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# Historical temporal trends of hydro-climatic variables and runoff response to climate variability and their relevance in water resource management in the Hanjiang basin

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**Summary** The Danjiangkou reservoir lies in the upper Hanjiang basin and is the source of water for the middle route of the South-to-North Water Diversion Project (SNWDP) in China. Any significant change in the magnitude or timing of runoff from the Danjiangkou reservoir induced by changes in climatic variables would have significant implications for the economic prosperity of the area in the Hanjiang basin as well as for the South-to-North Water Diversion Project. In this paper the following issues are investigated: (1) Temporal trends of annual and seasonal precipitation and temperature from 1951 to 2003 in the Hanjiang basin are analyzed using the Mann–Kendall and the linear regression methods; spatial distributions of precipitation and temperature are interpolated by the inverse distance weighted interpolation method. (2) Temporal trends of runoff, precipitation and temperature from 1951 to 2003 in the Danjiangkou reservoir, an upper stream basin of the Hanjiang River, are further tested. (3) To assess the impact of climate change on water resources and predict the future runoff change in the Danjiangkou reservoir basin, a two-parameter water balance model is used to simulate the hydrological response for the climate change predicted by GCMs for the region for the period of 2021–2050.

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The results indicate that (1) at the $\alpha = 0.05$ significance level precipitation in the Hanjiang basin has no trend, but the temperature in the same region has significant upward trends in most parts of the Hanjiang basin. (2) The mean annual, spring, and winter runoffs in the Danjiangkou reservoir basin have decreasing trends. (3) The results simulated for the period 2021—2050 show that runoff of the Danjiangkou reservoir would increase in all the seasons, mainly in response to the predicted precipitation increase in the region. Sensitivity analysis shows that a 1 °C and 2 °C increase in temperature would reduce the mean annual runoff to about 3.5% and 7%, respectively. A decrease/increase of the mean monthly precipitation of 20% and 10% would decrease/increase the mean annual runoff to about 30% and 15%, respectively. The results of this study provide a scientific reference not only for assessing the impact of the climate change on water resources and the flood prevention in the Hanjiang basin, but also for dimensioning the middle route of the SNWDP in China.



## Introduction

Investigations of regional and global climatic changes and variabilities and their impacts on the society have received considerable attention in recent years. According to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001), the global average surface temperature has increased by about 0.6 ± 0.2 °C over the 20th century, and rainfall has decreased over much of the Northern Hemisphere sub-tropical regions by about 0.3% per decade during the 20th century. In some regions, such as parts of Asia and Africa, the frequency and intensity of droughts have been observed to increase in recent decades. Much attention had been paid to analyze climatic changes in China (Guo et al., 2002; Gemmer et al., 2004; Wang et al., 2004; Xiong and Guo, 2004; Guo et al., 2005; Zhang et al., 2005; Huang et al., 2005; Xu et al., 2006; Zhou and Yu, 2006). Guo et al. (2002) studied the impact of climate change on water resources of the Hanjiang basin based on a semi-distributed monthly water balance model and their results showed that the precipitation change is the main factor for the change in runoff. Wang et al. (2004) demonstrated that an increasing trend in precipitation variations was observed during the second half of the 20th century in West China, but a similar trend was not found in East China, where the 20- to 40-year periodicities were predominant in the precipitation variability. Huang et al. (2005) showed that the temperature rise in winter was shown to be linked to the presence of an anomalously strong zonal circulation in Eurasia and a weak polar vortex since the 1980s. Xu et al. (2006) analyzed the future climate change responses in the time-slice of 2071—2100 (2080s) under SRES B2 scenario over China. According to their results, there would be an obvious surface air temperature increase in the north of China relative to that in the south of China, and there would be an overall increase of the simulated precipitation in the 2080s under SRES B2 scenario over most areas of China. At the same time there would be significant precipitation decreases in South China in winter and obvious precipitation decreases in Northeast China and North China in summer with high surface air temperature increases. Zhou and Yu (2006) examined variations of the surface air temperature over China and the globe in the 20th century simulated by 19 coupled climate models driven by historical natural and anthropogenic forcings. These studies will be very helpful to analyze and assess the impact of climatic change on the water resources in China.

Observational and historical hydro-climatic data are generally used for planning and designing water resources projects. There is an implicit assumption of so-called stationarity, implying time-invariant statistical characteristics of the time series under consideration, in virtually all water resources engineering works. Such an assumption can no longer be valid if the global climate changes as a result of the increase of greenhouse gases in the atmosphere. This, of course, results in major problems (e.g., dislocation and inefficiencies) in regional water resources management (Kahya and Kalaycı, 2004). Therefore, the need to study the climatic change trends in the Hanjiang basin, such as precipitation, temperature and runoff, is urgent.

There are many parametric and non-parametric methods that have been applied for detection of trends (Zhang et al., 2006). Parametric trend tests are more powerful than non-parametric ones, but they require data to be independent and normally distributed. On the other hand, non-parametric trend tests only require the data be independent and can tolerate outliers in the data. One of the widely used non-parametric tests for detecting a trend in hydro-climatic time series is the Mann—Kendall (MK) test (Hirsch et al., 1982; van Belle and Hughes, 1984; Zetterqvist, 1991; Zhang et al., 2001; Burn and Elnur, 2002; Yue et al., 2002; Yue and Wang, 2002; Yue and Pilon, 2004; Burn et al., 2004; Zhang et al., 2005; Arora et al., 2005; Aziz and Burn, 2006; Gemmer et al., 2004; Zhang et al., 2006; Zhu and Day, 2005). Burn and Elnur (2002) developed a trend detection framework which utilized the MK test to identify trends in hydrological variables. Kundzewicz and Robson (2004) outlined and presented a brief overview of trend detection tests. Yue and Pilon (2004) applied Monte Carlo simulation to compare the power of the statistical tests: the parametric *t*-test, the non-parametric MK, bootstrap-based slope, and bootstrap-based MK tests to assess the significance of monotonic trends. Their simulation results indicate that the *t*-test and the BS-slope test (slope-based tests) have the same power and the MK and BS-based MK tests (rank based tests) have the same power. For normally distrib-