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Dramatic variations in water discharge and sediment load from Nanliu River (China) to the Beibu Gulf during 1960s–2013

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ABSTRACT

River discharge and sediment variation is vital to material transport between river and sea, which is the focus of research on river–sea interaction. This study takes Nanliu River, a typical independent river into the sea in Beibu Gulf as an example, analyzing river regimen and river bed morphology variations during 1960s–2013 in response to climate change and human activities based on wavelet analysis and Man–Kendall test methods. The results indicate that river discharge and sediment in Nanliu River have significant seasonal characters with over 70% and 90% river discharge and sediment occur in summer half year. Compared with 1960s–1980s, the time of peaked monthly river water discharge and Suspended Sediment Concentration (SSC) during 1990s–2000s had shifted from June/August to July and from April to July, respectively. Meanwhile, both river flow and SSC present 4–6 years and 11 years fluctuations. In the recent 50 years, annual river discharge and SSC present downward trends with discharge decreased by 13.9% and 22.28% respectively in upstream and downstream while SSC decreased by 33.72% and 49.05% in upstream and downstream, respectively. Rating-curve between flow and SSC turns from clockwise rotation with enveloped area during 1965–1989 to a relatively narrow appearance during 1990–2012 in upstream, but indicates relatedly mild variation in downstream. Evolution of river bed morphology is characterized by “erosion in flood season and deposition in dry season”. Moreover, the river flow entering the sea is dominated by precipitation while the sediment entering to the sea is controlled by middle and lower reaches supply. Human activities, including soil erosion, forest conservation and hydraulic engineering along the river, are responsible for the decrease of river water and sediment discharge entering the sea.

1. Introduction

Transport of water discharge and sediment load from river to sea plays a key role in earth surface processes, which could induce dramatic geomorphological evolution in the river, estuarine delta and continental environment (Syvitski et al., 2005; Zhang et al., 2008; Milliman and Farnsworth, 2011; Dai and Liu, 2013). Variations in river water discharge and sediment load have profound impacts on catchment and estuarine delta developments, population and economic growth since the industrial revolution in the 18th century (Syvitski et al., 2005, 2009). However, most large river basins and estuarine deltas around the world are under growing risks of water resources shortage, riverbed undercutting, coastal retreat and infrastructure loss due to impacts of intensive human activities on river water discharge and sediment load (Petit et al., 1996; Meybeck et al., 2003; Milliman and Farnsworth, 2011). Thereafter, there is increasing concerns on inter-annual variability and long-term changes in water discharge and sediment load from river to ocean worldwide (Walling and Fang, 2003; Oki and Kanae, 2006; Dai et al., 2008).

In the past decades, some studies indicated that water discharge and sediment load in most large rivers around the world had been seriously regulated by anthropogenic activities, such as irrigation, diversions and dam operations (Nilsson et al., 2005; Syvitski et al., 2005). In the Colorado River, the declining river discharge and sediment load induced delta recession with flow transformation from an estuarine setting to a hypersaline

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and inverse-estuarine environment (Kowalewski et al., 2000; Carriquiry et al., 2001; Mujumdar, 2013). Because of human interference, diversion of water and sediment load in the Mississippi River has caused substantial wetland loss in the delta (Rosen and Xu, 2013). It is reported that the Colorado River lost almost 100% of its sediment load since 1941, while the Danube lost 35% of its sediment load compared to the last century (Milliman and Farnsworth, 2011). The Yellow River (Huanghe) in China had world's largest sediment load in the nineteenth century, which had sharply decreased to less than 100 × 10^6 t/yr with water discharge regulation due to dam construction (Yang et al., 2004). Meanwhile, due to operation of the world's largest dam, Three Gorges Dam, sediment decreased by about 70% in the Changjiang with water discharge represented as 'no flood in the flood season, no drought in the drought season' (Dai et al., 2008, 2014; Yang et al., 2014; Mei et al., 2015a,b). Similar results due to dam regulation can be also found in the Red River (Dang et al., 2010; Gao et al., 2015), Ebro River (Batalla, 2003; Batalla et al., 2004), Mekong River (Lu and Siew, 2006), and Nile River (Aleem, 1972). Furtherly, researchers tried to detect all the possible impact factors on water discharge and sediment load variations. Yang et al. (2015) highlighted that 60%–70% of water discharge decline in Changjiang River over 1950–2012 can be attributed to decreased precipitation while TGD explained approximately 65% of sediment decline over the same period. Wang et al. (2015) found that landscape engineering, terracing and check dams construction were the primary factors resulted in sediment load reduction over Yellow River from 1970s to 1990s while large sale vegetation restoration projects reduced soil erosion to some extent since 1990s. Mei et al. (2015a,b) quantified the average contributions of precipitation variation, human activities in the Poyang Lake catchment and TGD regulation to the Poyang Lake recession as 39.1%, 4.6% and 56.3%, respectively. It is worth noting that impacts of human activities on river regime can be overruled by episodic extreme climates. Dai et al. (2012) quantified that the contribution of the extreme climate (drought) on discharge and SSD reduction over Yangtze River in 2006 were as high as 95% and 82% of the total, respectively. While there are extensive studies on changes in water discharge and sediment load in large rivers over American, Europe, and Asian, little concern has been given to the inter-annual and long-term river hydrological variations of small rivers, such as Beibu Gulf in China.

The Nanliu River, located in the northern part of Beibu Gulf, is the largest river in the southwest China (Fig. 1). The total area of the river basin is 9700 km^2 with a length of 287 km. The Nanliu River is controlled by the distinct monsoon climate with rainy reason from May to October and dry season from November to April. The mean annual rainfall in the Nanliu River catchment is between 1400 and 1760 mm with average temperatures ranging from 21.5 °C to

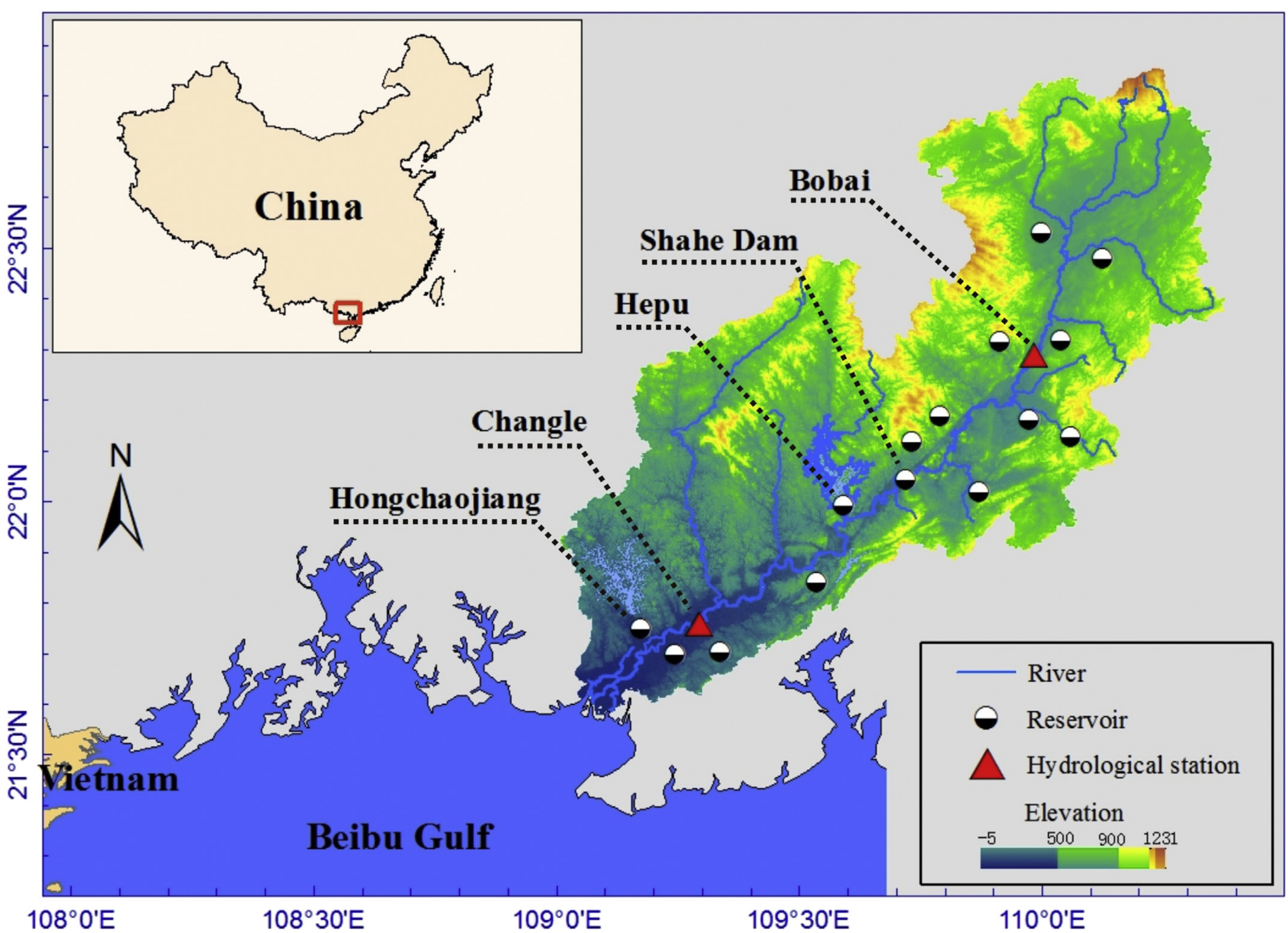

Fig. 1. Location of Nanliu River with hydrological stations and reservoirs.