Regional Studies in Marine Science 7 (2016) 88–99

Contents lists available at ScienceDirect

Regional Studies in Marine Science

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

# Salinity and suspended sediment transport in a shallow estuary on the east coast of India

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## HIGHLIGHTS

- Pronounced seasonal variations in the transport of salt and suspended sediments were observed in the Muthupet estuary.
- The salt moved in the upstream and downstream direction from the salt plug.
- Salt transport affected the movement and removal of Fe from the water column.
- Concentration of Cu and Cd was affected by resuspension of sediments.
- The cause of more transport of suspended sediments was due to lower settling velocity of suspended sediments.

## ARTICLE INFO

*Article history:*
Received 26 August 2015
Received in revised form
19 May 2016
Accepted 31 May 2016
Available online 6 June 2016

*Keywords:*
Salinity
Suspended sediments
Transport
Shallow estuary
Muthupet estuary, India

## ABSTRACT

Velocity, salinity, tidal depth and suspended sediment concentrations were monitored at the two stations located at the mouth and head of the Muthupet estuary during the spring and neap tides of post-monsoon, pre-monsoon and monsoon seasons. There was a pronounced seasonal variation in the salinity and suspended sediment concentration during the study period. The total transport of salt at the station near the mouth varied between 4.78 kg/s/m and 0.038 kg/s/m. The transport of suspended sediments was in the range of 0.021 kg/s/m and 0.121 kg/s/m. The direction of transport of salt and suspended sediments also varied over a seasonal scale. The transport of salt and suspended sediments occurred in the downstream direction during the post-monsoon and monsoon, while it was in the upstream direction during the pre-monsoon. Fluvial advection was identified as the main controlling factor in the transport of salt and suspended sediments. The formation of salt plug during the pre-monsoon affected the transport of salt; the transport of salt was from the location of salt plug to the upstream and downstream directions. The spatial variability in the transport of suspended sediments was evident, with higher transport at the downstream station than that at the upstream station. The transport of salt was correlated with the concentration of Fe in the estuary obtained from previous studies. Further, it was observed that the concentration of Cd and Cu was dependent on the resuspension of sediments due to tidal action. The study proved that all the suspended sediments transported towards the upstream from the downstream reaches do not reach the upstream station, but are removed from the water column; the transport of suspended sediments were correlated with the settling velocity established from previous studies.



## 1. Introduction

The transport of suspended and dissolved particles through the estuary has caught attention in the recent years, the knowledge of which may help us to identify the physical processes causing the transport of other soluble conservative pollutants. The dynamics of suspended sediments reflect on the dynamics of pollutants in the estuary (Dyer, 1997). The understanding on the transport of suspended sediments would throw light on the pollution characteristics of an estuary, since many contaminants are adsorbed on the suspended sediments and are transported through the estuary (Nicholas, 1986). The estuarine hydrodynamics plays a key role in the transport processes of suspended and dissolved particles, and these processes are often more complex than that of rivers and lakes. On the other hand, an understanding of the major processes causing the transport can serve as an indicator of the hydrodynamics of the estuary.

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http://dx.doi.org/10.1016/j.rsma.2016.05.015
2352-4855/

The transport processes are controlled by the tides, fresh water discharge, waves, winds and topography of the estuary. The transport of suspended sediments in a well mixed estuary is different from that in a partially stratified or a stratified estuary. The harmonic tidal constituents, friction and morphology may affect the transport processes in well mixed estuaries and the estuary may act as a filtering media to retain the suspended and dissolved particles (Siegle et al., 2009).

The main processes causing the transport of sediments in a shallow estuary are tidal asymmetry, gravitational circulation and channel–shoal erosion (Van Straaten and Kuenen, 1957; Postma, 1961). The transport of sediments is considerably affected by the fresh water flow. The sediment resuspension during the dry season and flocculent settling during the flood season have been reported elsewhere (Wu et al., 2012). The shallow estuaries are more vulnerable to become shallower due to the deposition of sediments. Only a few studies have been reported on the dynamics of shallow estuaries (Uncles, 2002; Uncles and Stephens, 1996; Dyer, 1997; Largier et al., 1998; Masselink et al., 2009; Ruhl and Schoelhamer, 2004). Hence, there is a necessity to analyse the processes affecting the transport of suspended sediments in a shallow estuarine environment. One of the shallow estuaries, which is in threat to degradation is the Muthupet estuary, located in the south-east coast of India and has been selected for the study. This Ramsar site has undergone changes in its geomorphic characteristics. The water spread area of the estuary is 18.35 sq km as per IRS (Indian Remote Sensing) satellite imagery of 2011. The water spread area obtained from the Survey of India toposheets of 1973 was 15.87 sq km. The reason for the increase in water spread area coupled with a reduction in the average depth is unknown. Some of the earlier studies have concentrated on the concentration of heavy metals in the estuarine waters and bed sediments (Janaki-Raman et al., 2007; Thilagavathi et al., 2011). Priya et al. (2015a) reported the longitudinal and vertical profiling of salinity and suspended sediments under different fresh water flow conditions of the Muthupet estuary. The settling velocity of suspended sediments of Muthupet estuary was also studied over a seasonal and spatial scale and the controlling parameters were identified (Priya et al., 2015b). On a study of the trace metal distribution in the Muthupet estuary, the concentration of Cu, Cd and Zn were reported to be high at the mid-estuarine reaches during the pre-monsoon (Priya et al., 2014). The behaviour of soluble pollutants can be well understood only if the transport mechanism of salt is studied. The water chemistry of the estuary has a major impact on the phase change of heavy metals from soluble state to adsorbed state. From the earlier studies on trace metals, the authors identified the removal of Fe from the water column at mid-estuarine reaches (Priya et al., 2014). Hence, the main objective of the present study is to identify the processes causing the transport of salinity and suspended sediments in the shallow Muthupet estuary under different fresh water flow and tidal conditions.

## 2. Study area

The Muthupet is a shallow estuary with an average depth of 1 m. The maximum depth of the estuary is 1.7 m at the sea mouth. The fresh water discharge into the estuary is seasonal, the relevant seasons being pre-monsoon (March–July), monsoon (August–November) and post-monsoon (December to February). The fresh water is supplied to the estuary from the Cauvery river having a total drainage area of 87 900 sq km (Central Water Commission, GoI data). The tributaries of Cauvery river, namely Korayar and Paminiyar drain into the estuary, the flow from Korayar being predominant. The river discharge varies from 0 to 120 $m^3/s$ throughout the year. During the field data collection, the freshwater discharge varied between 0 $m^3/s$ (pre-monsoon) and 60 $m^3/s$ (post-monsoon). The estuary has mangroves mainly comprising of *Avicennia marina* species on its periphery. The estuary forms a part of the Point Calimere wetland system, the only Ramsar site in Tamil Nadu State of India.

The soil texture is clayey silt to clay near the mouth and the middle reach of the estuary, while sand predominates on the upstream side. The tide entering the estuary through the mouth of 1 km width moves towards the eastern and western directions. The geometry of the mouth causes 80% of the tide to move towards the eastern side (Priya et al., 2012). The estuary experiences an average tidal range of 0.5 m. As the average depth of the estuary has reduced from 2 to 1 m in two decades, there are possibilities of sediments being transported into the estuary. To understand the salinity and suspended sediment transport, two stations (S1 and S2) at the seaward and upstream ends were monitored during the spring and neap tides of the post-monsoon and pre-monsoon seasons (Fig. 1). As the tidal dynamics is very less in the western side (towards the Paminiyar river branch) and the fresh water flow from the Paminiyar river is not as appreciable as from the Korayar river, the study is concentrated only at the stations S1 and S2 in the eastern branch of the estuary.

## 3. Materials and methods

### 3.1. Field measurements

Field experiments were conducted during the spring and neap tides of the post-monsoon (23 January 2012 and 17 February 2012 respectively), pre-monsoon (10 March 2012 and 18 March 2012 respectively) and monsoon (14 December 2012 and 7 December 2012 respectively) seasons. Boats were anchored at two stations, one near the mouth (S1) and the other close to the head (S2) to avoid the disturbance caused due to moving boats. The average depth of water at station S1 was 1.5 m and that at S2 was 0.8 m and the average width at S1 and S2 were 1000 m and 150 m respectively. The water level and vertical profiles of current, salinity and suspended sediments were measured every hour for one complete tidal cycle (12 h 25min). The water samples were collected from four depths (0.1 D, 0.3 D, 0.6 D and 0.9 D, where D being the water depth). The current speed and direction were measured using a direct reading direction finding current meter (EMCON, Cochin: Range 2 to 400 cm/s). Salinity was measured using a conductivity meter (Eutech—Cyberscan Con 11: Range: 0 to 99.9 ppt) after calibration using the standard potassium chloride solution. Suspended sediments were determined gravimetrically by filtering aliquots of 1000 mL water through 0.45 μm Millipore filter paper (Merck Specialities Pvt Ltd, Mumbai, India). The filters were washed with deionized water to remove the salt and then dried in an oven at 65 °C for 1.5 h. The filters were further desiccated for 30 min to adjust them to room temperature and then weighed.

### 3.2. Theoretical considerations

#### 3.2.1. Water, salt and sediment flux

The relative importance of the mechanisms in transporting salt has been quantified by many authors using the decomposition method (Bowden, 1963; Fischer, 1976; Lewis and Lewis, 1983; Uncles and Jordan, 1980; Uncles et al., 1985). The time varying discharge ($m^3/s$) is obtained as,

$$Q_t = \bar{u} * A_t \quad (1)$$

where $\bar{u}$ (m/s) is the depth average velocity at time $t$ and $A_t$ ($m^2$) is the cross sectional area at time $t$.