Holocene sea-level and climatic fluctuations: Pulicat lagoon – A case study

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Pulicat lagoon situated in the Palar Basin, is the second largest lagoon on the east coast of India. The north-western margin of the desiccated lagoon is an irregular and elevated hard surface. Palynological studies were carried out in sedimentary soil samples from four pits dug across this part of the lagoon. Vegetational reconstruction from peat beds at 4.98 m (a.m.s.l.) and 1 m (a.m.s.l.) in the west at Sulurpet and Kasdredinilem, respectively, is indicative of a palaeoshoreline. The sea level reached its maximum around 6650 ± 110 yrs BP in Sulurpet, 18 km west from the present shoreline. The radiocarbon dates of peat bed at Kasdreddinilem reveals an age of 4608 ± 122 yrs BP, indicating the shift in mangrove line eastwards during the regressive phase. The Late Holocene radiocarbon dates of shells (bivalves) at Attakanitippa and Sriharikota island are the chain of intermittent regressive phases since then. The peat sediment below this shell bed at 9 and 15 m below the mean sea level was perhaps deposited during the transgressive phase. No evidence of mangrove pollen in the late Holocene soil sediments indicates that sea-level fluctuation and climatic conditions during mid and late Holocene led to the decline in mangroves in the area.

The present-day vegetation mainly comprises psammophytes around the semi-stabilized strand with commercially planted woody forest on the stabilized strands. *Casuarina, Prosopis* and *Acacia* sps. are grown and exploited commercially around the lagoon that hinders the natural vegetational succession and the ecosystem not favourable for mangroves. The past and present vegetation coupled with sea-level fluctuations, climate and the anthropogenic activity since Holocene has been discussed in the paper.

BIOLOGICAL forms that are bound to certain tide levels can be reliable indicators of sea-level changes[1]. Mangroves (littoral forest) play an important role to preserve the imprint of sea-level fluctuations related to either climate, eustasy or tectonic movements[2]. Because of small size, decay-resistant exines and high potential for dispersal, the pollen/spores are the most abundant plant remains in the sediments. These form the basis for the reconstruction of past vegetation and its ecological conditions. Any minor or major sea-level changes subject the mangrove vegetation to stress conditions and disturb its zonation[3–5]. Therefore, palynostratigraphical record of mangroves has its implications in understanding the magnitude, direction and duration of the coastal and climatic changes.

Pulicat lagoon, also called as lake of the Palar Basin[6], is the second largest lagoon on the east coast of India. The Pulicat lagoon is situated between 13°20′ and 13°40′N lat. and 80°14′ to 80°15′E long. with its narrow (1–1.5 km) opening into the Bay of Bengal through the south-eastern margin near the Pulicat town which is 70 km north of Chennai. The Kalangi river debouches into the north-west corner of the lagoon at 13°40′N lat. However, the dried part of the lagoon (Playa) extends up to 13°60′N lat. Thus, the past and present margins of the Pulicat lagoon lie between the present Swarnamukhi river and the palaeo Palar river delta.

The western and eastern margins of the lagoon with sand ridges are more or less aligned parallel to the coastline. The lagoon is separated from the Bay of Bengal by a sand barrier spit complex known as Sriharikota island. Two sand barrier islands, viz. Irkam and Venad, aligned N-S and lying at the central part, separate the lagoon into eastern and western sectors. The margins of the lagoon exhibit four different types of morphology. The northern margin is an irregular and elevated hard surface. The eastern margin (Sriharikota island) is a sand barrier complex with high and low dunes and traces of five older spit heads on the lagoon side[7],

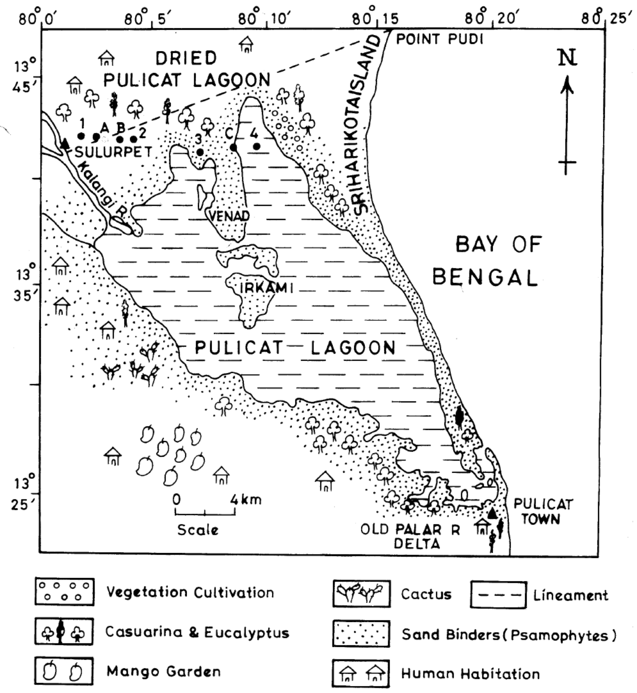

Figure 1. Map showing the present vegetational scenario and the present Pulicat lagoonal configuration. Pits 1–4, ref. 7; Pits A–C, Present study.

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whereas its seaward margin is smooth and curvilinear. The southern margin, a low-lying, flat and wide plain, is a palaeo-deltaic lobe of the Palar river[8] fringed by marine landforms along the coast. The western margin is occupied by a pediplain, older sand ridges and small-scale fluvial plains built by ephemeral streams.

Surface sediments, heavy minerals[9,10] and present evolution of the lagoon[11] have been studied earlier from this area. The present paper embodies palynological studies of the sedimentary soil samples from four pits dug across the north-western dried part towards east of the lagoon, viz. Sulurpet (Pit 1); Kasdreddinilem (Pit A); Cheruvukandriga (Pit B) and Attakanitippa (Pit C) (Figure 1). Palynological analysis was carried out following Erdtman[12]. The peat sediment was observed only in Pit 1 and Pit A at 4.98 m (a.m.s.l.) –20 cm and 1 m (a.m.s.l.) –12 cm, respectively (Figure 2). The present shoreline is 18 km E of Pit 1. The palynological reconstruction of the vegetation from peat beds is shown in Figures 3 and 4. Abundance of Rhizophoraceae members that includes sps. of *Rhizophora, Ceriops* and *Bruguiera* are associated with meagre representation of *Derris, Excoecaria, Aegiceras* and *Lumnitzera* sps. About 25 per cent of the total pollen count includes the upland taxa, fresh water forms and some unidentified resting bodies of algal/fungal origin. The percentage of taxa is out of total 200 pollen counts. Abundant identifiable cuticular/epidermal fragments of similar nature with rare to nil amorphous organic debris in peat samples from both the pits indicate the preservation *in situ* and under anoxic state during the time of deposition. The peat sediment in Pit 1 yielded a radiocarbon date of 6650 ± 110 yrs BP and that in Pit A yielded 4608 ± 122 yrs BP. Since the Rhizophoraceae members occupy the littoral zone, it is understood that the area experienced the good water runoff through tides, rivers and streams, favouring the establishment and growth of mangroves. The absence of mangrove pollen or its associates coupled with the gypsum crystals in the sediments above the peat up to the ground surface, shows a highly disturbed sea-level that led to repeated desiccation not favourable for the mangrove establishment. This led to the mass extinction of the littoral forest from the area during the regressive events of high magnitude and long duration. Both these events, either transgressive or regressive, tend to asphyxiate the littoral forest if it is of higher magnitude and longer duration. The sub-surface sediments 50 to 60 cm deep from the

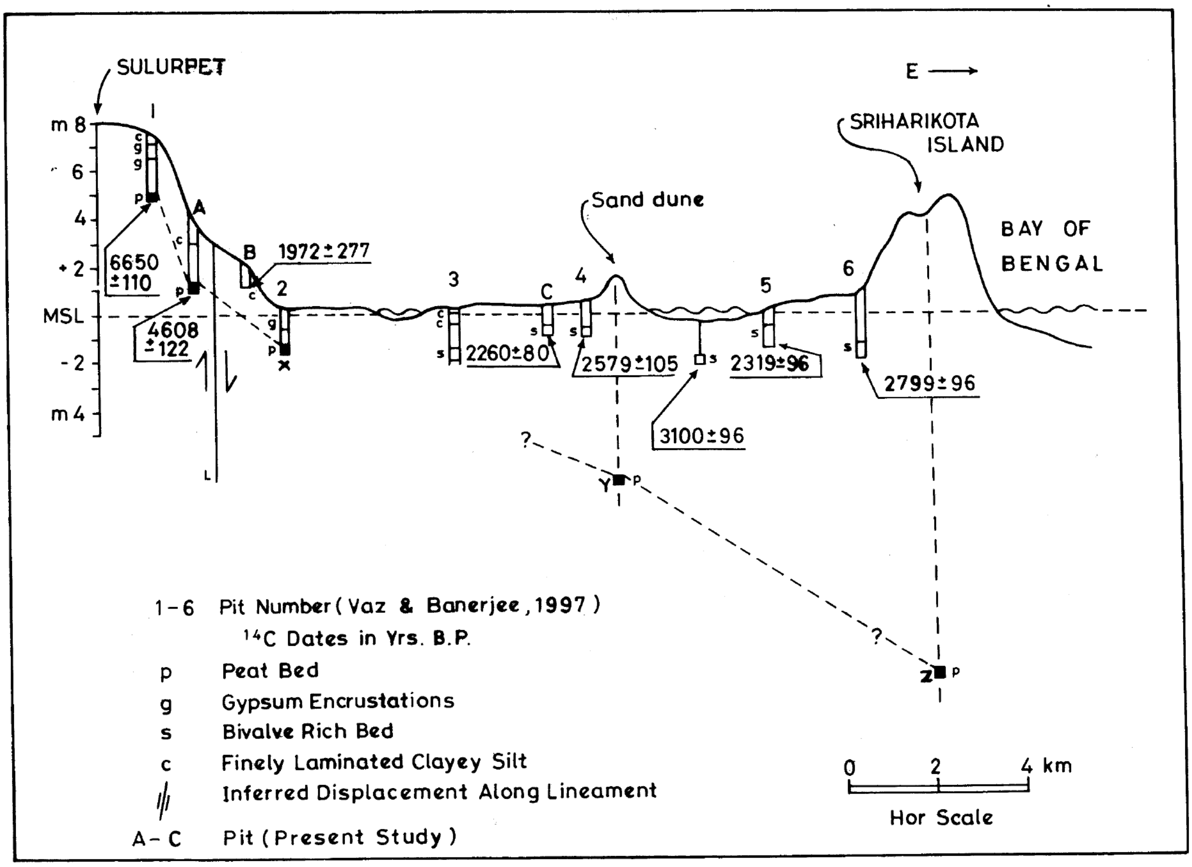

Figure 2. Diagrammatic section of the Pulicat lagoon (Modified after Vaz and Banjerjee[7]).

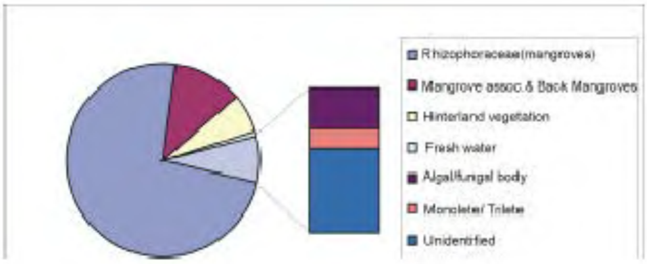

Figure 3. Palynological reconstruction of vegetation around 6650 yrs BP at 4.98 m a.s.m.l. at Sulurpet.

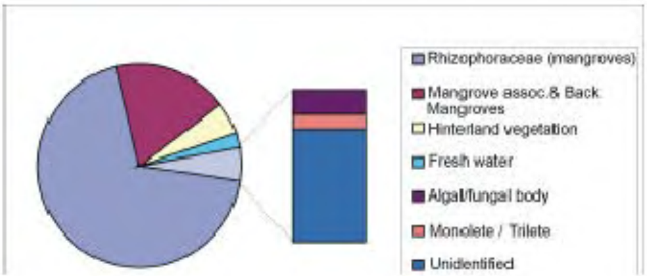

Figure 4. Palynological reconstruction of vegetation around 4608 yrs BP at 1 m a.m.s.l. in Kasdredinilem, Sulurpet.

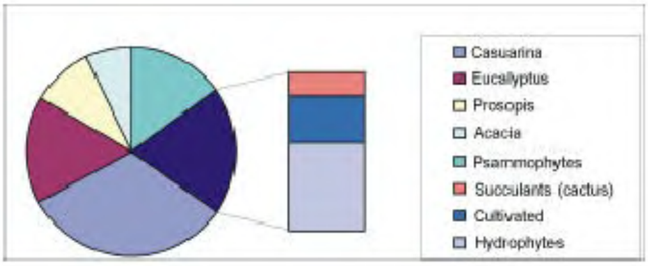

Figure 5. Present vegetation around the Pulicat lagoon.

ground surface shows pale brown, finely laminated clayey sand with small lenses of carbonized organic debris of lacustrine facies. The vegetal tissue is nil and if encountered is either amorphous or unidentifiable. Few algal/fungal fruiting bodies were observed with rare occurrence of microforaminifera testaes only at depth 1.5 m (a.m.s.l.) in Pit A.

Pit B (1.5 m, a.m.s.l.) shows sandy clay with reddish-brown layers in between. The radiocarbon dates of the sediments at 1 m (a.m.s.l.) reveal an age of 1972 ± 277 yrs BP. Small lenses of peaty patches and variation in the grain size indicate fluctuation in the energy regime. However, a very thin percentage of oxidized organic debris and lots of carbonized wood between the sandy clay, point to the fluvial sediment. There was no evidence of mangrove or other taxa throughout the sediments, except few pollen grains of Poaceae.

Pit C and others as shown in Figure 2 in an area of Attakanitippa (4–5 sq km) show two intertidal zones, evident by the radiocarbon age of pellicipods one at 0.75–1 m below mean sea level (2250–2599 yrs BP) and at 2 m below mean sea level (2799–3100 yrs BP). This part is 8 to 9 km west of the present shoreline. The shell layer indicates the intertidal environment during Late Holocene. The sediments have been earlier studied in detail from Attakanitippa[7]. No evidence of mangrove pollen or other taxa could be recorded. The unidentifiable vegetal tissue was rare or absent. The microforaminifera testaes were observed in few numbers only.

Since the radiocarbon dates of shells at 1 and 2 m below mean sea level are between 2260 ± 80 and 3100 ± 96 yrs BP at Attakanitippa and Sriharikota island, the peat beds observed at 9 and 15 m, respectively, below mean sea level (by Central Ground Water Board), are similar to those in Pit 1 and Pit A[7]. Therefore, this peat bed should be older than the peat at Sulurpet, indicating the palaeoshoreline during the global post LGM time period of sea-level rise[13]. This transgressive event reached its maximum around 6650 yrs BP in Sulurpet area (18 km from the present shoreline) as is evidenced by palynological reconstruction of mangrove vegetation that is an indicator of the sea level. It is interpreted that the mangrove line shifted landwards during the transgression and again during the regression phase only up to mid-Holocene. However, the absence of mangrove pollen in the late Holocene sandy clay sediments in the north-eastern part of the lagoon indicates that since then the mangroves declined drastically from the area.

Records of mangrove pollen from the southern flank of the lagoon in sediments dating back to 1800 to 1400 yrs BP have been reported[14]. It may be noted that the north-western part of the dried lagoon shows no mangrove record in the Late Holocene sediments. Therefore, it is interpreted that the mangrove line and the Pulicat lagoon boundary gradually shifted south-eastwards, acquiring the present-day boundary. The neotectonic upliftment of the north-western part along the lineament and subsequently shifting of the course of Kalangi river coupled with sea-level fluctuations[15] and later anthropogenic activity that strengthened around 200 yrs BP[14], perhaps brought about the configurational changes in the lagoon.

The present-day vegetation around the Pulicat margin (Figure 5) mainly comprises psammophytes and woody trees, e.g. *Casuarina, Eucalyptus, Acacia*, etc. The north-western part is a protected bird sanctuary near Sulurpet, with a number of hydrophytes, *Acacia* and *Prosopis* sps., that harbours the migratory and indigenous birds along with other diverse aquatic flora and fauna. The south-eastern part of the lagoon is navigable and the prograding NW sand spit shows very coarse sand and sparse vegetation except the planted *Casuarina* (Figure 6). *Spinifex littoreus*, along with few weeds on semi-stabilized and stabilized strands that include *Cyperus tuberosus, Fimbristylis, Launia nudicaulis, Phyla nodiflora, Sida*, Poaceae and Cyperaceae members all along the prograding NW Pulicat sand spit that runs parallel to the prograding SE Sriharikota sand spit.

The selection of *Casuarina* and *Eucalyptus* plants for commercial cultivation in the area is perhaps harmful as these absorb more sub-surface water through their shallow root system with high rate of transpiration. As a result, the soil is not conducive for the establishment of pioneer plant species (small herbs and shrubs) that help accrete silt and are dependent on the surface and sub-surface moisture. These species later lead to the mangrove succession. With the loss of sub-surface, moisture, the erosional processes, either eolian or fluvial, tend to increase. With this situation, the prograding NW and SE sand spits which provide an inlet for sea water, may get closed in due course of time. Presently, this flank is navigable. Fishing and shell collection are the main occupation here.

Large inflow of fresh water into the sea around India forces large changes in salinity and hence in the coastal sea level[16]. The weather in the region also plays a significant role in the sea-level changes. Recently, the analysis of storm surges along the east coast of India has been carried out[17]. The seasonal climatic changes, rainfall and its subsequent impact on sea level bring about changes in the mangroves. Their adaptation to these fluctuations have been studied from the east coast of India[18]. The abundance of mangroves is also controlled by continental waters, which is apparent from the global distribution of mangroves[19,20].

Figure 6. *Casuarina* plantation (background) on the north-west prograding sand spit that forms the south-eastern margin of the Pulicat lagoon near the Pulicat town. Semi-stabilized strand full of marine shells (foreground).

Monsoon appears to have increased in strength abruptly since the last deglaciation, firstly, between 13 to 12.5 ka and 10 to 9.5 ka and secondly, between 9.5 and 5.5 ka (ref. 21). The latter may have been punctuated by centuries-long periods of weaker monsoon circulation[22,23]. Records of maximum monsoon from the Arabian Sea and terrestrial sites in the adjacent areas of Africa and Asia and North Atlantic warmth were thus coincident with each other between 9.5 and 5.5 ka, and after 5.5 ka, the monsoon weakened more gradually in concert with slowly decreasing summer isolation in the Northern Hemisphere[24,25]. However, records of maximum winter precipitation in north-western India during the Indus Culture period of 5000 to 3500 yrs BP have also been reported[26,27].

The fluctuations of cold and warm climate have been recorded from both the Indian eastern coastal region and worldwide[28–32]. Several records of maximum humidity and strong monsoon during Early–Mid Holocene over India at 10°N and 15°N lat. are reported[33–36]. It was during this period that the Northern Hemisphere summer monsoon strengthened over the African–Eurasian land mass[37]. Reduction of monsoonal rainfall indicated by the decay of mangroves after 11,000 yrs BP (ref. 36) and a drier period in Central India, from 4500 to 3000 yrs BP and in Rajasthan from 4000 to 2000 yrs BP (refs 22, 24, 38) have also been reported. The dynamics of the south-west Indian monsoon and related sea-level over the last 18,000 years (refs 21 and 38) conforms with the changes recorded in the present study. The above records indicate that the transgression and strong monsoon should also have favoured the establishment of mangrove vegetation along this part of the Indian coast during Early Holocene. But the drier period cou-

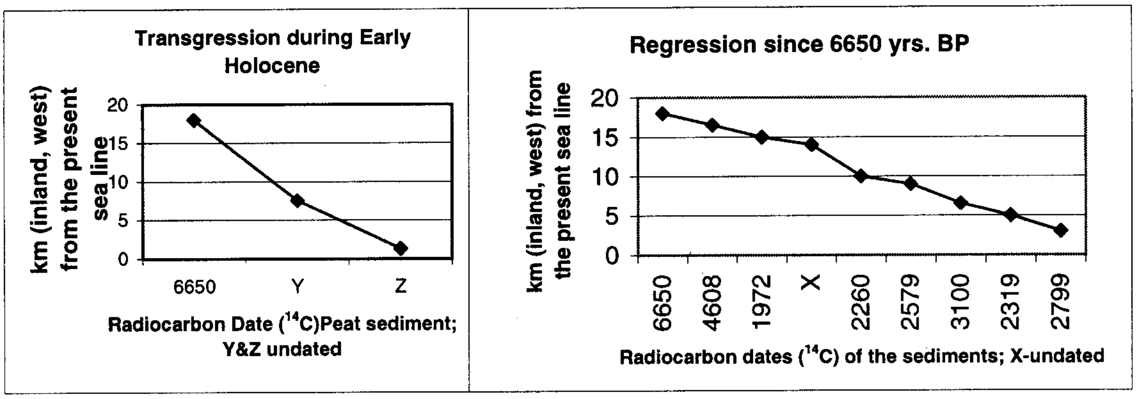

Figure 7. Sea-level fluctuation since Early Holocene in Pulicat lagoon, south-east coast in India.

pled with intermittent sea regression during late Holocene rendered the ecosystem not favourable for mangroves.

With the advent of Little Ice Age (16th century), there was again a sea-level fall that formed the Sriharikota island, reducing the navigability and affecting the port of this period, that flourished like that of Venice. Till this period, the area was fed by the Kalangi river. The sedimentary processes before this period perhaps initiated the seismogenic movement along the lineament (Figure 1), changing the course of the Kalangi river that gradually led to the closure of the port during the ninteenth century[15].

The post LGM sea-level rise[39] reached its maximum around 6650 yrs BP at Sulurpet and after this the area experienced regression and desiccation with the decelerating mangrove line too. The ongoing dynamic changes evidenced by the vegetational and sedimentation pattern related to sea-level fall/rise may further change the present lagoonal configuration, affecting the bird sanctuary, plant diversity and navigability. Stray occurrences of *Avicennia* and *Excoecaria* sps. near the present strandline in the northern part of the lagoon and the Pulicat Bird Sanctuary are conserved by the Forest Department, Sulurpet, Andhra Pradesh. Some salt-tolerant mangrove plants, e.g. *Rhizophora apiculata* and *Avicennia* sps. along with other salt-tolerant mangrove associates, viz. *Acanthus ilicifolius, Clerodendron inermi, Suaeda* sps., etc., should be planted to function as coastal guards in the buffer zone[5,18,40]. This would help in the protection of the present-day increasing coastal habitation from frequent cyclones and surges.

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