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Contributions of climate change and human activities to runoff change in seven typical catchments across China

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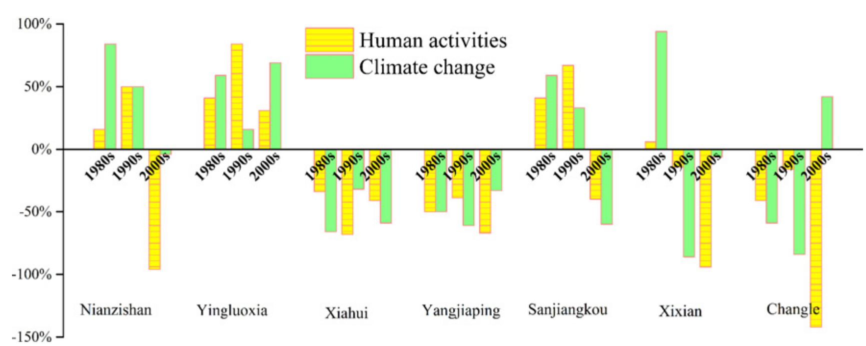
HIGHLIGHTS

- Changes in climate and runoff were investigated in contrasting catchments in China.
- Runoff change was attributed to climate change and human activities.
- Long-term hydrological observation data and VIC model were used.
- Human activities contributed more to runoff change after 2000.
- The results are supported by long-term climate, land use and water withdrawal data.

GRAPHICAL ABSTRACT



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ABSTRACT

Climate change and human activities are two major factors affecting water resource change. It is important to understand the roles of the major factors in affecting runoff change in different basins for watershed management. Here, we investigated the trends in climate and runoff in seven typical catchments in seven basins across China from 1961 to 2014. Then we attributed the runoff change to climate change and human activities in each catchment and in three time periods (1980s, 1990s and 2000s), using the VIC model and long-term runoff observation data. During 1961–2014, temperature increased significantly, while the trends in precipitation were insignificant in most of the catchments and inconsistent among the catchments. The runoff in most of the catchments showed a decreasing trend except the Yingluoxia catchment in the northwestern China. The contributions of climate change and human activities to runoff change varied in different catchments and time periods. In the 1980s, climate change contributed more to runoff change than human activities, which was 84%, 59%, −66%, −50%, 59%, 94%, and −59% in the Nianzishan, Yingluoxia, Xiahui, Yangjiaping, Sanjiangkou, Xixian, and Changle catchment, respectively. After that, human activities had played a more essential role in runoff change. In the 1990s and 2000s, human activities contributed more to runoff change than in the 1980s. The contribution by human activities accounted for 84%, −68%, and 67% in the Yingluoxia, Xiahui, and Sanjiangkou catchment, respectively, in the 1990s; and −96%, −67%, −94%, and −142% in the Nianzishan, Yangjiaping, Xixian, and Changle catchment, respectively, in the 2000s. It is also noted that after 2000 human activities caused decrease in runoff in all catchments except the Yingluoxia. Our findings highlight that the effects of human activities, such as increase in water withdrawal, land use/cover change, operation of dams and reservoirs, should be well managed.

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1. Introduction

Water resource plays an important role in ecology, society, and economics because it supports both human life and environment. It will lead to natural disasters and cause huge losses both in life and property if not well-managed. During recent decades, about 31% of 145 major rivers in the world have been shown to have statistically significant upward (9%) or downward (22%) trends in annual runoff because of climate change as well as increasing human activities (Walling and Fang, 2003). Runoff in many major rivers in China showed downward trends, especially in the Hai River basin and the Yellow River basin (Wang et al., 2010; Bao et al., 2012; Feng et al., 2016). Many areas have experienced frequent floods or droughts in recent years (Kunkel et al., 1999; Lindner et al., 2010; Zhang et al., 2015). For instance, the drought happened in the lower reach of the Yellow River basin and floods happened in the Yangtze River basin and Songhua River basin caused huge damage in 1997 and 1998 respectively (Xu et al., 2010). Understanding the reasons for runoff variation under a changing environment is of great importance to understand the hydrological change mechanism, and to relieve droughts and floods in the future.

Climate change and human activities are two important factors which influence the variation of runoff. Climate variability affects runoff mainly through influencing precipitation and potential evapotranspiration (Chien et al., 2013; Zhao et al., 2015). Extensive studies have shown that global warming will intensify global hydrological cycles (Huntington, 2006; Milliman et al., 2008). Both observed data and climate model studies have projected a significant increase in heavy rain events in a warming climate (Wu and Lau, 2016). Besides, with the increase of population and urbanization (Kuang et al., 2016), human activities, such as land use/cover change, operation of dams and reservoirs, soil and water conservation projects, and direct water extraction from surface water and groundwater, can have major impacts on water resources.

Quantitatively disentangling the impacts of climate change and human activities on runoff changes is of great significance for regional water resources planning and management (Fu et al., 2007). Numerous studies have tried to investigate the influence of climate change and human activities on runoff processes in different catchments using both elasticity-based methods and hydrological model methods (Wang et al., 2010; Bao et al., 2012; Huang et al., 2015; Chang et al., 2016). For example, Ma et al. (2010) used a distributed hydrological model (GBHM) and a climate elasticity model to analyze the impact of climate change and human activities on runoff decrease in the Miyun Reservoir catchment. Yong et al. (2013) used the Variable Infiltration Capacity (VIC) model to estimate the impacts of human activities and climate change on runoff in a typical semiarid basin of North China over the past 50 years. Ahn and Merwade (2014) quantified the relative impacts of climate and human activities on runoff using four methods including linear regression, hydrologic simulation, annual balance, and Budyko analysis in four U.S. states. All of them showed that human activities had a larger impact on runoff at most of the investigated stations than that of climate change. Wu et al. (2017) estimated the relative contributions of climate change and human activities to runoff change in the Loess Plateau in China using climate elasticity methods based on eight separate Budyko-based hypotheses. The dynamic hydrological modeling methods consider the impact of the inter-annual and intra-annual precipitation variability, but the elasticity-based methods do not (Chang et al., 2016).

Previous studies have shown that the impacts of climate change and human activities were different in different sub-catchments in China. For example, Ye et al. (2013) showed the changes in runoff over 1970–2007 were mainly influenced by climate change in the Poyang Lake catchment with reference to 1960s. Zhao et al. (2014) showed that in the middle reaches of the Yellow River basin, climate variability had a larger effect on runoff reduction in some catchments, while human activities attributed more to the runoff variation at other catchments. In addition, as for a certain catchment, the contribution of the factors to runoff change varied in different time periods. For instance, Chang et al. (2016) showed that the maximum contribution of human activities happened in 1981–1990 reaching 99%, while the contribution of human activities was 59.6% during 1991–2000. Luo et al. (2016) showed that in the Heihe River basin in the northwestern China, climate change contributed to the hydrological change by 21.3%, 57.3%, and 57.7%, respectively, in the 1980s, 1990s and 2000s.

Nevertheless, previous studies mainly focused on one catchment alone or several catchments located in the same basin (Wang et al., 2010; Bao et al., 2012; Chang et al., 2015; Huang et al., 2015). The objectives of this study are to 1) Compare the climate and hydrological changes in typical catchments located in contrasting basins across China over a long time period of 1961–2014. 2) Quantify the contributions of human activities and climate change to hydrological changes for each catchment and in the periods of 1980–1989, 1990–1999, and after 2000, based on the hydrological model VIC, together with the long-term hydrological observations, as well as the long-term and high resolution land use/cover data. The study is expected to accelerate the understanding of runoff variations for typical catchments in contrasting basins across China, providing a reference to water resources management across China.

2. Description of the study domain and datasets

2.1. Study domain

China has a wide variety of terrain. The terrain gradually ascends from east to west. The temperature increases from north to south, and precipitation decreases gradually from the southeastern to the northwestern inland area (Xie et al., 2007). There are ten main basins in China, including the Songhua River basin (SHR), Liao River basin (LR), Northwest River basins (NWR), Hai River basin (HR), Yellow River basin (YR), Yangtze River basin (YTR), Huai River basin (HuR), Southeast River basins (SER), Southwest River basins (SWR), and Pearl River basin (PR) (Liu et al., 2017). In this study, seven typical catchments located in different basins were investigated (Table 1). Each catchment has a completely different characteristic from others. The location of each basin and catchment, as well as the land use/cover of each catchment in 2000, are shown in Fig. 1. The total population in China was 560 million in the 1950s and has increased to > 1360 million in 2015. Most catchments in China have been experiencing intensive human activities with increasing population and expanding water withdrawal (Xu et al., 2010).

2.2. Data

The meteorological data, including daily time series of precipitation, maximum temperature, minimum temperature, and wind speed from 1961 to 2014, were obtained from 839 meteorological stations of China Meteorological Administration (CMA). The meteorological data were interpolated to each 0.5° × 0.5° grid through linear interpolation weighted by the inverse squared distances between the meteorological stations and the center of each grid cells (Xie et al., 2007).

Table 1
Information on the seven catchments (hydrological stations) investigated in this study.

Catchment	Basin	Longitude	Latitude	Area (km^2)
Nianzishan	SHR	122°53′	47°29′	13,567
Yingluoxia	NWR	100°11′	38°48′	10,009
Xiahui	HR	117°10′	40°37′	5340
Yangjiaping	YR	107°44′	35°20′	14,124
Sanjiangkou	YTR	111°18′	29°35′	15,242
Xixian	HuR	114°44′	32°20′	10,190
Changle	PR	109°25′	21°50′	6645