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Spatial and temporal patterns of climate variations in the Kaidu River Basin of Xinjiang, Northwest China

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ABSTRACT

This paper investigated the spatial and temporal climate variations of the Kaidu River Basin in Xinjiang from 1961 to 2009. The annual and monthly temperature and precipitation data were collected from six meteorological stations in the river basin and analyzed by a Mann–Kendall test and linear trend estimation. The results showed that: (1) temperature increased significantly in oasis areas over the past 49 years, while it does not display an increasing trend in mountainous areas over the same period; (2) precipitation exhibited a steep increasing trend in mountainous areas over the past 49 years, while the increasing trend in oasis areas is not significant; (3) with regard to seasonal variation, temperatures increased the most in spring and summer in the northern part of the mountainous area (Baluntai) and in the southern part of the oasis area (Yanqi County). The mean annual precipitation and the mean summer precipitation showed the largest increases in the northwestern part of the mountainous area (Bayinbuluke) and the largest decreases in the northern part of the oasis area (Hejing and Heshuo Counties). Temperature and precipitation increased from 2006 to 2009, showing a warming and wetting trend.

1. Introduction

Global climate is undeniably warming, which has become the most severe environmental problem that humanity has ever faced and the most complicated challenge for humans in the 21st century. Global warming has thus received widespread attention from both governments and the general public. According to the IPCC Fourth Assessment Report on climate change, in the past century the global temperature has increased by 0.74 C° (IPCC, 2007). In China, the average annual temperature increased by 0.5–0.8 C° in the past century and by 1.1 °C since the 1980s, which is much higher than that at global level (Ma and Liu, 2009). If warming is associated with drying due to increased evaporation, as stated in the IPCC report, Xinjiang could be seriously threatened. However, the warming seems to be accompanied by increasing precipitation in Xinjiang, especially since the 1980s. It is commonly agreed that the overall climate profile of Xinjiang is changing from a warm-dry mode to a warmer and humid mode (Chen et al., 2007, 2009; Jiang et al., 2008; C.C. Xu et al., 2010; Z.X. Xu et al., 2010). Can the increasing precipitation compensate for the loss of water resulting from the warming? This issue is especially important in the Kaidu River Basin, because it is the driest area of the hyper-arid Xinjiang, and the water resource is so critical both to ecological security and to socioeconomic development in the basin.

Kaidu River Basin is located in the hinterland of Xinjiang at the southern slope of the Tianshan Mountains. As a part of the Tarim River Basin and a typical arid region in China, its climate is sensitive to global climate change. Its ecological environment is particularly sensitive to changes in precipitation and temperature, as indicated by a large number of studies on the effects of precipitation and temperature changes on vegetation (Zhang et al., 2003; Chen et al., 2005; Ma et al., 2007), on runoff and glaciers (Ye et al., 1999; Jiang et al., 2005; Xu et al., 2008; Lan et al., 2010) and on evaporation (Liu et al., 2009, 2010; Xu et al., 2009; Shen and Chen, 2010; Shen et al., 2010). Related researches on the climate change of Kaidu River Basin (Zhang et al., 2004; Tao et al., 2007; Chen et al., 2009; Lan et al., 2009; Sun et al., 2010; Tao et al., 2011) also confirmed that the climate of Kaidu River Basin has also been becoming warmer and humid over the last 40 years. However, these studies only covered the time span between 1958 and 2005. Currently, no study

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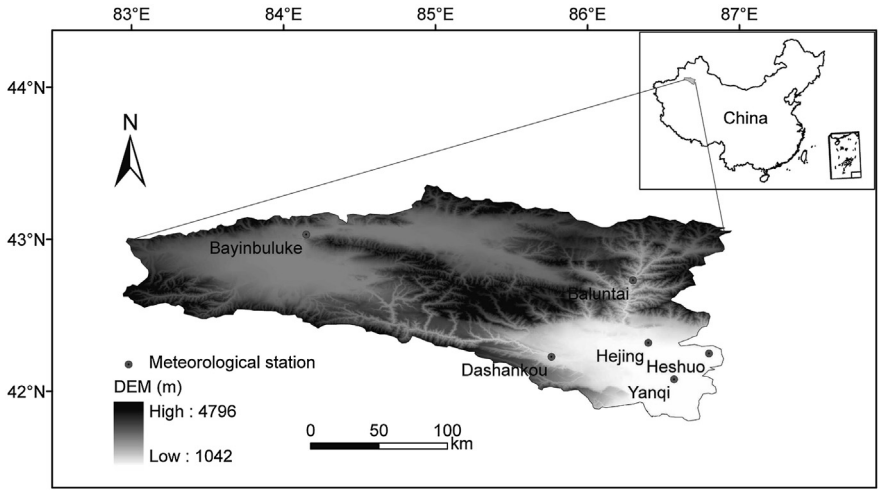

Fig. 1. Locations of the basic meteorological stations in Kaidu River Basin.

has been reported on the climate change of the basin since 2006. Despite the global temperature and precipitation increases and the overall trend of humidification in Xinjiang, it is uncertain whether Kaidu River Basin, the most arid area in Xinjiang, experienced simultaneous increases in temperature and precipitation or not. If the increase in precipitation falls short of temperature increase, evaporation may intensify and thus aggravate drought. Because the climate is an important driver of the hydrological cycle, the warming climate inevitably alters the distribution of water resources. In particular, temperature changes can directly affect glaciers, the most important source of water resources, and thus can significantly affect the water resources and environmental conditions of arid areas (Wang et al., 2003). Therefore, evaluating the future climate variation is very important for ecological environment and water resource management of the Kaidu River Basin.

Based on the meteorological data of 1961–2009, we attempt to investigate the temperature and precipitation variations over the time and the space in Kaidu River Basin. The results will lay a theoretical basis for further research on the mechanism of future climate change in Kaidu River Basin and may also be useful in guiding future water management.

2. Study area and methods

2.1. Study area

Kaidu River, the sole supply to Bosten Lake, originates in the southern slope of Yilianhabierga Mountain in the Central Tianshan Mountains whose high parts are covered with snow throughout a year. It covers watershed area of 22 000 km^2 and has an average annual runoff of 33.62 million m^3. In this river basin, there are 840 modern glaciers. Kaidu River's discharge is dominated by snow-melt water during springs and by ice-melt water and rainfall recharge during summers. About 70% of the runoff occurs from May to October. The average runoff is 7.8 million m^3 in spring, 15.5 million m^3 in summer, and 3.7 million m^3 in autumn. The average groundwater supply is 13.0 million m^3 and the average ice-melt and snow-melt water is 9.6 million m^3. The basin's main vegetation type is grass, accounting for 73.78% of the total area and soil type varies from meadow soil, marsh soil to frozen soil.

Kaidu River Basin has a typical alpine climate with an average annual temperature of −4.16 °C. It has a mean annual precipitation of 273 mm with a mean annual evaporation of 1157 mm. The precipitation varies with the elevations: high in its mountainous areas (200–500 mm) and very low in its basin area (50–80 mm). Precipitation also varies with seasons and more than 80% of the annual precipitation occurs from May to September. With population increase and economic expansion in the basin, water shortage becomes more evident. The large-scale development and utilization of water resources have caused a series of ecological environment problems.

Since 1956, six basic meteorological stations have been built in the Kaidu River Basin. Three counties (i.e., Hejing, Heshuo and Yanqi counties) are situated in Yanqi Basin and the weather stations in these three counties represent the oasis area. Bayinbuluke and Baluntai stations are located in the mountainous areas of Kaidu River basin, thus representing the mountainous area. The study area of this work is between Kaidu River and the downstream part of the Yanqi Basin (Fig. 1).

2.2. Data sources

The climate data including annual temperature, annual precipitation (1961–2009), monthly temperature, and monthly precipitation (1961–2009) were collected from the archives of the six meteorological stations and segmented into four time periods: spring (March–May), summer (June–August), autumn (September–October) and winter (November–February). Because the average temperature in November in the Kaidu River Basin is below 0 °C, the winter season of Kaidu River Basin is extended to include November.

2.3. Methodology

2.3.1. Non-parametric statistical test (Mann–Kendall method)

The Mann–Kendall non-parametric statistical test is used in this paper to analyze the trends in the variations of air temperature and precipitation. The Mann–Kendall method evaluates the trend in the time series of meteorological variables and has been widely used in trend analysis because it does not require the data samples to have a certain distribution (Kahya and Kalayci, 2004). The Mann–Kendall test has the following formula:

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{\mathrm{var}(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S+1}{\sqrt{\mathrm{var}(S)}}, & S < 0 \end{cases} \quad (1)$$