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Using the wavelet transform to detect temporal variations in hydrological processes in the Pearl River, China

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ABSTRACT

In this study, we updated the hydrological data from the 1950s to 2012 and analysed the temporal variations in the hydrological series of the Pearl River using the wavelet transform method. Furthermore, we quantified the climatic and anthropogenic effects on the changes in the hydrological processes in the Pearl River. The results of the combined methods of the wavelet transform method and the Mann-Kendall (MK) trend test (i.e., wavelet trend test) reveal that the water discharge series exhibited a statistically insignificant changing trend since the 1950s; however, the sediment load series displayed a statistically significant decreasing trend. Comparisons of the results of the MK trend test and the wavelet trend test indicate that annual and inter-annual periodic oscillations affect the trend changes in the hydrological series. Statistical analysis and the double mass curve indicate that climatic change dominates changes in water discharge, such as the El Niño Southern Oscillation (ENSO), and human activities were mainly responsible for the phase changes in the sediment load. From 1973 to 1986, deforestation in the basin dominated the sediment variability and caused 83.2% of the increase in the sediment load compared to the reference period of 1957–1972. Even though water and soil conservation projects have been carried out since the early 1990s, the vegetation cover in the catchment area decreased by 6.5×10^4 km^2 from the late 1980s to the late 2000s, as detected by Landsat TM images, and water and soil conservation projects had little effect on the sediment reduction. Since the 1990s, dam construction has dominated sediment variability. Compared to the reference period, the sediment load due to dam construction decreased by 83.4 kg/s and 993.3 kg/s in the periods of 1987–1998 and 1998–2006, respectively, and the reduction in the sediment load increased to 1329.5 kg/s in the period of 2007–2012, indicating the intensifying impact of dam construction on the sediment reduction. The sediment sources in the Pearl River basin have changed, and scouring of the river channel has become a new sediment source in response to dam construction. The alteration of hydrological processes in the Pearl River will continue to occur in the future in the context of global climatic change, which is becoming increasingly important for river management in the Pearl River basin.

1. Introduction

As an important link between the land and ocean, river discharge terrestrial materials, such as freshwater, sediment and nutrients, into the ocean greatly affect the coastal environment. The hydrological regime of rivers has been affected by climate change and human activities in the context of global climate change (Milliman et al., 2008). In recent decades, human activities (such as dam construction, land use change, and soil and water conservation practices) have become a major driving force resulting in variations in the hydrological regime (Syvitski et al., 2005). There have been multiple reports of reduced sediment load from rivers due to human activities and climate change, which has resulted in catastrophic morphological changes in

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river deltas, such as the Nile (Fanos, 1995), Colorado (Carriquiry and Sanchez, 1999), Mississippi (Blum and Roberts, 2009), Ebro (Mikhailova, 2003), Yellow (Wang et al., 2007, 2010; Liu et al., 2012a,b) and Yangtze rivers (Yang et al., 2006; Liu et al., 2014b). Consequently, the changes in the hydrological processes in global rivers have attracted attention worldwide (e.g., Walling and Fang, 2003; Siakeu et al., 2004; Walling, 2006; Panda et al., 2011).

The Pearl River, which flows into the South China Sea (SCS), is China's second-largest river in terms of water discharge and the nation's third-largest river in terms of sediment load. The history of human activities in the Pearl River basin, which is recorded in Chinese documents, can be traced back 2000 years (Qin Ministry) (Luo et al., 2002). Since the implementation of China's open-door and reform policies in the late 1970s, human activities in the Pearl River basin have intensified (Liu et al., 2014a). These human activities have disturbed hydrological processes in the Pearl River, and the Pearl River has become one of the world's most regulated rivers (Nilsson et al., 2005). In recent years, several studies have identified temporal variations in the hydrological series of the Pearl River and have discussed the anthropogenic and climatic impacts on these changes (e.g., Dai et al., 2008; Zhang et al., 2008; Wu et al., 2012; Liu et al., 2014a). Many of these studies concentrated on periods before the mid-2000s and focused on the lower reaches of the Pearl River. For example, Zhang et al. (2008) reported that the sediment load series in the main Pearl River, the West River, and the North River showed insignificant decreasing trends between the 1950s and 2004. In the Pearl River basin, water and soil conservation projects have been implemented to stop soil erosion since the 1990s, and many large dams have been constructed in the Pearl River basin since the 2000s, such as the Longtan and Baise dams. However, relatively less quantitative data on the magnitude of dam construction and land use changes in the Pearl River basin have been available since the 2000s. Detection of hydrological data in long-term series is an extremely long-term exercise with continuously updated data and is of scientific and practical importance in water resource management (Kundzewicz, 2004; Zhang and Lu, 2009). Furthermore, although previous studies have investigated long-term trend changes in hydrological series (eg., Zhang et al., 2008; Wu et al., 2012), these studies have all neglected the effects of high-frequency components in the time series on the detection of trend changes, which might mask the true trend of the time series (Liu et al., 2014a). Wavelet transform is a powerful tool for multi-scale identification and can decompose and reconstruct a time series at different time scales (e.g., Brechet et al., 2007; Liu et al., 2011; Nourani and Andalib, 2015). In this study, we updated the hydrological data from the 1950s to 2012 and used the wavelet trend test to analyse temporal variations in the hydrological series of the Pearl River. Furthermore, we investigated the magnitude of dam construction and land use changes in the Pearl River basin to examine the anthropogenic impact on the sediment variability, especially since the 2000s. Therefore, our main objectives are: (1) to explore the long-term trend of hydrological series using the wavelet trend test method; (2) to examine anthropogenic and climatic effects on the hydrological processes in the Pearl River basin, especially for the period after the mid-2000s; and (3) to quantify the anthropogenic and climatic effects on the hydrological processes in different periods. Our study not only improves our understanding of the relationships between hydrological processes, climate change, and human activities, which provides scientific guidelines for water resource management, but also provides useful methods to examine temporal variations in hydrological series for future studies.

2. Study area

As China's second-largest river in terms of water discharge, the Pearl River originates on the Yunnan Plateau and flows eastward through hill country and mountains to the SCS. The Pearl River drains the Yunnan, Guizhou, Guangxi, Guangdong, Hunan, and Jiangxi Provinces of China and the northern part of Vietnam, with a mainstream length of 2400 km and a catchment of 450,000 km^2 (Fig. 1). The Pearl River is a compound river system and has three main tributaries, including the West River, the North River, and the East River. The West River is the largest tributary and stretches over a length of 2214 km, with a basin area of 351,500 km^2. The average annual water discharge and sediment load at the Gaoyao station were 2174.3 $\times$ 10^8 m^3/a and 64.5 $\times$ 10^6 t/a, representing 77% and 89% of the Pearl River's total water discharge and sediment load, respectively. The North River is 468 km long and drains an area of 38,400 km^2. The North River's water discharge and sediment load at the Shijiao station were 415.7 $\times$ 10^8 m^3/a and 5.5 $\times$ 10^6 t/a, respectively. The East River extends over 562 km and has a basin area of 25,300 km^2. The East River's lowest water discharge and sediment load at the Buoluo station were 233.4 $\times$ 10^8 m^3/a and 2.4 $\times$ 10^6 t/a, respectively. The Pearl River basin is a subtropical to tropical monsoon climate region that straddles the Tropic of Cancer. The annual mean precipitation ranges from 1200 mm/a to 2200 mm/a and gradually decreases from the eastern to the western side of the river basin.

3. Data and method

3.1. Data

In this study, the hydrological data consist of the consecutive annual water discharge and sediment load at gauging stations on the Pearl River from the 1950s to 2012. These gauging stations include the Xiaolongtan, Tian'e, Qianjiang, Dahuajiangkou, Liuzhou, Nanning, Wuzhou, and Gaoyao stations in the West River; the Shijiao station on the North River; and the Boluo station on the East River. The hydrological data were collected from the Sediment Bulletins of China Rivers compiled by the Ministry of Water Resources of China (MWRC) and provided by the Water Bureau of Guangdong Province. In addition, annual precipitation data for the Pearl River basin, covering 1957 to 2012, were collected from the Information Centre of the China Meteorological Administration. The quality of the hydrological and meteorological data was strictly controlled by the authorities before their release. In addition, Landsat satellite images were used to detect land use changes in the Pearl River basin, including Thematic Mapper (TM) data from 1987 to 1989, 1997 to 1999, and 2007 to 2009, which were provided by GSCloud at the Computer Network Information Centre of the Chinese Academy of Sciences (http://www.gscloud.cn/).

3.2. Methods

3.2.1. Wavelet trend test method

There are many methods used to detect long-term trends in time series, including non-parametric statistic tests (e.g., Zhang and Lu, 2009), bootstrap methods (e.g., Burn et al., 2010), and regression models (e.g., Liu et al., 2014a). However, high frequency components (i.e., annual and inter-annual time scales) of a time series can affect the identification of trends in the series (Partal and Küçük, 2006). In this study, the wavelet transform method was used to eliminate the impacts of high frequency components on the detection of trends. The wavelet transform method, which is a powerful tool for multi-scale identification, can decompose and reconstruct a time series at different scales. The low frequency