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Investigation of changes in the annual maximum flood in the Yellow River basin, China

Peng Bai, Xiaomang Liu*, Kang Liang, Changming Liu

Key Laboratory of Water Cycle and Related Land Surface Process, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 100101 Beijing, China

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ABSTRACT

Flooding in the Yellow River basin (YRB) has changed significantly over the last few decades because of climate change and human activities. Determining how the flooding changed and identifying the main driving factors of flood change is crucial to flood risk assessment and water resources planning. However, few studies have been conducted, especially in the whole YRB. To fill this gap, we investigate the spatial and temporal change of the annual maximum flood (AMAXF) in the YRB using observed data from 32 key hydrological stations (including 15 mainstream stations and 17 tributary stations). The Mann–Kendall test combined with trend index method is used to evaluate the trend in precipitation and AMAXF. The trend results indicate the AMAXF over the whole basin is dominated by decreasing trends: 72% of the stations exhibit significant decreasing trends (at 0.1 significance level) and 22% of the stations show no significant decreasing trends in the AMAXF. Both flood trends and abrupt change time exhibit obvious regional differences: the flood decreases is more pronounced in the midstream basins than in the headwater of the basin; the abrupt changes mainly occurred in the early 1990s for the upper reaches, and in the late 1990s for the middle reaches. To investigate the causes of flood change, the trends of precipitation extremes are analyzed in relation to the trends of peak floods. The analysis reveals that the decreasing precipitation extremes only results in the AMAXF reduction in the upstream basin. The decreasing AMAXF in the midstream and downstream of the basin are mainly attributable to the impacts of human activities (mainly including dam construction and soil conservation practices). In general, anthropogenic impacts play an increasingly important role in the AMAXF changes in the YRB. According to the possible changes in forcing factors, the AMAXF over the whole basin is expected to further decrease in the near future. However, there are still large flood risks in the tributary basins due to the collapse of check dams caused by extreme storms.

1. Introduction

Flooding is one of the most common hazards and causes property damage and deaths worldwide. The occurrence and variability of flooding is a complex and dynamic process and is affected by various factors, including extreme precipitation, land use practices, dam construction, vegetation properties and soil type. In recent decades, precipitation intensity, frequency and type has changed along with climate warming. Human activities have substantially altered the relationship between rainfall and runoff. The combination of climate change and human activities has caused significant changes in flood trends in many regions around the world (Milly et al., 2008; Zhang et al., 2011b; Ishak et al., 2013). Changes in flood trends create challenges when assessing and managing flood risk. Understanding the spatial and temporal variability of flood trends is helpful for coping with the challenges.

Many studies have investigated the spatial and temporal variability of flood trends worldwide. Petrow and Merz (2009) analyzed the flood trends at 145 stations in Germany and found that flood magnitude increased at many stations. Cunderlik and Ouarda (2009) identified decreasing trends for the magnitudes of snowmelt flood in Canada over the past three decades. McCabe and Wolock (2002) revealed that few gauges had significant trends in flood magnitude in the United States. Kundzewicz et al. (2005) and Svensson et al. (2005) detected the trends in flood magnitudes on a global scale and concluded that flood magnitudes did not present

* Corresponding author.
E-mail address: liaoxfxm@163.com (X. Liu).

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significant trends globally. In these studies, the annual maximum flood (AMAXF) was used as the indictor for flood trend analyses (Adamowski and Bocci, 2001; Franks, 2002; Petrow and Merz, 2009; Bormann et al., 2011). The results of these studies showed that the changes of the AMAXF have regional differences.

The Yellow River is the second-longest river in China and the sixth-longest river in the world. It covers an area of approximately 742,443 km^2 and supports approximately 30% of China's population (McVicar et al., 2007; Xu et al., 2009a). The Yellow River is characterized by a high sediment load, accounting for approximately 6% of the global sediment discharge to the ocean (Milliman and Meade, 1983; Saito et al., 2001). Historically, the Yellow River was the one of the most flood-prone rivers in China. Frequent flood hazards in the Yellow River basin (YRB) have resulted in a large amount of deaths and property damage (Wang et al., 2007a). Over the last 50 years, the YRB has undergone unprecedented changes in land use. Numerous dams and reservoirs have been constructed to control floods and generate power. In addition, a series of soil conservation practices (SCP) have been implemented to reduce soil erosion (Huang and Zhang, 2004; Wang et al., 2006; Yang et al., 2008). The annual precipitation has also changed significantly in many sub-basins of the YRB (Xu et al., 2009a; Dong et al., 2011; Wang et al., 2012). As a result, significant changes in streamflow were observed in the YRB (Wang et al., 2006). Previous studies mainly focused on the changes in annual streamflow (Yang et al., 1998; Fu et al., 2004; Liu et al., 2008; Tang et al., 2008; Yang et al., 2009), while limited attention has been paid to flood trends. Studies about flood trends in the YRB focused on a single or a few gauges (Kang et al., 2001; Xu et al., 2009a; Yao et al., 2011). In this study, we investigate the spatial and temporal changes of the AMAXF for the whole YRB and analyze the reasons for the changes in floods.

2. Data and methods

2.1. Data

The runoff records at 32 key hydrological stations in the YRB were provided by the Yellow River Hydrological Bureau. Each station has at least 50 years of hydrological data. 22 of 32 stations are located in the middle reaches of the Yellow River, historically flood-prone (Xu et al., 2009a). Detailed information about the stations is shown in Table 1. The daily precipitation records from 79 national meteorological stations in the YRB were collected from the China Meteorological Data Sharing Service System. The datasets were checked for completeness and consistency before trend analyses. The spatial distributions of the hydrological and meteorological stations are shown in Fig. 1.

2.2. Trend test method

In this study, the non-parametric Mann–Kendall (M–K) test (Mann, 1945; Kendall, 1975) combined with the trend index (TI) method (Kundzewicz et al., 2005; Svensson et al., 2005) are used for trend analyses. The M–K test has been commonly used for trend detection because of its robustness for non-normally distributed data (Yue et al., 2002; Hamed, 2008). However, using the M–K test, it is hard to reflect the trend magnitude of a time series. Therefore, the results of the M–K test are further stated using the TI method to obtain the trend magnitude of a time series (Kundzewicz et al., 2005), which is defined as:

$$TI = \begin{cases} 100 - p & \text{for postitive trends} \\ -(100 - p) & \text{for negative trends} \end{cases} \quad (1)$$

where p is the significance level calculated by the M–K test. The value of TI is always between −100% and 100%. A positive value of TI indicates an upward trend, and a negative value indicates a downward trend. The larger the absolute value of TI, the stronger the trend magnitude (Kundzewicz et al., 2005). Compared to traditional methods, such as Sen's slope (Sen, 1968; Hirsch et al., 1982) and linear slope, the TI is not affected by the value of a time series and can better describe the relative change of a time series. Thus, it is widely used in meteorology and hydrology (Svensson et al., 2005; Hirsch and Ryberg, 2012).

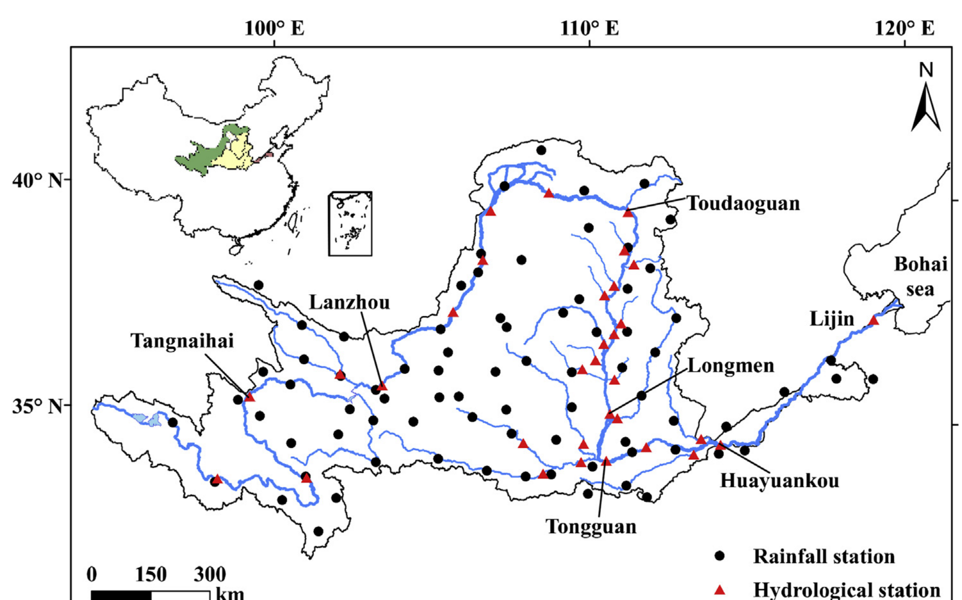

Fig. 1. Location of the study area. The upper reach of the river is the region above Toudaoguai; the middle reach is the region from Toudaoguai to Huayuankou; the river reach below the Huayuankou is the lower reach of the Yellow River.