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The influence of human activities on morphodynamics and alteration of sediment source and sink in the Changjiang Estuary

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ABSTRACT

Several works have discussed the morphological evolution in the Changjiang Estuary (CJE) in recent years. The erosion of its subaqueous delta in recent decades has been ascribed to a decline in fluvial sediment input. However, the interaction between the reduction of riverine sediment load and human activities in the estuary that could have caused morphological change has not been considered. In this work we provide evidence on the morphological evolution around the delta front zone since 1986 and use a numerical model to explore the correlation between the change in hydrodynamics and the evolution pattern. Bathymetric data analysis suggests a decrease of net accretion rate from 16.7 mm/year (1986–1997) to 9.1 mm/year (1997–2010) in the study area. Spatially, the tidal flats accreted whereas the subaqueous delta switched from deposition between 1986 and 1997 to erosion between 1997 and 2010. We used two indicators, tidal energy dissipation and erosion rate, to quantify the change in hydrodynamics and found that the erosion of the subaqueous delta in recent decades can readily be explained by the alteration of the hydrodynamics. The newly built navigation training works in the North Passage had a significant effect on the estuarine hydrodynamics, resulting in a local morphological adjustment. This erosion generated a new source of sediments to maintain the high suspended sediment concentration and tidal flat progradation. The erosion of the subaqueous delta may continue and gradually slow down until the altered hydrodynamics and morphology reach an equilibrium state in the future.

1. Introduction

An estuary is a transition zone between riverine and marine environments. Thus, estuary morphological change is sensitive to both human activities in the drainage area and adjacent coasts. Hydrological dams, soil and water conservation, and sand mining have resulted in a decrease in fluvial sediment load. The sediment delivery to deltas worldwide has been reduced during the past 50 years due to upstream damming (Syvitski et al., 2009). For example, a 50% reduction in suspended sediment load in the Mississippi River during the last few decades has been observed, which resulted in unsuitable conditions for wetland vegetation, yielding the loss of marsh habitat (Kennish, 2001). Human activities in estuaries, such as training wall construction, channel dredging, and land reclamation, can cause dramatic changes in the hydrodynamics, sediment transport, and morphological evolution patterns of estuaries (Sherwood et al., 1990; Nichols and Howard-Strobel, 1991; Spearman et al., 1998; Blott et al., 2006; Talke et al., 2009).

The Changjiang River has become a focal point for research because of the construction of the Three Gorges Dam (TGD). The effect of the TGD on river ecology and the geological disaster in the reservoir area after impoundment are the main concerns (Stone, 2008). Apart from this, the response of the Changjiang subaqueous delta to the impoundment of sediment by the TGD is also a topic of interest. Yang et al. (2003) predicted the potential morphological evolution after the TGD and concluded that the Changjiang Estuary (CJE) will become eroded once the annual sediment load is $<260 \times 10^6$ t/year. Similar critical values of 395×10^6 t/year and 184×10^6 t/year were reported based on linear regression analysis between river-born sediment and erosion/accretion volume of the delta (Chen and Zong, 1998; Li et al., 2004). However, these studies only covered part of the delta (<2000 km^2), and may not be representative of the entire delta. The sediment load from the river to the CJE has decreased since the 1980s and a notable decrease occurred after the impoundment of the TGD in 2003 (Gao et al., 2011). Even with a sharp decrease in sediment load, a recent study showed that erosion only occurred locally and there is no obvious trend of erosion within the CJE (Dai et al., 2014). Thus it is still debatable to what degree the morphology has responded to reduced riverine sediment load, and there is no consensus on any persistent evolution pattern. The underlying mechanisms of estuarine morphological changes are also not fully understood.

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The CJE is a large estuary with complex dynamics, thus it is difficult to distinguish the impacts of the changes in the upstream river basin from changes within the estuary (Chen et al., 1999). Huo et al. (2010) examined the long-term morphological evolution of Nanhui Shoal (Fig. 1) and found that the evolution of Nanhui Shoal is highly sensitive to the flow and sediment diversion in the upstream channels. Furthermore, the hydrodynamics of the CJE are complex as they are strongly influenced by the huge river flow as well as strong tidal currents and waves, which result in spatial and temporal variations of suspended sediment concentration (Shen et al., 2013).

In addition to the decrease in sediment supply to the estuary, the estuary has been influenced by the building of large infrastructures. Such changes can alter the dynamics of the estuary, resulting in a change of sediment transport processes (Xu et al., 2009; Wu et al., 2012; Ma et al., 2013). The recently observed transformation of a region of historical deposition to net erosion following construction of the TGD suggests a change from a sediment sink to a sediment source in the CJE (Liu et al., 2012). However, the cause of this change is not fully understood.

So far many studies of estuary dynamics and sediment transport processes in the CJE have been conducted, most of which focus on sediment dynamics and transport in the channels of the estuary. The effect of interactions between natural evolutionary processes and human impact on the recent change of the delta has not been studied in full. We hypothesize that local human intervention in the CJE in recent years has altered hydrodynamics to a major degree, which have contributed to the recent change of the morphological evolution pattern of the estuary. The questions as to how hydrodynamic conditions have been changed in response to evolved morphology and engineering works and how a change in hydrodynamic conditions contributes to the shifting of the sediment sources and sinks are insufficiently studied. Thereby, the objectives of this study are to investigate: 1) the correlation between the change in hydrodynamics and the change of erosion and deposition patterns; 2) the contribution of the change in dynamic conditions to the alteration of sediment transport processes in the estuary; and 3) the causes of possible switching between sediment sources and sinks under the influence of bathymetric change and man-made construction. We used a numerical model to reproduce the hydrodynamics under varying bathymetries. Two indicators, tidal energy dissipation and erosion rate, were applied to quantify the change in hydrodynamics and we detected the interaction between hydrodynamics and morphological evolution. In that sense, this work enables us to establish the main factors that control morphological evolution and the change of the large-scale net sediment transport pattern on a decadal time scale.

2. Study site

The Changjiang River is the largest river leading to the Western Pacific. The annual river discharge and suspended sediment load in the period 1950–2010 are approximately 900×10^9 m^3/year and 390×10^6 t/year at Datong Gauge Station, about 640 km upstream of the river mouth, where daily discharge is measured. About half of the total sediment load is deposited within the estuary (Milliman et al., 1985; Liu et al., 2006). The comparison of the present coastline with the ancient coastline suggests that about 12,000 km^2 of estuarine waters have become land in the past 2000–3000 years due to deposition of riverine sediment (Chen et al., 1988; Yang et al., 2001).

The CJE is first divided into the South Branch and the North Branch by Chongming Island, and then the South Branch is divided into the South Channel and the North Channel by Changxing and Hengsha Islands. Finally the South Channel branches into the South Passage and the North Passage by Jiuduansha Shoal (Fig. 1). The turbidity maximum zone, formed under the combined effects of gravitational circulation (Shen et al., 1986a, b), sediment flocculation (Tang et al., 2008) and sediment resuspension (Li and Zhang, 1998), is located in the lower reach of North Channel, North Passage and South Passage. The CJE is a mesotidal regime. The mean tidal range at Zhongjun tide-gauge station is 2.66 m and the tidal range decreases further upstream along the South Branch.

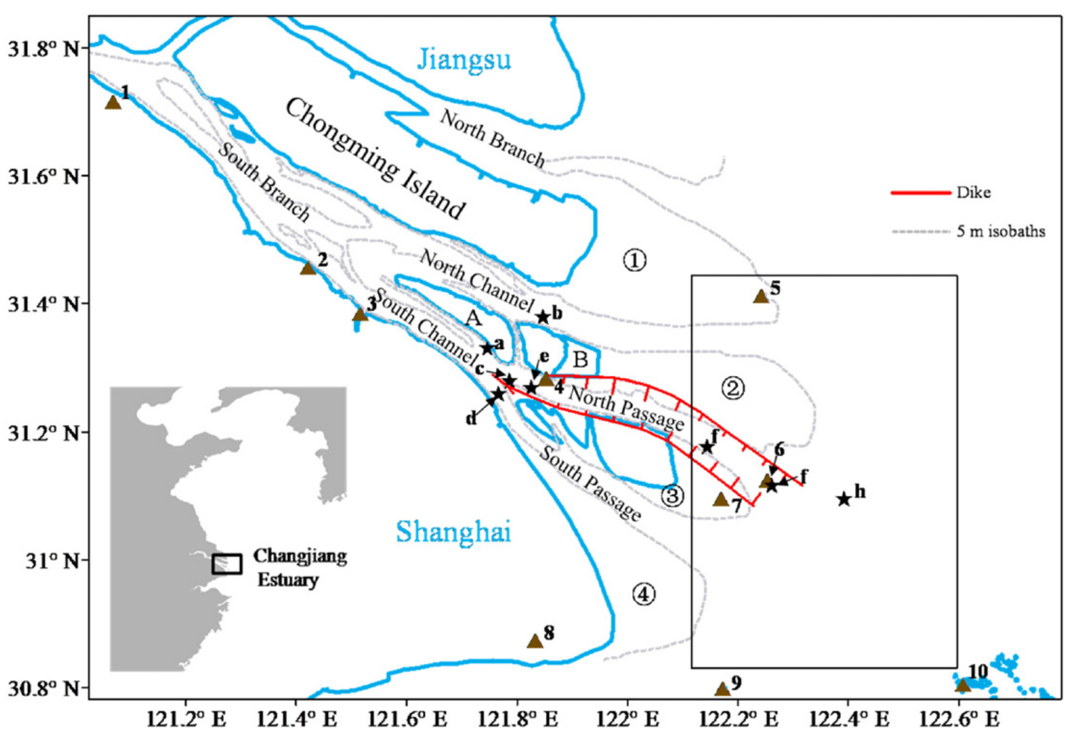

Fig. 1. Study area and measurement sites (A. Changxing Island, B. Hengsha Island; 1. Baimao, 2. Shidongkou, 3. Wusong, 4. Hengsha, 5. Sheshan, 6. Niupijiao, 7. Jiuduandong, 8. Luchaogang, 9. Dajishan; a. NG2, b. BG1, c. CB1, d. NC1, e. CS0, f. CS3, g. CS4, h. CS5; the rectangle is where the morphological evolution is detected; ①: Chongming East Shoal, ②: Hengsha East Shoal, ③: Jiuduansha Shoal, ④: Nanhui Shoal).