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Statistical analysis of stream discharge in response to climate change for Urumqi River catchment, Tianshan Mountains, central Asia

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ABSTRACT

Understanding the impact of climate change on water resources is essential to sustainable development. Urumqi River, a medium-size headwater catchment in the Tianshan mountains, was chosen to evaluate the impact of climate change on its discharges, where impacts of human activities on water are negligible and the influence of glacier melt is minor as far as the mountainous outlet is concerned. Analysis of the time series of temperature, precipitation and river discharge of the hydrological station at the mountainous outlet from 1959 to 2006 was carried out using different statistical methods, including linear regression, Mann–Kendall test and wavelet analysis. Although both temperature and precipitation show a significant upward trend with a gradient of 0.02 °C/y and 2.08 mm/y, respectively, there is no significant rising trend in the stream discharge. The reasons are attributed to the hysteresis and buffering effects of groundwater in conveying the change from precipitation to stream discharge. Common short periods of less than 8 years exist in the three time series, which is a common trend in NW China. Precipitation has stronger influence on stream discharge than air temperature throughout the 48 years of instrumental records in the Urumqi River catchment.

1. Introduction

Climate warming during the last century has been recognized as a fact supported by both theoretical analysis and instrumental data (IPCC, 2007; Gregory et al., 2012). Changes in air temperature and precipitation have significant impacts on hydrological processes and water resources. Previous studies have mostly focused on the impact of climate change on river discharge to which glacier-melt water contributes a substantial part (Lafreniere and Sharp, 2003; Labat et al., 2004; Li et al., 2010) while few have done for non-glacier dominated catchments. Furthermore, human activities exacerbate the complexity of stream behavior through altering the natural recharge, flow and discharge. It is difficult to differentiate the individual impact of climate change from that of human factors on water resources (Jones, 2011; Tao et al., 2011). In order to avoid such ambiguity, an alternative method is to study river catchments in regions without human disturbance so as to focus on the single impact of climate change on water resources (Kong and Pang, 2011). Headwaters in alpine regions are one of the most appropriate research subjects for studies in this regard. This is because (1) alpine headwaters are almost free from the effects caused by human activities and (2) they are constituted of glacier-melt water, which is quite sensitive to temperature change. A wide variety of recent studies addressed this issue and examined the significance of climate change on water resources (Chen et al., 2006, 2008; Immerzeel et al., 2010; Li et al., 2011, 2010; Xu et al., 2011a,b).

Urumqi River, located in an alpine region in Northwest China, is a good example of this kind. Previous studies found that at Glacier No.1, which is the source of Urumqi River, discharge increased greatly due to the rise of temperature and precipitation from 1959 to 2006 (Li et al., 2007, 2010). Discharge of Urumqi River at Yingxiongqiao hydro-meteorological station, which is its mountainous outlet, is mainly composed of groundwater, with less than 9% glacier-melt water (Kong and Pang, 2012). Thus, the change of mountainous discharge and its response to climate change must be different from that at the source (Glacier No.1). The mechanism of Urumqi River's response to climate change could be comparable to other rivers that are not significantly affected by glacier-melt.

This paper examines the trend of change of climate and discharge of Urumqi River catchment and the interrelationship between them. Several statistical methods including linear regression, Mann–Kendall test, and wavelet analysis are used to

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delineate the changes, aiming at: 1) to detect any climate change effects in the time series of temperature, precipitation and discharge; 2) to identify possible co-variability of the three parameters; and 3) to assess impact of climate change on stream discharges at different time scales.

2. Study area

The Urumqi River catchment is located in Eastern Tianshan, Xinjiang Uygur Autonomous Region of China (Fig. 1). It is the main water source for the city of Urumqi. The shortage of water resources is one of the key restricting factors of the development of the city. For better water resources management in the future, it is vital to assess the impact of climate change on the Urumqi River and ascertain the mechanism of discharge change.

Xinjiang represents one sixth of China's land area. There are three major mountains that "border" the region, which are Altay Mts. in the north, Tianshan Mts. in the middle and Kunlun Mts. in the south. Between these mountains, there are two large basins, Junggar Basin and Tarim Basin.

There are five major air masses that influence the meteorological and pluviometric regime of Southeast Asia, and westerlies dominate Xinjiang (Pang et al., 2011; Kong et al., 2013). Xinjiang has a typical continental arid climate, where the annual average ambient temperature is 9–12 °C. In the mountainous region, precipitation is about 200–800 mm, and in the basin 10–200 mm. Throughout Xinjiang, the potential evaporation of open surface water bodies is 800–1200 mm in alpine regions and 1600–2200 mm in basins. Bare soil evaporation is 100–300 mm in the mountain regions, 250–400 mm in the agricultural development zone and 10–100 mm in deserts (Dong and Deng, 2005).

Urumqi River originates from Glacier No.1, flanking Tianger Peak II, the highest peak in the southeastern Tianshan Mountains with an elevation of 4484 m a.s.l. The total length of Urumqi River is 214.3 km with a drainage area of 4684 km^2, and the length in the mountainous area above the outlet (Yingxiongqiao station) is 62.6 km with a drainage area of 924 km^2 and an average altitude of 3483 m a.s.l. (Fig. 1).

3. Data and methods

3.1. Data

Two meteorological stations, Daxigou and Houxia, and five hydro-meteorological stations, Glacier No.1, Dry Circle, Total Control, Yuejinqiao, and Yingxiongqiao Stations are located along the main course of Urumqi River (see Fig. 1). The elevations of these stations range from 1900 m a.s.l. at Yingxiongqiao station to 3800 m a.s.l. at Dry circle station.

Stream flow and meteorological parameters were measured at the seven hydro-meteorological stations. Daily temperature and precipitation amount data at each meteorological station are monitored and internally published in annual reports of the Tianshan Glaciological Station (1980–2006), usually with a delay of a few years after data collection.

It is necessary to carry out data quality control before performing statistical analysis in order to eliminate the influence of erroneous outliers. The computer program RClimDex (available from http://cccma.seos.uvic.ca/ETCCDI/software.shtml), developed

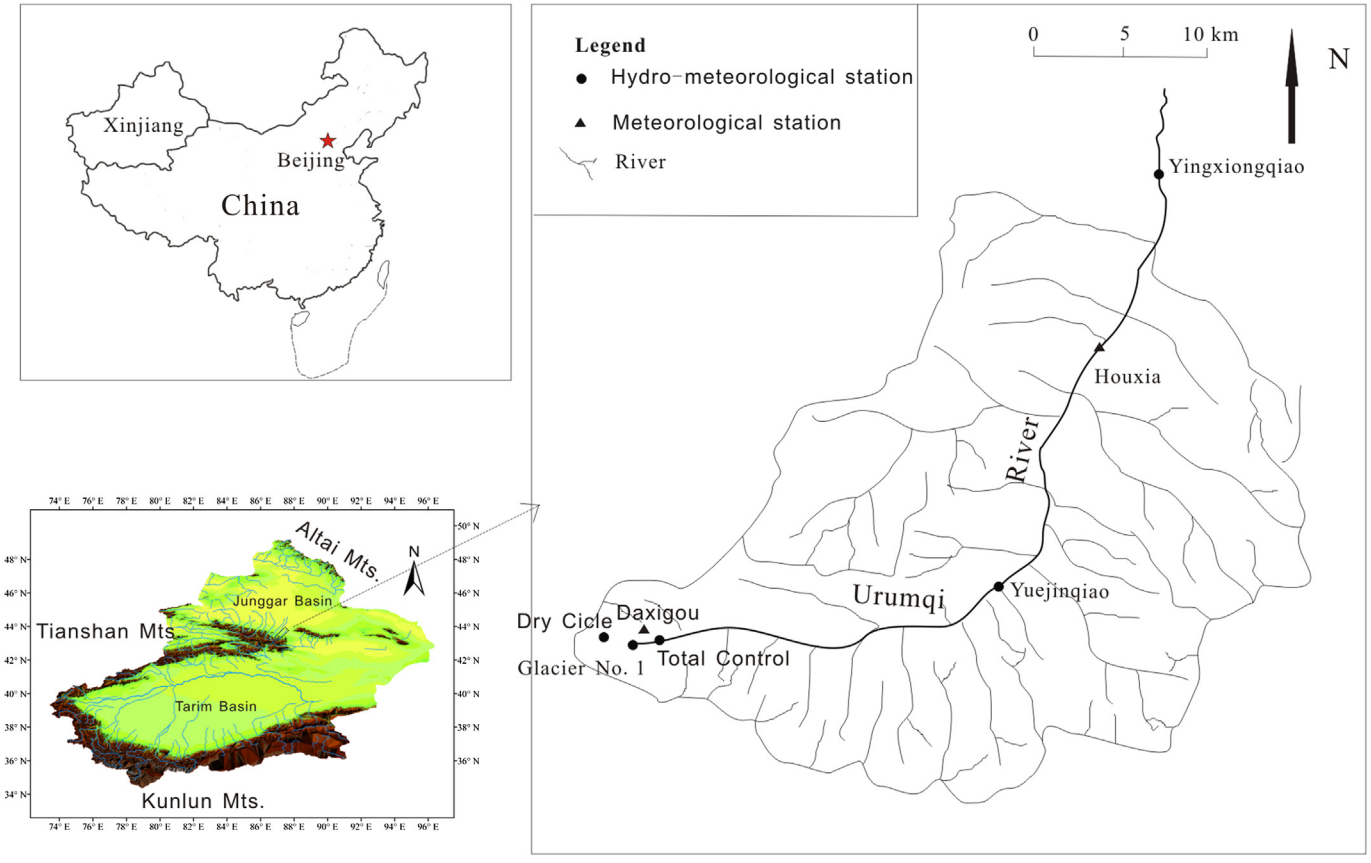

Fig. 1. Sketch map showing the location of Urumqi River catchment as well as the meteorological and hydro-meteorological stations along the river.