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Quantifying the anthropogenic and climatic impacts on water discharge and sediment load in the Pearl River (Zhujiang), China (1954–2009)

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SUMMARY

Anthropogenic and climate influences on temporal changes in water discharge and sediment load were examined in the Pearl River in China. Increasing, undulating, and decreasing phases were found in the years 1954–1983, 1984–1993, and 1994–2009, respectively. Between 1954 and 1983, water discharge and sediment load increased by 18% and 32%, respectively. During an undulating phase between 1984 and 1993, a marked up in water discharge and sediment load was followed by suddenly rebounded discharge. From 1994 to 2009, water and sediment decreased by 32% and 83%, respectively. These trends were generally in agreement with changes in precipitation, suggesting climatic influences on a decadal timescale, although the changes in sediment load were also related to human activities. Human impact on sediment load can also be identified as three major phases. In the 1950–1970s, deforestation in the catchment was balanced by dam construction, resulting in no significant net change in sediment load. In the 1980s, however, the influence of the deforestation outweighed dam construction, resulting in an increase in sediment load. Since the 1990s, dam construction and soil preservation have decreased sediment load quickly, and the monthly sediment loads were lower in post-dams period than in the pre-dams period. Since the closure of the Longtan and Baise Dams in 2006, the sediment load in the Pearl River has decreased by ~70% relative to the level of the 1950–1980s. Of this change, ~90% was caused by dam construction and ~10% was due to by climate change. In the coming decades, the sediment load in the Pearl River will probably continue to decrease as the new dams are built within the watershed.

1. Introduction

By discharging freshwater, as well as solid and dissolved matter, rivers provide the primary link between the land and sea, and largely determine the nature of estuarine and coastal environments (Milliman and Farnsworth, 2011). In recent decades, the water discharge and sediment load of the world's rivers have been increasingly altered by human activities and climate change (e.g., Vörösmarty et al., 2003; Nilsson et al., 2005; Walling, 2006; Meade and Moody, 2010). For example, since its construction in 2003, the Three Gorges Dam has retained ca. 150 Mt/yr of sediment, which has reduced the Yangtze River's sediment discharge to the sea by about one third (Yang et al., 2007b). In the Yellow River, water and sediment discharges have decreased to less than 20% of their pre-dam levels in 1950–1960s owing to a decrease in precipitation, water withdrawal, soil conservation, and dam construction (e.g., Xu, 2003; Wang et al., 2007; Chu et al., 2009). Conversely, some rivers have shown significant increases in water discharge due to an increase in precipitation or thawing of glaciers and permafrost under climate warming (Walling and Fang, 2003), or have shown significant increases in sediment discharge due to deforestation and mining activity (Walling, 2006). It has been predicted that current trends of glacier melt and potential climate change may cause the Ganges, Indus, Brahmaputra and other rivers to become seasonal rivers under the control of monsoon in the near future (Immerzeel et al., 2010). The causes of changes in water discharge and sediment load differ from river to river and vary through time. There is a need to add and update knowledge of these influences for specific rivers, particularly large rivers, to aid global as well as regional environmental management.

The Pearl River is one of the world's 25 largest rivers in terms of annual water discharge and sediment load (Eisma, 1998; Zhao et al., 2000). In China, the Pearl River ranks second (after the Yangtze River) in terms of water discharge and third (after the Yellow and Yangtze rivers) in terms of sediment load. Since the 1980s, China has entered an era of rapid economic growth, which has resulted in an upsurge in dam construction (e.g., Yang et al., 2005). Since the 1990s, soil preservation measures have been increasingly employed, and more projects have been conducted to reduce soil erosion in the drainage basins of these rivers.

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Numerous studies have examined recent changes in water discharge and sediment load, as well as the anthropogenic and climatic causes of these changes in the Yangtze River (e.g., Yang et al., 2002; Yang et al., 2006; Chen et al., 2005; Zhang et al., 2006; Xu et al., 2007; Hu et al., 2011) and in the Yellow River (e.g., Yang et al., 1998; Xu, 2003; Lu, 2004; Wang et al., 2007; Peng et al., 2010). In comparison, relatively less is known of the Pearl River. Although a few studies have examined temporal changes in water and sediment discharges and their causes (e.g., Dai et al., 2008; Zhang et al., 2008), they were based on annual datasets before 2005. In 2006, the Longtan Dam (LD), the largest in terms of reservoir storage capacity in the Pearl River basin, was closed across the upper main river. The impact of this dam closure on annual water discharge and sediment load is not known. In addition, the anthropogenic impact on seasonal distribution of the annual water discharge and sediment load in the Pearl River has not been examined in the previous studies (Dai et al., 2008; Zhang et al., 2008). More importantly, a greater understanding of anthropogenic and climatic influences on water discharge and sediment load in the Pearl River is needed. Specifically, separating anthropogenic impacts from climate influences on water and sediment discharge is necessary, particularly on a decadal scale, and quantitatively analyzing the contribution rate of climate influence and human activities.

In the present study, we focus on anthropogenic and climatic influences from seasonal to decadal changes on water discharge and sediment load in the Pearl River, using datasets on precipitation, water and sediment discharge from 1954 to 2009. Information of relevant human activities within the river catchment, such as dam construction, deforestation/afforestation, and soil preservation, are used to explain these changes. Our main objectives are to: (a) identify phases during which temporal trends and/or significant changes in annual water discharge and sediment load can be recognized, and to assess the relative contributions of human activities and climate change during these phases; (b) examine the impacts of recently constructed major dams on annual water discharge and sediment load, and; (c) examine the temporal changes in seasonal patterns of water discharge and sediment load, and their anthropogenic causes. In comparison with previous studies from the Pearl River, this article is new in aspects: (1) revealing the anthropogenic impact on annual water and sediment discharge since the construction of the LD (the largest dam) in 2006; (2) examining the anthropogenic impact on seasonal distribution of annual water and sediment discharge since 1954; and (3) separating anthropogenic impacts from climate influences on water and sediment discharge in difference periods since the 1950s. The methodology of this article is assumedly to be also useable for studies of other rivers in terms of quantifying anthropogenic and climatic influences on water and sediment discharge.

2. Regional setting

The Pearl River originates from the Yunnan Plateau, crossing hill country and even mountainous areas (Wu and Zhou, 2001), and extending 2400 km eastwards to the South China Sea. The river catchment is 450,000 km^2 in area, and experiences a subtropical and tropical monsoon climate straddling the Tropic of Cancer. The dry season extends from October to March, followed by a rainy season from April to September. The multi-year mean annual temperature within the catchment is 14–22° and the catchment-wide average precipitation is 1470 mm/yr (Dai et al., 2008). The Pearl River is an important freshwater source for large cities in the delta region, including Hong Kong, Macau, Guangzhou, and Zhuhai (Zhang et al., 2008). The compound river system comprises three major tributaries: the West River (WR), the North River (NR), and the East River (ER), as well as smaller rivers draining into the Pearl River delta (Fig. 1). The "Pearl River" water and sediment data in this study are defined as the sum of these three tributaries. As the largest

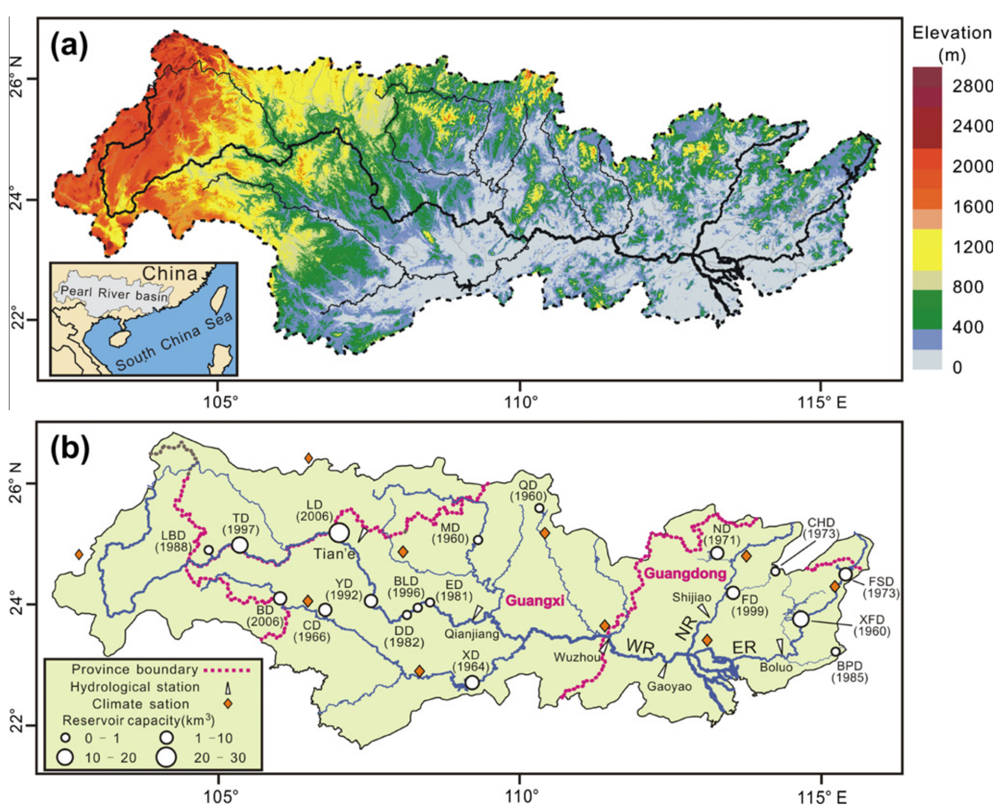

Fig. 1. Sketch map of the Pearl River basin, with locations of major gauging stations and reservoirs.