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# Suspended sediment dynamics on a seasonal scale in the Mandovi and Zuari estuaries, central west coast of India

V. Purnachandra Rao*, R. Shynu, Pratima M. Kessarkar, D. Sundar, G.S. Michael, Tanuja Narvekar, Viegas Blossom, Prakash Mehra

*National Institute of Oceanography, CSIR, Dona Paula 403 004, Goa, India*

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ABSTRACT

Suspended particulate matter (SPM) collected at regular stations from the Mandovi and Zuari estuaries indicates that the peaks of high SPM coincide with peaks of high rainfall and low salinity and also with peaks of moderate/low rainfall coupled with high salinity during the monsoon. The estuarine turbidity maximum (ETM) is a characteristic feature, it occurs in the channel accompanying spring tide during the monsoon and pre-monsoon, and shifts to the bay on neap tide during post-monsoon. ETM remains at the same position in the Mandovi River, both during the monsoon and pre-monsoon, whereas in Zuari it stretched upstream during monsoon and migrates seaward of the channel during pre-monsoon. The ETM coincides with the freshwater–seawater interface during the monsoon and is formed by the interaction between tidal currents and river flows. The ETM during pre-monsoon is associated with high salinities and is generated by tidal and wind-induced currents. The turbidity maximum on neap tide during post-monsoon may be due to the erosion and resuspension of sediments from the emergent tidal flats and transport of these turbid waters into the bay. Funneling effect of the narrowing bay in the Zuari estuary and associated physical processes effectively enhance the magnitude of the currents and transports sediments to the channel. SPM retention percentage indicates that the estuarine channel is prone to siltation.



## 1. Introduction

Knowledge on the suspended sediment dynamics in the estuarine system has received considerable attention in recent years in response to the fact that the estuaries receive agricultural, industrial and domestic waste runoff from their watersheds; they are impacted by nutrients and pollutants, and siltation in the channels leads to navigational problems (Oslen et al., 1982; Regnier and Wollast, 1993; McKee et al., 2000; Kistner and Pettigrew, 2001; Patchineelam and Kjerfve, 2004; Hossain et al., 2004). Dynamic estuarine processes control the manner in which suspended sediments are distributed and transported. Understanding the suspended sediment movement on a seasonal scale is important for monitoring water quality, fate of pollutants, and for the success of dredging operations. Investigations revealed that the distinctive feature in estuaries is the occurrence of estuarine turbidity maximum (ETM), where the concentrations of suspended particulate matter (SPM) are higher than the SPM concentrations both seaward and landward (Schubel and Kennedy, 1984; Nichols and Biggs, 1985; Dyer, 1988). ETM is important because of its influence on primary productivity, pollutant flushing, fish migration and dredging (Mitchell et al., 1998). ETM may occur in any part of the estuary (Schoelhamer, 2001), but is usually present near the saltwater–freshwater interface, which in turn is determined by the strength of estuarine circulation (Postma, 1967; Festa and Hansen, 1978), or away from the saltwater–freshwater boundary as a result of tidal processes, which resuspend sediment from the bed (Allen et al., 1980; Gelfebaum, 1983; Uncles and Stephens, 1989; Le Bris and Glemarec, 1996; Mitchell et al., 1998, 2003). Freshwater discharge and tidal forcing produce gravitational circulation and salinity stratification within estuaries and can be directly related to the distribution of SPM concentrations and location of the ETM (Geyer, 1993). Seasonal migration of turbidity maximum towards downstream/upstream positions of the estuary was reported (Wellershaus, 1981; Uncles et al., 1994; Mitchell et al., 1998, 2003). A cycle of deposition, bed erosion and resuspension can also contribute to the ETM formation (Uncles et al., 1994; Wolanski et al., 1995). Comparison between estuaries reveals large differences in SPM concentrations due to differences in freshwater discharge, tidal characteristics and sediment sources. Moreover, no two estuaries

* Corresponding author.
*E-mail address:* vprao@nio.org (V. Purnachandra Rao).

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are alike in terms of the parameters responsible for their sediment characteristics (Althausen and Kjerfve, 1992). Studies related to the suspended sediment concentrations on seasonal timescales are somewhat neglected for Indian estuaries. The objectives of this study are: (1) To compare the SPM variability and position of turbidity maximum on a seasonal scale in two adjacent estuaries of the rivers of nearly the same length, sharing similar terrain and rainfall conditions. (2) To identify the processes that influence sediment transport in the Mandovi–Zuari estuarine system.

## 2. Background

The Mandovi and Zuari Rivers are tropical, minor rivers of Goa in the central west coast of India (Fig. 1). They originate in the Western Ghats (mountain ranges) and flow through a narrow coastal plain. The length of the Mandovi and Zuari are ~50 km each and the average depth is 5 m. The estuarine portion of the rivers has two parts, a channel and a bay through which the channel is connected to the Arabian Sea. The size and morphology of the bays are, however, different (Fig. 1). The Aguada Bay, off Mandovi River, is small and semi-circular in shape, with an area of ~4.36 $km^2$, a width of 3.33 km at the mouth and 1 km at the joining point of the channel and an average depth of 5 m. The Mormugao Bay, off Zuari River, is relatively large with an area of ~46.7 $km^2$; it has a length of 10 km and is funnel-shaped with a width of 5 km at the mouth and narrows down to 1 km at the joining point of the channel. A narrow canal, called the Cumbarjua canal, connects these two estuaries. Several tributaries join the Mandovi and Zuari rivers. The estuaries of the rivers are meso-tidal, and the tidal ranges are ~2.3 and 1.5 m during the spring and neap tides, respectively (Shetye et al., 2007; Manoj and Unnikrishnan, 2009). The tides are of mixed semi-diurnal type (Sundar and Shetye, 2005) and vertical mixing of the water column is mainly due to tidal activity. Both flood and ebb currents are stronger in the Zuari than in the Mandovi estuary (Manoj and Unnikrishnan, 2009). Simulation data show that the magnitude of tidal currents in the downstream regions of the estuaries during the spring and neap tides are ~0.8 m $s^{-1}$ and 0.4 m $s^{-1}$, while the measured values are 1.0 m $s^{-1}$ and 0.65 m $s^{-1}$, respectively (De Souza, 2000).

## 3. Materials and methods

Two types of data were collected in the Mandovi and Zuari estuaries: (1) Salinity data and surface waters were collected every day at one station in the mid-channel of the estuaries during monsoon (June–September) 2007 for Mandovi, and during monsoon 2008 for Zuari estuary. This station is referred here as the "regular" station (Fig. 1). (2) Salinity data, surface water, and bottom sediments were also collected fortnightly at five stations along the main channel of the Mandovi estuary (hereafter referred to as "transect" stations) during June–September 2007, using a mechanized boat. Further, from October 2007 to May 2008, two stations were added towards the river-end of the estuary. Similarly, salinity data and surface water were collected during spring and neap tides of every month between June and September 2008 at 7 transect stations in the Zuari estuary and from October 2008 to May 2009 two stations were added towards the river-end of the estuary. Data collection was repeated during January–May 2009 for Mandovi and October 2009–May 2010 for Zuari at the same stations. In case of Mandovi, sampling stations are confined to the main estuarine channel, while in Zuari sampling stations cover both the channel and bay parts (see Fig. 1). Five liters of surface water collected at each station were filtered through 0.4-μm Millipore filter paper. Three filter papers were used for each station, and the

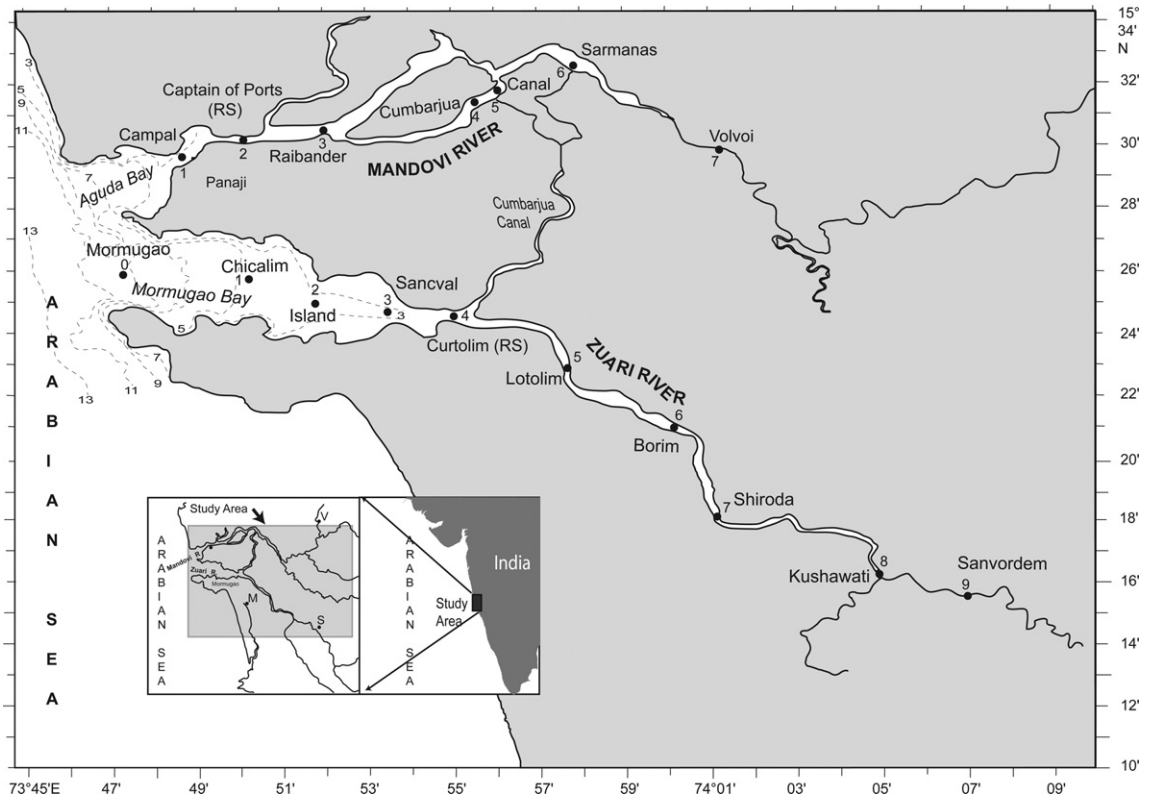


**Fig. 1.** Location of samples in the Mandovi and Zuari River estuaries, central west coast of India. RS – regular station; M and S in the insert figure are rain guage stations, M – Madgaon and S – Sangeam.