

Seasonal Distribution of Surface Sediments and Hydrodynamic Conditions in Zuari Estuary, Goa, Central West Coast of India

DEEPTI V. G. DESSAI and G. N. NAYAK

Department of Marine Sciences, Goa University, Goa - 403206

Abstract: The seasonal distribution of surface sediments and hydrodynamic conditions prevailed during their deposition have been studied within the Zuari estuary. Surface sediments collected from 18 stations all along the length of the Zuari estuary, during three different seasons viz. monsoon, post-monsoon and pre-monsoon, were analyzed for sand, silt, clay and organic carbon. The study revealed that upper half of the estuary is mostly dominated by sand while the lower half is enriched with the clay and silt components in all the three seasons, with minor variations. Organic carbon is also noticed to be higher in the lower half of the estuary with a general decreasing trend towards the mouth. Further, finer sediment distribution and higher concentration of organic carbon is specifically noted during pre-monsoon season compared to other two seasons at most of the stations. Significant positive correlation between organic carbon and clay (0.7603 – Avg. of three seasons) supports the association of organic carbon with finer sediments. However, sand shows inverse relationship with organic carbon. Based on sediment characteristics, an attempt has been made to understand the hydrodynamic conditions prevailed in the Zuari estuary in three different seasons.

INTRODUCTION

Estuaries, important environments of coastal zone, are favorable domains for deposition of sediments derived from both the terrestrial and also from marine sources. Sediment distribution in estuaries is mainly controlled by the influence of tidal and river currents in addition to the source. However, other factors such as geo-morphology and circulation pattern also can modify the distribution. Dispersal of sediments in the estuary is controlled further by the changes in properties of river water in the estuarine environment, which result in the accumulation of fine-grained sediment with a high organic matter content. Anthropogenic activities in the recent years have resulted in elevated release and concentration of organic carbon in sediments. Sources of organic carbon include organic matter from land runoff, shoreline erosion and primary productivity, product of these eventually settle to the bottom and are incorporated into the sediments. Measurement of different sediment parameters viz. sand, silt, clay and organic carbon is important since they can strongly reflect the environmental condition of deposition. So in the present study an attempt was made to understand the distribution, association of sediment components all along the estuary in different seasons and hydrodynamic conditions prevailed during the deposition of sediment.

STUDY AREA

The river Mandovi and Zuari are major rivers of Goa (Fig. 1). Both Mandovi and Zuari are interconnected through Cumbharjua canal and both form an important estuarine complex on the West Coast of India. The present work focuses on the Zuari estuary. The river Zuari is tide dominated coastal plain estuary with a tidal range of about 2 m and it is geomorphologically classified as drowned river valley estuary (Murty et al., 1976). The Zuari River is fed by monsoon precipitation and receives discharge from the catchment area of 550 sq km. The river receives large supply of water and sediments from its tributary known as Kushawati. The average rainfall of Goa is about 3000 mm per year. The region preferably experiences three defined seasons i.e. monsoon (June to September), post-monsoon (October to January) and pre-monsoon (February to May). There are many large as well as small-scale mines in the catchment area of Zuari estuary. Mining activities in the catchment area and transportation of ore from jetties in the upper estuarine region to Marmugao Harbour, located on the southern bank near the mouth, through barges are the major activities carried out in the Zuari estuary. The river has wide mouth and the width remains almost same in the lower estuarine region.

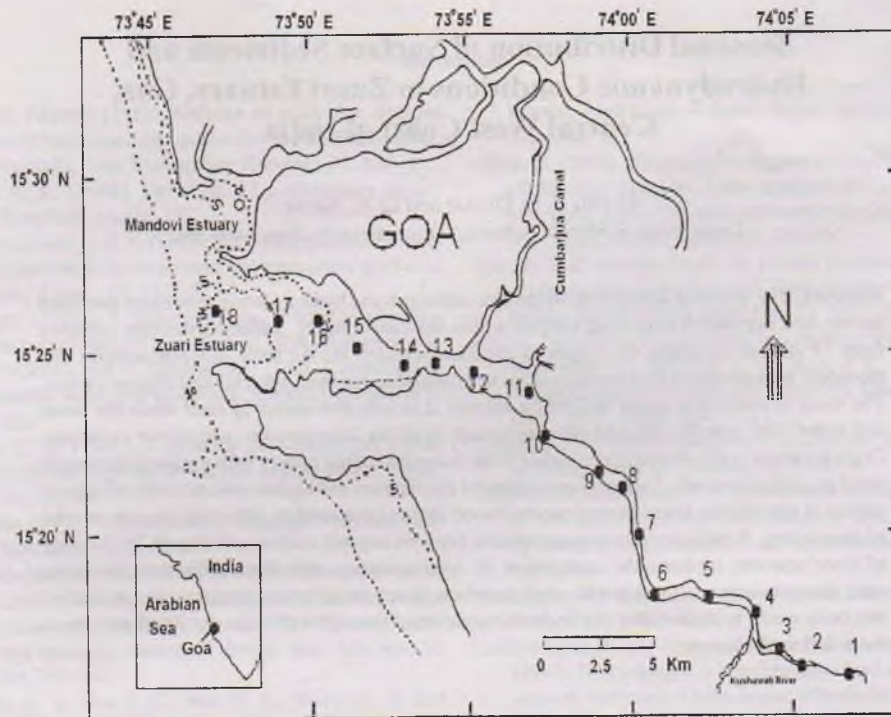


Fig.1. Map showing sample locations within Zuari estuary.

METHODOLOGY

Sediment samples were collected by using a Van Veen grab sampler representing three seasons viz. monsoon, post-monsoon and pre-monsoon from 18 stations (Fig. 1.). Sub samples were taken from the upper 5 cm representing surface sediments. Collected samples were transferred to pre-cleaned polyethylene bags and were then preserved in the deep freezer. Later samples were oven dried at 60°C. Part of the sediment sample was powdered for organic carbon analysis. Organic Carbon was determined following Walkley Black method, adopted and modified by Jackson (1958). Another part of the sample was used to obtain sand: silt: clay ratio by pipette analysis (Folk, 1968).

RESULTS AND DISCUSSIONS

Distribution of different sediment components viz. sand, silt, clay and organic carbon in different seasons in the Zuari estuary is depicted in the Figure 2. Sand content ranges from 2.30 to 94.79 %, silt from 1.66 to 64.44 %, clay from 2.40 to 57.44 % and organic carbon ranges from 0.03 to 2.41 % during monsoon season. During post-monsoon sand content ranges from 28.83 to 95.43 %, silt from 0.51 to 25.29 %, clay from 1.15 to

63.68 % and organic carbon ranges from 0.09 to 2.25 % and during pre-monsoon, sand ranges from 2.51 to 98.38 %, silt from 0.07 to 30.61 %, clay from 1.55 to 68.53 % and organic carbon ranges from 0.18 to 2.63 %. Further, based on the geomorphological setup and distribution pattern of the sediment components, the Zuari estuary is divided into two parts i.e. upper estuary (from station 1 to 10) and lower estuary (from station 11 to 18).

Sand

During monsoon, sand content is observed to be higher (Avg. 84.49 %) in the upper estuary and comparatively lower (Avg. 36.51%) values are observed in the lower estuarine region with some peak values at few stations. The increasing trend is seen from station 4 to 8; further down it shows a constant decrease up to the station 10 in the upper estuary. Further downstream that is in the lower estuary, large variation of sand content is observed at different stations. Sharp decrease in value is observed from station 10 to station 11. Lower values are also observed at stations 13, 14 and 17. However at stations 12, 15 and 18 higher values have been recorded. During post-monsoon, also sand content is observed to be higher (Avg. 86.59 %) in the upper

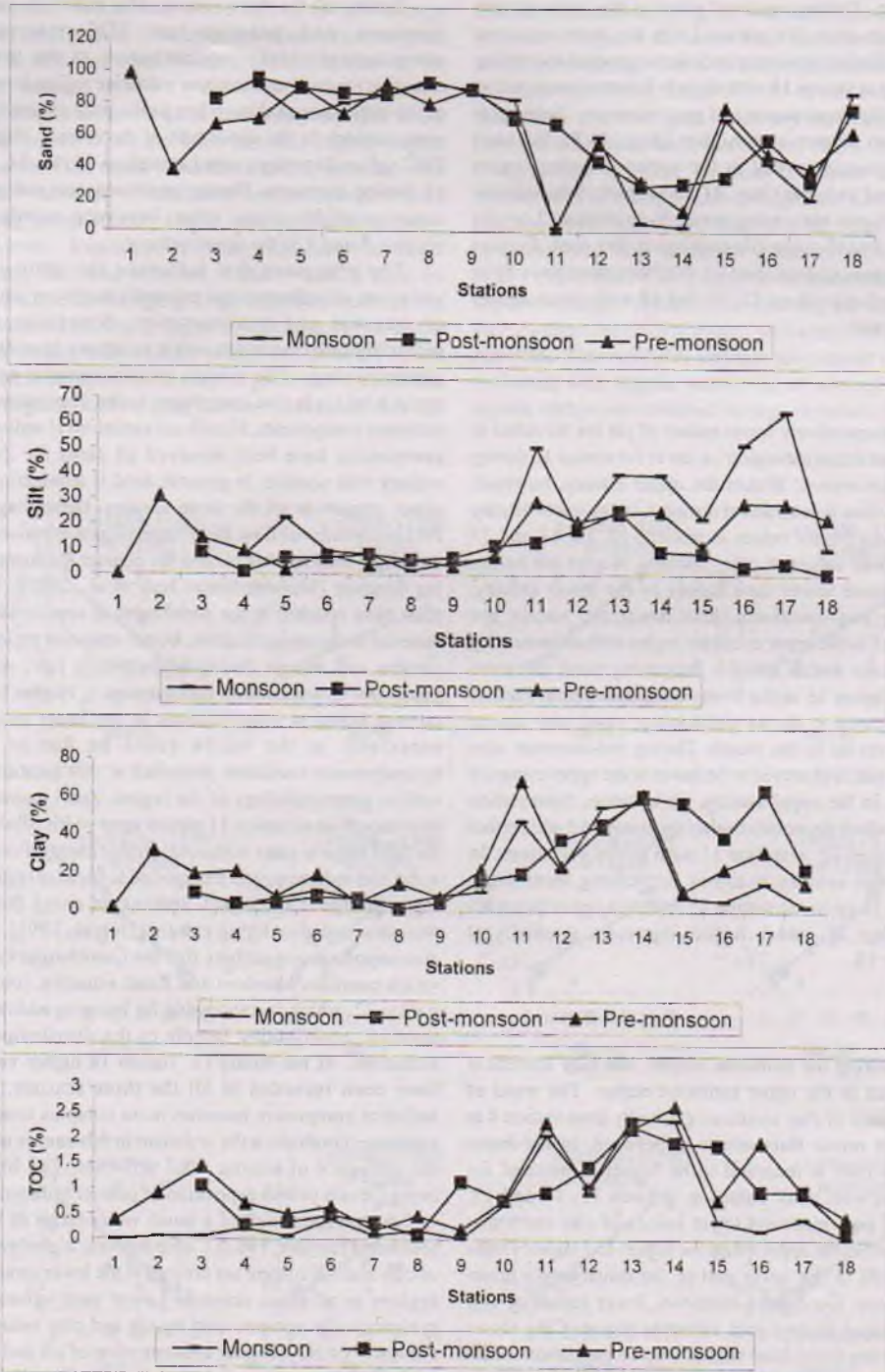


Fig. 2. Seasonal distribution of surface sediment components within the Zuari estuary.

estuarine region. The decreasing trend is seen from station 1 up to the station 10 with minor variations in between. Decreasing trend noted in the upper estuary continues up to the station 13 in the lower estuarine region. Further downstream it shows gradual increasing trend up to station 18 with slightly lesser value at station 17. Similar to monsoon and post-monsoon, during pre-monsoon season also higher (Avg. 76.80 %) sand content was recorded in the upper estuarine region compared to lower (Avg. 41.59 %) part of the estuary. Sand shows increasing trend from station 2 to the station 9 with some fluctuations in between. Further it decreases up to station 11. Higher values have been recorded at stations 12, 15 and 18 with lower values in between.

Silt

Comparatively lower values of silt are recorded in the upper estuarine region i.e. up to the station 10 during monsoon season. Within the upper estuary, however, higher value is recorded at station 5. In the lower estuary silt shows higher values at stations 11, 13, 14 and 17 with lower values at other stations. Higher silt values compensate lower sand values in the lower estuary. During post-monsoon, also lower silt values are recorded in the upper estuarine region with an increasing trend from station 4 to 10. Increasing trend continues up to station 13 in the lower estuarine region. Further downstream it shows decreasing trend with minor variations up to the mouth. During pre-monsoon also silt content is observed to be lower in the upper estuarine region. In the upper estuary, silt increases from station 1 to 2, which decreases further up to station 5 and further it increases up to station 11 with minor variations. In the lower estuary it shows decreasing trend from station 11 up to the station 15 and then again increases at station 16, which further decreases gradually at station 18.

Clay

During the monsoon season, low clay content is recorded in the upper estuarine region. The trend of percentage of clay increases gradually from station 4 to 10 with minor fluctuations in between. In the lower estuary clay is recorded to be higher at most of the stations with peak values at stations 11, 14 and 17. During post monsoon lower values of clay content is recorded in the upper estuarine region and higher values are noted in the lower part of the estuary with minor variations. During pre-monsoon, lower values of clay are noticed in the upper estuarine region. Clay shows decreasing trend from station 2 up to the station 9 with minor fluctuations. From station 9 the value increases up to the station 11 in the lower estuary. Higher values are also seen at stations 14 and 17 with lower clay values in between.

Total Organic Carbon (TOC)

During all the three seasons viz. monsoon, post-monsoon and pre-monsoon TOC maintains comparatively higher concentration in the lower estuarine region than the upper estuarine region at most of the stations even though few peaks were observed at some stations in the upper part of the estuary. Higher TOC values have been noted at stations 11, 13, 14, 12, 10 during monsoon. During post-monsoon and pre-monsoon, slightly higher values have been recorded at stations 2 and 3 in the upper estuary.

The processes that influence the grain size variations of sediments are primarily supply or source of material and transportation, deposition and redistribution of sediments within an estuary. In addition geomorphology of the estuary, water movements owing to the tidal cycle also contributes to the distribution of sediment components. Significant variations in sediment components have been observed all along the Zuari estuary with seasons. In general, sand is dominating in upper estuary in all the three seasons. Depending on the competency of flow, finer material gets entrained in the water, thus leaving behind the coarser sediments as lag deposits (Muraleedharan Nair et al., 2002). This must have resulted in the enrichment of coarser sandy material in the upper reaches. Upper estuarine region is narrow and except during highest high tide, water generally flows towards downstream. Higher sand content noted at some stations in the lower estuary especially at the mouth could be due to the hydrodynamic condition prevailed at this location as well as geomorphology of the region. Zuari maintains from mouth up to station 11 almost same width, allowing the tidal surge to enter with considerable energy. Further, water and sediments gets transported to the Zuari estuary from Mandovi through Cumbharjua canal during monsoon and also during ebb tide (Nayak, 1993). It is also important to note here that the Cumbharjua canal, which connects Mandovi and Zuari estuaries, joins at station 12, which is responsible for bringing additional material, contributing largely to the distribution of sediments. At the mouth i.e. station 18 higher values have been recorded in all the three seasons. The sediment component becomes more complex near the estuarine mouth since the sediment in this zone is under the influence of intense tidal activities. The higher energy levels permit deposition of coarser sediments as well as transportation of a much wider range of finer sediments (Bryant, 1982). Comparatively higher values of clay and silt content are noticed in the lower estuarine regions in all three seasons. Lower sand values are systematically compensated by silt and clay values in the lower estuary. Higher concentration of silt and clay in the lower estuary may be due to settling of these particles in low energy conditions. The flocculation process during estuarine mixing helps in faster settling of fine colloidal aggregates in this region. Near the

mouth due to high-energy turbulent conditions, finer grains do not settle instead they are carried away to far distances, which then settle down, to low energy conditions (Nayak, 1996). For this reason coarser grain size is seen near river mouth and finer interior in the lower estuary.

TOC is observed to be comparatively less in the upper estuary in all the three seasons. Slightly higher values of TOC noted at station 2 and 3, coincide with higher values of silt and clay content recorded here during pre-monsoon and at station 3 during post-monsoon. Kushawati tributary that joins the Zuari estuary between stations 3 and 4 and it may be responsible for bringing large organic matter as the agricultural activity is higher in catchment area. In the lower estuary TOC content is high except at the mouth region. A comparison of data on grain size distribution and organic carbon distribution revealed that the

organic carbon content increases with increasing finer fractions and decreases with the increasing coarser fractions in sediments (Fig. 2). The main cause for the increase of organic carbon in finer particles is in the similarity in settling velocity of both organic constituents and finer particles (Trask, 1939). It has been also established that TOC gets selectively enriched in fine particles of estuarine sediments (Hunt, 1981). The ratio C-org/surface is higher for finer sediments than for coarser, such as sand particles (Hedges and Keil, 1995; Hedges, 2002; Wakeham, 2002). Fine (clay + silt) particles having larger surface to volume ratio (Williams et al., 1994; Rae, 1997) tend to be associated with negative charges. Therefore on entering the seawater, their surfaces are quickly coated with a layer of organic materials. This results in stronger association of finer sediments with organic matter. On an average higher organic carbon was obtained during pre-monsoon (1.02

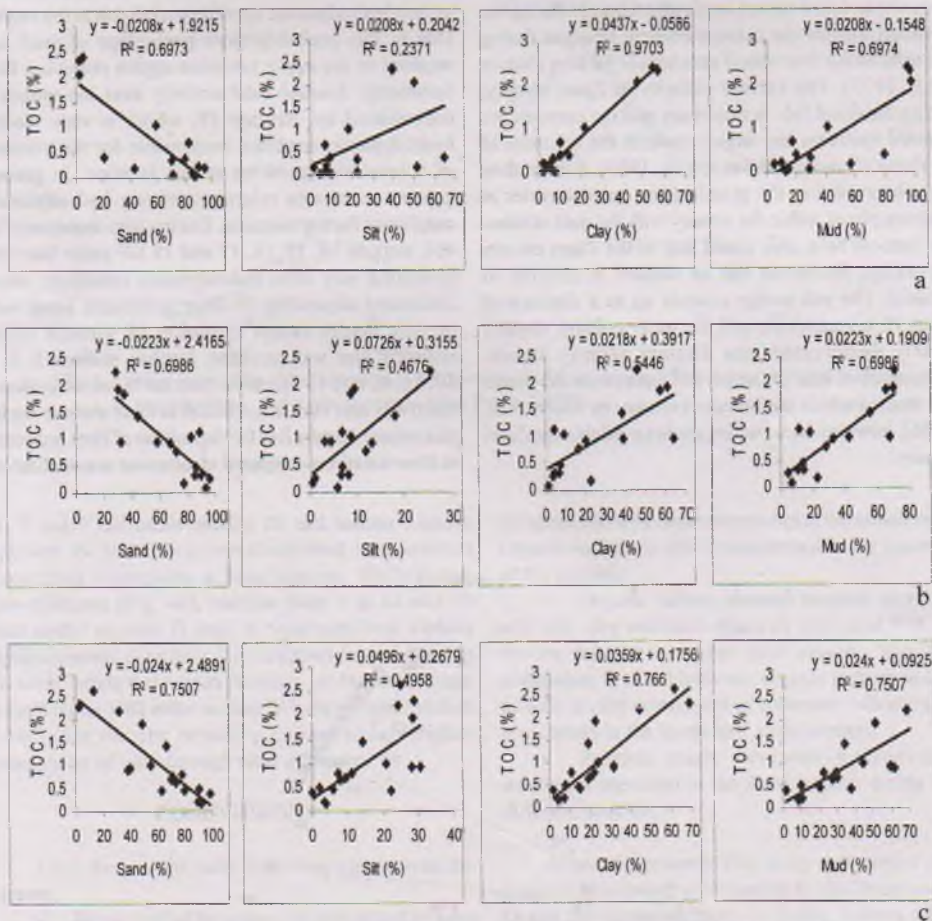
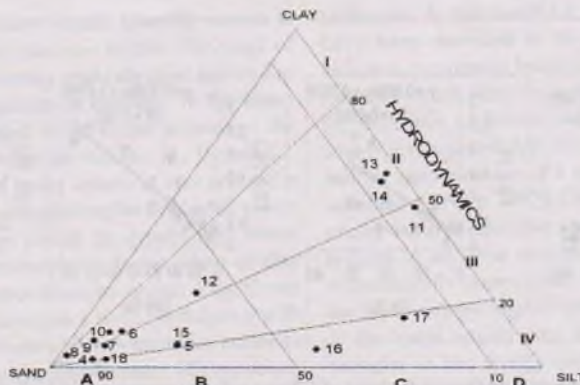


Fig. 3. Relationship between Total Organic Carbon and different sediment components in Zuari estuary during different seasons viz. a. monsoon, b. post-monsoon, and c. pre-monsoon.

%) followed by post-monsoon (0.94 %) and monsoon (0.59 %), which is the least. From this it can be inferred that the adsorption of organic compounds onto clay minerals was promoted under saline conditions (Nair et al., 1993) during pre-monsoon season. Organic coatings on clay minerals affected the settling rates of inorganic particles and thus contributed to the increase in both clay-size particles and organic matter during this period. Correlation of organic carbon with sand, silt, clay and also mud (silt + clay) showed positive correlation with silt, clay and mud and negative with sand in all three seasons (Fig. 3a to 3c) A significant correlation is noted between TOC and mud as well as clay in all the three seasons strongly supports their association and setting in a similar depositional environment.

Zuari estuary can be classified as a tide-dominated coastal plain estuary, which exhibits homogenous vertically but has lateral variations in salinity (Quasim and Sen Gupta, 1980). The average current speed was observed to be stronger during the flood tide in the pre-monsoon and post-monsoon months whereas during the monsoon months the current become stronger during ebb tides as the river runoff accelerates the flow (Varma et al., 1975). The current velocity in Zuari estuary, during the flood tide is maximum and the currents are directed upstream and largely towards the left sides of the rivers (Quasim and Sen Gupta, 1980). Further they also observed that the speed of the current varies at different places within the estuary with the state of tides. The authors have also stated that in the Zuari estuary salt-wedge formation can be studied in relation to distance. The salt-wedge extends up to a distance of about 12 km upstream and the water column remains clearly demarcated into distinct salinity layers. Bathymetry of inlet of the sea and waves over the shoals was studied within the Mandovi estuary by Murty et al. (1976), however such studies are not available for Zuari estuary.

Various approaches to understand the bathymetry and hydrodynamic conditions of Mandovi and Zuari estuaries using the distribution of various parameters like salinity and its gradients (Shetye and Murty, 1987), river runoff and tidal propagation (Shetye, 1999; Unnikrishnan et al., 1997) were tried. In this paper, however, an attempt has been made to understand the hydrodynamics using sediment components namely sand, silt, clay and with the help ternary diagram proposed by Pejrup (1988). The diagram has four sections labeled I to IV. Section I indicates very calm hydrodynamic conditions and section II to IV indicate increasingly violent hydrodynamic conditions. During monsoon (Fig. 4a), stations 6, 8, 9, 10, 12, 13 and 14 fall under Section II; stations 4, 5, 7, 11 and 15 fall under Section III and stations 16, 17 and 18 which are near the mouth fall under Section IV. During monsoon all the stations fall under Sections II, III and IV, indicating strong hydrodynamic conditions prevailed during this season. Stations 4, 5 and 7 of the upper estuary, which fall within Section III, indicate relatively violent hydrodynamic conditions available at this region. Due to this probably more percentage of sand was retained in the upper estuarine region removing finer sediments. Intense tidal activity near the mouth is represented by, Section IV, which is very violent hydrodynamic condition responsible for the presence of coarser size particles at this location. In general estuary maintains relatively strong hydrodynamic conditions during monsoon. During post-monsoon (Fig. 4b), stations 14, 15, 16, 17 and 18 fall under Section I indicating very calm hydrodynamic conditions which facilitated deposition of finer sediments along with organic matter except at station 18 wherein higher sediment size was recorded. Further, stations 3, 4, 6, 10, 11, 12 and 13 fall under Section II, which indicates relatively less violent condition at these stations during this season responsible for deposition of finer sediments at these locations compared to monsoon season. Stations



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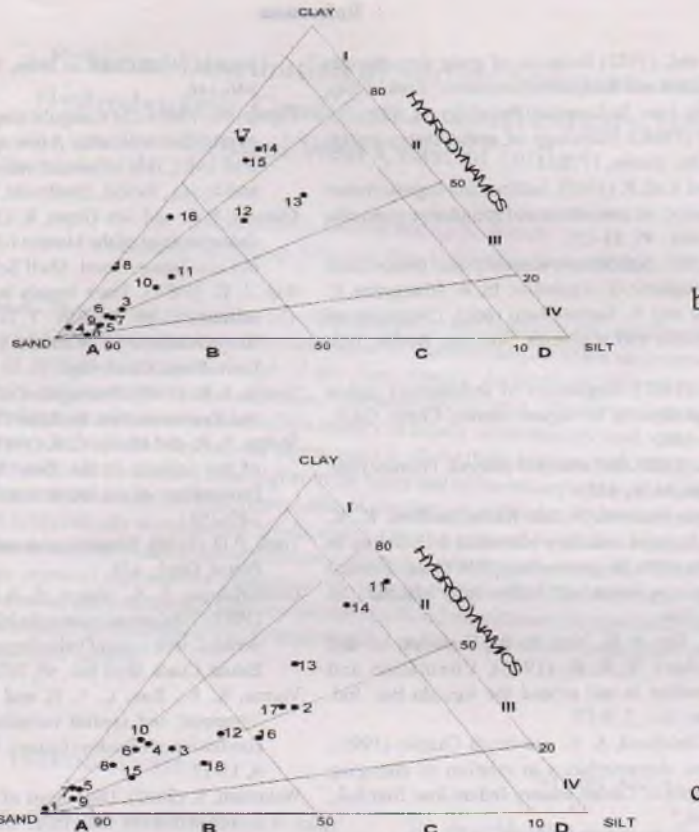


Fig. 4. Ternary diagram for classification of hydrodynamic conditions during different seasons viz. a. monsoon, b. post-monsoon, and c. pre-monsoon after, Pejrup (1988).

5, 7 and 9 fall under section III and station 8 under section IV indicating relatively and very violent conditions respectively at these stations. While during pre-monsoon (Fig. 4c), stations from 1 to 14 and 17 fall under section II that is relatively less violent hydrodynamic condition, which allows finer sediments to settle during this season. Stations 15, 16 and 18 (near mouth region) fall under section III indicate rather violent conditions thereby retaining comparatively higher percentage of sand through tidal influence.

CONCLUSIONS

From the present study following conclusions are drawn.

- Upper half of the estuary is dominated by sand whereas lower half is enriched with clay and silt

components of the sediment except at the mouth region. Organic carbon is also concentrated in the lower half of the estuary.

- Organic carbon showed positive correlation with silt, clay and mud where as with sand it showed inverse relation in all the three seasons. Significant correlation is noted between organic carbon and mud as well as clay component of sediment indicating their association in the lower half of the estuary.

- Present study revealed hydrodynamic conditions prevailed in the Zuari estuary during three different seasons,.

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References

- Bryant, Edward. (1982) Behavior of grain size changes on reflective and dissipative foreshores, Broken Bay, Australia. *Jour. Sedimentary Petrology* 52, 431.
- Folk, R. L. (1968). Petrology of sedimentary rocks. Hemphills, Austin, 177.
- Hedges, J. and Keil, R. (1995). Sedimentary organic matter preservation: an assessment and speculative synthesis. *Mar. Chem.*, 49, 81-115.
- Hedges, J. (2002). Sedimentary organic matter preservation and atmospheric O₂ regulation. In: A. Gianguzza, E. Pelizzeti and S. Sammartano (eds). *Chemistry of marine water and sediments*. Springer, Berlin, 105-123.
- Hunt, C. D. (1981). Regulation of sedimentary cation exchange capacity by organic matter, *Chem. Geol.*, 34, 131-149.
- Jackson M. L. (1958). Soil chemical analysis. Prentice Hall. New York, N. Y., 485
- Muraleedharan Nair, M. N. and Ramachandran, K. K. (2002). Textural and trace elemental distribution in sediments of the Beypore estuary (SW Coast of India) and adjoining innershelf. *Indian Jour. Mar.Sci.*, 31 (4), 295-304.
- Murty, C. S., Das. P. K., Nair, R. R., Veerayya, M. and Varadachari, V. V. R. (1976). Circulation and sedimentation in and around the Aguada Bar. *Ind. Jour. Mar. Sci.*, 5, 9-17.
- Nair, C. K., Balchand, A. N. and Jacob Chacko (1993). Sediment characteristics in relation to changing hydrography of Cochin estuary. *Indian Jour. Mar.Sci.*, 22, 33-36.
- Nayak, G. N. (1993). Studies on sediment flux of rivers, estuaries and adjoining coastal waters of Goa, West Coast of India, Tech. Rep. Submitted to Dept. of Environment, Govt. of India, 69.
- Nayak, G. N. (1996). Grain size parameters as indicator of sediment movement around a river mouth, near Karwar, West Coast of India, *Indian Jour. Mar.Sci.*, 346-348.
- Pejrup, M. (1988). The triangular diagram for classification of estuarine sediments: A new approach, P. L. de Boer et al. (eds), *Tide influenced sedimentary environments and facies.*, Reidel, Dordrecht, 289-300.
- Quasim, S. Z. and Sen Gupta, R. (1980). Environmental characteristics of the Mandovi-Zuari estuarine system in Goa. *Estuar. Coast. Shelf Sci.*, 13, 557-578.
- Rae, J. E. (1997). Trace metals in deposited intertidal sediments. In: Jickells, T. D., Rae, J. E. (Eds.), *Biogeochemistry of Intertidal Sediments*. Cambridge Univ. Press, Cambridge. 16-31.
- Shetye, S. R. (1999). Propagation of tides in the Mandovi and Zuari estuaries. *Sadhana* 24, 5-16.
- Shetye, S. R. and Murty, C. S. (1987). Seasonal variation of the salinity in the Zuari Estuary, Goa, India. *Proceedings of the Indian Academy of Sciences*, 96, 249-257.
- Trask, P. D. (1939). Recent marine sediments, *Amer. Assoc. Petrol. Geol.*, 428.
- Unnikrishnan, A. S., Shetye, S. R. and Gouveia, A. D. (1997). Tidal propagation in the Mandovi-Zuari estuarine network, west coast of India: Impact of freshwater influx. *Estuar. Coast. Shelf Sci.*, 45, 737-744.
- Varma, K. K., Rao. L. V. G. and Cherian, T. (1975). Temporal and spatial variations in hydrographic conditions of Mandovi Estuary. *Indian Jour. Mar.Sci.*, 4, 11-17.
- Wakeham, S. (2002). Diagenesis of organic matter at the water-sediment interface. In: A. Gianguzza, E. Pelizzeti and S. Sammartano (eds). *Chemistry of marine water and sediments*. Springer, Berlin, 146-164.
- Williams, T. P., Bubb, J. M. and Lester, J. N. (1994). Metal accumulation within saltmarsh environments: a review. *Mar. Pollut. Bull.*, 28, 277-290.