Continental Shelf Research 80 (2014) 49–56

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Research papers

Shoreline dynamics and littoral transport around the tidal inlet at Pulicat, southeast coast of India

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ARTICLE INFO

Article history:
Received 24 August 2013
Received in revised form
12 February 2014
Accepted 23 February 2014
Available online 12 March 2014

Keywords:
Tidal inlets
Satellite data
Sediment dynamics
Shoreline oscillation
Geographical information system
Sediment trend analysis

ABSTRACT

Pulicat is India's second largest brackish water lagoon with its mouth opening in the Bay of Bengal. The dynamics of the tidal inlet at Pulicat has been reported in this study on the basis of long term analysis using satellite remote sensing aided with Geographical Information System (GIS) and berm crest data. In addition, the short term analysis was carried out using monthly in situ Global Positioning System (GPS) profiling and sediment grain size analysis. The study of the shoreline dynamics along the inlet using the Linear Imaging Self – Scanning Sensor (LISS) – III along with the Survey of India toposheet of 1954 reveals that the inlet once with a single mouth is divided into two, over the period of time with the southern mouth migrating towards north with an inconsistent migration pattern of the northern mouth. The overall extent of migration is found to be within 3 km. The outcome of the 25 year berm crest data starting from 1978 revealed the coastline around Pulicat is eroding upto 1990 and thereafter it is accreting with the net shoreline erosion rate of 20.34 m/yr. The monthly in situ beach profiling studies from August 2004 to July 2005 revealed that the Pulicat inlet follows a variable migratory pattern with a shift of upto 914 m North during August to December with a reversal migration of 600 m thus leading to a net migration towards the north. The grain size analysis has unravelled the sediment transport around Pulicat inlet. The study of the inlet using satellite imagery during monsoon has clearly justified the dominant fresh water inflow regulatory force over the tidal forces and the positive influence of the Tsunami on opening the inlet during monsoon failure.

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1. Introduction

Coastlines which divide the land from sea are geological environment unique in their composition and the physical processes affecting them. The impact of climate change indicators like sea level rise, increase in extreme weather condition, both cyclones and droughts including anthropogenic interventions (urbanization, abridged sediment supply) along the coasts has led to significant transformation of the coastal zones worldwide and their morphology. (Roebeling et al., 2011; Cenci et al., 2013). Coastal lagoons and Estuaries are considered most important ecosystems for their commercial, recreational and ecological values. Increased population and urbanization has led to the degradation of the lagoon water quality exhibiting remarkable spatial and temporal variability mainly due to the fluctuation in nutrient and sediment load delivery by the river tributaries and in exchanges with sea (Janzen and Wong, 1998; Wei et al., 2004; Guyondet and Koutitonsky, 2008; Panda et al., 2013). The exchange and transport between lagoons and oceans influencing the contemporary phases of lagoon transformation dependent critically on the number of inlets (Aubrey et al.,1993), their length, width and depth (Phleger, 1976; Kjerfve, 1986), inlet cross-sectional area (Bruun and Gerritsen,1959; O'Brien,1969; Vincent and Corson, 1980), intermittently open-closed coastal lagoon entrances (Haines et al., 2006; Morris and Turner, 2010), inlet migration and stability (Walton and Adams, 1976; Chandramohan and Nayak, 1994), and circulation pattern (waves, tides and currents) demanding a clear understanding on the geomorphologic changes and the associated processes occurring around the inlets (Panda et al., 2013). In particular, long term datasets from the major factors of geomorphologic archives like river flow, sediment discharge, tide currents and wave fields within estuarine environments (Thomas et al., 2002; Van der Wal et al., 2002; Lane, 2004; Blott et al., 2006; Elias and van der Spek, 2006; Wang et al., 2008; Wheeler et al., 2010) enable quantitative analysis of the morphological evolution of estuaries and channels, especially over the time scale of a century (Wang et al., 2013).

A tidal inlet is defined to be a narrow waterway which connects either a bay or a lagoon to the ocean maintained by the tides (Watt, 1905; Chapman, 1923; Brown, 1928; O'Brien, 1931; Escoffier, 1940; Bruun and Gerritsen, 1960; Keulegan, 1967; Eads, 1971; Mehta and Joshi, 1988; Machemehl et al., 1991). The main channel through the strait of the tidal inlet is maintained by the tide (Escoffier, 1940; Dissanayake et al., 2009) with the littoral sediment transport

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http://dx.doi.org/10.1016/j.csr.2014.02.018
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determining the stability and dynamic equilibrium of the inlet. Stability of the inlet depends on the resultant state of the forcing parameters between the tidal prism, i.e., the amount of water flow into the inlet between two consecutive slack tides and the littoral drift across the mouth (Chandramohan and Nayak, 1994). Seasonally open tidal inlets are those which are closed for most of the months in a year because of the littoral currents that overcome the dwindling riverine flow from the lagoon. These inlets generally have a small inlet width of the order of 100 m and occur in microtidal, wave-dominated coastal environments where strong seasonal variations of stream flow into and off the estuary/lagoon connected to the inlet and wave climate are experienced (Fitzgerald, 1988; Largier et al., 1992; Cooper, 1994; Ranasinghe et al., 1999). According to Hayes (1979), tidal inlets occur usually in meso-tidal environments, with moderate wave energy (about 0.6 to 1.5 m) (Castelle et al., 2007). Some of the tidal inlets that open seasonally are Krishnapatnam and Ponnani estuaries in India (Bruun, 1986), Wilson, Irwin and Parry Inlets in Western Australia (Hodgkin and Clark, 1988), Narrabeen and Wollumboola lagoons in New South Wales, Australia (Gordon, 1990), Palmiet (Largier et al., 1992), Mtamvuna and Mvoti estuaries in South Africa (Cooper, 1994) and Chilaw lagoon in Sri Lanka (Lanka Hydraulic Institute, 1997).

During summer, these inlets seal themselves to the ocean by the formation of a sand bar across the entrance when the stream flow into the lagoon/estuary is low or nil and long-period swell waves dominate or when longshore sediment transport rates are high. In addition to using these inlets as harbours for small boats, both for fishing as well as recreational activities, the water quality, ecology as whole of the estuary/lagoon, is highly dependent on the opening and exchange of the waters. Many of these inlets are being used extensively as harbours for small fishing boats and as recreational facilities and hence, the seasonal closure of the inlet presents a two-fold problem. First, ocean access for boats that use the estuary/lagoon as a harbour is limited and second the water quality in the estuary/lagoon could deteriorate during the months of inlet closure. Hence most of these inlets are dredged manually to keep the inlets open throughout the year which has proved to be highly challenging and tricky for engineers. Taking into account the economical and environmental importance of tidal inlets, management of tidal inlets is not only concerned with maintaining navigable channels but also by new issues: adjacent littoral stability (Elias et al., 2006), sand reserves for beach nourishments (Castelle et al. 2006, 2007), water replacement in the lagoons for aquaculture (Bertin et al., 2005) and water quality (Newton and Mudge, 2005; Sennes et al., 2007) thus demanding for a proper understanding of the dominant processes causing the inlet closure over a considerable period of time is a pre-requisite for the sustainable engineering solution to address this issue (Ranasinghe et al., 1999).

Conventional methods of shoreline delineation using in situ field surveys are factitious which required a significant amount of time and manpower. Later on, with periodic over flights, aerial photographs were applied for this purpose considerably reducing the time taken but demanded a higher cost factor. In such a context, satellite remote sensing combined with GIS proved to be a suitable tool for the retrieval of the shorelines over larger areas at relatively low costs (Cracknell, 1999; Nayak, 2000). Various studies have validated the application of satellite imagery and GIS on mapping shorelines and inlet dynamics (Kurosawa and Tanaka, 2001; Gilvear et al., 2004; Rajawat et al., 2007; Pari et al., 2008; Ryu et al., 2008; Chen and Chang, 2009; Avinash et al., 2012, 2013; Jana and Bhattacharya, 2013; Panda et al., 2013) demonstrating that remote sensing satellite imagery has the potential to be used as an useful tool for panoptic mapping of the geomorphology and dynamics of the tidal inlets, rivers and estuaries (Chen and Chang, 2009).

Sediment trend analysis, pronounced as a technique using the relative changes in grain-size distributions of the sediments to establish the patterns of net sediment transport has been applied to enormous environments especially to the open marine environment lacking in a priori transport directions (Poizot et al., 2006) in addition to the various other environments like closed embayments (Gao and Collins, 1992), the direction of littoral drift along a deltaic coastline (Masselink, 1992), sandbanks (Gao et al., 1994), the inner continental shelf (Vousdoukas et al., 2011), river floodplains (Asselman, 1999), estuaries (Van Lancker et al., 2004), a variety of beach intertidal zones (Pedreros et al., 1996; Masselink et al., 2008) and on breakwaters (Plomaritis et al., 2008). Most of these studies applied the method on a regional scale, with only intermittent application of the method to the smaller-scale environments (Pedreros et al., 1996; Plomaritis et al., 2008, 2013).

Pulicat also has been in the prime focus of research on its inlet dynamics applying remote sensing and GIS (Kumar et al., 2008, 2009; Pandian et al., 2004, 2006). This study deals on the geomorphologic changes undergone by the Pulicat inlet as long term as well as short term analysis. The closure of the inlet due to the formation of sand bar at the inlet entrance has drastic implications such as water quality degradation, prevention of navigation and obstruction to the flushing mechanism. Hence a detailed study in and around the inlet was carried out using the long term backshore data, satellite imagery and GPS profiling in addition to grain size analysis of sediments.

2. Study area

Being the second largest brackish water lagoon in India shared over the districts of Thiruvallur in Tamil Nadu and Nellore in Andhra Pradesh, with an area of about 460 km^2 parallel to the Bay of Bengal, Pulicat lagoon covers a length of about 59 km from north to south and has maximum east-west width of 19 km at the northern sector of the lagoon (Fig. 1). The major source of fresh water input to the lagoon is through land run off from the three rivers viz., Arani at its southern end, Kalangi at its mid-western side and Swarnamuki at its northern end that debouch into the lagoon. The lagoon at its southern end, near Pazhaverkadu opens into Bay of Bengal through a narrow inlet of 200 m width, with an average depth of about 1 m (depth varies from 0.5 m to 6 m) which is a permanent opening. Pulicat lagoon is subjected to a limited tidal influence, the average difference between high and low tides being rarely more than 30 cm (Chacko et al., 1952). The lagoon is characterised by relatively calm waters, because the barrier spit keeps off larger waves from the open sea.

The general hydrographic status of the nearshore regions surrounding the inlet suggests that the average wave height is around 0.57 m to 1.0 m with the currents influenced by the seasonal circulation in Bay of Bengal in the coastal region flowing towards the North from March to October and towards south from November to February. The net sediment movement along with the inlets dynamics are mainly dependant on this phenomenon as the tidal induced currents are expected to be low of the order of 10–20 cm/s (NIOT, 2004). It has a high and low water spread area of 460 km^2 and 250 km^2, respectively. These fluctuations are due to fresh water input during northeast monsoon and severe drought from June to September. Pulicat inlet is regulated mainly by the fresh water input during monsoon and tidal action of the sea. On contrary, the fresh water input to the lagoon is decreasing due to the deficit in rainfall. However, northeast monsoon washes away the sand deposition. The failure or inadequacy of monsoon over a prolonged period could result in the closure of the lagoon inlet. In case of monsoon failure, the inlet becomes narrower, shallow and shifted towards north and gets closed. The sediments deposited due to the northern littoral drift forces the inlet to shift towards the north (Chandramohan et al., 1990). Hence the frequency of opening of the tidal inlet is dependent on the monsoon.

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