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Impacts of recent climate change on the hydrology in the source region of the Yellow River basin

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ABSTRACT

Study region: The source region of the Yellow River (SRYE) in the northeastern Tibetan Plateau.
Study focus: The spatial-temporal changes of hydrological and meteorological variables and their linkages over the SRYE were investigated for 1961–2013. Meanwhile, we quantified the impacts of precipitation and evapotranspiration on hydrological changes through climate elasticity by applying a land surface hydrological model. Furthermore, the impacts of warming climate on the seasonal snow cover and spring flow over the SRYE were examined.
New hydrological insights for the region: Decreased precipitation and lightly increased evapotranspiration both contributed to reduced runoff in the 1990s, with the decreased precipitation playing a more important role (70%) than the increased evapotranspiration (30%). In the 2000s, precipitation contributed 3% to the runoff reduction, while the increased evapotranspiration accounted for 97%. Along with rapid warming, evapotranspiration is playing an increasingly important role in affecting runoff changes in the SRYE. During 2001–2012, snow cover in May decreased over the region. Spring peak flow mainly caused by snowmelt occurred earlier for about 15 days at the Jimai hydrological station due to an earlier snow melt associated with the climate warming in the past 3 decades.

1. Introduction

The Yellow River originates from the Tibetan Plateau (TP), and flows across eight provinces from west to east across China (Fig. 1). It is 5464 km long with a basin area of 752,443 km^2, the sixth longest river in the world and the second in China (Fu et al., 2004). The Yellow River plays an important role not only in the water supply for 107 million people (Wang et al., 2006) but also in the agricultural production in China because 13% of the countries' total cultivated area depends on the water resources from this basin (Cai and Rosegrant, 2004). The drainage area upstream of the Tangnaihai (TNH) hydrological station (Fig. 1), located in the northeast of the TP, is generally considered as the source region of the Yellow River (SRYE) basin. The SRYE is the "water tower" of the Yellow River basin since it contributes about 35% of total annual runoff from

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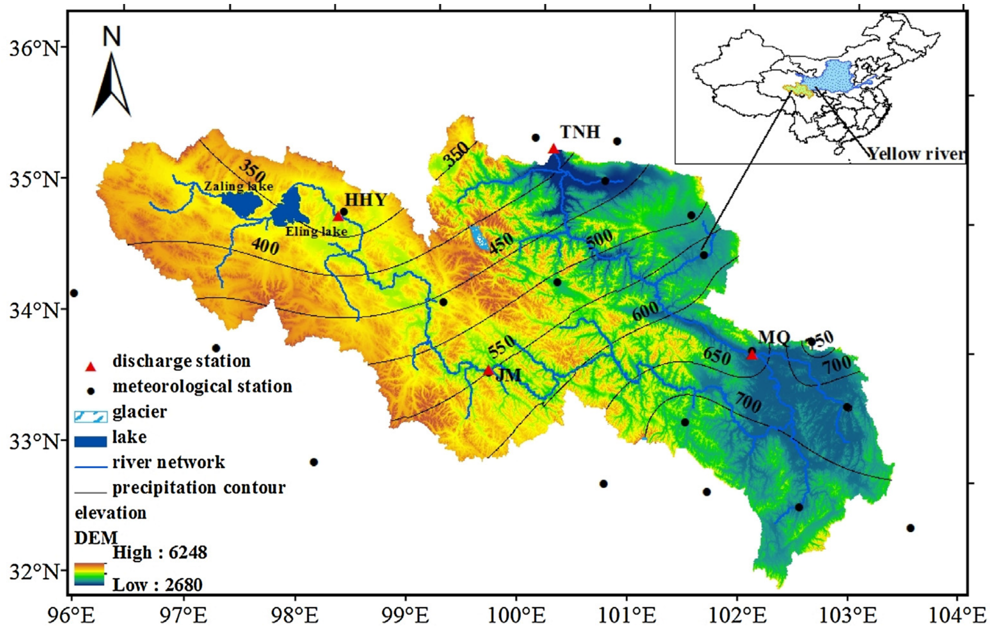

Fig. 1. Location and topography of the source region of the Yellow river (SRYE). Red triangles denote discharge stations. From up to downstream, these are Huangheyan (HHY), Jimai (JM), Maqu (MQ) and Tangnaihai (TNH) stations, respectively. Black points represent meteorological stations. Mean annual precipitation contours (mm) are also indicated. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

about 16% of the basin area (Lan et al., 2010b). Therefore, it is of vital importance in meeting downstream water resources requirements (Zheng et al., 2007).

Similar to other regions, climate change is taking place in the Yellow River basin (Wang et al., 2014; Yang et al., 2004; Zhao et al., 2007). Studies of long term climatic records suggested a noticeable warming trend of 0.31–0.35 °C/10yr over the SRYE in the past 5 decades (Cuo et al., 2013; Hu et al., 2011; Lan et al., 2010b). No significant long-term trends have been observed in the basin-wide precipitation (Hu et al., 2012), although large decadal and spatial variations in precipitation exist in this region (Lan et al., 2010b; Zhou and Huang, 2012). Along with the changing climate, mean annual flow at the TNH has decreased in the past 50 years (Cuo et al., 2013; Hu et al., 2011; Lan et al., 2010b; Li et al., 2012). It has been noted that the flow in the 1990s suffered a serious decrease in this region (Chen et al., 2007), accompanied with an increase in the number of zero-flow days at the most upstream gauging site—the Huangheyan (HHY, Fig. 1) station (Zhang et al., 2004a). Attempts have been made to understand the causes of the changes in streamflow over the SRYE (Cuo et al., 2013; Hu et al., 2011; Lan et al., 2010a; Zhao et al., 2009; Zhou and Huang, 2012). It is generally recognized that the hydrological changes are mostly attributed to climate change and climate variability. Studies show that changes in seasonal and spatial distribution of precipitation played an important role in regional hydrology (Hu et al., 2011; Lan et al., 2010a; Zhou and Huang, 2012). However, it is still not clear to what extent precipitation and the climate warming affected the streamflow regimes over the region.

Through statistical analysis, Hu et al. (2011) suggested that decreased precipitation in the wet season and rising temperature over the period 1959–2008 may be responsible for the general flow reduction over the SRYE. Sato et al. (2008) developed a new hydrological model to investigate the water balance of the SRYE basin during 1960–2000. Although an increase in evapotranspiration was detected, they concluded that the decrease in precipitation was the main factor for the decrease in river discharge. Zhou and Huang (2012), using a point scale land surface model and surface meteorological observations for 1960–2006, investigated the influences of climatic changes on the water budget over the SRYE. Their results suggested that the changes in spatial precipitation pattern was an important factor for streamflow changes. In addition, increase in evapotranspiration due to rising temperature was another cause for runoff decrease.

Although hydrologic response to climate changes over the SRYE has been intensely discussed, most of the investigations focused on statistical analyses of the long-term trends in precipitation, temperature and runoff (Hu et al., 2012, 2011; Zhao et al., 2007; Zheng et al., 2007). Few studies quantitatively examined physical mechanisms and processes of hydrological changes and variations (Cuo et al., 2013; Zheng et al., 2009). Furthermore, most studies focused on change detections at individual stations in a basin or region (Hu et al., 2012; Wang et al., 2014; Zhou and Huang, 2012), rather than spatial analyses over the basins. The causes for discharge changes over the SRYE seem controversial. Thus, a comprehensive study to quantify temperature and precipitation changes and their impacts on streamflow changes over time and space is necessary.

Rising temperatures may lead to earlier snow melt and runoff over the cold regions (Barnett et al., 2005; Stewart, 2009). Snow melt contributes 40% of spring runoff (Lan et al., 1999) and 5–13% of annual runoff (Cuo et al., 2013) in the SRYE. It