 µg/l) > Suratkal (1- 18.49 µg/l; av. 6.12 µg/l) > Harbor area (0.5 – 15.8 µg/l; av. 4.78 µg/l) with increasing values away from the shore. Vertical distribution of Cd shows higher values in bottom layer compared to surface layer. Spatial distribution showed increasing Cd away from the shore, more prominent off Kulai and Suratkal (Fig. 5e). Hg exhibited uniform distribution, both spatially and vertically, with values ranging within 0-100 ng/l, except one localized, significantly high value of 900 ng/l in the bottom water in Harbor area (Stn. H3; Fig.5f).

ii) Sediment Quality

The distribution of total phosphorous (TP), total nitrogen (TN), Organic carbon and the trace metals, including their ranges of variation and the averages are given in Table 4. TP and TN indicate higher values of TP (38.92 – 50.35µg/g; av. 45.9 µg/g) and TN (190-224 µg/g; av. 210.5 µg/g) in Harbor area, moderate values of TP (31.72-52.52 µg/g; av. 39.5 µg/g) and TN (135.8 – 286-3 µg/g; av. 203.7 µg/g) off Suratkal and low values of TP (24-46.64 µg/g; av. 36.6 µg/g) and TN (48.5 – 255.5 µg/g; av. 162.6 µg/g) off Kulai area, indicating a gradual decrease upto Kulai and thereafter an increase further. The stations away from the coast show relatively higher values (Fig. 5).

The sediment organic carbon shows higher values in Harbour area (1.47 – 2.67 %; av. 2.08%) followed by those at stations off Suratkal (1 – 2.82%; av. 1.89%), with relatively lower values off Kulai (0.21 – 2.52%; av. 1.55%). The distribution shows increasing Org. C away from the shore, with the highest values at mid stations along the 3 transects.

Trace metals show lower values of Pb (9.45 – 26 µg/g; av. 18.43 µg/g) in Harbour area, gradually increasing at Kulai (14.31 – 26.16 µg/g; av. 21.74 µg/g), with a further increase off Suratkal (18.42 – 26.7 µg/g; av. 23.46 µg/g). The stations away from the shore show higher concentrations of Pb. The Cd increases gradually from Harbor (0.99 – 1.50 µg/g; av. 1.19 µg/g) to Kulai (0.93 – 1.59 µg/g; av. 1.42 µg/g) with a further increase north off Suratkal (1.2 – 2.0 µg/g; av. 1.53 µg/g). The mid stations along the transects show virtual high values of Cd. The Hg remains high in sediments relative to water column. The highest Hg values are observed in Kulai area (18.18 – 922.7ng/g; av. 222.7ng/g), and the

lowest values (13.64 – 72.73ng/g; av. 35.78ng/g) in the northern stations off Suratkal. The Harbour region shows relatively moderate values (104.97 – 222.73 ng/g; av. 63.67ng/g).

3.3 Biological aspects:

i) Water Quality

Chl.a in seawater shows higher values in surface layer increasing from Harbour to Suratkal in the north. In Harbour area, the Chl.a varies from 0.2 to 0.45mg/l (av. 0.3mg/l), while in Kulai it varies from 0.11 to 0.63 mg/l (av. 0.29 mg/g). In Suratkal area, Chl. a shows relatively higher values (0.09 – 0.74 mg/l; av. 0.32mg/l; Fig. 5c). Phaeophytin also shows a similar trend of variation as that of Chl. a and varies from 0.02 to 0.28 mg/l (av. 0.12 mg/l) in Harbour area, and from 0.01 to 0.17 mg/l (av. 0.09 mg/g) in Kulai area. In Suratkal, its variation is from 0.05 to 0.63 mg/l (av. 0.16 mg/g).

The Chl.a /Phaeophytin ratios show higher values in bottom water in Harbour area (2.6 – 10; av.5.5) and Kulai region (2 – 6.9; av. 2.6), while Suratkal shows higher values in surface (1.6 – 7.5; av. 4.2), relative to bottom water. Ratios show gradual increase from harbour (av. 4.5) to Kulai (av. 5.46) with a decrease at Suratkal (av. 3). Lower ratios of 1 and below 1 are observed in bottom waters off Suratkal.

ii) Sediment quality

Chl. a and Phaeophytin in sediments increase gradually from Harbour to Suratkal. In Harbour area, the Chl. a variation is from 0.11 to 0.31 mg/g (av. 0.23 mg/g), while at Kulai it increases from 0.20 to 0.34 mg/g (av. 0.28 mg/g), with a further increase off Suratkal (0.21 to 0.42 mg/g; av. 0.30 mg/g). This variation show increasing values away from the shore at Kulai and Suratkal and a reverse trend in Harbor area. Phaeophytin follows the trend of Chl. a variation and shows increasing values from Harbour to Suratkal area. In Harbour area, the phaeophytin varies from 1.11 to 2.02 mg/g (av. 1.70 mg/g), while off Kulai it varies from 1.73 to 2.10 mg/g (av. 1.87 mg/g). In Suratkal area, its variation is from 1.26 to 2.31mg/g (av. 1.80 mg/g), with a distribution similar to that of Chl.a.

4.0 Discussion

The data shows large variation in chemical parameters particularly ammonia, nitrite, nitrate, PHc, phenols, cadmium and mercury. The significance of these variations was judged by comparing it with the earlier studies from the same environment. Literature surveys indicate that despite various studies (as seen in the internal reports) carried out in this environment in the past few decades, publication of the physico-chemical data is rare. Most of these studies have been carried out by the National Institute

of Oceanography, Goa from 1995 to 1998 for impact assessment of developmental activities. Also, data on various water and sediment quality parameters along the Karnatak coast has been collected over a period of 20 years (1977 to 1997) by NIO's research vessels, R.V.Gaveshani and CRV Sagar Paschimi and these data have also been analyzed for this work.

All this data indicate increase in nutrients and PHc, and low trace metals during 1996 along the Kulai-Padubidri coastal sector where, increases in ammonia was found to trigger phytoplankton bloom during 1996 (NIO, 1996). Higher concentration of subsurface nitrite (1.52 $\mu\text{mol/l}$) and nitrate (10.8 $\mu\text{mol/l}$) values during the post monsoon period of 1995 and 1998 were observed due to their release from bottom sediments and land drainage (NIO, 1995, 1998). The high phosphates and ammonia were observed to the extent of 2.34 $\mu\text{mol/l}$, while trace metals concentration was much less (Pb: 1-5.1 $\mu\text{g/l}$; Cd: ND – 2.2 $\mu\text{g/l}$ and Hg: 0.33 – 1.53 $\mu\text{g/l}$). Near shore sediments showed low Cd (1.6 ppm) as compared to Pb (14.86ppm) and Hg (0.07ppm). Similarly, increase in PHc was also reported near the Kulai region (NIO, 1998). Other studies carried out during 1996 for the COMAPS (Coastal Ocean Monitoring and Prediction Systems) work, showed increases in ammonia from 15 – 4.3 $\mu\text{mol/l}$ accompanied by a decrease in DO (2.45 – 3.73ml/l). Our data when compared with these observations indicate further increases in ammonia, nitrate, nitrite, PHc, phenols and the trace metals such as cadmium and mercury, which show a gradual increase in the coastal stretch from New Mangalore harbour to Suratkal. No natural sources have been observed to increase the concentration of these parameters in the coastal water. All the available information indicate anthropogenic activity as a source. One of the techniques used recently in identifying the sources is the PCA. This technique was applied separately to the water quality parameters of the surface and bottom water layers due to stratification caused by the riverine flow, both of which helped in identifying dominant parameters in the environment.

Surface water

The PCA of water quality parameters from the surface water indicates that in surface layer, altogether 6 factors (principal components) explain 86.9% of the total variance. **Factor 1** accounts for 26% of the total variance and is associated with strong positive loadings of silicate, phosphate, nitrite, nitrate; moderate positive loading of TSS, weak positive loading of PHc and a strong negative loading of pH (Table 5). In this factor, the nutrients (phosphate, nitrite, nitrate and silica) correlate significantly with each other and with TSS (Table 6), suggesting a common source. They correlate negatively with pH, indicating that at higher pH, the nutrients and TSS get decreased. Results show that the nearshore water, which contains high nutrients (Fig. 4a – c) and TSS (Fig. 3f) exhibit low pH values as compared

to offshore waters (Fig.3b). Hence, the strong negative loading of pH by this factor with positive scores of nutrients therefore represents a riverine influence and suggests that the nutrients and TSS are contributed by rivers. Hence, Factor 1 can be termed as the Riverine Factor, **Factor 2** explains 42% of the total variance and is associated with strong positive loadings of mercury and lead, weak positive loading of phaeophytin, moderate negative loading of PHc and a weak negative loading of TSS. In this case, mercury correlates positively with lead, suggesting a common source. Similarly, the TSS correlates positively with PHc and negatively with mercury, while the relationship of TSS with lead is not significant, indicating that the contribution of TSS to Hg and Pb is insignificant, and Hg and Pb are not associated with a riverine source. On the other hand, the significant positive correlation of TSS with PHc indicates that the TSS serves as a base to hold the PHc adsorbed on to the suspended particulates in these coastal water. The Factor 2 can therefore be called a Metal Contamination Factor,

Factor 3 explains 58% of the total variance and is associated with strong positive loadings of BOD and DO, weak positive loading of chlorophyll a and a strong negative loading of salinity. In this case, DO and BOD correlate positively with each other and negatively with salinity, indicating a decrease in their content with increasing salinity. Hence, the higher DO values at nearshore waters are due to the incursion of less saline riverine water as compared to high saline offshore waters. Moreover, the increased BOD with a decreasing salinity also indicates that BOD is contributed by the riverine source. However, the weak correlation between Chl.a and salinity and a weak positive correlation with DO and BOD suggests that Chl.a is not much influenced by other loadings but remains independent under the existing environmental conditions in this coastal environment. This factor can therefore be termed as the Productivity Factor, **Factor 4** explains 69% of the total variance and is associated with a strong positive loading of ammonia and moderate positive loading of phaeophytin with a moderate negative loading of temperature. In this case, ammonia does not correlate significantly with phaeophytin. Neither the phaeophytin nor ammonia correlates well with temperature. This factor therefore suggests the dominance of ammonia. Fig (4d), shows localized pockets of high ammonia concentrations near Mangalore harbour and offshore at Suratkal, more evident in bottom layer. The discharge of effluents from bottom water probably from the industrial outfall appears to be the cause of this possible contamination. This factor can be termed as the Ammonia Contamination Factor,

Factor 5 explains 79% of the total variance and is associated with a strong positive loading of cadmium, moderate negative loading of Chl.a and a weak negative loading of salinity. In this case, the cadmium correlates negatively with salinity. The salinity gradient observed in this region is the result of dilution by riverine water nearshore and increasingly saline water offshore. The enhanced cadmium concentrations in the coastal seawater (Fig. 5e) are observed as a patch of high concentrations from

near shore to offshore at Kulai and a localized hot spot in the offshore at Suratkal. This can arise either from effluent discharges in the coastal water or due to waste discharges from nearshore activities. The Chl. a does not correlate significantly with cadmium or with salinity, indicating insignificant influence of cadmium on Chl.a. This factor thus shows the contamination of Cd due to its strong positive loading and the fifth factor can therefore be termed as a Cadmium Contamination Factor. **Factor 6** explains 86.9% of the total variance and is associated with a strong positive loading of phenol and a weak negative loading of temperature. This shows that the presence of phenol in coastal water is independent of other variables and suggests its dominance. However, its negative correlation with temperature is not significant but indicates only a virtual reverse trend. Fig.(5b) shows localized high phenol concentrations nearshore at Kulai and offshore at Suratkal, from where it dissipates in the surrounding area. The source of phenol could therefore be closer to the shore at Kulai, where the industrial discharge from refinery is located and this factor can therefore be termed the Phenol Contamination Factor.

Three major clusters account for grouping of stations in surface layer. Cluster-I is related to river water influenced stations (can be considered as natural background type) and the similar characteristics are acquired by the area off Kulai (Station-K6). Cluster-II is related to harbor activity and can be treated as highly polluted group separated from others. Cluster-III is associated with industrial discharges and these stations are distantly related to stations off Mangalore harbor and off Kulai (Fig.6).

Bottom water

The bottom waters exhibited a different scenario. Altogether six factors account for 82.4% of the total observed variance in bottom water layer. **Factor 1** explains 20.7% of the total variance and is strongly loaded positively with phosphate, silicate and TSS, weakly loaded positively with phaeopigments and nitrite, and weak negative loadings of phenol and salinity. The phosphates, silicates, nitrites and TSS correlate positively with each other, but the correlations of salinity with phosphates, nitrites and silicates with TSS and that of phaeopigments with phenols are negative but not very significant. This suggests that the contribution of nutrients to the coastal water is mostly from riverine sources. This factor being similar to that observed in surface water, could therefore be termed as the Riverine Factor. **Factor 2** explains 36.7% of the total variance and is associated with strong positive loadings of DO, nitrate and PHc, moderate negative loading of phaeopigments and a weak negative loading of salinity (Table 5). Salinity does not show any valid relationship with DO, nitrate and PHc (Table 6), while, higher PHc values can be seen in Mangalore harbour area (Fig.5a), decreasing towards offshore. The dominance of PHc in this region is largely due to shipping and other harbour activities. This dominance of PHc in

the coastal water indicates contamination, and this factor can be termed as the PHc Contamination Factor.

Factor 3 explains 50.2% of the total variance and is associated with a strong positive loading of Chl.a and a moderate positive loading of pH, with a moderate negative loading of ammonia and a weak negative loading of cadmium (Table 5). The correlation of pH with Chl.a is not significant, but with ammonia and cadmium, it is negative and significant. However, Chl.a shows negative, insignificant correlations with cadmium and ammonia (Table 6). The moderate to weak negative loadings of ammonia and cadmium respectively and their significant negative correlation with pH indicates a source towards the shore. Fig. 4d, shows high concentrations of ammonia nearshore at Harbour and offshore at Suratkal. Similarly, Fig. 5e shows hot spots of cadmium from nearshore to offshore at Kulai and away from the coast off Suratkal. These contributions of ammonia and cadmium appear to come from external sources, mostly from the industrial effluent discharges in the coastal water and from nearshore waste discharges. Fig. (5c) shows a patch of high Chl.a in surface in the offshore at Kulai and Suratkal, while a patch of high concentration in the bottom water layer near the harbor region, suggesting the dominance of Chl. a in these areas where ammonia and cadmium remain high. This indicates that Chl.a is independent of the presence of ammonia and cadmium and suggests productive waters. So, Factor 3 can therefore be termed as the Productivity Factor. **Factor 4** explains 63% of the total variance and indicates strong positive loading of lead, moderate positive loading of nitrite with weak negative loadings of temperature, phenol and ammonia (Table 5). Lead and nitrite do not correlate well with each other to indicate any common source, neither they correlate well with temperature, phenol and ammonia (Table 6). This factor shows the dominance of lead due to its strong loading, which is seen as a patch of high concentrations in surface and bottom layers away from the shore in the north off Suratkal (Fig. 5d). The Factor 4 can thus be called the Lead Contamination Factor.

Factor 5 explains 75% of the total variance and shows strong positive loadings of BOD and cadmium and weak negative loadings of phenol and pH (Table 5). Cadmium correlates positively with BOD and negatively with pH, whereas the correlations of BOD with phenol and pH and those of cadmium with phenol are not significant (Table 6). This apparently indicates that cadmium is associated with waste discharges in the coastal water, which can be seen as a patch of high concentrations from nearshore to offshore water at Kulai (Fig. 5e). This waste water discharge could contain BOD as well as phenol along with cadmium. So, Factor 5 can be termed as the Cadmium Contamination Factor. **Factor 6** explains 82.4% of the total variance and is loaded weakly positively with temperature and strongly negatively with mercury. The negative correlation of mercury with temperature is not significant. This shows that mercury is independent of other variables and does not indicate a riverine source but rather

a source within the coastal water, probably from the wastewater discharge, which shows increasing concentrations from nearshore to offshore in surface waters off Suratkal area (Fig.5f). This factor can therefore be termed as the Mercury Contamination Factor.

Two major clusters clearly distinguish the stations of different characteristics. Cluster-I is associated with riverine influenced stations off Suratkal but similar conditions have been described by Station-K6 off Kulai area. Cluster-II is related to pollutants discharged from harbor as well as industries getting saturated along the water column.

Sediments

In the case of sediments, total 4 factors explain about 86.8% of the total variance. **Factor 1** explains 37.7% of the total variance and is associated with strong positive loadings of total nitrogen (TN), organic carbon and total phosphorous (TP), moderate positive loadings of lead and cadmium and a weak negative loading of mercury. The strong positive loadings of TP, TN and organic carbon explain the enrichment of sediment with organic matter, which reflects either high productivity or the addition of organic substances from external sources, whereas, the moderate positive loadings of lead and cadmium and their significant positive correlation with each other (Table 8) as well as with TN, TP and organic carbon indicate their association with organic matter in sediments. In the coastal environment, the cadmium is found to be complexed with chloride ions in seawater and also with the organic matter (Mouchel, 1990). The weak negative loading of mercury and its inverse relation with OC and TN indicates that its contribution to sediments is not directly from external organic matter. This factor could be associated with the Organic matter of sediments. **Factor 2** is responsible for 55.3% of the total variance and shows a moderate positive loading of cadmium, a weak positive loading of mercury and a strong negative loading of the overlying water salinity. This shows that cadmium and mercury are added to the sediments at decreasing water salinity levels. A decrease in salinity is observed in the nearshore region where wind induced turbulence brings about mixing of riverine water with coastal seawater and the settled sediments get re-suspended due to shallow depth. These suspended particles in the water column adsorb cadmium and mercury and remove them to sediments. So, Factor 2 can be called the Adsorption Factor.

Factor 3 explains 71% of the total variance and shows strong positive loadings of lead and overlying water pH, indicating that the lead in sediment increases with higher pH. The higher pH is seen offshore where the source of lead could only be that adsorbed on to suspended particles, which are settled to sediment during transport. This Factor 3 therefore is the Lead Contamination Factor. Lastly, the **Factor**

4 contributes to 86.8% of the total variance and shows a strong positive loading of Chl.a and phaeophytin. Both show a common source as the phaeophytin are the result of Chl.a degradation. The strong loading of Chl. a in sediments indicates productivity status of the coastal sediments. So, Factor 4 can therefore be termed as the Productivity Factor.

Table 9 highlights the significant β (beta) values as well as significance level (p- value) of predictor variable on criterion variable (Chlorophyll-a) obtained from multivariate analysis. The Table shows that Chl.a is strongly influenced by PHc, Phenol, etc. Two clusters account for the grouping among the stations in the benthic environment. Cluster-I is associated with stations in the offshore region and Cluster-II distinguishes two major stations influenced by harbor activity and industrial discharge.

5.0 Conclusions

The physico-chemical and biological characteristics of water and sediments were studied in the coastal region from Mangalore Harbour to Suratkal to understand their quality in view of growing industrialization in the area. The results indicated large variations in ammonia, nitrite, nitrate, PHc, phenols, cadmium and mercury, suggesting anthropogenic inputs. The R-mode factor analyses were applied separately for the data sets of surface and bottom water layers (due to stratification by riverine flow) as well as to sediment quality data to understand the environmental status of the region and to trace the sources. The factor analyses indicated 6 factors explaining 86.9% of the total variance in surface water and 6 factors explaining 82.4% of the total variance in the bottom water. In sediments, total 4 factors explained 86.8% of the total variance.

The study indicated the addition of nutrients and TSS from natural sources due to weathering and transport by rivers, while the contamination by heavy metals such as cadmium and mercury, ammonia, PHc and phenols was due to anthropogenic activities related to industrial effluents, waste water discharges, boat traffic and other harbour activities. Despite the anthropogenic influence, the strong seasonal currents and strong winds keep the coastal water well mixed and aerated, which disperse the contaminants. The consistency in Chl.a content of these waters suggests that the coastal region from Mangalore harbour to Suratkal is a biologically active zone.

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Reference:

1. APHA, 1992. Standard Methods of Seawater Analyses. American Public Health Association, NY.
2. Galloway JN, Schlesinger WH, Levy H II, Michaels A, Schnoor JL., 1995. Nitrogen fixation: Anthropogenic enhancement—environmental response. *Global Biogeochemical Cycles* 9: pp235–252.
3. GESAMP, 1990. The State of the Marine Environment. Blackwell Scientific Publication, Oxford, UK, pp. 146.
4. Govindasamy C, Azariah J., 1999. Seasonal variation of heavy metals in the coastal waters of Koromandal coast, Bay of Bengal. *Indian J. Mar. Sci.*, pp.249-256.
5. Grasshoff, K., 1999. Methods of seawater analyses. Verlag Chemie, Weinheim.
6. Helena, B., Pardo, R., Vega, M., Barrado, E., Fernandez, J.M. and Fernandez, L., 2000. Temporal evolution of ground water composition in alluvial (Pisuerga river, Spain) by principal component analysis. *Water Res.*, 34: pp.807-816.
7. Liu, C.W., Lin, K.H., Kuo, Y.M., 2003. Application of factor analysis in the assessment of ground water quality in a black foot disease area in Taiwan. *Science of the Total Environment*, 313: pp.77-89.
8. Mandal, S., Chandramohan, P., Raju, N.S.W. and Pathak, K.C., 1996. Ocean outfall off mangalore, west coast of India. *Int. Conf. in Ocean Engineering, COE '96, IIT, Madras, India, 17-20 Dec., 1996*: pp. 537-540.
9. Mouchel, J.M., 1990. Adsorption behaviour of several trace metals in the Changjiang Plume. *Proceedings of the International Symposium on Biogeochemical Study the Changjiang Estuary and its Adjacent Coastal Waters of the East China Sea*. China Ocean Press, pp.263-279.
10. NIO, 1995. Oceanographic and environmental impact assessment studies for the disposal of effluent for BASF India Ltd., Mangalore. NIO Technical Report No. NIO/SP-17/1995, pp. 1-58.
11. NIO, 1996. Coastal Ocean Monitoring and Prediction System (COMAPS). NIO Technical Report No. NIO/SP-24/1996, pp. 1-147.
12. NIO, 1998. Comparative environmental impact assessment for proposed facilities for Mangalore Power Plant at Padubidri, Karnataka. NIO Technical Report No. NIO/SP-17/1998, pp. 1-141.
13. Panigrahy, P.K., Das, J. and Sahoo, R.K., 1999. Evaluation of the influence of various physico-chemical parameters on coastal water quality around Orissa by factor analysis. *Indian J. Mar. Sci.*, 28: pp.360-364.

14. Preston, S.D., and Summers, R.M., 1997. Estimation of nutrient and suspended-sediment loads in the Patuxent River Basin, Maryland, water years 1986-90: U.S.Geological Survey Water-Resources Investigations Report 96-4175, 69 p.
15. Rath, P., Bhatta, D., Sahoo, B.N. and Panda, U.C.,2000. Multivariate statistical techniques in hydrogeochemical studies: an example from Karnataka, India. *Water Res.* 36: pp.2437-2442.
16. Richman, M.B.,1986. Rotation of principal components. *J. of Climatology*, 6:pp.293-335.
17. Sahu, K.C., Panda, U.C. and Mohapatra, D.M.,1998. Geo-chemistry and mineralogy of sediments in Rushikulya estuary, east coast of India. *Chemical Environ. Res.* 7: pp.77-92.
18. Simenova, P., Simenova, V. and Andrew, G.,2003. Analysis of the struma river water quality. *Central European Journal of Chemistry*, 2: pp.121-126.
19. Singh, K.P., Malik, A., Mohan, D. and 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 Res.* 38: pp.3980-3992.
20. Strickland, S.C. and Parsons, T.R.,1979. A practical handbook of seawater analyses. Ottawa, Bulletin of Fisheries Research Board of Canada.
21. Vega, M., Pardo, R., Barrado, E. and Deban, L.,1998. Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. *Water Res.*32: pp.3581-3592.
22. Verlecar, X. N., Desai, S. R., Sarkar, A. and S G Dalal.,2005. Biological indicators in relation to coastal pollution along Karnataka coast, India. *Marine Pollu. Bull*, 50 (1):pp.73-91.
23. 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: Suquia river basin (Cordoba-Argentina). *Water Res.* 35, pp.2881–2894.
24. Zingde, M. D. and Desai, B.N., 1987. Pollution status of estuaries in Gujarat – An overview. Contribution in Marine Science – Dr. S.Z. Qasim Felicitation volume. Ed.: Rao, T.S.S., Natarajan, R., Desai B.N., Narayanswamy, G., Bhat, S.R.. NIO Publ. pp: 245-268.
25. Zingde, M.D. and Govindan, K., 2000. Health status of coastal waters of Mumbai and regions around. In “ Environmental problems of coastal areas in India. Ed.: Sharma, V.K., Bookwell publ., New Delhi, India: pp.119-132.

Legends to the Figures:

Figure 1: Map Showing location of sampling stations and the current meter positions. (RCM)

Figure 2(a&b): Speed and direction of currents off Suratkal and off Mulki.

Figure 3(a-f): Hydrographic parameters of sea water in the coastal regions off Mangalore.
[Temperature ($^{\circ}\text{C}$), Salinity (psu), DO and BOD (ml^{-1}), TSS (mg^{-1})]

Figure 4(a-e): Nutrients levels of sea water in the coastal regions off Mangalore.
[$\text{PO}_4\text{-P}$, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, $\text{NH}_3\text{-N}$, $\text{SiO}_4\text{-Si}$ are in μmol^{-1}]

Figure 5(a-f): PHc, Phenol, Chlorophyll-a and trace metals in the coastal sea water off Mangalore to Suratkal.
[PHc, Phenol, Pb, Cd are in μg^{-1} , Chlorophyll a(mg^{-1}) and Hg is in ($\text{ng} \text{ l}^{-1}$)]

Figure 6: Dendogram showing relationship among stations off Mangalore region (between group=15)

Legands to tables:

Table 1: List of small medium and large size industries along the Karnataka coast.

Table 2: Techniques used for physico-chemical parameter determination.

Table 3: Maximum, minimum and the average values of physico-chemical variables in the coastal water from Mangalore harbor to off Suratkal.

[Temperature($^{\circ}$ C),Salinity(psu), DO and BOD(ml l^{-1}),TSS(mg l^{-1}),(PO₄-P, NO₂-N, NO₃-N, NH₃-N, SiO₄-Si are in $\mu\text{mol l}^{-1}$, PHc,Phenol,Pb,Cd are in $\mu\text{g l}^{-1}$, Chlorophyll-a(mg l^{-1}) and Hg is in (ng l^{-1}).]

Table 4: Sediment characteristics in the coastal region off Mangalore to Mulki.

[OC (%), TN, TP, Pb, Cd ($\mu\text{g g}^{-1}$), Chl-a, Phaeo (mg g^{-1})]

Table 5: R-mode varimax sorted factor analysis of physico-chemical parameters of coastal waters off Mangalore (N=15).

Table 6: Correlation matrix among the physico-chemical parameters of coastal waters off Mangalore area (N=15).

Table 7: R-mode factor analyses of physico-chemical parameters in sediments of coastal region off Mangalore to Suratkal.

Table 9: Predictor variables and the β (beta value) and significance level.

Table 8: Correlation matrix of physico-chemical variable in sediments.

Table 10: Station clusters in surface and bottom water layers and in sediments.

Table 11: Certified and observed trace metals (Pb, Cd and Hg) values in Certified Reference Material - MESS from IAEA.

Table 1: List of small, medium and large industries along the Karnataka coast.

Sr. No.	Industry	Product	year
1.	M/s Blue Water Food (Exports)	Sea Food Export.	2005
2.	M/s Rajashra Packer Industries, Industrial Area, Baikampady, Mangalore	Refined Oil & Vanaspati.	2004
3.	M/s Ruchi Soya Industries, Baikampady, Mangalore	Vanaspati & Refined Oil.	2001
4.	M/s ELF Gas (India) Ltd., Baikampady, Mangalore	LPG	1999
5.	M/s Ultra Tech Co. Ltd., Panamburu	Cement Packers	1998
6.	M/s B.A.S.F. Industries	Dyes and Dispersants	1996
7.	M/s Kudremukh Iron and Steel Company	Steel	1995
8.	Hindustan Petroleum Corporation Limited, POL terminal, Katipalya, Mangalore	Petroleum Products, LPG	
9.	M/s Mangalore Refinery and Petrochemicals Ltd. (MRPL)	Petroleum Products.	1989
10.	M/s Hindustan Liver Sultan Battery Bolur, Mangalore	Detergent Bar & Powder.	1987
11.	Indian Oil Corporation Limited, Panambur, Mangalore	Petroleum products	

12.	M/s Campco Chocolate Industries Ltd., Puttur	Coco Malt	1986
13.	M/s Bharat Petroleum Corporation Ltd., Baikampady, Mangalore	Petroleum Products.	1986
14.	M/s Prakash Offset Printers	Offset Printing	1982
15.	M/s Kudremukh & Iron and Steel Company	Iron Palletization unit.	1976
16.	M/s Laxmina Suspension products, Baikampadi Industrial Area	Automobile Leaf Springs.	1975
17.	M/s Canara Wood and Plywood Industries	Plywood & Blackboard.	1972
18.	Mangalore Chemicals & Fertilizers Ltd	Urea, NH ₃ , NH ₄ PO ₄ , NH ₄ HCO ₃ , naptha etc.	1971
19.	M/s Canara Shop, Hurali, Mangalore	Auto Springs 2 Brake drums.	1943
20.	M/s Canara Printing & Publishing House Ltd., Mangalore	Offset Printing.	1938
21.	M/s Mangalore Trading Associates Carstreet, Mangalore	Printing	1906
22.	Puttur Petrochemicals Private Limited, Mittur, Idkudi village, Bantwal Taluk, D.K	LPG	

Table 1, Contd.

Table 2: Techniques used for physico-chemical parameter determination.

Parameter	Abbreviation	Techniques / Instruments used	Unit
Temperature	Temp.	CTD (SeaBird)	$^{\circ}\text{C}$
Salinity	Sal.	CTD (SeaBird)	psu
PH	PH	pH probe (Eutech)	-
Total Suspendes Solids	TSS	Filtration (Aspirator Vacuum)(<i>Preston et al., 1997</i>)	mg l^{-1}
Dissolved Oxygen	DO	Titration (<i>Strickland and Parsons, 1979</i>)	ml l^{-1}
Biochemical Oxygen Demand	BOD	Titration (<i>Strickland and Parsons, 1979</i>)	ml l^{-1}
Petroleum Hydrocarbons	PHc	Spectrofluorimetry (<i>Grasshoff, 1999</i>)	$\mu\text{g l}^{-1}$
Phenolic Compounds	PhOH	Spectrophotometry (APHA, 1998)	$\mu\text{g l}^{-1}$
Lead (seawater)	Pb	Flame AAS	$\mu\text{g l}^{-1}$
Cadmium (seawater)	Cd	AAS	$\mu\text{g l}^{-1}$
Mercury (seawater)	Hg	Cold Vapour AAS	ng l^{-1}
Ammonia	NH_3	Spectrophotometry (<i>Grasshoff, 1999</i>)	$\mu\text{mol l}^{-1}$
Nitrite	NO_2	Spectrophotometry(<i>Grasshoff, 1999</i>)	$\mu\text{mol l}^{-1}$
Nitrate	NO_3	Spectrophotometry(<i>Grasshoff, 1999</i>)	$\mu\text{mol l}^{-1}$
Phosphate	PO_4	Spectrophotometry(<i>Grasshoff, 1999</i>)	$\mu\text{mol l}^{-1}$
Silicate	SiO_2	Spectrophotometry(<i>Grasshoff, 1999</i>)	$\mu\text{mol l}^{-1}$
Chlorophyll - a	Chl - a	Turner fluorimeter	mgm^{-3}
Pheophytene	pheo	Turner fluorimeter	mgm^{-3}

Table 3: Maximum, minimum and the average values of physico-chemical variables in the coastal water from Mangalore harbor to off Suratkal.

[Temperature($^{\circ}$ C), Salinity(psu), DO and BOD(ml l^{-1}), TSS(mg l^{-1}), ($\text{PO}_4\text{-P}$, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, $\text{NH}_3\text{-N}$, $\text{SiO}_4\text{-Si}$ are in $\mu\text{mol l}^{-1}$), (PHc, Phenol, Pb, Cd are in $\mu\text{g l}^{-1}$, Chlorophyll-a (mg l^{-1}) and Hg is in (ng l^{-1})]

Surface Water					Bottom Water			
Variable	Min.	Max.	Avg.	Std.dev.	Min.	Max.	Avg.	Std.dev.
Temp	30.1	32.1	31.1	0.6	29.9	31.3	30.6	0.5
Salinity	12.4	35.5	31.4	7.6	35.2	35.4	35.3	0.1
pH	7.7	7.8	7.8	0.0	7.7	7.8	7.7	0.0
TSS	14.0	49.8	29.7	11.6	19.4	124.7	49.0	28.8
DO	4.5	7.7	5.3	0.7	3.6	5.2	4.6	0.4
BOD	0.2	2.5	1.1	0.7	0.5	3.2	1.1	0.8
PHc	9.2	212.3	85.5	76.4	3.7	275.6	91.1	91.7
Phenol	0.7	9.0	4.0	2.3	0.5	17.4	5.4	4.3
Lead	0.1	1.3	0.4	0.3	0.1	1.5	0.3	0.4
Cadmium	0.6	18.5	5.4	5.9	0.4	26.6	9.1	8.7
Mercury	0.0	100.0	62.7	30.1	20.0	900.0	125.3	215.7
$\text{NH}_3\text{-N}$	1.6	12.7	5.3	3.4	1.6	9.3	4.5	2.5
$\text{NO}_2\text{-N}$	0.1	1.3	1.0	0.4	1.0	1.6	1.3	0.2
$\text{NO}_3\text{-N}$	0.6	3.7	2.2	0.9	1.1	4.2	2.5	0.8
$\text{PO}_4\text{-P}$	0.3	1.3	1.0	0.2	0.4	1.7	1.0	0.4
$\text{SiO}_4\text{-Si}$	4.4	12.9	9.5	2.6	8.7	14.5	10.6	1.8
Chl-a	0.1	0.7	0.4	0.1	0.1	0.6	0.3	0.1
Pheo	0.1	0.3	0.1	0.1	0.0	0.2	0.1	0.1
Chl-a:pheo	7.5	1.2	3.7	2.1	31.0	0.4	4.8	7.6

Table 4: Sediment characteristics in the coastal region off Mangalore to Mulki.

[OC(%), TN, TP, Pb, Cd (μgg^{-1}), Chl-a, Phaeo (mgg^{-1})]

Sediment				
Variable	Min.	Max.	Avg.	Stdv.
OC	0.21	2.82	1.79	0.79
TN	48.50	286.30	188.62	64.32
TP	24.09	52.52	39.63	8.35
Pb	9.45	26.70	21.77	5.35
Cd	0.93	2.01	1.42	0.29
Hg	13.64	922.73	133.40	231.53
chl-a	0.11	0.42	0.28	0.07
Pheo	1.11	2.31	1.81	0.30

Surface water							Bottom water						
Variable	Factor-1	Factor-2	Factor-3	Factor-4	Factor-5	Factor-6	Variable	Factor-1	Factor-2	Factor-3	Factor-4	Factor-5	Factor-6
SiO ₄ -Si	0.944						SiO ₄ -Si	0.904					
PHc	0.405	-0.720					Pheo	0.544	-0.670				
NO ₂ -N	0.848						NO ₂ -N	0.424			0.722		
NO ₃ -N	0.800						PO ₄ -P	0.924					
PO ₄ -P	0.862						TSS	0.896					
TSS	0.703	-0.459					Salinity	-0.442	-0.499				
pH	-0.886						Phenol	-0.460			-0.527	-0.511	
Pheo		0.506		0.742			DO		0.845				
Lead		0.769					PHc		0.732				
Mercury		0.925					NO ₃ -N		0.816				
Temp				-0.609		-0.474	pH			0.700			-0.458
NH ₃ -N				0.840			Chl-a			0.857			
Salinity			-0.850		-0.432		Cadmium			-0.466			0.794
DO			0.884				NH ₃ -N			-0.649	-0.414		
BOD			0.918				Lead				0.806		
Chl-a			0.444		-0.603		Temp				-0.584		0.421
Cadmium					0.850		Mercury						-0.819
Phenol						0.892	BOD						0.844
Eigen value	4.677	2.892	2.882	1.999	1.779	1.404	Eigen value	3.727	2.871	2.439	2.339	2.116	1.336
% variance	26.00	16.07	16.01	11.11	9.88	7.80	% variance	20.71	15.95	13.55	12.99	11.76	7.42
Cumulative %	25.99	42.05	58.06	69.17	79.05	86.85	Cumulative %	20.71	36.65	50.20	63.19	74.95	82.37

Table 5: R-mode varimax sorted factor analysis of physico-chemical parameters of coastal waters off Mangalore (N=15).

Table 6: Correlation matrix among the physico-chemical parameters of coastal waters off Mangalore area (N=15).

Correlation matrix of surface water system

Variables																		
	SiO ₄ -Si	Pheo	Temp	Salinity	pH	DO	BOD	PHc	Lead	Cd	Hg	NH ₃ -N	Phenol	NO ₂ -N	NO ₃ -N	PO ₄ -P	Chl-a	TSS
SiO ₄ -Si	1																	
Pheo	0.018	1																
Temp	0.04	-0.23	1															
Salinity	-0.236	-0.267	-0.032	1														
PH	-0.811	-0.114	0.234	0.035	1													
DO	0.137	-0.32	0.131	-0.615	0.078	1												
BOD	0.065	0.091	-0.001	-0.757	0.161	0.748	1											
PHc	0.233	-0.008	-0.136	0.066	-0.41	-0.072	-0.312	1										
Lead	0.302	0.298	-0.103	-0.147	-0.247	-0.036	0.431	-0.469	1									
Cd	0.191	0.152	0.242	-0.549	-0.038	0.152	0.2	-0.116	-0.04	1								
Hg	-0.178	0.486	0.277	-0.082	0.333	-0.247	0.193	-0.774	0.521	0.262	1							
NH ₃ -N	-0.237	0.405	-0.39	0.01	-0.158	-0.216	-0.28	0.465	-0.346	-0.33	-0.299	1						
Phenol	-0.067	0.151	-0.169	-0.158	0.128	0.23	0.288	-0.331	-0.005	0.381	0.227	-0.217	1					
NO ₂ -N	0.782	0.197	-0.014	-0.107	-0.771	-0.165	-0.317	0.483	-0.018	0.147	-0.295	0.109	-0.363	1				
NO ₃ -N	0.708	0.288	0.077	0.11	-0.655	-0.199	-0.126	0.341	0.295	-0.034	-0.045	-0.028	0.012	0.552	1			
PO ₄ -P	0.843	-0.001	0.064	-0.193	-0.668	0.172	0.022	0.412	0.179	0.036	-0.307	-0.185	-0.367	0.826	0.512	1		
Chl-a	0.113	-0.059	-0.003	-0.074	0.083	0.439	0.458	-0.182	0.223	-0.232	0.071	-0.287	0.003	-0.11	0.235	0.151	1	
TSS	0.636	-0.109	-0.309	-0.106	-0.629	0.398	0.132	0.573	0.036	-0.11	-0.649	0.026	0.018	0.491	0.451	0.669	0.191	1

Table-6 (Contd.)

Correlation matrix of bottom water system

Variables		SiO ₄ -Si	Pheo	Temp	Salinity	pH	DO	BOD	PHc	Lead	Cd	Hg	NH ₃ -N	Phenol	NO ₂ -N	NO ₃ -N	PO ₄ -P	chl-a	TSS	
SiO ₄ -Si	1																			
Pheo	0.18	1																		
Temp	0.026	-0.035	1																	
Salinity	-0.416	-0.111	-0.369	1																
pH	-0.05	0.025	-0.371	0.27	1															
DO	-0.159	-0.175	-0.137	-0.375	-0.328	1														
BOD	-0.082	0.453	0.432	-0.18	-0.289	0.134	1													
PHC	0.239	-0.02	-0.12	-0.286	0.176	0.402	0.11	1												
Lead	-0.01	0.613	-0.464	0.193	0.256	0.023	0.063	-0.263	1											
Cd	0.063	0.107	0.318	-0.407	-0.65	0.283	0.573	-0.004	-0.156	1										
Hg	-0.221	-0.135	-0.385	0.168	0.317	-0.208	-0.166	-0.093	-0.072	-0.286	1									
NH ₃ -N	-0.332	-0.339	0.295	-0.083	-0.588	0.289	0.008	-0.013	-0.228	0.313	-0.16	1								
Phenol	-0.441	-0.425	0.274	0.375	0.056	-0.203	-0.232	-0.182	-0.251	-0.457	0.099	0.398	1							
NO ₂ -N	0.562	0	-0.253	-0.023	-0.017	-0.198	-0.093	-0.301	0.265	0.208	-0.02	-0.3	-0.559	1						
NO ₃ -N	0.274	0.181	-0.107	-0.374	0.154	0.645	0.234	0.557	0.31	0.19	-0.367	-0.137	-0.408	0.108	1					
PO ₄ -P	0.744	0.191	0.052	-0.346	-0.003	-0.274	0.006	0.361	-0.148	0.146	-0.151	-0.318	-0.534	0.317	0.11	1				
chl-a	-0.179	0.263	-0.13	0.296	0.401	-0.227	-0.098	0.232	-0.043	-0.402	0.009	-0.434	-0.156	-0.265	-0.143	0.234	1			
TSS	0.742	0.13	0.24	-0.265	-0.106	-0.372	0.083	0.147	-0.19	0.122	-0.152	-0.211	-0.247	0.221	-0.034	0.844	-0.071	1		

Table 7: R-mode factor analyses of physico-chemical parameters in sediments of coastal region off Mangalore to Suratkal.

Variables	Factor-1	Factor-2	Factor-3	Factor-4
Pb	0.642		0.702	
TN	0.971			
OC	0.944			
Cd	0.600	0.676		
TP	0.852			
Hg	-0.557	0.526		
Av.water salinity		-0.914		
av.water pH			0.881	
Pheo				0.833
Chl-a				0.870
Eigen value	3.765	1.764	1.593	1.555
% variance	37.66	17.65	15.93	15.55
Cumulative %	37.66	55.30	71.23	86.78

Table 8: Correlation matrix of physico-chemical variable in sediments.

Variables	avg. water								avg.	
	Hg	chl a	OC	Pheo	Pb	TN	Cd	salinity	water pH	TP
Hg	1									
Chl a	-0.115	1								
OC	-0.485	-0.065	1							
Pheo	0.026	0.463	-0.1	1						
Pb	-0.433	-0.008	0.651	-0.138	1					
TN	-0.499	0.044	0.903	-0.083	0.586	1				
Cd	-0.066	0.108	0.529	-0.362	0.698	0.541	1			
Avg.water salinity	-0.539	-0.199	0.284	0.152	0.088	0.183	-0.404	1		
avg. water pH	-0.13	-0.031	-0.176	0.108	0.382	-0.25	-0.075	0.211	1	
TP	-0.357	0.22	0.766	0.107	0.259	0.859	0.282	0.12	-0.413	1

Table 9: Predictor variables and the β (beta value) and significance level.

Predictor/Independent variable	Beta value(β)	Significance (p-value)
Pheopigments	0.694	$p \geq 0.05$
PHc	-0.523	$p = 0.05$
NH₃-N	-0.613	$p \geq 0.05$
Phenol	-0.726	$p > 0.01$
TSS	-0.794	$p \geq 0.05$
DO	0.338	$p = 0.05$
BOD	0.363	$p = 0.05$

Table 10: Station clusters in surface and bottom water layers and in sediments.

Clusters	Surface	Bottom	Sediment
I	(K6 -S5 -S6 -S3 -S1 -S4) - (S2)	(S2-S6-S5-K6-S1-S3)	(K2-K6-S2-K3-S6-S3-S4-S5-H1-H3-S1-K1)
II	(H2 -K2)	(H2-K4-K2-K5-H1-K1-K3)	(H2-K5)
III	(K3 -K5 -H1),(H3 - K1)	-	-

Table 11: Certified and observed trace metals (Pb, Cd and Hg) values in Certified Reference Material - MESS from IAEA.

Metals	Certified values (ppm)	Observed values (ppm)
Lead (Pb)	34.0 ± 0.61	32.0 ± 0.60
Cadmium (Cd)	0.59 ± 0.10	0.49 ± 0.15
Mercury (Hg)	0.171 ± 0.014	0.165 ± 0.012

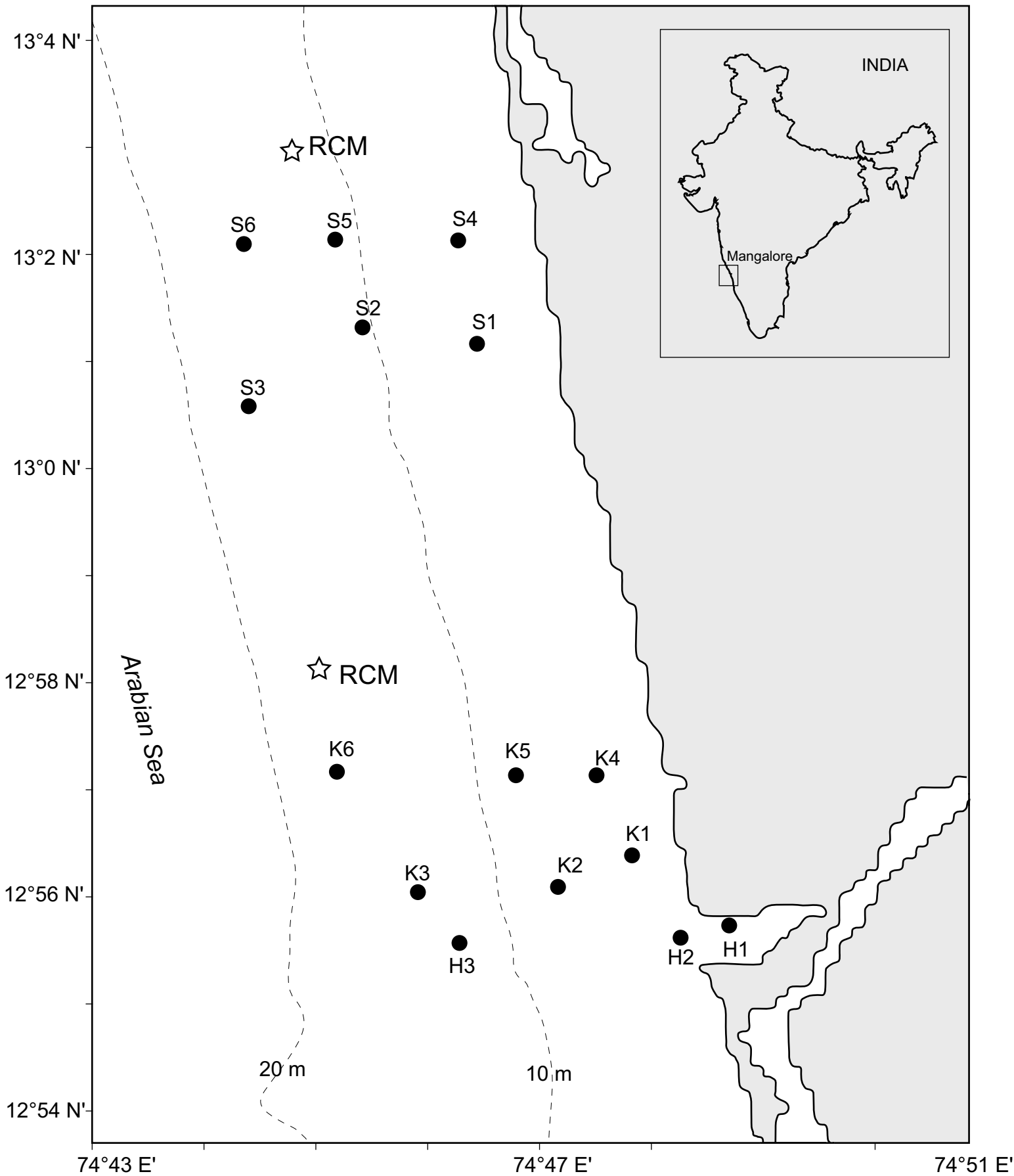
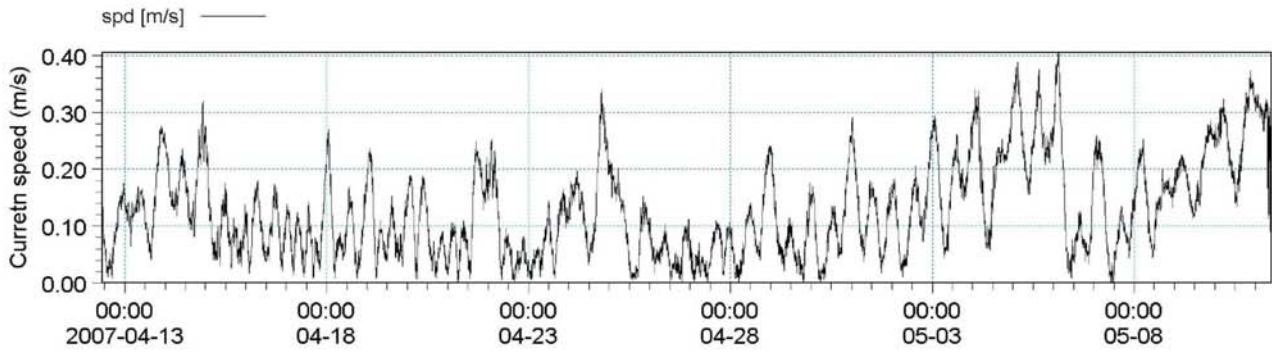
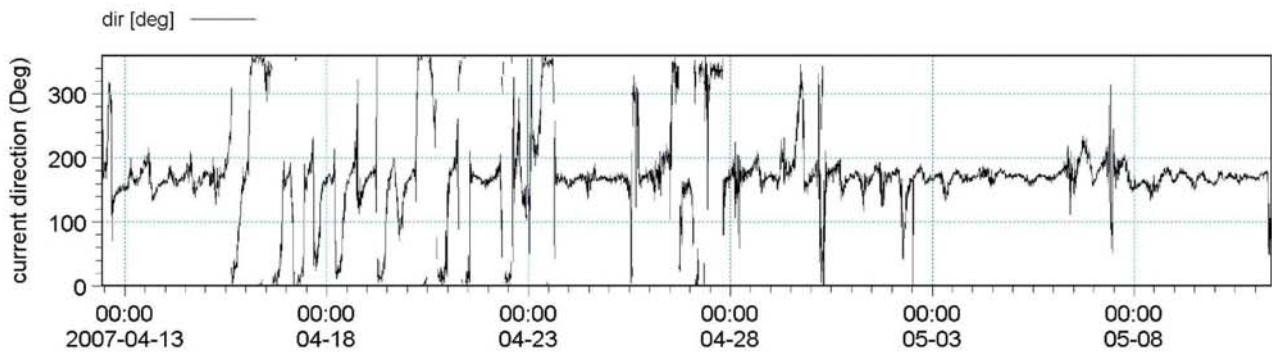
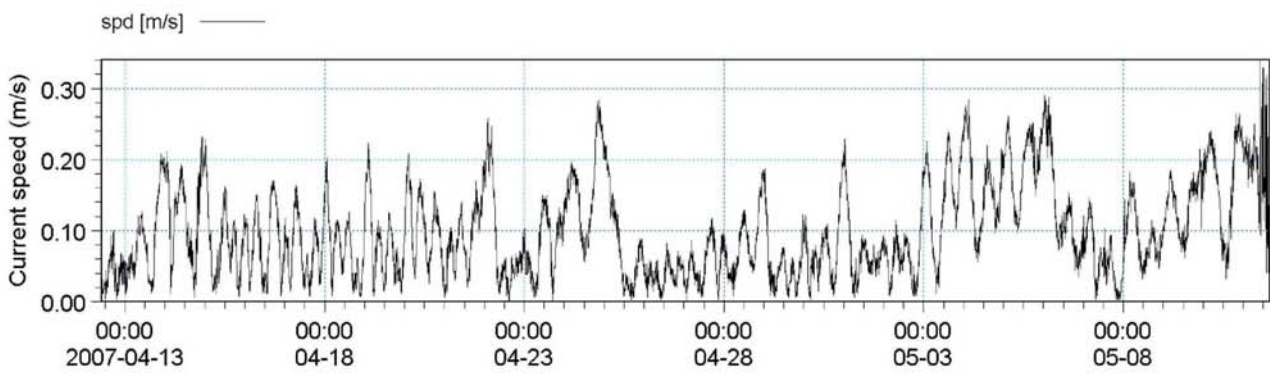
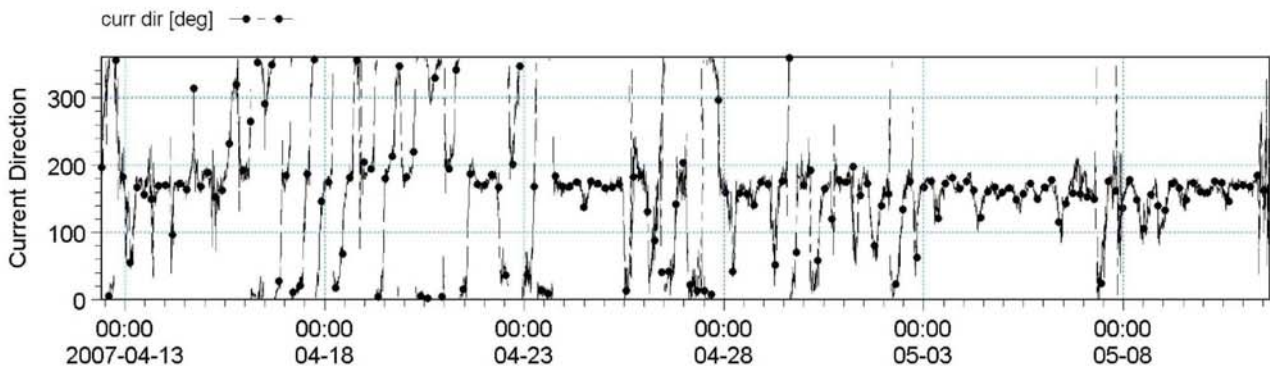


Fig. 1: Map Showing location of sampling station and the current meter position(RCM)



(a) Suratkal



(b) Mulki

Figure-2(a,b): Speed and direction of current off suratkal and off Mulki.

Longitude⁰E

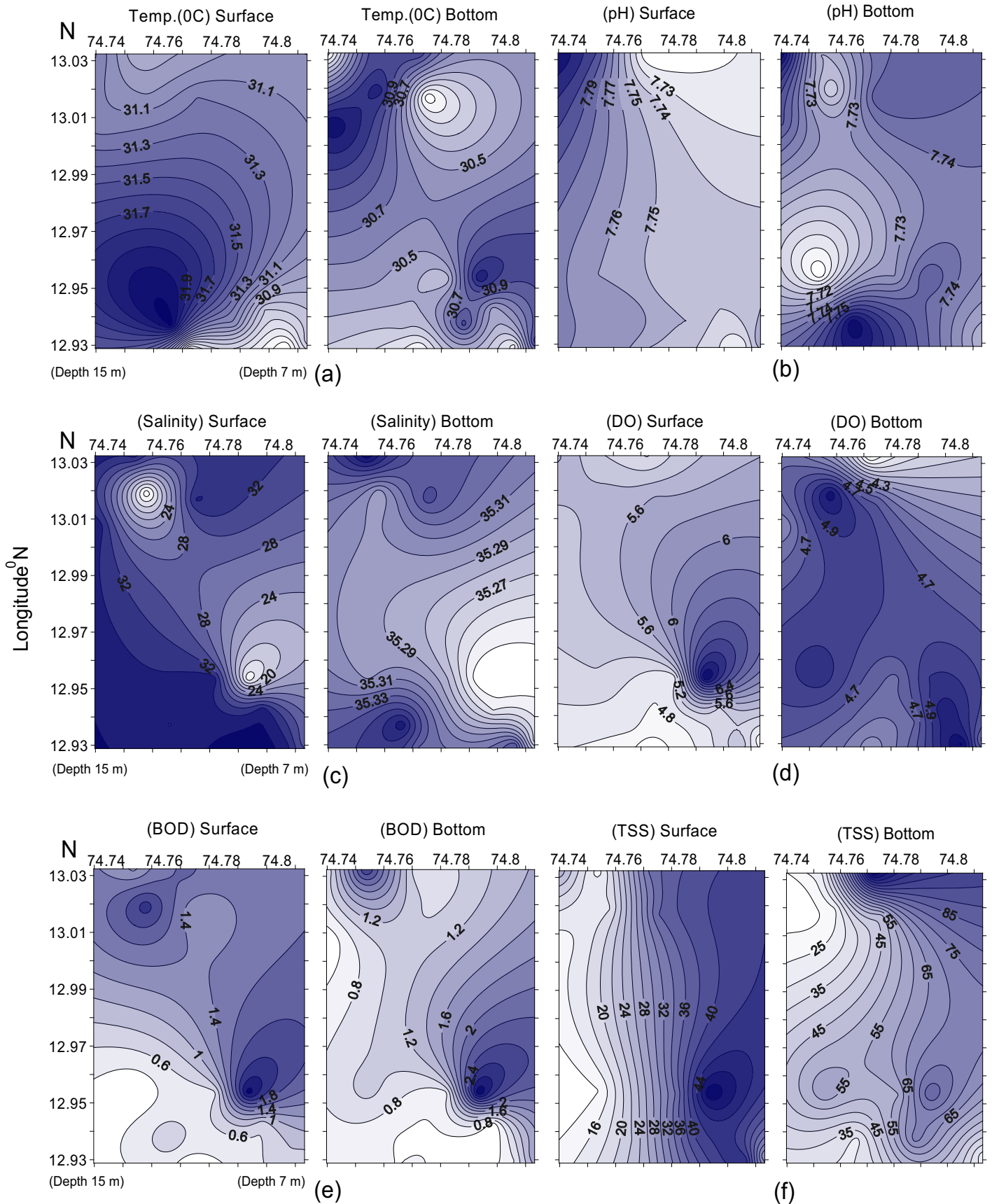


Figure-3 (a-f): Hydrographic parameters of sea water in the coastal regions off Mangalore
(Temperature 0C,pH in pH units,Salinity psu,DO and BOD ml/l TSS in mg/l)

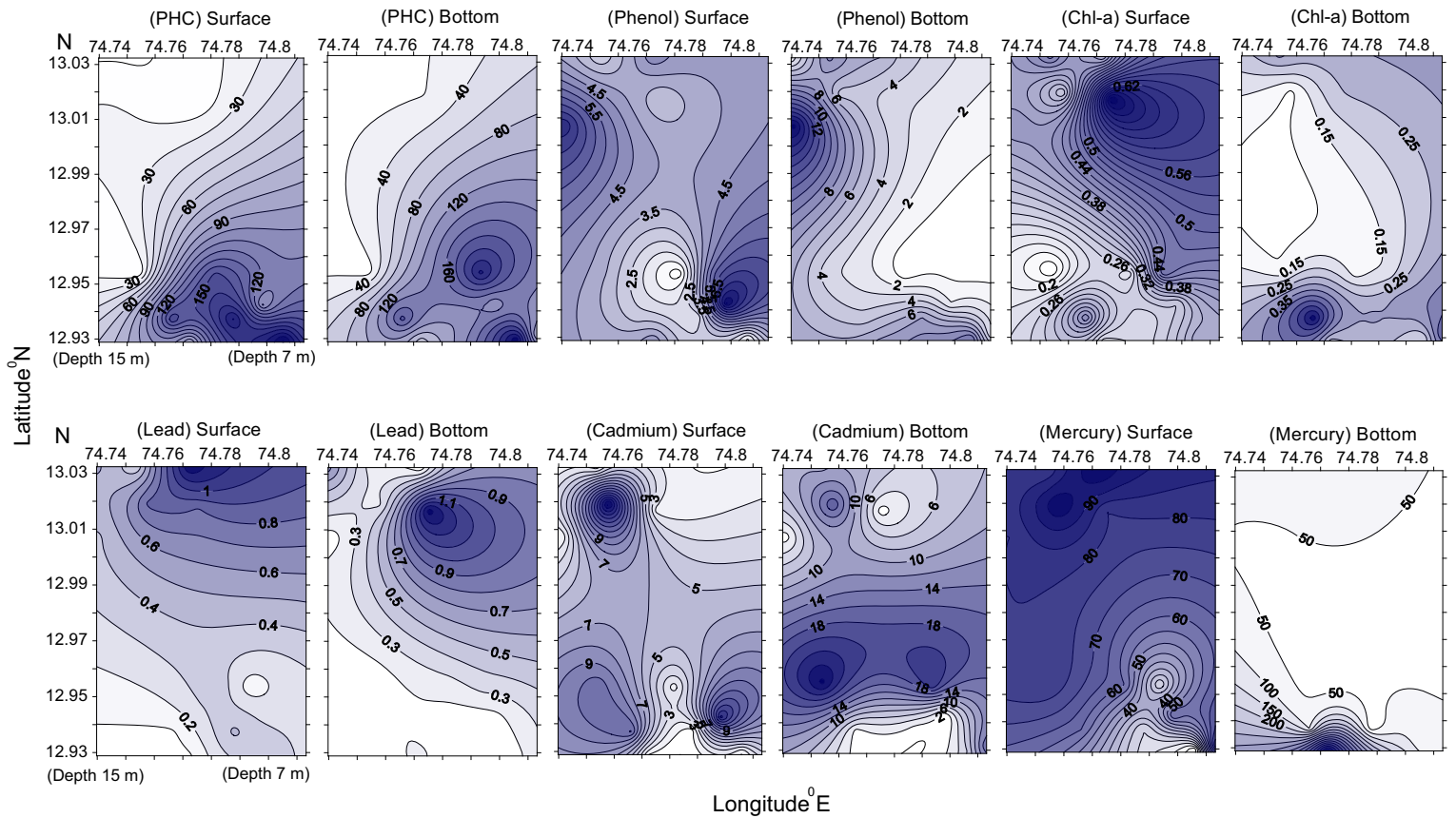


Figure-5 (a-f):PHc,Pheno,chlorophyll a and trace metals in the sea waters of the coastal regions off Mangalore (PHc,Phenol,Lead and Cadmium are in $\mu\text{g/l}$, Chlorophyll a is in mg/l and Mercury in ng/l)

Figure 6 : Dendrogram showing relationship among station off region (Between group = 15)
Rescaled Distance Cluster Combine

