

Distribution of biochemical constituents in the surface sediments of western coastal Bay of Bengal: Influence of river discharge and water column properties

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Abstract

Biochemical composition of surface sediment samples from off major and minor rivers along the east coast of India revealed that spatial distribution of sediment organic carbon (SOC) composition was mainly governed by differential characteristics of discharged water and associated biogeochemical processes in the water column. The northwest (NW) region of coastal Bay of Bengal was influenced by discharge from Ganges river while peninsular (monsoonal) rivers influenced the southwest (SW) region. The NW region characterized by low nutrients, suspended particulate matter (SPM), high phytoplankton biomass in the water column and high SOC while contrasting to that observed in the SW region. The isotopic ratios of SOC (-22‰) in the NW region were close to that of organic matter derived from phytoplankton (-23‰) suggesting *in situ* production is the major source whereas terrigenous source contributed significantly in the SW region (-19.6‰). Though low *in situ* biological production in the SW region, relatively higher total carbohydrates (TCHO) were found than in the NW and insignificant difference of total and free amino acid concentrations between NW and SW were resulted from faster removal of organic matter to the sediment in association with SPM in the SW region. Higher Proteins concentrations than total amino acids indicate that nitrogenous organic matter is preserved in the former form. The protein to TCHO ratio was lower in the SW suggesting significant contribution of aged and non-living organic matter in this region.

Key words: Sediment organic carbon, Carbohydrates, Proteins, labile organic carbon, Sediments, Bay of Bengal.

1. Introduction

Organic matter (OM) in the sediment represents a sink for atmospheric carbon dioxide, which gets lost from the biosphere through burial hence its preservation, has global importance (Pocklington et al. 1991). The OM in the near shore and coastal sediments are derived from both internal and external sources, such as plankton production in the water column, benthic microalgae, terrestrial plants, domestic sewage and industrial wastes (Hedges and Keil 1995; Hedges et al. 1997). Large accumulation of OM occurs in the coastal sediments due to high primary production, terrestrial inputs through river runoff, faster scavenging of this matter to sediment in association with suspended particulate matter (SPM) and shallower water column depth (Degens and Ittekkot 1985; Ittekkot et al. 1985; Ittekkot and Arain 1986). The preservation of organic matter in the coastal sediment is also determined by the water column oxygen levels, and sediment depositional rates as these two determine amount of OM decomposed in the water column and sediments respectively. The initial input of organic matter constitutes major class of naturally occurring organic compounds, such as carbohydrates, amino acids, proteins, lipids, pigments and other constituents of living organisms (Walsh et al. 1981). The labile carbon is preferentially oxidized before it reaches to the sediment surface (Altabet and Deuser 1985). The decomposition of individual organic constituents in the water or sediment surface depends on number of factors including their chemical stability, biochemical usefulness, and their interaction with clay minerals during the sedimentation (Premuzic et al. 1982; Degens and Ittekkot 1984; Stein et al. 1986; Ittekkot et al. 1991). Therefore the fraction of labile to the total organic carbon in the sediment is an indicator to judge efficiency of bacterial oxidation and recycling in the water column and sediment.

The study region, Bay of Bengal, receives large quantity of fresh water ($1.6 \times 10^{12} \text{ m}^3 \text{ y}^{-1}$) and sediments (1.1×10^9 tones; Milliman and Meade 1983 ;Milliman and Syvitski 1992) from the major rivers such as Ganges, Brahmaputra, Mahanadi, Godavari, and Krishna (Rao 1985), which lead to low surface salinity and strong stratification (Varkey et al. 1996). This prevents the transport of nutrients from the subsurface to surface water. Weak winds are unable to break the thermocline and as a result cyclones are frequently developed in the Bay of Bengal. Cyclones are significant source of nutrients to surface that result in a formation of localized algal bloom (Vinaychandran and Mathew 2003). The Bay of Bengal is traditionally consider to be a region of low biological productivity due to low nutrient levels in the surface, low light availability resulting from high turbidity and cloud cover (Madhupratap et al. 2003 and references therein). Unlike in the Arabian Sea, upwelling in the Bay of Bengal is confined very

close to the coast during the south west monsoon (Murty and Varadhachari 1968; Shetye et al. 1991) and offshore Ekman transport of upwelled water is hindered by equatorward flow of fresh water plume (Gopala Krishna and Sastry 1985). Nutrients discharged by rivers are mostly utilized within the estuarine mouth itself and its contribution to the Bay of Bengal are rather small (Sarma et al. 2009; Sarma et al. 2010). Prasanna Kumar et al. (2002) suggested that the primary production in the Bay of Bengal is strongly controlled by the availability of nutrients. Recently Maneesha et al. (2011) found that extreme atmospheric events brings significant amount of nutrients to the surface lead to formation of phytoplankton blooms.

So far, very few studies have been conducted on sediment organic carbon distribution in the coastal Bay of Bengal (Rao 1960; Bezrukov 1964; Bhosle et al. 1988; Paropkari et al. 1999; Jacob et al. 2008). Broecker et al. (1980) found that incompletely oxidized OM reaches to the sea floor in the Bay of Bengal due to faster scavenging in association with SPM. (Ittekkot et al. 1991) suggested that ballasting of OM from the water column through association with SPM decreases its residence time that lead to incomplete oxidation in the water column. Jacob et al. (2008) observed that the contribution of labile constituents (carbohydrates and proteins) to the surface sediments are higher in the Bay of Bengal compared to Arabian Sea due to faster scavenging of organic matter. The Bay of Bengal receives both SPM and OM from different peninsular and glacial rivers with variable characteristics in their nature. In addition to this, the mechanisms involved in the sedimentation of organic matter from the water column may also vary depending on the water column characteristics. The purpose of this study is to understand the influence of different rivers on distribution of bulk organic carbon and their constituents in the sediments during the peak monsoon (discharge) period along the west coast of Bay of Bengal and examine impact of water column properties on their sedimentation to the ocean floor.

2. Description of Study region and material and method

2.1. Study region

The Northern Indian Ocean (NIO) is a unique region in terms of its geographical setting, as it is semi enclosed and connected to the Indian Ocean in the south, and circulation pattern. The NIO is split into two zones by the Indian subcontinent, i.e., northwestern (Arabian Sea) and northeastern (Bay of Bengal). The Bay of Bengal is a region of positive water balance where precipitation and river runoff far exceeds evaporation, which leads to low surface salinities and strong stratification (Varkey et al. 1996).

Due seasonal reversal in winds, the currents change their direction, for instance, the East Indian Coastal Current (EICC) flows northeastward from February to September with a strong peak in March–April and flows southwestward from October to January with strongest flow in November (Schott and McCreary 2001).

The southwestern (SW) coastal Bay of Bengal receives fresh water discharge from peninsular (monsoonal) rivers such as Krishna ($823 \text{ m}^3 \text{ s}^{-1}$), Godavari ($1050 \text{ m}^3 \text{ s}^{-1}$), whereas northwestern (NW) part of the coastal Bay of Bengal is predominantly influenced by glacial river, Ganges ($>14,000 \text{ m}^3 \text{ s}^{-1}$), than monsoonal rivers, Mahanadi, Vamsadhara and Hyadri ($<700 \text{ m}^3 \text{ s}^{-1}$; Sarma et al. 2012; Fig. 1). In order to examine the impact of discharges from different rivers on the organic matter composition in the coastal sediments, samples were collected on board ORV Sagar Nidhi (#SN42) during 23th July to 10th August 2010, representing peak discharge period, along the western coastal Bay of Bengal covering major rivers such as Krishna, Godavari, Vamsadhara, Hyadri and Mahanadi (Fig. 1). Seventy three stations were occupied in 9 transects off riverine out flow for water column while surface sediment samples were collected at 36 locations in 9 transects covering water column depth ranging from 25 to 500 m. Study region has been divided in to two parts, namely, southwest (SW) region that includes transects KN (off north of Krishna river), KS (off south of Krishna river), GN (off north of Godavari river) and GS (off south of Godavari river), and northwest (NW) region which covers transects VD (off river Vamsadhara), HD (off river Hyadri), MN (off north of Mahanadi river) and MS (off south of river Mahanadi) (Fig. 1). Samples were also collected off Visakhapatnam city (transect V) which represent the region of no river discharge. Along the coast, stations with water column depth $<200 \text{ m}$ isobaths were taken as inner shelf and $>200 \text{ m}$ isobaths were taken as outer shelf.

2.2. Sampling and methodology

Water column temperature and salinity was measured using portable Conductivity-Temperature-Depth profiler (CTD; SBE-19 plus, Sea-Bird Electronics, USA). Dissolved oxygen (DO) was estimated following Winkler titration using automated potentiometric detection (Carritt and Carpenter 1966) using Tritrinado 835 Metrohm autotitrater. Nutrients (Nitrate, Phosphate, Silicate) were analyzed following standard colorimetric procedure (Grashoff et al. 1992). The analytical precision, expressed as a standard deviation, was $\pm 0.07\%$ RSD for DO whereas for nitrate, phosphate, and silicate of ± 0.02 , ± 0.02 , $\pm 0.01 \mu\text{M}$ respectively. A 2 to 5 L water samples were filtered through GF/F filter (Whatman) and

phytoplankton biomass retained on that was extracted with *N,N*, dimethyl formamide at 4°C in dark for 12 h, and then measured fluorescence by spectrophotofluorometer (Varian Eclipse Spectrofluorometer, USA) following Suzuki and Ishimaru (1990). The analytical precision for Chl *a* analysis was ±4%. Total bacterial count was analyzed following DAPI method Portar and Feig (1980). The SPM was measured based on weight difference of the matter retained on 0.22 µm pore size polycarbonate filters. For sediments, samples essentially representing the top 0-2 cm of deposit were immediately stored at -20°C. Before analysis, samples were thawed, dried at 50°C and ground to a fine powder and sub sample of this homogeneous sediment was used for analysis. The content (SOC) and isotopic ratio of carbon ($\delta^{13}\text{C}$) in the sediment was measured using elemental analyzer coupled with Isotope Ratio Mass Spectrometer (EA-IRMS-Delta V, Finnigan, Germany). Contents were reported as mg/g of dry sediment and isotopic ratios as per mil (‰) deviation from the conventional standards (δ notation) such as Pee Dee Belemnite for carbon (Coplen 1996). The high purity gas of CO₂ was calibrated with internal reference materials and was used as working standards. The long term precision of this instrument is about 0.2‰ for carbon. Total carbohydrates (TCHO) were measured using spectrophotometric method following (Dubois et al. 1956). Carbohydrates fractions (acid, and base extractable carbohydrates) were obtained following method of (Hitchcock 1977) and Gerchakov and Hatcher (1972) using UV-1800 Spectrophotometer (Shimadzu Corporation, Japan). Free (FAA), combined (CAA) and total Amino Acids (TAA) were separated as suggested by (Muller 1984) and analyzed by Fluorescamine (Udenfriend et al. 1972). Proteins were analyzed following the method of Herbert et al. (1971) and Gerchakov and Hatcher (1972) using UV-1800 Spectrophotometer. Samples were analyzed in duplicate and reported as mean values of duplicate samples. Precision for carbohydrates, amino acids and proteins were ±0.11, ±0.01 and ±0.2 µM respectively.

2.3. Graphical representation and statistical analyses of data

The softwares “Surfer” and “Grapher” were used for graphical representation of contours and X-Y plots of our data respectively. We have used Krigging method to interpolate data while preparing contour maps. Student t-test was conducted for all the parameters in order to estimate the significance of variance between SW and NW regions using Microsoft Excel.

3. Results

The water column temperature in the southwestern (SW; KS, KN, GS, and GN transects) was relatively cooler in the inner shelf than in the northwestern (NW; VD, HD, MS, and MN transects) coastal Bay of Bengal (Fig. 2a). The temperature gradient between NW and SW region was small in the outer shelf (Fig. 3a). The salinity in the upper 25m was lower in the NW (<23 psu) and increased towards SW region (Fig. 2b) in the inner shelf while lower salinity was observed in the former region (<26 psu) and increased to >34 psu in the SW region of outer shelf (Fig. 3b). Higher SPM was found in the SW ($27.21 \pm 13 \text{ mg l}^{-1}$) than NW ($12.7 \pm 7 \text{ mg l}^{-1}$) part of both inner and outer shelf region (Fig. 2c and 3c). The concentrations of nitrate varied from 0.32 to $12.62 \text{ }\mu\text{M}$ in SW region and lower concentrations, almost to near detection limits, were noticed in the NW region (Fig. 2d, 3d) whereas phosphate concentration were also followed similar trend (Fig. 2e, 3e). Dissolved silicate concentrations were relatively higher in the NW region in both inner and outer shelf (Fig. 2f, 3f). The phytoplankton biomass, represented as Chl-a, was showed higher in the NW region in the inner shelf ($4.96 \pm 1.47 \text{ mg m}^{-3}$ with maximum of 13.4 mg m^{-3}) was observed than at SW region (Fig. 2g) whereas low concentrations ($1.22 \pm 0.6 \text{ mg m}^{-3}$) were found in the outer shelf with maximum of 8.5 mg m^{-3} at off Godavari river (GN; Fig. 3g) in the SW region. The dissolved oxygen concentrations were relatively lower in the SW than NW and showed upsloping of contours were noticed in the SW in both inner and outer shelf (Fig. 2h, 3h). The bacterial cell count varied from 0.66 to $1.21 \times 10^6 \text{ cells ml}^{-1}$ (Figure not shown) with higher abundance in the NW than SW region. Sediment organic carbon (SOC) ranged between 6.27 and 18.15 mg g^{-1} dry sediment (Fig. 4a). Relatively higher concentration of SOC was found in the inner than outer shelf and this difference was larger in the NW than SW region. Total Carbohydrate (TCHO), acid leachable (ACHO) and base leachable carbohydrates (BCHO) concentration varied from 2.8 – 4.71, 0.3–0.59, and 0.3–1.04 mg g^{-1} dry sediment respectively (Fig. 4b–d). The concentrations of TAA, CAA and FAA varied from 0.01 to 0.14, 0.001 to 0.046 and 0.001 to 0.13 mg g^{-1} respectively, and the average value only TAA is statistically different between SW and NW region (Table 1). The concentration of proteins (pro) varied from 0.65 – 1.09 mg g^{-1} dry sediment with relatively higher concentration in the inner shelf than outer (Fig. 4h). The contribution of labile carbon was higher at off major river discharge regions (KS, KN, GS, GN, MS and MS) than off minor rivers (VD, HD) and no discharge regions (V) (Fig. 4i).

4. Discussion

The sediments in the NW coast of Bay of Bengal were influenced by glacial river (Ganges) while SW region was influenced by peninsular rivers (Godavari, Krishna). The characteristics of organic carbon brought by these rivers were expected to be different as it depends on the material received by the rivers and their modification in the estuary. Since huge amount of sediments were discharged to the coastal regions during peak monsoon period, the surface sediment represents the characteristics of individual rivers influence. The water column characteristics further modifies organic matter composition *en route* to bottom. Hence, the results were interpreted in terms of sediment characteristics along with water column processes to understand controlling mechanisms on composition of SOC in the western coastal Bay of Bengal.

4.1. Spatial variation in water column properties during peak discharge period.

Surface salinity was low in the NW (22.20 ± 1.46 psu) than SW (32.11 ± 4.2 psu) coastal Bay of Bengal (Fig. 2b, 3b) due to high fresh water discharge from Ganges. The occurrence of low saline water over a large area of the northern bay was reported earlier by (Conkright et al. 1994). In contrast, relatively cooler surface temperature (~ 26.7 - 28.5° C) was observed in the SW than in the NW region (~ 28.7 - 30° C) (Fig. 2a, 3a). The salinity difference between surface and 50 m was < 0.5 psu in the SW, which is as high as 13 psu in the NW region suggesting strong stratification in the latter region (Fig. 2b, 3b). Such weak stratification and winds from the southwest direction led to mild upwelling in the SW region. Shetye et al. (1991) reported occurrence of weak upwelling confined close to the coast in the SW coastal Bay of Bengal. The north-south difference in the salinity distribution arises from seasonally reversing coastal circulation (Varkey et al. 1996). During the southwest monsoon, a well-developed western boundary current, a part of the seasonal subtropical gyre, transports high-salinity waters northward (Shetye 1993).

Despite high river runoff resulting in low salinity in the NW region, low SPM (12.71 ± 7.13 mg l⁻¹) was found in the NW compare to SW region (27.21 ± 13.5 mg l⁻¹; Fig. 2c, 3c and Table 1) and it is attributed to major eastward flow of Ganges sediments (Rao et al. 1988). The average Chl-a was higher in the NW (4.96 ± 1.47 mg m⁻³) than in the SW region (1.22 ± 0.6 mg m⁻³) (Fig. 2g, 3g), which was associated with low SPM in the former than latter (Fig. 2c, 3c), suggesting that reduced light penetration into the water column in the latter region led to low Chl-a (Fig. 2d,3d). It is also supported by low nutrient

concentrations (for example $<1 \mu\text{mol kg}^{-1}$ of nitrate) in the NW region compared to SW (2 to 6 $\mu\text{mol kg}^{-1}$) region (Fig. 2d, 3d) suggesting efficient utilization of nutrients in the NW region by the phytoplankton. Although higher nutrients levels were observed in the SW region, a contribution by both discharge of Godavari and Krishna rivers and coastal upwelling, phytoplankton biomass in the inner shelf was lower by nearly 10 times than NW region due to low light penetration caused by high SPM load (Fig. 2c, 3c). The surface total bacterial count (TBC) was found to be high in NW ($8.7 \pm 3.1 \times 10^5$ cells ml^{-1}) compared to SW ($2.6 \pm 0.7 \times 10^5$ cells ml^{-1}). According to Goosen et al. (1997) the salinity and bacterial abundance is inversely proportional, i.e., the low salinity (22.20 ± 1.4 psu) was concomitant with high bacterial cells ($8.7 \pm 3.1 \times 10^5$ cells ml^{-1}), suggesting that rivers bring significant amount of bacteria to the Bay of Bengal (Fernandes et al. 2008). The bacterial respiration was also found to be higher in the NW compared to SW (Mrs. G. Lata personal communication) suggesting active regeneration occurs in the NW region due to availability of fresh organic matter.

4.2. Potential mechanism associated with spatial variability in SOC

The concentration of SOC increased from south to north with less variability between inner and outer shelf sediments in the SW while significantly higher concentrations were found in the inner than outer shelf in the NW region (Fig. 4a). The highest concentration of SOC was found at transect V where seasonal upwelling and urban sewage may be possible source to the sediments as one of the major cities (Visakhapatnam) in the east coast of India is located closed to this transect. The significant difference between inner and outer shelf was mainly driven by enhanced shelf width towards north along the east coast of India, differential contribution of organic matter from various rivers and localized physical processes. In addition to this, frequent occurrence of cold core eddies were found in the NW regions (Prasanna Kumar et al. 2004) that led to pumping of nutrient rich subsurface waters and formation of phytoplankton blooms. The enhanced SOC concentrations in the inner shelf at north of HD were caused by enhanced production driven by eddies. The mean SOC in the SW was higher ($11.45 \pm 1.7 \text{ mg g}^{-1}$) compared to NW region ($10.1 \pm 1.2 \text{ mg g}^{-1}$) (Fig 4a). The SOC did not show significant relationship with phytoplankton biomass in the surface ($r^2=0.104$; $df=54$) suggesting other sources of organic matter to the sediments. High SPM ($27.21 \pm 13.6 \text{ mg l}^{-1}$) and high SOC (Table 1) was found in the SW region suggests effective scavenging of organic matter, both *in situ* and river borne, from the water column through association with mineral particles to the sediment. Such mechanism was initially proposed by Ittekkot et al. (1991) in the Bay of Bengal. On the other hand, high phytoplankton biomass, low SPM and low

SOC, observed in the NW region suggests that aggregation and faster sinking of plankton could be a potential transport mechanism in the NW region. In order to further confirm the quality of OM reaching to the sediments, carbon isotopic ratio ($\delta^{13}\text{C}$) and molar C/N ratios of SOC were examined. Relatively heavy $\delta^{13}\text{C}$ isotopic ratio of SOC (-19.6‰) and high C/N (23 ± 8) in the SW indicates terrestrial source of organic matter whereas lighter $\delta^{13}\text{C}$ (-23.2‰) and lower C/N (15 ± 9) in the NW region suggest dominant contribution from marine plankton (Thornton and McManus 1994; Galvan et al. 2008; Kao and Liu 1999).

The amount of sinking organic matter that reaches the sediment is also depending on the water column oxygen levels as it represents the active regeneration rates. In order to examine changes in sinking organic matter in the water column vertical profiles of dissolved oxygen (DO) was compared from SW and NW regions (Fig. 5). The DO concentrations in the mid depth (100 – 500 m) was relatively higher ($\sim 5 \mu\text{M}$) in the SW compared to NW region ($< 0.5 \mu\text{M}$) suggesting that efficient regeneration of organic matter in the latter region. The relatively higher concentrations of DO in the SW region could possibly due to faster scavenging of organic matter in association with high suspended matter resulting in decreased residence time in the water column. On the other hand, low DO levels in the NW indicates efficient bacterial respiration in the water column facilitated by fresh organic matter and high resident time of organic matter due to low SPM (Fig. 2c, 3c).

4.3. *Spatial distribution of labile organic components in sediments*

The distribution of labile organic components such as carbohydrates, amino acids and proteins showed significant spatial variability and were associated with water column properties. Relatively higher levels of labile organic components were found in the NW compared to the SW region and were associated with Chl-a and DO content in the water column.

4.3.1. Distribution of carbohydrates

The total carbohydrates (TCHO) concentrations ranged from 2.8 to 4.7 mg g^{-1} dry sediment in the study region and showed significant difference between SW and NW regions (Table 1). The TCHO concentration decreased from SW region to HD and then increased slightly towards NW region. The TCHO concentrations observed in this study were consistent with the values reported by Jacob et al. (2008; 1.28 to 4.43 mg g^{-1} dry sed.), while lower than that of Bhosle et al. (1988; 2.03 to 9.67 mg g^{-1}

dry sed.) in the west coast of Bay of Bengal. Such differences could possibly due to seasonal bias as samples were collected in the present study during peak river discharge period whereas reported values were obtained during lean or no discharge period. In addition to this, inter-annual variability in river discharge and water column production may also contribute to some extent. Nevertheless, these values are higher than those reported from sediments elsewhere, i.e., San Diego trough 0.9 mg g^{-1} dry sed.; Degens et al. 1963) Baltic Sea ($0.5\text{-}3.5 \text{ mg g}^{-1}$; Naik and Poutanen 1984) and Santa Barbara Basin, California (2.2 mg g^{-1} dry sed.; Prashnowsky et al. 1961). The mean acid (ACHO) and base (BCHO) dissolvable carbohydrate values were 0.38 ± 0.1 and $0.63\pm 0.17 \text{ mg g}^{-1}$ dry sed respectively. The ACHO concentrations were relatively higher in the inner shelf in the NW region and contrasting to this was found for BCHO (Fig. 4c,d). The contribution of ACHO and BCHO to TCHO was 10-18% in the study region with no significant spatial variability. Less contribution of ACHO and BCHO to TCHO suggests that they were either utilized preferentially in the water column during the sedimentation or by benthic organisms (Bhosle et al. 1988). Hitchcock (1977) suggested that when water column depth increases, the contribution of acid and base extractable carbohydrates decreases indicating that preferential removal of these fractions through biological processes in the water column itself. High concentrations of residual carbohydrates ($2.73\pm 0.46 \text{ mg g}^{-1}$ and 70 to 74% of TCHO) denote that these compounds are resistant to biological and chemical degradation. Despite high phytoplankton biomass in the NW region, lower levels of TCHO, ACHO and BCHO than SW region, suggest an efficient regeneration of these compounds through microbial processes in the former region. This is supported by low concentration of DO (Fig. 5) and high bacterial abundance and respiration rates in the NW region, indicating that efficient regeneration of organic matter in the water column. On the other hand, though low phytoplankton biomass was found in the SW compared to NW region, however, high TCHO concentrations in the former region were mainly caused by faster removal from the water column into the sediments. In addition to this, sedimentation rates are expected to be high due to high SPM load in the SW region that helps to escape from the sediment diagenesis as well.

4.3.2. Distribution of Amino acids

The concentrations of amino acids (total, free and combined) were lower in the inner shelf than outer shelf, except off Vamsadhara river (Fig 4e-g) with significant north-south variations (Table 1). Slight decrease in the concentration of TAA, and FAA was observed from SW to NW region whereas CAA decreased from KS to V and then increased towards MN transect. Relatively higher concentrations of

CAA were found off major rivers suggesting that rivers are major contributor of CAA to the coastal region. Equal concentrations of CAA and FAA in the surface sediments suggest that nitrogenous organic matter was present in both the forms (Kemp and Mudrochova 1973; Gonzalez et al. 1983). Both FAA and CAA contributed equally (~50% each) to the TAA in the SW region whereas CAA contributed substantially more (59%) than FAA (41%) in the NW region suggesting that FAA were preferentially decomposed in the latter region. The amount of amino acids in the sediments was governed by several physico-chemical conditions and activity of heterotrophic organisms, which are responsible for decomposition of amino acids in the sediments. It has been observed that higher amount of benthic organisms abundance in the NW than SW region (Mr. S.A. Naidu personal communication 2012) that could lead to decomposition of high amount of FAA in the former region.

4.3.3. Distribution of Proteins

Proteins concentrations ranged from 0.65 to 1.04 mg g⁻¹ and were higher than TAA suggesting that major portion of the amino acids were preserved in the nitrogenous organic matter form (Fig 4h). Proteins concentrations were relatively higher in the inner compared to outer shelf region. The concentration of proteins was slightly increased from SW to NW. Proteins contributed to 4 to 13% to the SOC and its contribution was relatively higher in the NW (8.6%) than SW region (6.5%). The high contribution of proteins (6-8%) than amino acids (<1%) suggesting that nitrogenous organic matter were preserved in the form of proteins or peptides than amino acids. Organic nitrogen (i.e., protein) is widely considered as the major limiting factor for deposit-feeders. High Protein concentrations in the NW region was supported by high benthic organisms in this region compared to SW (Mr. S.A. Naidu, Personal Communication 2012) indicating the former region is more conducive for high biological activity in the sediment.

Pusceddu et al. (1999) suggested that protein to TCHO ratio is an indicator for source of organic matter to the sediment. The lower ratio suggests the presence of aged organic matter (Danovaro et al. 1993) and a role of proteins as a potentially limiting factor for benthic consumers (Fabiano et al. 1995). This ratio ranges from lower than 0.1 in oligotrophic deep-sea sediments in the Eastern Mediterranean Sea (Danovaro et al. 1993) to higher than 10 in coastal Antarctic sediments (Pusceddu et al. 1999). The mean ratio of protein to TCHO was 0.18 in the SW and 0.25 in the NW indicating that SW region sediments are characterized by a large amount of aged, and/or non-living organic matter.

4.3.4. Contribution of labile carbon to the total organic carbon in the sediments

Though SOC in the surface sediments was higher in the SW than in the NW region, the percentage of contribution to labile compounds (sum of total carbohydrates, amino acids, and proteins) were significantly higher in the latter (50-60%) than former region (44%) (Fig 4i). Among the labile compounds, TCHO and proteins contributed about 33% and 6% respectively to SOC. The residual carbohydrates alone contributed up to 20% to the total SOC, suggesting that this fraction of carbohydrates is escaped bacterial degradation both in the water column and in the sediment supporting the result of isotopic ratios of bulk organic carbon.

5. Summary and Conclusions

Coastal Bay of Bengal receives nutrients, SPM and OC from several rivers during monsoon (June – September). The characteristics of the organic matter that reaches to the sediment depend on the biogeochemical conditions in the water column. Low nutrients and SPM coupled with high phytoplankton biomass were found in the water column of NW region, which is influenced by discharge from the Ganges. In contrast, high nutrients, SPM and low phytoplankton biomass was noticed in the SW region, which is affected by discharge from the peninsular rivers. SOC was relatively higher in the SW than NW in the inner shelf and contrasting to that was found in the outer shelf due to high plankton production in the NW region of inner shelf. The isotopic composition of bulk organic carbon suggests significant contribution of *in situ* phytoplankton production to the SOC in the NW region whereas terrigenous organic matter in the NW region. Despite higher phytoplankton biomass in the NW region, higher total carbohydrates (TCHO) concentrations was observed in the SW than NW region suggesting that faster removal of organic matter, in association with SPM, leading to lower decomposition of organic matter in the water column. Though SPM concentrations were significantly low in the NW region, however, formation of thick oxygen minimum zone in the water column led to sinking of undecomposed organic matter to sediment. Total and free amino acids were decreased from SW to NW region while high concentrations of combined amino acids were found off major rivers suggesting that rivers are major contributor of combined amino acids to the coastal region. Relatively higher protein than total amino acids were found suggesting that major portion of the amino acids was preserved in the nitrogenous form. The percentage of contribution of labile compounds to total organic carbon was higher in the NW (50-60%) than SW region (44%).

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Table 1: Mean (\pm standard deviation) of water column and sediment properties and ANOVA statistical significance of variation is given between SW and NW regions.

Parameter	SW	NW	t-test	df	<i>p</i>
Salinity (psu)	32.11 \pm 4.2	22.20 \pm 1.46	7.52	46	<0.001
TSM (mg l ⁻¹)	27.21 \pm 13.5	12.71 \pm 7.13	3.15	46	<0.001
Chl-a (mg m ⁻³)	1.22 \pm 0.6	4.96 \pm 1.47	-7.94	46	<0.01
TBC (cells ml ⁻¹)	2.6 \times 10 ⁵ \pm 1.1 \times 10 ⁵	8.7 \times 10 ⁵ \pm 3.1 \times 10 ⁵	-5.23	46	<0.01
SOC (mg g dry sed ⁻¹)	11.45 \pm 1.7	10.07 \pm 1.24	2.10	33	<0.05
TCHO (mg g dry sed ⁻¹)	4.18 \pm 0.8	3.32 \pm 0.83	2.51	31	<0.05
ACHO (mg g dry sed ⁻¹)	0.44 \pm 0.1	0.36 \pm 0.1	1.65	31	<0.05
BCHO (mg g dry sed ⁻¹)	0.74 \pm 0.2	0.66 \pm 0.16	1.11	31	<0.05
RCHO (mg g dry sed ⁻¹)	3.01 \pm 0.4	2.25 \pm 0.8	2.62	31	<0.05
TAA (mg g dry sed ⁻¹)	0.05 \pm 0.02	0.06 \pm 0.02	-1.22	30	<0.01
FAA (mg g dry sed ⁻¹)	0.03 \pm 0.01	0.02 \pm 0.01	0.55	30	NA
CAA (mg g dry sed ⁻¹)	0.02 \pm 0.02	0.03 \pm 0.01	0.61	24	NA
Pro (mg g dry sed ⁻¹)	0.76 \pm 0.13	0.82 \pm 0.07	-1.22	24	<0.01
Pro/TCHO ratio	0.18 \pm 0.6	0.25 \pm 0.6	1.72	24	<0.001

df=degrees of freedom

Figure 1: Station locations where samples were collected in the water column and sediments along the east coast of India.

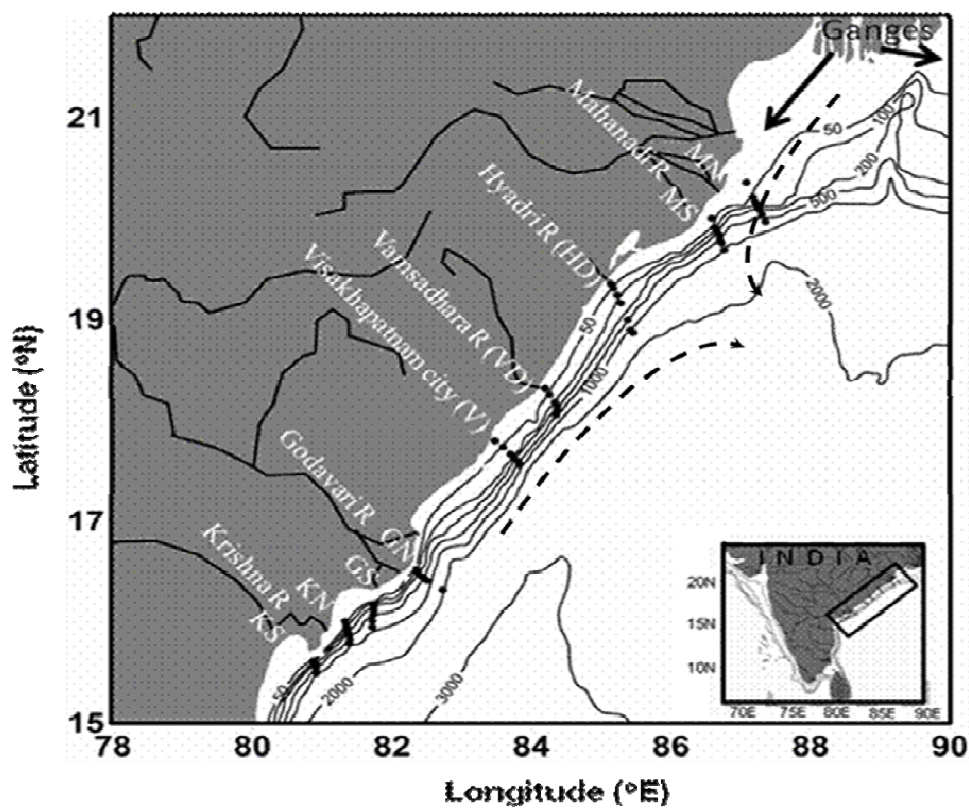


Figure 2: Spatial distribution of water column properties, a) temperature ($^{\circ}\text{C}$), b) salinity (psu), c) SPM (mg l^{-1}), d) nitrate (μM), e) phosphate (μM), f) silicate (μM), g) chlorophyll-a (mg m^{-3}) and h) dissolved oxygen (μM) in the inner shelf of coastal Bay of Bengal.

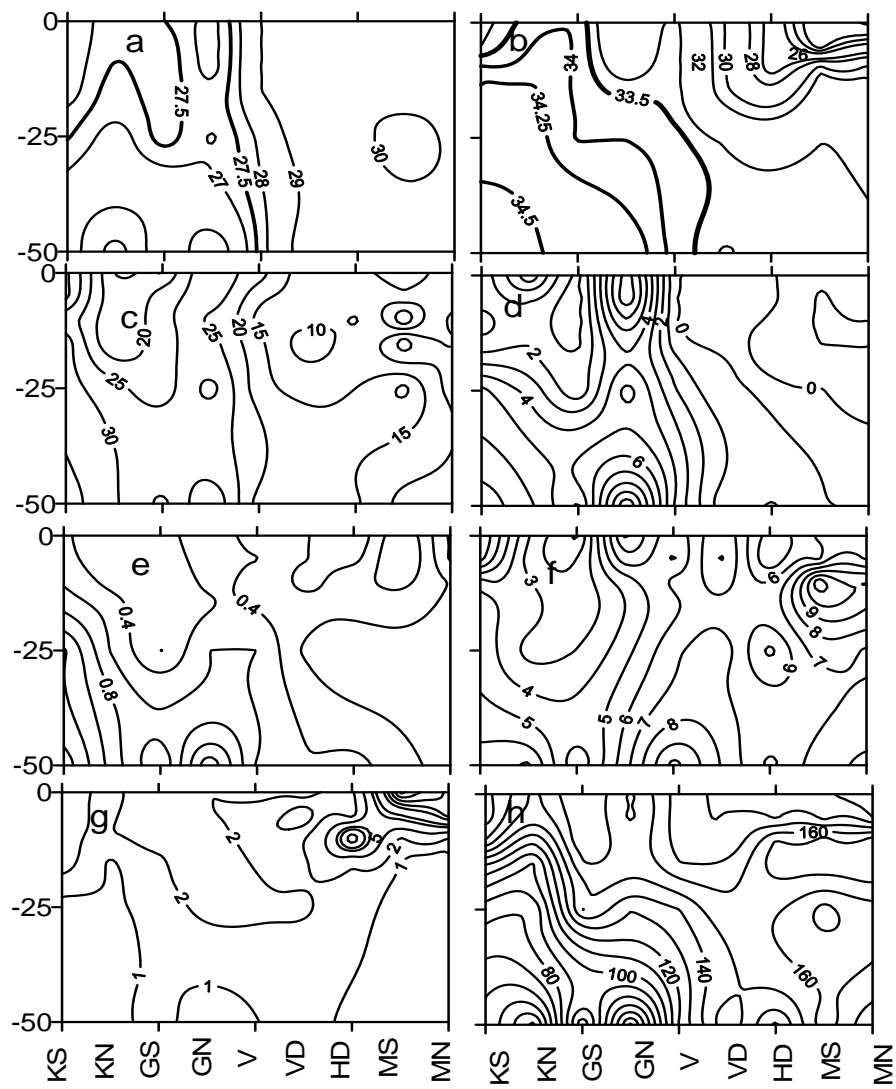


Figure 3: Same as in figure 2 for outer shelf of the coastal Bay of Bengal

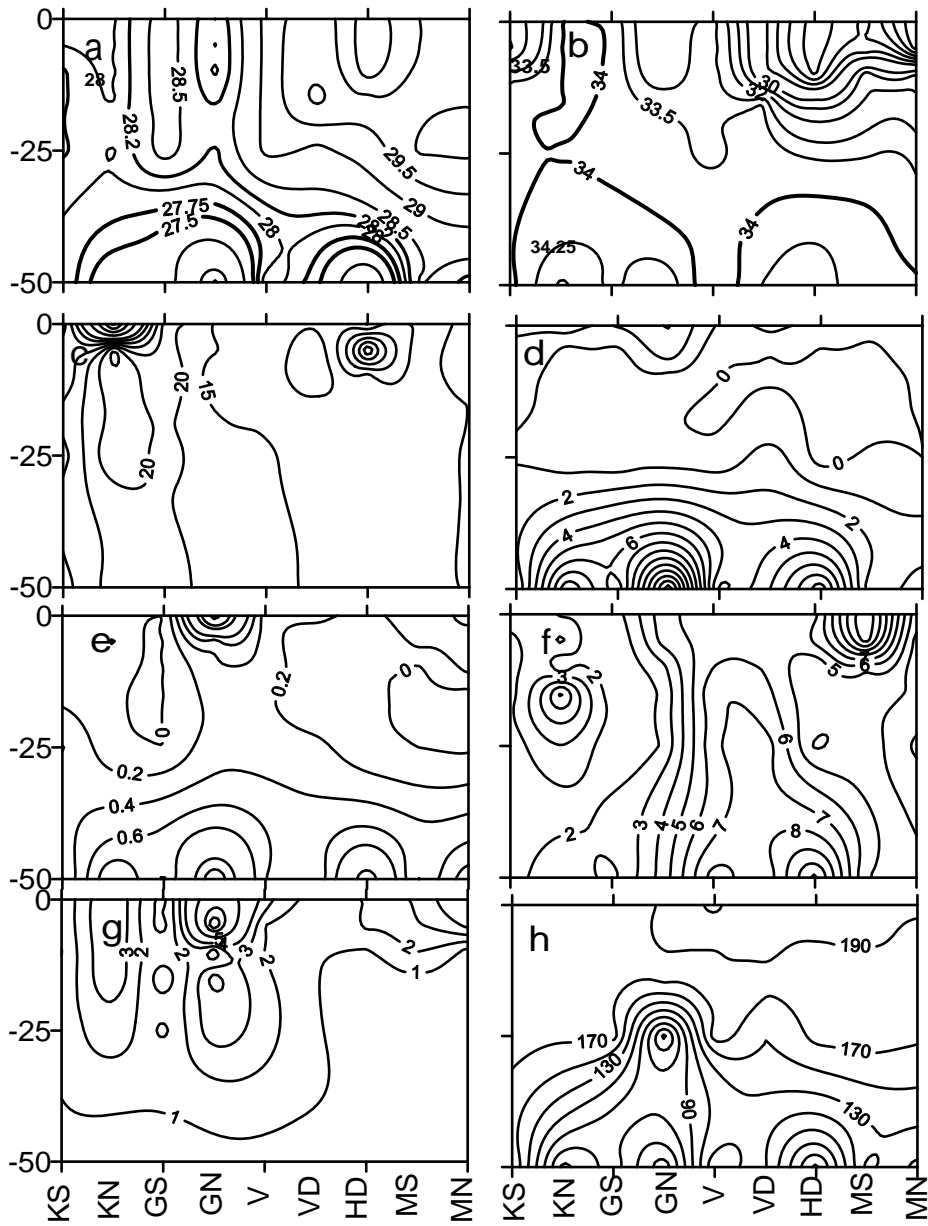


Figure 4: Spatial variations in a) SOC, b) TCHO, c) ACHO, d) BCHO, e) TAA, f) FAA, g) CAA, h) Proteins and i) percentage of labile carbon to SOC in the inner shelf (open circles) and outer shelf (closed circles) in the coastal Bay of Bengal.

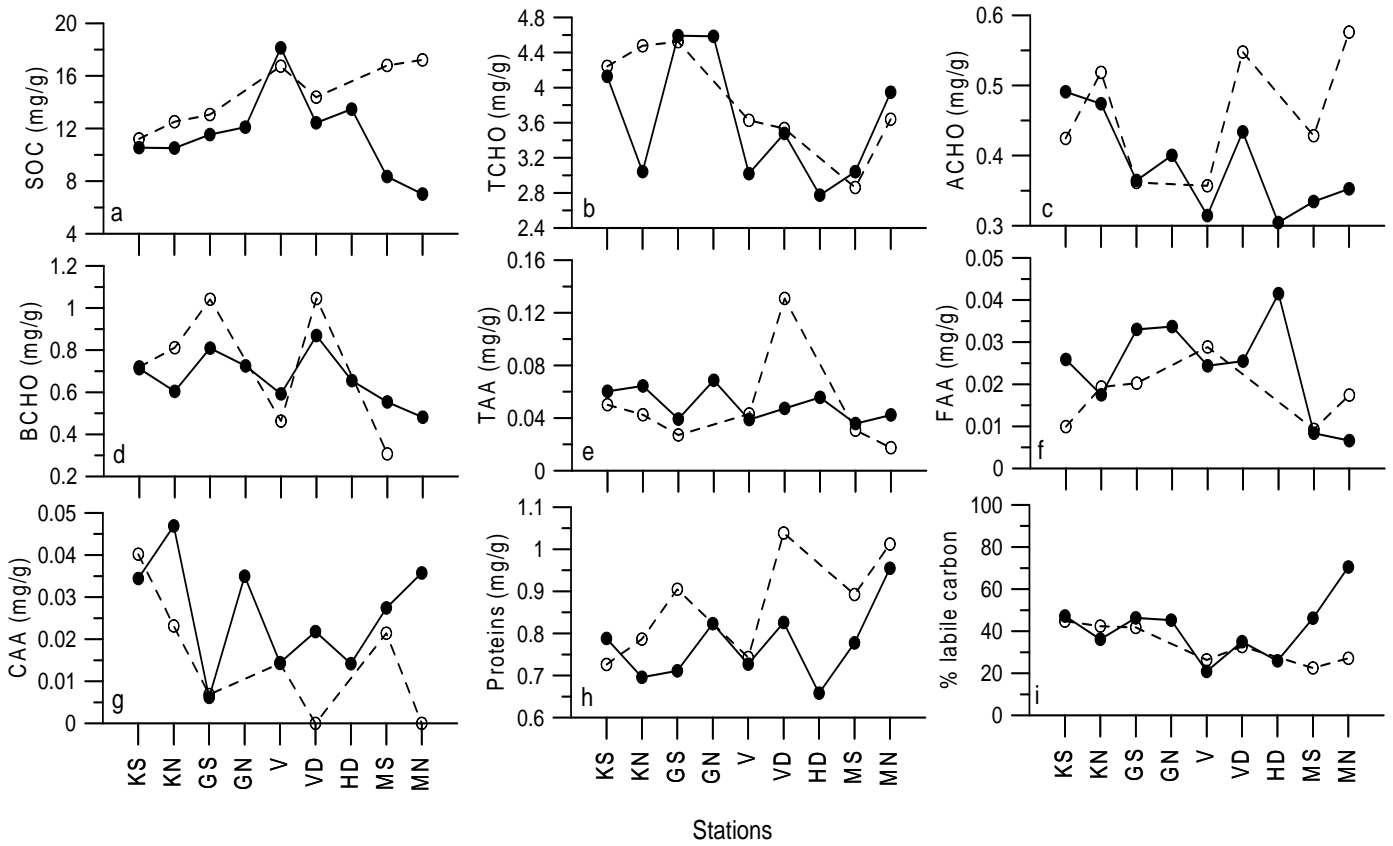


Figure 5: Vertical distribution of dissolved oxygen in the SW (closed circles) and NW (open circles) region of coastal Bay of Bengal.

