International Journal of Geology, Earth and Environmental Sciences ISSN: 2277-2081 (Online)
An Online International Journal Available at http://www.cibtech.org/jgee.htm
2012 Vol. 2 (1) January-April, pp.7-15/ Srivastava et al.

Research Article

SEDIMENTOLOGY AND SALINITY STATUS IN PICHAVARAM MANGROVE WETLAND, SOUTH EAST COAST OF INDIA

***Jyoti Srivastava[1], Anjum Farooqui[1], S.M Hussain[2]**
[1]*Birbal Sahni Institute of Palaeobotany, 53 University Road, Lucknow -226007, U.P.*
[2]*University of Madras, A.C. College Campus, Chennai-600025, Tamil Nadu*
**Author for Correspondence*

ABSTRACT
Salinity in coastal wetland plays a vital role in the distribution of mangrove species, their productivity and growth. It is normally controlled by climate, hydrology, rainfall, topography and tidal flooding. Textural analysis of two sedimentary soil cores (2-5m deep) from Pichavaram mangrove wetland, Cauvery River delta shows the overall predominance of fine clay with intermittent phases of sand. The results show high salinity in the aqueous soil solution of clayey sediment (average 4.0 and maximum 10.2) facilitating the accumulation of salts in the root zone or at the soil surface when the capillary water evaporates. However, the intermittent sandy zones, within a core have larger pore size which shows lower salinity (average 1.6 and maximum 2.2) perhaps due to percolation of salts through capillary action. The ultimate source of salinity in the mangrove habitat is the seawater ingression which is higher during summer than during monsoon. Restriction of inland water input to estuaries by damming water for agriculture and various other purposes coupled with weak monsoonal pattern allows excess water evaporation from exposed wetlands. This results into salt accretion and increase in salinity. Thus low energy rivers/ streams flowing in gentle relief deposits fine silty/ clayey sediments in the wetlands that act as reservoirs of high salt accumulation which is vulnerable for a mangrove forest. The paper deals with the past sediment depositional environment induced by climatic and relative sea level changes.

Key Words: *Salinity, Mangroves, Core Sediments, Salt Accumulation, Pichavaram*

INTRODUCTION
Mangrove wetland is highly productive and occupies the intertidal zone in tropical and sub-tropical regions, which are characterized by small topographic gradients and large tidal amplitude. The sediment dynamics in such an ecosystem is mainly regulated by both internal (flocculation, dissolution, mixing, etc.) and external (e.g. river input, agricultural runoff, pollution) factors. Mangroves stabilize the coastal zone from erosion by acting as a buffer zone between land and sea. These forests in the sheltered boggy hydro environment make possible the deposition of fine sediments normally enriched with nutrients, metals and minerals. Thus, mangrove sediments play a pivotal role in the biogeochemical processes by behaving as both source and sink for nutrients and other materials. The interactions of mangrove plants and sediments are complex and dynamic as they cope with a harsh saline intertidal environment (Saenger, 2002) despite of degradation by human activities (Klekowski et al., 1994) as well as by natural disturbances (Seralathan et al., 2006). Salinity is one of the important stress factors in a mangrove wetland. A variation in soil salinity in the estuary is due to distance from the coast, tidal incursions and freshwater inputs. Anthropogenic pressures and sea level changes influence the mechanism of salt-water intrusion and freshwater run-off which in turn decides the fate of mangroves in the low-lying deltaic areas along the south-east coast of India. The soil is repeatedly flooded and well drained in the Pichavaram estuary which supports luxuriant growth of mangroves. The composition of mangroves is mainly determined by the tolerance of different species to substrate and saline conditions, which in turn determines the dominance of one or various species at a specific site. At present, most of the estuaries and near shore wetlands along the South-east coast are covered by salinity tolerant back mangroves like *Avicennia* and *Suaeda* species. Most of the areas along the South-east coast were inhabited by diverse species of mangroves in the past (Farooqui and Vaz, 2000; Farooqui and Achyuthan, 2006) and are either

at the verge of decline or have migrated to a more conducive area in small pockets due to rapid changes in the habitat. Thus there is a need of more focused research on the low-lying landforms along the south-east coast vulnerable to a range of salinity pressures. A gradual increase in salt tolerant plants such as *Avicennia* and *Suaeda* species is of great concern and needs investigation for the rapidly changing mangrove habitat. The status of salinity, pH and metal content in relation to sediment texture plays a major role in mangrove sustenance and therefore the present study highlights the above parameters in the estuarine sediment and rhizosphere of mangrove plants.

DESCRIPTION OF THE STUDY AREA

The Pichavaram mangrove ecosystem (latitude 11º 25' N and longitude 79º 47' E) is a shallow estuarine complex sandwiched between two prominent estuaries, the Vellar estuary in the north and Coleroon estuary in the south (Fig. 1) with a total area of 1100 ha. It has 15 islets ranging in size from 10 m^2 to 2 km^2 separated by intricate waterways, that connect the Vellar estuary in the north and the Coleroon estuary in the south (Ramanathan, 1997). The Coleroon estuary part is largely dominated by mangroves, while the Vellar estuary is dominated by mud-flats. Tidal water enters the Pichavaram mangrove through a small direct connection with the Bay of Bengal at Chinnavaikal and estuarine water finds its way through the two adjacent river systems. *Avicennia marina* is the most dominant mangrove species followed by *Avicennia officinalis, Excoecaria agallocha, Rhizophora apiculata* and *Rhizophora mucronata*. The tides in the Pichavaram mangroves are semi-diurnal and vary in amplitude from 0.15 to 1 m (Kathiresan, 2000).

The geomorphology of the ecosystem is mostly covered by flood plain, sedimentary plain and beach sand. Most of the soil along the western part is alluvium whereas fluvial marine and beach sand dominates in the eastern part. The climate is sub-humid and the ratio of precipitation to evapo-transpiration (P/Etp) ranges from 0.5-0.75 (Selvam, 2003) with maximum precipitation during the northeast monsoons. The annual temperature variation is 18.2-36ºC. The biogeochemical processes in this ecosystem are ruled by a heavy input of sediments and anthropogenic discharges from the Vellar and Coleroon River. Uppanar River and Khan Saheb Canal contributes the discharge during monsoon season. The anthropogenic input from nearby agricultural, domestic and industrial sources through Khan Saheb Canal has made this pristine ecosystem vulnerable for heavy metal contamination (Yeon CHO et al., 2004; Prasad, 2005).

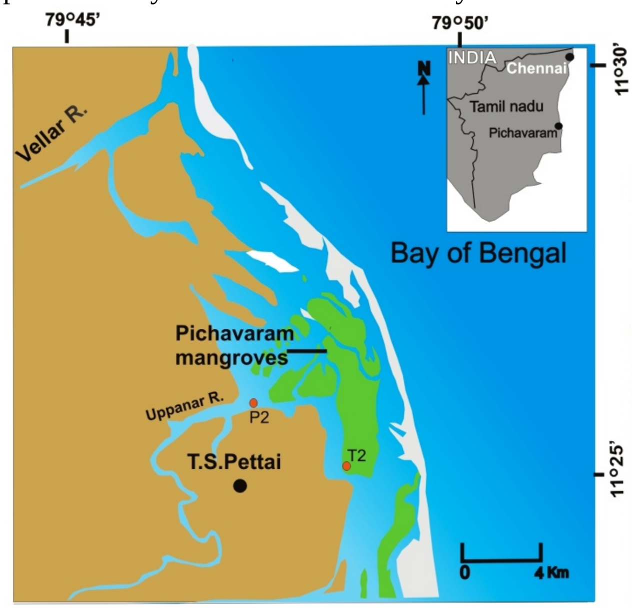

Fig. 1 Map of the Pichavaram Mangrove (India) showing the sampling locations

Fig. 2 Showing the vegetation at the Core site P2 (A) and T2 (B)

MATERIALS AND METHODS

The cores were collected from the swampy area as well as from the exposed land with an objective to understand the salinity pattern in both the environments which was visually distinguishable by the vegetative pattern. Two sediment cores P2 and T2 measuring 2.5 and 5m depth, respectively were studied. P2 is located in the central part of Pichavaram estuary and is mainly inhabited by *Avicennia officinalis, A. marina and Suaeda sp.* (Fig.2) with fringes of *Rhizophora sp*. along the backwater channel. T2 is located south of Pichavaram close to the village TS Pettai and the habitat was similar to as observed in P2 area. The sediment core was obtained using hand operated augur cum piston corer (Eijelkamp, Netherlands). Immediately, after collection the P2 and T2 core was sub-sampled at 2cm and 5cm interval, respectively. The samples were stored in air-tight polythene bags without any preservative. In laboratory sediment color was identified using Munsell color chart (Munsell and Farnum, 1941) and texture was analyzed on the basis of percentage of sand in the sediment following density method (USDA, 1992). Then after salinity was measured in 10g of air dried soil sample dissolved in 100ml of deionized water. Prior to measuring, the soil solution was kept overnight after rigorous shaking for an hour. The samples were homogenized for 30 minutes before measuring the salinity using 'Orion-5 star (Thermo-Orion, Scientific Equipment, USA) at standardized 25ºC temperature. The metal content was estimated in dried soil samples using 'Innvox-systems' Metal Analyzer, USA (a-4000S).

RESULTS

Chronology

Five calibrated Radiocarbon dates (^{14}C) were obtained following Stuiver *et al*. (1998). Two dates are from core P2 and three from the core T2. The deepest 250 cm sediment from P2 dates back to 3440 ± 190 yrs BP and at 60 to 80 cm it is 590 ± 150 yrs BP. The bottom sediment from T2 (480-500 cm) dates back to 3630 ± 100 yrs BP. Sediment in T2 from 85-90 cm dates back to 2750 ± 220 yrs BP and at 25-35 cm to 760 ± 80 yrs BP. Thus, the two cores from Pichavaram estuary provide an age period of sediment deposition since the beginning of Late Holocene.

Sedimentology and salinity of Core-P2

Phase Ia: The heterogeneous type of sediment in the bottom Phase Ia (2.5-1.2m) is dominated by blackish to brown (5Y2/2) silty clay punctuated by four broad to thin bands of brownish (5Y4/2) fine sand (Fig.3). The clayey bands constitute about 85 per cent of clay followed by 10 per cent silt and 5 per cent sand which indicates low energy sediment input. The intermittent bands of sand constitute 60-85 per cent sand with low silt and clay content. The salinity in this phase ranges from 1.9 chiefly in the sandy intervals to 5.4 in the clayey fraction with an average value of 3.6. The ratio of heavy metals analyzed in this phase is Co/Cu-3.7; Cu/Pb-1.6; Mn/Ti-0.05; Mn/Pb-3.6; Cu/Zn-1.2; Fe/Rb-968.0; Fe/Zn-841.6 and Na/K-71 (Fig.4).

Phase Ib: This phase (1.2-0.85m) is of a short interval and the sediment is brownish (5Y4/2) fine to coarse sand constituting about 90 per cent sand. It reveals lower salinity ranging from 2.1 to 2.4 with an average of 2.2. The ratio of heavy metals recorded in this phase comprises of Co/Cu-5.1; Cu/Pb-0.7; Mn/Ti-0.07; Mn/Pb-3.4; Cu/Zn-0.6; Fe/Rb-616.6; Fe/Zn-223.3 and Na/K-53.

Phase II: (0.85-0m) Fine blackish to brown (5Y3/2) sticky sediment constitutes an average of 86 per cent clay. This Phase shows salinity ranging from 2.8 to 5.1 with an average of 4.1. The ratio of heavy metals analyzed is Co/Cu-4.7; Cu/Pb-1.0; Mn/Ti-0.02; Mn/Pb-2.0; Cu/Zn-1.2; Fe/Rb-1045.6; Fe/Zn-961.7 and Na/K-71.9.

Sedimentology and salinity of Core T2

Phase I: The bottom Phase I (5.0-2.2m) is dominated by brownish (5Y3/4) silty sand interspersed by six broad to thin bands of blackish to brown (5Y4/2) fine sticky clay. The sandy bands constitute about 90 per cent sand with 7 per cent silt and 3 per cent clay which indicates a fast runoff with greater deposition of coarser sediment. The intermittent bands of clay constitute about 76 per cent clay with 15 per cent sand followed by 9 per cent of silt (Fig. 3). The salinity ranges from 0.8 to a maximum of 4.2 which is mainly in the clayey bands with an average value of 1.7. The ratio of heavy metals analyzed in this phase is Co/Cu-1.5; Cu/Pb-1.0; Mn/Ti-0.1; Mn/Pb-5.6; Cu/Zn-0.7; Fe/Rb-562.6; Fe/Zn-333.6 and Na/K-62.7 (Fig.5).

4.3.2 Phase II: The upper Phase II (2.2-0m) is dominated by blackish to brown (5Y4/2) fine sticky clay with a single band of clayey sand at 0.15m depth. This phase constitutes about 86 per cent of clay with low per cent of silt and sand while the single clayey sand band constitutes 63 per cent sand with 32 per cent clay followed by 5 per cent silt. The salinity ranges from 2.9 to a maximum of 10.4 with an average value of 3.6. The ratio of heavy metals analyzed in this phase comprises of Co/Cu-5.6; Cu/Pb-1.8; Mn/Ti-0.1; Mn/Pb-5.0; Cu/Zn-1.4; Fe/Rb-977.6; Fe/Zn-764.8 and Na/K-471.8.

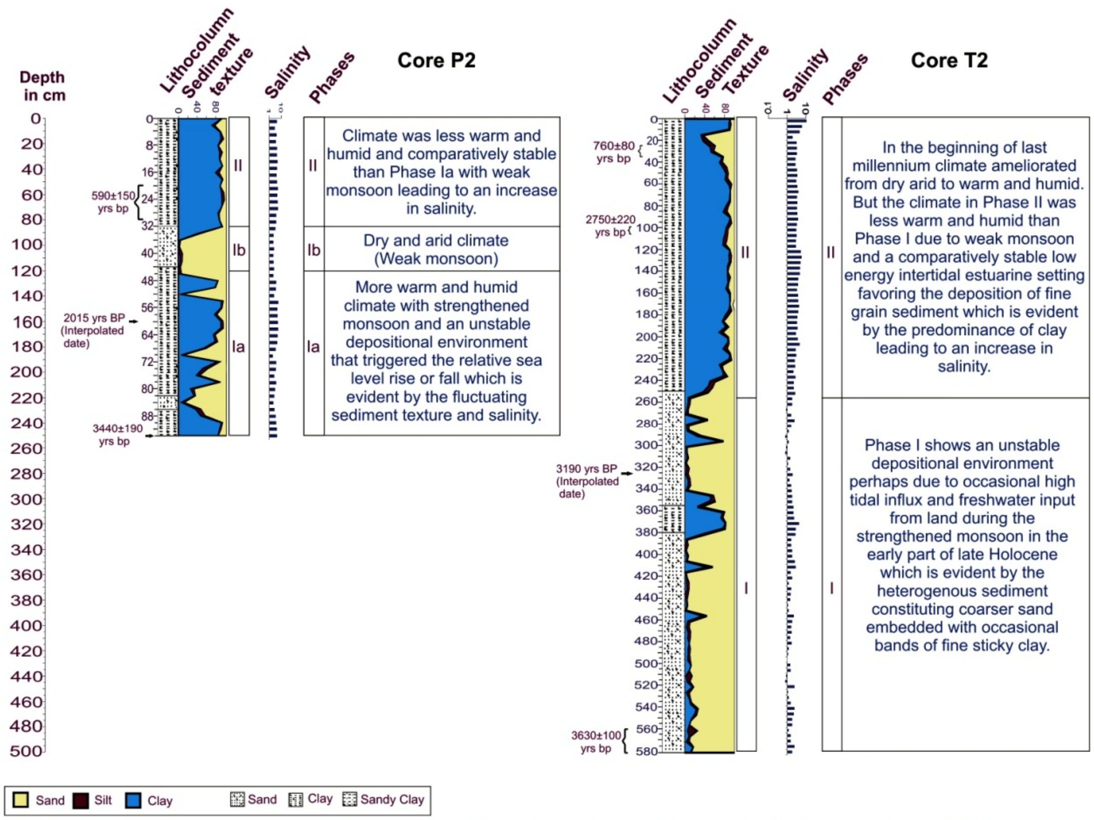

Fig 3. Sediment texture, salinity and radiocarbon dates of the studied cores from Pichavaram

DISCUSSION

Ingression of sea water in the back water channels is common in Pichavaram which results into a salinity gradient with the distance from the shoreline towards land. A low reliability of the monsoonal rainfall, unscientific agricultural practices and intrusion of saline sea water in the coastal strips has adversely affected several areas along the Indian coastline. As the sea water is heavier in density it occupies the bottom level making its removal impossible. Therefore, it becomes easy for the sea water to percolate down to the depths through capillary action from high to low salinity gradient. The precipitation of salt through capillary action during dry months in exposed land is common in the coastal wetlands (Farooqui,

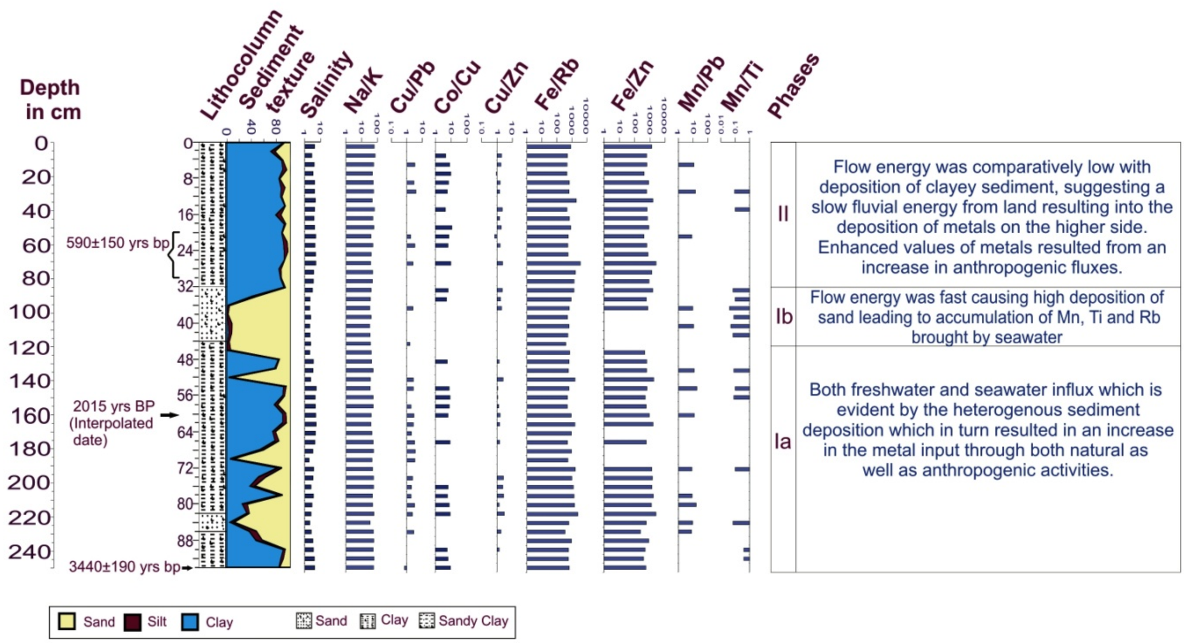

Fig.4 Sediment texture, salinity and ratio of metal content in Sediment core P2 from Pichavaram

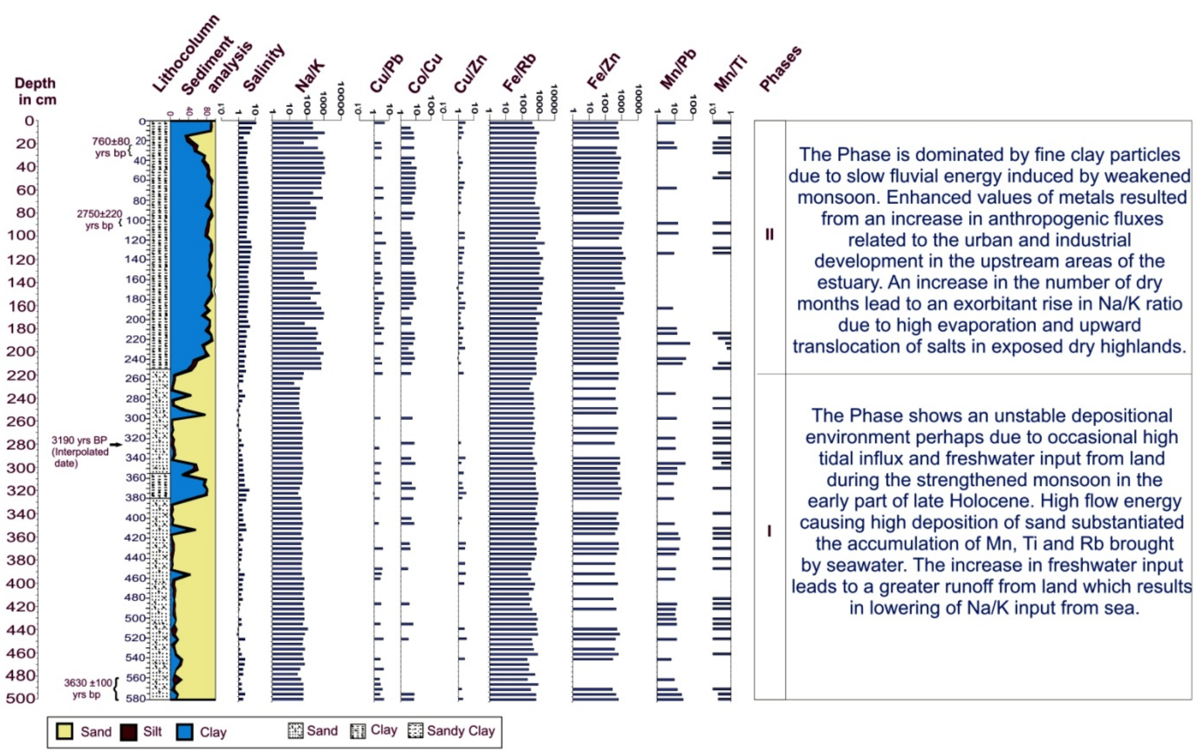

Fig.5 Sediment texture, salinity and ratio of metal content in sediment core T2 from Pichavaram

2010). The vertical translocation of salt depends on the sediment texture. The present study reveals high salinity and metal content in clayey sediment as compared to sandy sediment. The clay particles are flexible and plastic because of their lattice-like design and have large surface area which is chemically reactive to attract and hold positively charged nutrient ions readily available to plant roots (Hiller 2003). This feature allows the clayey soil to absorb water and other substances into their structure. Therefore, such type of soil allowed salt, water and heavy metal retention in the core sediment. In clayey soil, salt accumulation is common due to the development of strong aggregates which do not allow significant vertical capillary movement or percolation of water.

Regarding textural composition, both the sites showed a variable admixture of sand, silt and clay with an overall range from coarse sand to very fine clay in the bottom Phase I. This wide array of textural differences may be attributed to vigorous estuarine mixing, suspension-resuspension and flocculation-deflocculation processes. Heterogeneous sediment constituting coarser sand embedded with occasional bands of fine sticky clay reflects a strengthened monsoon in the Late Holocene (~3500 yrs. BP). The deeper sediment in the cores was deposited at a comparatively faster rate which also suggests increased precipitation that led to more sediment runoff. On the other hand, the predominance of clay in Phase II may be referred to its relatively low energy intertidal estuarine settings perhaps due to reduced precipitation enhanced by anthropogenic activities that allowed deposition of fine-grain sediment.

Salt in the soil is best washed away by freshwater but the clay and silt is relatively impermeable, the filtration process called leaching is slow. In some relatively dry zones, salt has already accumulated on the surface and crystallized. As a result the salinity problems may persist for a long period unless measures are taken to remove the salts by flushing or leaching (Sparks, 1995). High salinity observed in clay dominated sediment in both the cores reveals an alarming habitat for mangroves which is likely to disrupt the uptake of water and competitive nutrients into roots. In such a situation of high salinity the physiologically active water required for plants becomes limited and salt displacement also takes place (Farooqui et al., 2010). In sandy soils, due to larger pore size between particles, the retention of salts and nutrients is comparatively greater which is evident by the low salinity and metal content in both the cores.

The distribution pattern of heavy metals exhibit variations between sites and depths in the core samples which is attributed to the metal deposition in mangrove sediments through natural processes as well as anthropogenic activities (Forstner and Wittman 1983). Moreover enhanced values of metals are resulted from an increase in anthropogenic fluxes related to the urban and industrial development in the upstream areas of the estuary. Increase of heavy metals in the mangrove sediment may also be ascribed to the abundance of fine clay particles with greater surface area (Forstner and Wittman 1983; Salmons and Forstner 1984) and precipitation of metals as hydroxide coating (mainly Fe and Mn) over such finely dispersed particles (De Groot and Allersma, 1975). Factors such as enhanced organic matter content, flocculation due to varying salinity regimes (Sholkovitz 1976) and transportation of deep shore sediments to the coastal zone (Rubio et al 2000; Seralathan et al. 2006 and Ramesh et al. 2006) also contribute significantly towards the enrichment of heavy metals in sediments.

The heavy metals analyzed in core P2 showed a higher ratio of Cu/Pb, Cu/Zn, Fe/Rb, Fe/Zn and Na/K in Phase II whereas a higher ratio of Mn/Pb and Co/Cu was recorded in Phase I. Since Phase I both a and b shows unstable depositional environment perhaps due to occasional high tidal influx and freshwater input from land during the strengthened monsoon in the early part of late Holocene (3440-1000 yrs BP). In Phase Ia both freshwater and seawater influx increased the metal input through both natural as well as anthropogenic activities. However in Phase Ib flow energy was fast therefore the sand deposited was high which substantiated the deposition of metals brought by seawater which included Mn, Ti and Rb. The flow energy in Phase II was comparatively low with deposition of clayey sediment, which suggests a slow fluvial energy from land resulting into the deposition of metals on the higher side. Similarly the ratio of heavy metals in core T2 also showed a similar trend with higher ratio of Co/Cu, Cu/Pb, Cu/Zn, Fe/Rb, Fe/Zn and Na/K in Phase II whereas a higher ratio of Mn/Pb was recorded in Phase I. The increase in freshwater input leads to a greater runoff from land which results in lowering of Na/K input from sea.

Research Article

However Phase II in both the cores is dominated by clayey silt due to slow fluvial energy induced by weakened monsoon and an increase in the number of dry months which lead to an exorbitant increase in Na/K ratio attributed to two factors, 1) High evaporation due to dry climate and 2) Upward translocation of salts due to capillary action in exposed dry highlands.

The prime source of Fe is weathering and construction of dam which has checked the freshwater inflow into the mangrove estuarine complexes (Prasad 2005). The presence of floating old rusty and stranded barges is also the source for particulate Fe which settle down and mix with the bottom sediments. The higher proportion of Cobalt also reveals metal contamination due to anthropogenic inputs chiefly sewage and industrial wastes (Selvaraj et al., 2004). Fungicides and algaecides used in fish farming are other sources of pollutants, mainly consisting of copper compounds (Spencer and Green, 1981). The possible anthropogenic contributors of Cu are the use of antifouling boat paints in harbor and tourist areas (Marmolejo-Rodriguez et al. 2007), industrial effluent discharge and input of untreated domestic sewage, as the element has a preferential association with the organic matter (Hirner et al. 1990). During the past decades there has been a rapid increase in the number of aquaculture ponds as well as the cultivation pattern that has changed drastically (Ranjan et al. 2007). As a result of which the wastes are being transferred to the estuarine complexes through Vellar estuary, Uppnar estuary and Khan Saheb Canal. All these together may have lead to the accumulation of Cu in both the sites of Pichavaram mangrove ecosystem. The presence of Nickel indicates the presence of mobile fraction of the metal successively bound to humic acids in the mangrove sediments (Calace et al. 2005). Effluent discharge from nearby chemical industries could also be a potential source for Ni in mangrove sediments (Khan et al. 2004). In Pichavaram, increase in Lead concentrations may be due to the direct input of nitrate compounds from external sources, largely from the aquaculture effluents, agricultural runoff and domestic sewage (Purvaja and Ramesh 2000; Subramanian 2004). Pb is derived from lead-bound paint industries and input of effluents from the thermal power plants situated in the upstream of the estuary together with auto exhaust emission, atmospheric deposition and operation of a large number of mechanized fishing boats in the area (Settle and Petterson 1982; Nolting and Helder 1991). The presence of Rubidium throughout the core supports the sea water ingression in the study area. It is another element generally present in seawater, which is easily ionized, like sodium and potassium and therefore, human body tends to concentrate rubidium ions in the body's electrolytic fluid. Taken in excess it can be dangerous, as it is radioactive (Bradley and Greene, 1967). High concentration of Titanium recorded in the study also supports seawater ingression and transportation of heavy minerals containing ilmenite. The element Ti occurs within a number of mineral deposits, principally rutile and ilmenite. Benthic fluxes may also be a significant source of Ti to estuaries and the ocean (Skrabal and Terry, 2002). The concentration of heavy metals tends to increase as the size fractions get finer. However for certain metals (Cu, Ni and Pb) the coarser particles show similar or even higher heavy metal concentrations than finer ones. The higher residence and presence of coarser particles from agricultural and industrial wastes are possibly responsible for higher metal content in the coarser size fractions (Singh et al. 1999).

Conclusion

The 2.5m sediment in Pichavaram estuary (P2) was deposited since 3440±190yrs BP and 5m sediment in TSPettai (T2) was deposited since 3630±100yrs BP. Thus net rate of sedimentation was higher in the latter area. Two phases (I and II) were demarcated on the basis of texture and salinity. Phase I is more sandy in core T2 whereas in P2 intermittent thin to broad sandy bands were observed which reveals unstable depositional environment. Phase II is dominated by clayey sediment which reveals stable low energy depositional environment. Both salinity and metal content was comparatively high in clayey sediment which reveals that as compared to sandy sediment the clayey/silty sediment retains more salts and heavy metals which is likely to affect the mangrove habitat. The increased salinity in the sediment up to 5m is alarming and may limit the physiologically active water available for mangroves as the roots penetrate 1-2m depth. Thus, high metal contamination, salinity in the coastal sediment is a major threat to mangrove habitat and freshwater aquifers.

ACKNOWLEDGEMENTS

Authors are grateful to the Director BSIP for providing necessary facilities to accomplish this work. One of authors (JS) is thankful to the Department of Science and Technology, New Delhi for providing financial support as JRF. We also wish to thank Dr. S.A. Farooqui, Joint Director, U.P. Directorate of Geology and Mining, Khanij Bhawan, Lucknow for providing facilities to analyze metal content in soil samples and Mrs. Indra Goel for help during analysis of soil samples.

REFERENCES

Bradley J N and Greene P D (1967). Biological effects "Relationship of structure and ionic mobility in solid MAg4I5"; *Transactions of the Faraday Society* **63** 2516.

Calace N, Ciardullo S, Petronio B, Pietrantonio M, Abbodanzi F, Campisi T and Cardellicchio N (2005). Influence of chemical parameters (heavy metals, organic matter, sulphur and nitrogen) on yoxicity of sediments from the Mar Piccolo (Taranto, Ionian Sea, Italy); *Microchemical Journal* **79** 243–248.

De Groot A J and Allersma E (1975). Field observations on transport of heavy metals in sediments; In P. A. Krenkel (Ed.) *Heavy Metals in the Aquatic Environment* 85–95. Oxford: Pergamon Press.

Farooqui A (2010). Salt water intrusion, metal accumulation and mangroves along the Pednapatnam, Machlipatnam coastline, Andhra Pradesh, India; *Journal of Applied Geochemistry* **12**(1) 126-138.

Farooqui A and Vaz G G (2000). Holocene sea- level and climate fluctuations: Pulicat lagoon- A case study; *Current Science* **79**(10) 1484-1488.

Farooqui A and Achyuthan H (2006). Evidences of Middle to Late Holocene vegetation in Adyar Estuary, Chennai; *Journal of Geological Society of India* **68** 230-238.

Forstner U and Wittman GT (1983). Metal pollution in the aquatic environment. Springer-Verlag, Berlin.

Hiller S (2003). Clay mineralogy 139-142. *In*: G.V. Middleton, M. J. Church, M. Coniglio, L. A. Hardie & F. J. Longstaffe (eds.) *Encyclopedia of Sediments and Sedimentary Rocks.* Kluwer Academic Publishers, Dordrecht.

Hirner A V, Kristsotakis K, Tobschall H J (1990).Metal-organic association in sediments—I. Comparison of unpolluted recent and ancient sediments and sediments affected by anthropogenic pollution; *Applied Geochemistry* **5** 491–505.

Kathiresan K (2000).A review of studies on Pichavaram mangroves, Southeast India; *Hydrobiologia* **430** 185-205.

Khan S A, Murugesan P, Lyla P S and Jaganathan S (2004). A new indicator macro invertebrate of pollution and utility of graphical tools and diversity indices in pollution monitoring studies; *Current Science* **87** 1508–1510.

Klekowski E J, Lowenfeld R L and Hepler P K (1994).Mangrove genetics II. Outcrossing and lower spontaneous mutation rates in Puerto Rican Rhizophora; *International Journal of Plant Science* **155** 373-381.

Marmolejo-Rodriguez A J, Prego R, Meyer-Willerer A, Shumilin E and Cobelo-Garcia A (2007). Total and labile metals in surface sediments of the tropical river-estuary system of Marabasco (Pacific coast of Mexico): influence of an iron mine; *Marie Pollution Bulletin* **55** 459–468.

Munsell A H and Farnum R B (2004). A color notation: An illustrated system defining all colors and their relations 1941. Kessinger Publishing.

Nolting R F and Helder W (1991).Lead and zinc as indicators for atmospheric and riverine particle transport to sediments in the Gulf of Lions; *Oceanologia Acta* **14**(4) 357–367.

Prasad M B K (2005).Nutrient dynamics in Pichavaram mangroves, southeast coast of India. Ph.D. Thesis. Jawaharlal Nehru University, New Delhi, India.

Purvaja R and Ramesh R (2000).Human impacts on methane emission from mangrove ecosystems in India; *Regional Environmental Change* **1** 86–97.

Ramanathan A L (1997). Sediment Characteristics of the Pichavaram mangrove environment; *Indian Journal of Marine Sciences* **26** 319-322.

Ramesh R, Kumar A, Inamdar A B, Mohan P M, Prithviraj M and Ramachandran S (2006) .Tsunami characterization and mapping in Andaman and Nicobar islands. In G. V. Rajamanickam (Ed.) 26th December 2004 tsunami causes, effects remedial measures, pre and posttsunami disaster management, a geoscientific perspective 150–74 New Delhi: New Academic Publisher.

Ranjan R K, Ramanathan A L and Singh G (2007). Evaluation of geochemical impact of tsunami on Pichavaram mangrove ecosystem, southeast coast of India; *Environmental Geology*, DOI 10.1007/s00254–007–1019–9.

Rubio B, Nombela M A and Vilas F (2000). Geochemistry of major and trace elements in sediments of the Ria de Vigo (NW Spain): An assessment of metal pollution; *Marine Pollution Bulletin* **40** 968–980.

Saenger P (2002). Mangrove Ecology, Silviculture and Conservation. Kluwer, Dordrecht.

Salmons W and Forstner V (1984). Metals in the hydrocycle 347. New York: Springer.

Selvam V (2003).Environmental classification of mangrove wetlands of India; *Current Science* **84** (6) 757-765.

Selvaraj K, Ram Mohan V and Szefer P (2004).Evaluation of metal contamination in coastal sediments of the Bay of Bengal, India: geochemical and statistical approaches; *Marine Pollution Bulletin* **49** 174–185

Seralathan P, Sreenivasulu S, Ramanathan A L, Rajamanickam G V, Nagendra R, Singarasubramaniam S R, Mukesh M V and Manoharan K (2006). post-tsunami sediment characteristics of Tamilnadu coast. In: Rajamanikkam, G.V. (Ed.), 26th December 2004 Tsunami: Causes, Effects Remedial Measures, Pre and Post Tsunami Disaster Management. A Geoscience Perspective; *Department of Science and Technology Report*, New Delhi, 196-209.

Settle D M, Petterson C C (1982). Magnitudes and sources of precipitation and only deposition fluxes of industrial and natural leads to the North Pacific at Ene Watak; *Journal of Geophysical Research* **87**, 8857–8869.

Sholkovitz E R (1976). Flocculation of dissolved organic and inorganic matter during the mixing of river water and seawater; *Geochimica* et *Cosmochimica Acta* **40** 831–845.

Singh A K, Hasnain S I and Banerjee D K (1999).Grain size and geochemical partitioning of heavy metals in sediments of the Damodar River—Atributary of the lower Ganga, India; *Environmental Geology* **39**(1) 90–98.

Skrabal S A and Terry C M (2002).Distributions of dissolved titanium in pore waters of estuarine and coastal marine sediments; *Marine Chemistry* **77** (2-3) 109-122.

Sparks D L (1995)."Environmental Soil Chemistry", Academic Press, London.

Spencer D F and Green R W (1981). Effects of nickel on seven species of fresh water algae. *Environmental Pollution* **25** 241–247.

Subramanian A N (2004).Status of Indian mangroves: Pollution status of the Pichavaram mangrove area, southeast coast of India. In M. Vannucci (Ed.) Mangrove management and conservation 59–75. Tokyo: United Nations University Press.

U.S.D.A (United States Department of Agriculture) (1992).Soil Conservation Service, Soil Survey Laboratory Methods Manual. *Soil Survey Investigation Report* **42** Washington, DC.

Yeon CHO Hong, Lakshumanan C and Natesan U (2004).Coastal wetland and shoreline change mapping of Pichavaram, south east coast of India using Satellite data, 2004—Map India Conference, Beijing, China.