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Spatiotemporal variability of climate and streamflow in the Songhua River Basin, northeast China

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SUMMARY

The Songhua River Basin (SRB) is located in the high latitude region of China's far northeast and is sensitive to global warming. This study utilized long-term meteorological and river discharge records in the SRB to assess spatiotemporal variability and trends in temperature, precipitation, and discharge. Daily precipitation and temperature data were collected from 37 meteorological stations across the SRB for the period from January 1960 to December 2009. Monthly discharges from 33 major river gauge stations in three sub-basins of the SRB were gathered for the same period. The modified Mann–Kendall tests, flow duration curves and correlation statistics were performed to identify the long-term trend and interrelation of the hydrometeorological variables. The results showed that temperature in the SRB has steadily increased in the past five decades, while precipitation fluctuated greatly among the years and the decades with a declining trend since 1980s. The largest change in temperature was found in the last two decades, with a decadal increase of about 1 °C. Concurrently, a declining trend in annual discharge from the SRB was found after 1990, while intra-annual variation of discharge increased. Overall, annual discharge at most gauge stations across the SRB showed a downward trend in the past five decades, with a significantly decreasing trend in the Lower Songhua River. Seasonally, the declining trend in discharge was prevalent in spring and discharge mainly declined in the lower Nenjiang River and the Lower Songhua River throughout most of a year. The flow duration analysis showed a decrease in high flow (Q_5), but an increase in low flow (Q_{95}) after 1990 at most mainstream stations of the SRB. However, both the lowest and highest monthly discharge displayed a declining trend during 1960–2009. Because precipitation in this river basin is concentrated during the summer and fall months, annual discharge was closely and positively correlated with precipitation amount occurred during these two seasons.

1. Introduction

It has been widely recognized that global climate change, mainly in the form of global warming, will significantly influence both natural ecosystems and the available water resources (Houghton et al., 2001; Kamga, 2001). Global temperature increase may accelerate earth's hydrological cycle, leading to changes in the spatial and temporal distributions of regional water resources (Boer et al., 2000; Nijssen et al., 2001; Labat et al., 2004; Ramanathan et al., 2005). In the recent decade, research on the impacts of climate change on regional water resources has intensified (e.g., Lettenmaier et al., 1999; Xu and Singh, 2004; Chen et al., 2006; Gardner, 2009; Zhang et al., 2009). As human activities (e.g., agricultural practice, urbanization) and river managements can also alter runoff generation and discharge conditions, studies on effects of land use changes on water resources have also been carried out (e.g., Hundecha and Bárdossy, 2004; Liu et al., 2008; Cao et al., 2009; Tomer and Schilling, 2009). In China, recent studies (Hao et al., 2008; Yang and Tian, 2009; Shi et al., 2013) have shown a decreasing trend of runoff in many river basins across the country; At the same time, the frequency and intensity of extreme events, such as droughts and floods, have increased, making an increasing challenge to China's water resources management and agriculture.

Occupying a land surface area of 556,800 km^2, the Songhua River Basin (SRB) lies in the far northeast of China and it is one of the country's most important commodity grain production

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bases. Agriculture is intensive in the middle and lower basin areas of the SRB, where many wetlands exist. In this region, stream and river flows are the most relevant water sources for agricultural irrigation and water use. The river waters are also crucial for the surface water wetlands that support diverse ecosystems and many endangered wildlife species (e.g., red crane) in the Songnen Plain. In recent years, the Chinese government has been promoting the region to become China's future major grain production base. In order to develop best management strategies for effective utilization and protection of the limited water resources in the SRB, it is crucial to improve our understanding of spatial and temporal variability of the temperature and precipitation changes as well as their effects on long-term trends of streamflows across the basin. Two recent studies (Yu et al., 2011; Lu et al., 2012a) reported an increasing trend in average temperature and a declining trend in precipitation for the river basin, respectively. However, the studies did not analyze potential effects of the climatic changes on stream and river flows in the river basin. Also, the studies provided no information on the temperature and precipitation changes among the sub-basins, a knowledge that is essential to identify climate change effects on streamflow across this large river basin.

In the recent years, there has been a growing realization of the importance in assessing the long-term streamflow in the SRB. Several studies have reported long-term runoff changes in the SRB (Feng et al., 2011; Miao et al., 2011; Li et al., 2012; Meng and Mo, 2012; Mu et al., 2012). While these studies provided insights in the long-term streamflow trend from a few gauge stations on the Songhua River mainstream, no study has investigated spatiotemporal characteristics of the changes in a holistic way to identify hydrometerological interrelations across this large river basin. Against the above context, this present study utilized long-term (1960–2009) climatic records from 37 meteorological stations and river discharge records from 33 gauge stations distributed in three sub-basins of the SRB. The study aimed to (1) identify the spatiotemporal variability and trends in temperature, precipitation and streamflow during 1960–2009 across the river basin, and (2) investigate the relationships among the hydrometeorological variables. The primary goal of this study is to evaluate the impact of climate change on streamflow and provide the basic information for water resources management in the region.

2. Study area

The Songhua River Basin is located in the far northeast of China (119°52′ to 132°31′E and 41°42′ to 51°38′N, Fig. 1) and is one of China's seven major river basins. The basin covers an area of 556,800 km^2, occupying a large part of Heilongjiang Province, Jilin Province and the northeastern part of Inner Mongolia Autonomous Region. There are three primary mountains in the Songhua River Basin: the Great Khingan Mountain in the west extending from northeast to southwest with an elevation range between 700 and 1700 m; the Little Khingan Range in the northeast, extending from northwest to southeast with an elevation range between 1000 and 2000 m; the Changbai Mountain stretching from the east to the southeast with an elevation range between 800 and 2700 m (Li et al., 2012). Soils in the SRB are fertile. The Songnen plain located in the center of the SRB and with an elevation range of 50–200 is one of China's major crop production regions. Dominant crops in the basin include soybean, corn, sorghum, and wheat. Besides, there are also numbers of wetlands in the basin. The Songhua River is the major freshwater source for industry, agriculture and drinking water in northeast China.

The SRB is composed of three sub river basins: the Nenjian River Basin (NRB) in the west, the Upper Songhua River Basin in the south (USRB, a.k.a., the Second Songhua River), and the Lower Songhua River Basin in the northeast (LSRB, a.k.a., the mainstream of Songhua River). The Nenjiang River tributary originating from the Yilehuli Mountain in the Great Khingan Mountains travels a total length of 1370 km from northwest to southeast and drains an area of 297,000 km^2. The Upper Songhua River originates from Tianchi Lake in the Changbai Mountain and travels 958 km from southeast to northwest draining a land area of 73,400 km^2. With gentle slope and wide surface, the Lower Songhua River carries the combined flow from the Nenjiang and Upper Songhua Rivers, flowing northeastward 939 km before entering the Amur River. The geography and hydrological network of the Songhua River Basin are shown in Fig. 1. Because of the large geographical extent and elevation difference, climatic and hydrologic conditions of the SRB are complex. Precipitation is mainly concentrated during the months from June to September with an annual total of ~455 mm in the NRB, ~668 mm in the USRB, and ~455 mm in

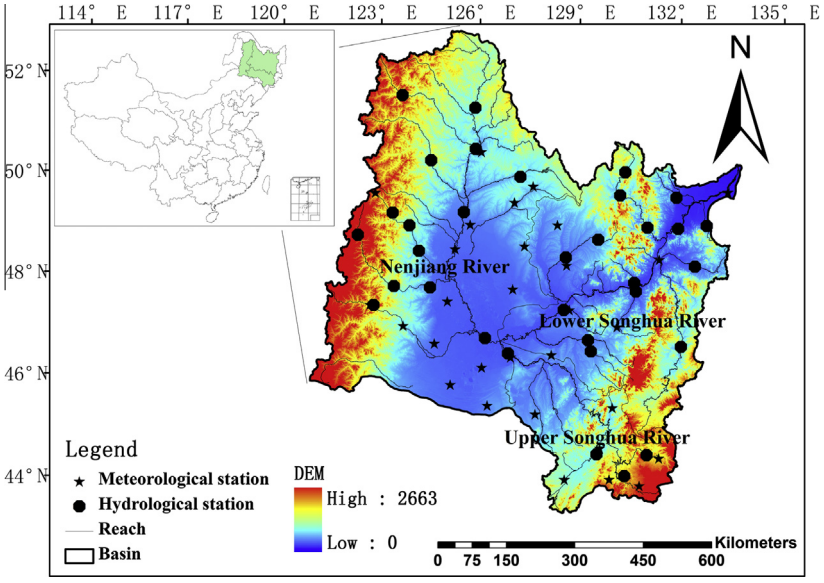

Fig. 1. The Songhua River Basin in northeast China and the gauge (dots) and meteorological (stars) stations used in this study.