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Recent human impacts on the morphological evolution of the Yangtze River delta foreland: A review and new perspectives

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ABSTRACT

This paper reviews the morphological change in the Yangtze River delta due to increasing human impacts from three major aspects. The first is the reduction of sediment supply to the ocean due to dam construction, soil conservation, and sand mining within the Yangtze River basin. The reduced sediment supply has decreased the progradation rate of the delta and triggered erosion in the front of the delta. The second impact relates to the reclamation of intertidal wetlands by human activities. Since the 1950s, approximately 1100 km^2 of intertidal land has been embanked, resulting in the disappearance of salt marshes and even the entire intertidal zone along some sections of the coastline. The third change in the delta due to human interference is the construction of deep-waterway structures at the mouth bar, which has greatly modified the local hydrodynamics and morphology. Sediment accretion has increased significantly in these areas as a result of sheltering by these deep-waterway structures. This review shows that human activities have severely altered the natural balance among the hydrodynamics and sediment supply, affecting the morphological features of the Yangtze River watershed and delta. Human impacts on the morphological evolution of deltaic coasts in general are becoming an increasingly concern, and more attention should be paid to the management and mitigation of these effects.

Contents

1. Introduction

Human impacts on the morphological evolution of estuarine deltas have been progressively intensified in recent years. During

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last several decades, sediment discharge from many rivers in the world has decreased sharply due to dam construction, soil conservation, water diversion. These activities have slowed accretion rates and even induced erosion of sediment in some areas (Woodroffe, 2003). For example, the Colorado River in the USA once supplied more than 150 Mt/yr of sediment to the Gulf of California. River diversions and especially sediment trapping by dams have prevented a great portion of sediment from reaching the Colorado delta, which has resulted in coastal recession (Carriquiry et al., 2001). The Nile sediment discharge was once between 100 and 124 Mt/yr. Nowadays, <10% of the former sediment load is delivered to the Nile delta due to the construction of the Aswan High Dam. Erosion of the Rosetta and Damietta promontories formed at the mouths of two active tributaries is the most rapid (Fanos, 1995). The Ganges-Brahmaputra is among the world's three largest river systems in terms of sediment load. Large-scale diking of numerous branches of the delta began in the 1960s has resulted in a decrease of inflow of river water and sediments into the inner parts of the delta (Mikhailov and Dotsenko, 2007). As a result, the delta front is sediment starved and is undergoing retreat (Allison, 1998). Similar situation occurred at Mississippi (Blum and Roberts, 2009), Ebro (Sánchez-Arcilla et al., 1998), and Yellow (Chu et al., 2006). Meanwhile, human activities in the estuaries also play an important role in the morphological evolution of the deltas. For example, the completion in 1986/87 of an open storm-surge barrier in the inlet and of dams in the landward parts of the Oosterschelde tidal basin (SW Netherlands) has had a significant impact on geomorphological developments. The formerly eroding basin enclosing expanding channels and aggrandizing sandy shoals, has changed into the opposite (Mulder and Louters, 1994). Dredging in the Elbe River estuary has dramatically altered the nature of the silted river channel to erosional since the last century (Li et al., 2014). Some engineering works at the estuary of Seine River, such as training walls and embankments, have modified the estuary-shelf sedimentology (Avoine et al., 1981).

The Yangtze River watershed has a population approaching half a billion of people and, hence, is one of the most heavily impacted watersheds by human activities. In order to store water resource, minimize flooding, generate hydroelectric power, and facilitate irrigation, more than 50,000 dams, especially the Three Gorges Dam (TGD), have been built throughout the Yangtze River watershed since 1950 (Yang et al., 2011). Although there are some disagreements in sediment balance estimations from various studies due to spatial and temporal variations in sediment loading in the Yangtze delta, these studies have shown that the human activities have had a tremendous impact on the sediment balance in the lower Yangtze River and the subaqueous delta (Chen et al., 2008; Dai et al., 2008; Xu and Milliman, 2009; Yang et al., 2011). With the TGD in operation, the change in sediment discharge and, hence, the response of the delta will be the focus of the future study. Since 1990, soil conservation synchronized with dam construction in the Yangtze River Basin. It is commonly believed that soil conservation will greatly reduce the river sediment discharge, the current studies have not shown strong evidence to support this argument (Guo et al., 2004; Yang and He, 2005; Xu and Sun, 2007; Dai et al., 2008; Shi and Du, 2009; Liao et al., 2010). Although illegal sand mining in the middle and lower reaches of the Yangtze River was a very serious problem during the last decades (Yuan, 2006; Leeuw et al., 2010), the investigations in sand mining in China focused only on the riverbed evolution, and the advantages and disadvantages of the sand mining as well as the related countermeasures (Luo et al., 1999; Ma, 2000). The environment impact of sand mining on delta is still missing.

Along with the exploitation of coastal resources over the past several decades, large-scale infrastructure projects have been implemented in the Yangtze River estuary. For example, approximately 1100 km^2 of intertidal wetland has been enclosed since the 1950s in the estuary area (Fig. 1B). The Deep Waterway Project (DWP) was built between 1998 and 2010 at the North Passage, and involved excavating a waterway to depths of 6–12.5 m. To maintain this channel, dike–groyne systems as long as approximately 50 km were constructed on both sides of the channel (Fig. 1B). In recent years, many studies have been done on reclamation and DWP as well as their influence (Liu et al.,2005; Gao and Zhao,2006; Wang and Du, 2006; Du, 2012; Liu et al.,2012). However, there has been insufficient information regarding the impact of these activities on the delta. Little is known, for example, about the effect of these projects on the morphology of adjacent ocean basins, and whether oceanic processes have offset the decrease in riverine sediment discharge.

The Yangtze River is one of the most important rivers in the world. It is the third longest in length, the fourth largest in sediment load and ninth largest in catchment basin. Its water discharge is the largest in the western Pacific Ocean and the fifth largest in the world (Eisma, 1998). The Yangtze River mouth, a typical of large river mouths with a width of 90 km at the outer limit, can be compared with many large river mouths in the world, e.g. Nile River, Ganges-Brahmaputra River and Mississippi River. The tidal flats at river mouths are less sheltered and their sediment dynamics are greatly influenced by wind-induced waves, unlike some estuaries behind barrier islands or embayment. These local distinguishing features, together with others, make this study important to improve our knowledge of the delta morphological evolution. This article focuses on human activities in the Yangtze River drainage basin and estuary, and their impact on the morphological change of the Yangtze River delta, which can lead to a better understanding of the coastal environmental evolution mixed with human activities.

2. Human activities in the Yangtze River watershed and downstream impacts

2.1. Sediment flux

The Yangtze River sediment load is influenced by climate change and human activities such as dam construction, soil conservation, and sand mining (Walling and Fang, 2003). Although it is difficult to distinguish anthropogenic impacts from climate change effects, it is thought that climate change is the dominant factor over longer periods, while human activities are more important during a short time period (Yang et al., 2002; Dai et al., 2008; Wei et al., 2011). Dai (2006) reviewed the possible causes of the sediment load decrease, which are thought to be, in order of priority, dam trapping, sand extraction, and soil conservation measures. Most recently, Yang et al. (2015) estimated the impacts of various human activities and climate change on the Yangtze sediment load for the past six decades.

Datong Hydrological Station (Fig. 1A) is the lowest station along the Yangtze River. The water discharges and sediment loads recorded at Datong Station are considered to be the amount entering the estuary. The sediment discharge of the Yangtze River estuary reached a maximum of 510 Mt/yr in 1960s, and has progressively declined since then (Yang et al., 2002). The time series record of annual sediment discharge shows three inflection points around 1970, 1990, and 2003, which correspond to the closure of Danjiangkou dam, the implementation of soil conservation measures, and the closure of the Three Gorges Dam (TGD), respectively (Fig. 2).