Quaternary International 392 (2016) 147–154

Contents lists available at ScienceDirect

Quaternary International

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

Delta changes in the Pearl River estuary and its response to human activities (1954–2008)

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A R T I C L E I N F O

Article history:
Available online 8 May 2015

Keywords:
Delta
Sediment load
Human activities
Pearl River

A B S T R A C T

This paper is concerned with delta evolution in response to human activities in the Pearl River estuary. Utilizing more than 50 years data bathymetric data, together with simulation fluvial discharge data, the net accretion rate in the Lingdingyang subaqueous delta decreased from 16.6 mm/y over the period 1955–1964 to 1.6 mm/y for the period 1998–2008 because there was a dramatic downward trend in the sediment load. In particular, the closure of the Longtan Dam (LTD) in 2006 resulted in the sediment load entering the Pearl River falling from 75 Mt/y (annual average: 1954–2006) to 25.2 Mt/y, a decrease of ~67%. Another reason may be sand mining in the Lingdingyang estuary. Based on the linear relationship between sediment load and accumulation rate, an annual average sediment load of 21.7 Mt/y carried into the Lingdingyang estuary is the critical threshold value that separates delta progradation from recession. However, the outer subaqueous delta in the Modaomen estuary underwent deposition in the same period, because there is no obvious change in sediment load into the area during 1954–2008. In the coming decades, ongoing human interferences will reduce the fluvial sediment load entering the sea, which probably will result in a phase of general delta recession replacing delta progradation.

1. Introduction

Many of the world's river deltas currently face serious problems due to the combined pressure of human development and climate change (Day and Giosan, 2008). Throughout recorded history, dams and irrigation, as well as improved soil and water conservation practices, have reduced the sediment loads carried by many rivers. Consequently, the accretion/erosion response of deltas to this decline in the fluvial sediment supply has become a topic of global concern (Milliman, 1997; Syvitski et al., 2009; Edmonds, 2012). For example, an expanse of coastal land the size of 0.05 km^2 disappears from the Mississippi River delta every hour due to the decreasing sediment load and sea level rise (Edmonds, 2012). The sediment load in the river Nile in Egypt was once between 100 × 10^6 and 124 × 10^6 t, but today there is almost no net annual sediment input to the Nile delta due to the Aswan High Dam, which began operating in 1964, and the delta is degrading with a shoreline erosion rate of 143–160 m/y (Stanley and Warne, 1993, 1998; Fanos, 1995; Frihy et al., 2003). The sediment load of the river Ebro located in northeastern Span was reduced from ~1.0 × 10^7 Mt/y to 0.3 × 10^6 Mt/y, after the construction of the Ribarroja–Mequinenza dam in the lower Ebro at the end of the 1960s. Currently, the load ranges from 0.1 × 10^6 to 0.2 × 10^5 Mt/y. More than 99% of the sediment load has been trapped in the reservoirs, which was the major cause of recession in the river mouth area (Ibàñez et al., 1996; Sánchez-Arcilla et al., 1998). The Colorado River, one of the most highly regulated rivers in the word due to the numerous dams, once supplied more than 150 × 10^6 Mt/y of sediment to the Gulf of California. At present, the dams and course diversions effectively trap most of the sediment, and this has led to coastal erosion (Carriquiry and Sánchez, 1999; Huh et al., 2007). In China, the Yangtze River, one of the largest rivers in the world, carried a sediment load of around 490 Mt/y in the 1950s and 1960s, but this fell to 150 Mt/y after the closure of the Three Gorges Dam (TGD). In response to this drastic decrease in sediment supply, the river channel has changed from net accretion to net erosion, and the deltaic coast has shifted from progradation to recession (Yang et al., 2003, 2005, 2011; Luo et al., 2012; Dai and Liu, 2013; Dai and Lu, 2014). The Yellow River (Huanghe) once carried the second

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http://dx.doi.org/10.1016/j.quaint.2015.04.009
1040-6182/

largest sediment load in the world (Milliman et al., 1987), but now carries only 14% of the widely cited estimate of the peak load of 1.08 Gt/y, due to both natural processes and human activities over the past 56 years (Wang et al., 2007). This dramatic decrease in sediment load has caused the whole delta to switch from a state of accretion to erosion (Peng et al., 2010).

As the second largest river China, and the 25th largest river in the world in terms of water discharge, the Pearl River is considered one of the world's most complicated fluvial networks. It is a compound river system, comprising three major tributaries (the West, North, and East rivers), and some other small rivers draining into the Pearl River delta (Fig. 1), which occupies an area of ~17,200 km^2. The Pearl River delta is one of the most developed areas in China owing to implementation of China's open-door and reform policies since the 1980s, and at least 8636 reservoirs had been constructed in the watershed by the late 1990s. As a consequence, the hydrological regime of the Pearl River basin has been substantially altered by this intensive human activity, and the Pearl River has become one of the most highly impacted rivers in the world (Nilsson et al., 2005). Over recent years, previous studies have focused on various aspects of the changing water and sediment load of the Pearl River (e.g., Dai et al., 2008; Zhang et al., 2008, 2009; Wu et al., 2012; Wu et al., 2012; Zhang et al., 2012; Liu et al., 2014) and channel changes (Lu et al., 2007). These papers indicate that human activities, in particular dam construction and soil conservation, have altered the natural sediment transport regime. However, to the best of our knowledge, no previous work has demonstrated the collective impact of changes to the subaqueous delta of the Pearl River caused by the changing sediment supply. Therefore, in this paper, we investigate the evolution of the subaqueous delta in response to human activities, based on hydrological data and bathymetric maps covering the period from 1950s to 2008.

2. Physical setting

The Pearl River originates on the Yunnan Plateau and crosses low-terrain hills and even mountains as it runs 2400 km eastwards to South China Sea (Wu and Zhou, 2001). Due to its long-term average annual water discharge of 3260 $\times$ 10^8 m^3/y, it plays an important role in fresh water supply to the large cities in the Pearl River delta region, such as Macau, Hong Kong, Zhuhai, and Guangzhou. The annual suspended sediment load of the river is

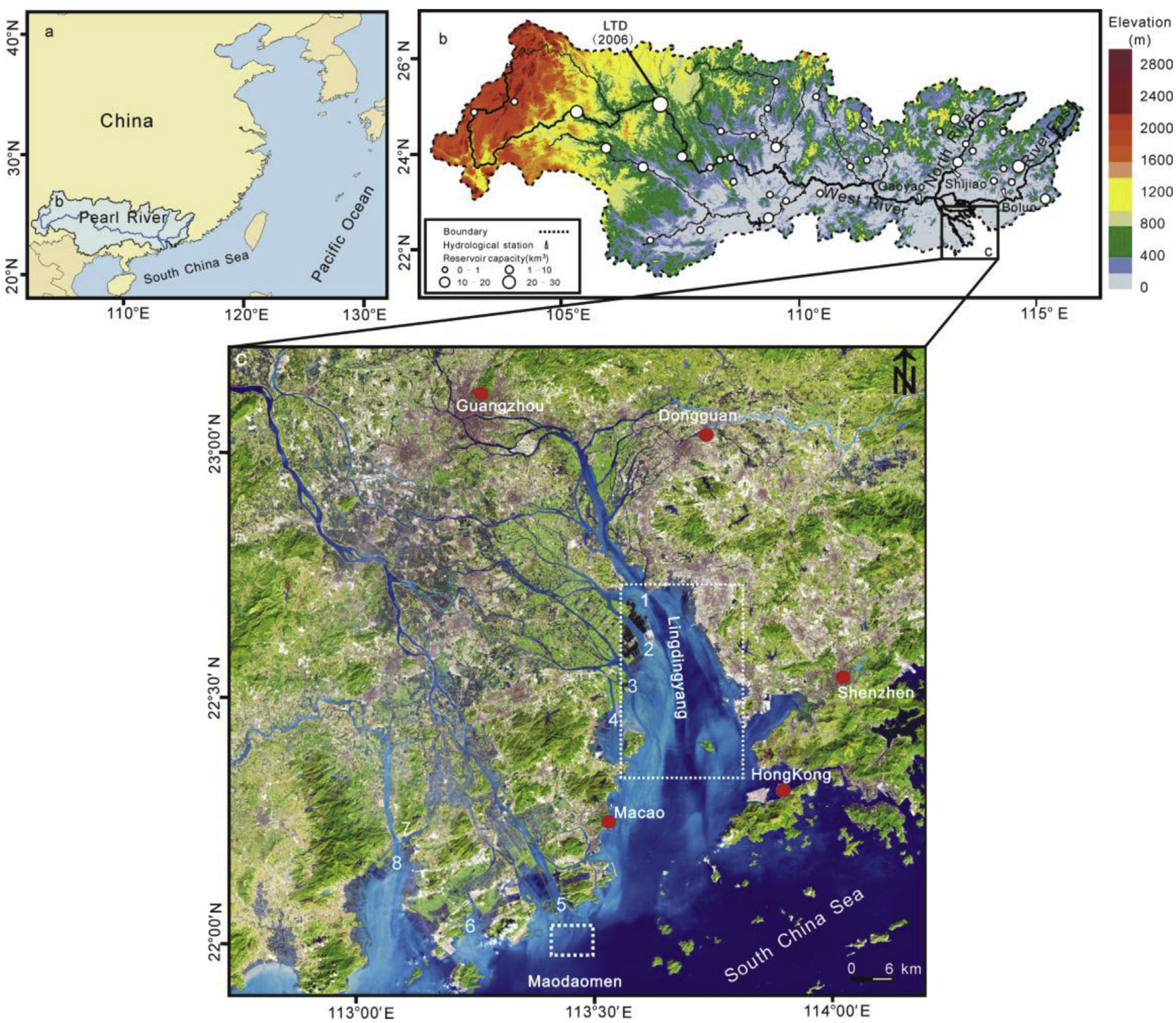

Fig. 1. (a) The Pearl River basin in South China. (b) The Pearl River chorographic map, including the Longtan Dam (LTD) and the Gaoyao, Shijiao, and Boluo gauging stations. (c) the Pearl River subaqueous delta, showing the Lingding Bay and Modaomen areas (dashed boxes). Numbers on the map represent eight "gates": 1, Humen; 2, Jiaomen; 3, Hongqili; 4, Hengmen; 5, Modaomen; 6, Jitimen; 7, Hutiaomen; 8, Yamen.