

Potential relationships between the river discharge and the precipitation in the Jinsha River basin, China

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Abstract. The relationships between the river discharge and the precipitation in the Jinsha River basin are discussed in this study. In addition, the future precipitation trend from 2011-2050 and its potential influence on the river discharge are analysed by applying the CCLM-modelled precipitation. According to the observed river discharge and precipitation, the annual river discharge at the two main hydrological stations displays good correlations with the annual precipitation in the Jinsha River basin. The predicted future precipitation tends to change similarly as the change that occurred during the observation period, whereas the monthly distributions over a year could be more uneven, which is unfavourable for water resources management.

1. Introduction

Climate change will lead to temporal and spatial changes in precipitation, and changes in precipitation will have direct effects on hydrological processes at multiple time scales [1]. Thus, the water cycle will change, and the distribution patterns of water resources will eventually be influenced [2]. According to the worldwide observations, the frequencies of droughts and floods displayed increasing trends over the last several decades. Many flood disasters have been reported to be more severe than those observed during the observation period [3].

In China, temporal and spatial distributions of water resources have also changed in the past several decades, e.g., the three river basins, including the Songhua River basin, the Liaohe River basin and the Haihe River basin located in northeastern China, experienced more frequent droughts [4]. With population growth and economic development, the frequent occurrences of droughts and floods and the increasingly prominent contradiction between the supply and demand of water resources will restrict the national economic development [5].

Recently, the regional climate in the Yangtze River basin has been very sensitive to climate change at larger scales. The mean precipitation has changed in different areas of the Yangtze River basin [6], and extreme precipitation has continuously increased in the Yangtze River basin over the last several decades [7]. Surface water resources showed an increasing trend in the source region of the Yangtze River from 1961-2011, especially after 2004, according to the research by Li et al [8].



Therefore, temporal and spatial variations of precipitation will cause water resources and hydrological processes to change in the Jinsha River basin, which is one of the most important tributary of the Yangtze River. Hence, changes in precipitation and river discharge over the last several decades in the Jinsha River basin require investigation. In addition, analysis of precipitation responses to different future greenhouse gas emission scenarios could provide very useful information for water resources projections.

This paper is organized as follows: Introduction of the research area and database is described in Section 2. The methods are presented in Section 3. Relationships in the observed river discharge and precipitation in the Jinsha River basin are analyzed in Section 4. Future changes in precipitation and its effects on the river discharge under different greenhouse gas emission scenarios are presented in Section 5. The last section provides the conclusion and discussion.

2. Study area and database

2.1. The Jinsha River basin

The Jinsha River basin is located in the upper Yangtze River basin. The topography of the Jinsha River basin is higher in the northwest part and lower in the southeast part. The terrain is very complex in the basin, with great mountains and deep valleys. Due to its location and the complicated geography, the Jinsha River basin has many types of climate patterns, including a typical plateau climate, the Hengduan Mountains' vertical climate, and a monsoon climate. Moreover, the Jinsha River basin is the largest hydropower base in China and is the main hydropower source of the national "Transporting Western Power Eastward" project. The location of the Jinsha River basin can be observed in Figure 1.

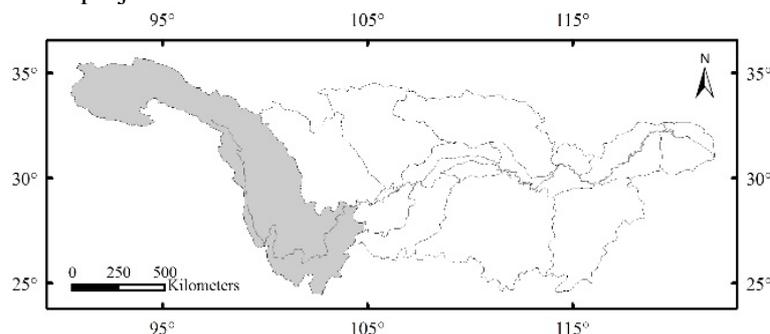


Figure 1. The location of the Jinsha River basin in the Yangtze River basin.

2.2. Database

In the present study, discharges at two controlling hydrological stations, the Shigu station and the Xiangjiaba station in the Jinsha River basin are studied to represent the hydrological processes of the upper region and the lower region. Consequently, precipitation at the meteorological stations located in the upper region represents rainfall information of the upper region controlled by the Shigu station, and precipitation at all of the meteorological stations located in the entire basin represents rainfall information of the entire region controlled by the Xiangjiaba station.

Two types of data are applied in this study, including the observed river discharge and precipitation and the simulated and projected precipitation given by a regional climate model.

The measured monthly river discharge data during 1961-2010 at the two controlling hydrological stations are used, which are derived from the hydrological yearbook. The observed daily precipitation during 1961-2010 at 32 national meteorological observation stations located in the Jinsha River basin are used, which are provided by the China Meteorological Administration. Among the 32 meteorological stations, there are 10 stations in the region controlled by the Shigu station, and there are 22 stations in the region controlled by the Xiangjiaba station. The locations of the two hydrological stations and the 32 meteorological stations are shown in Figure 2.

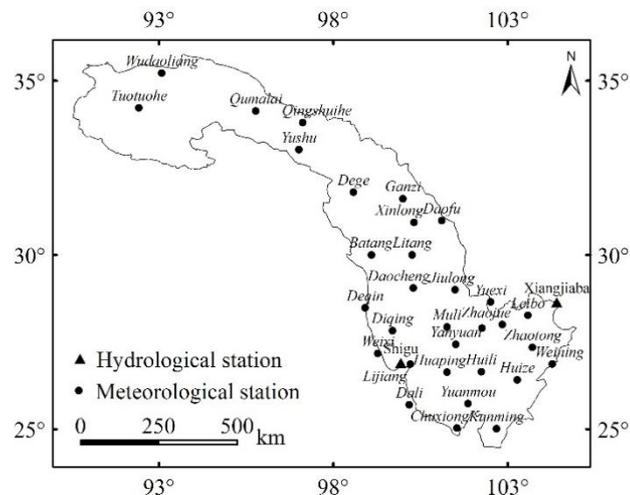


Figure 2. The observation stations in the Jinsha River basin.

In this study, the simulated and projected precipitation is given by the regional climate model CCLM (COSMO model in Climate Mode, abbreviated as COSMO-CLM or CCLM) [9]. The simulated precipitation represents the experimental period of 1961-2005, and the projected precipitation is for the period of 2011-2050. For the projection period 2011-2050, the climate change scenarios RCPs (Representative Concentration Pathways) are considered, which are the greenhouse gas emission scenarios released by the IPCC in 2011 [10]. In this present study, the RCP4.5 scenario is considered.

3. Correlation analysis and impact assessment

Statistician Karl Pearson designed a statistical indicator, the correlation coefficient, which could reflect the close correlation degree among the variables [11]. In addition, a linear regression equation may be applied between two variables having a high relevance, which can be used to describe the linear relationship between dependent variable Y and independent variable X. The least squares method is adopted to find the linear regression equation in the following form.

In the present study, linear regression equations are established between the runoff and the precipitation by analyzing the correlation coefficients between them on different time scales. In addition, the determination coefficient R^2 is used to judge the degree of goodness of fit for each linear regression [12], and the coefficient equals the ratio of the regression sum of the squares to the total sum of the squares, which reflects the variability percentage of the dependent variable that can be explained by the regression model.

In addition, impacts of precipitation on river discharge during 2011-2050 at multiple time scales are assessed in this research, by applying the linear regression equations. Hence, the projected precipitation and river discharge are analyzed.

4. Relationships between the river discharge and the precipitation

4.1. Relationships between the annual river discharge and precipitation

The correlation coefficients between the annual river discharge and the precipitation in the same year for the two hydrological stations are calculated. The correlation coefficients for the Shigu and Xiangjiaba stations are 0.712 and 0.777, respectively. Additionally, the correlation coefficients between the annual river discharge and the precipitation one year ago are calculated, and the coefficients are significantly smaller than those for the annual river discharge and precipitation in the same year. Thus, only the annual precipitation in the same year as the annual river discharge is considered to establish the linear regression function.

By plotting the observed annual river discharge and the precipitation from 1961-2010, the two linear regression functions are established for the Shigu and Xiangjiaba stations, which can represent the relationships between the annual river discharge and the precipitation (Figure 3). The determination coefficients for the Shigu and Xiangjiaba stations are 0.506 and 0.603, respectively.

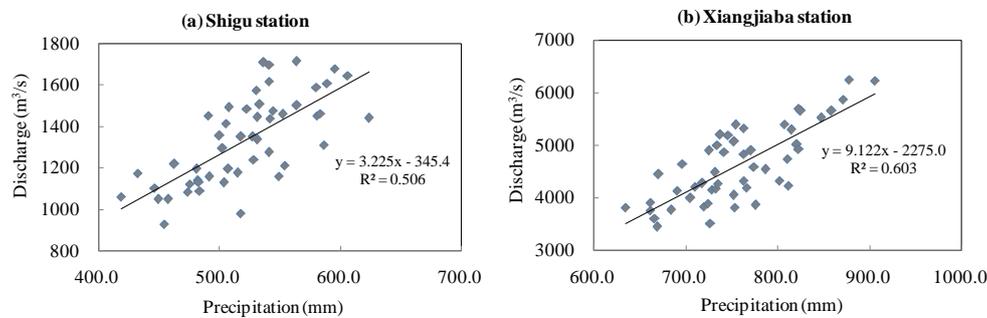


Figure 3. Relationships between the river discharge and precipitation at the two stations.

4.2. Relationship between the monthly river discharge and precipitation

Due to the analysis on the monthly distribution over one year, the main flood season (including July, August, and September) is studied to establish the relationships between the monthly river discharge and the monthly precipitation for the Shigu and Xiangjiaba stations. The correlation coefficients between the monthly river discharge and the precipitation with different time lags are shown in Table 1. It can be observed that the river discharge in July, August and September has good relationships with the precipitation in the same month and one month prior. Moreover, the river discharge in September appears to be related to the precipitation in June, which may be due to the similarity of the precipitation in June and in August. The monthly river discharge in the main flood season has good relationships with the precipitation, which shows that the natural climate has a big impact on the hydrological process, and changes of the precipitation can leads to changes of the river discharge in the Jinsha River basin.

Table 1. Correlation coefficients between the monthly river discharge and precipitation in the Jinsha River Basin.

Station	Month	Coe _{-(Q_m,P_m)}	Coe _{-(Q_m,P_{m-1})}	Coe _{-(Q_m,P_{m-2})}	Coe _{-(Q_m,P_{m-3})}	Coe _{-(Q_m,P_{m-4})}
Shigu	July	0.48	0.52	0.09	0.23	-0.10
	August	0.61	0.43	0.09	0.01	-0.05
	September	0.30	0.68	0.15	0.35	0.08
Xiangjiaba	July	0.49	0.52	0.20	0.29	0.07
	August	0.71	0.31	0.25	0.04	-0.04
	September	0.38	0.68	0.03	0.36	0.07

Notes: *m* represents month, *m-1* represents one month prior, etc. *Q* represents the river discharge, and *P* represents the precipitation.

The linear regression functions between the river discharge in July and the precipitation in July and in June for the Shigu and Xiangjiaba stations are established. The establishment of the functions for the river discharge in August and in September is the same as in July. The functions are listed below.

For July, the river discharge at the Shigu and Xiangjiaba stations has the following functions:

Shigu station: $Q_{Jul} = 15.743 * P_{Jul} + 22.353 * P_{Jun} - 1310.587$ ($R^2 = 0.514$)

Xiangjiaba station: $Q_{Jul} = 48.929 * P_{Jul} + 48.653 * P_{Jun} - 5229.603$ ($R^2 = 0.518$)

For August, the river discharge at the Shigu and Xiangjiaba stations has the following functions:

Shigu station: $Q_{Aug} = 23.988 * P_{Aug} + 18.573 * P_{Jul} - 1778.667$ ($R^2 = 0.564$)

Xiangjiaba station: $Q_{Aug} = 65.325 * P_{Aug} + 35.918 * P_{Jul} - 5399.149$ ($R^2 = 0.578$)

For September, the river discharge at the Shigu and Xiangjiaba stations has the following functions:

Shigu station: $Q_{Sep} = 11.569 * P_{Sep} + 18.840 * P_{Aug} - 124.673 \quad (R^2 = 0.507)$

Xiangjiaba station: $Q_{Sep} = 48.187 * P_{Sep} + 54.936 * P_{Aug} - 3299.536 \quad (R^2 = 0.591)$

5. Impacts of projected precipitation on the river discharge

5.1. Changes of annual river discharge and precipitation from 2011-2050

From 2011-2050, for the greenhouse gas emission scenario RCP4.5, the annual river discharge and precipitation show an obvious increasing tendency, and their variations are smaller than 16% compared with the average annual river discharge and precipitation during the reference period of 1971-2000 (Figure 4).

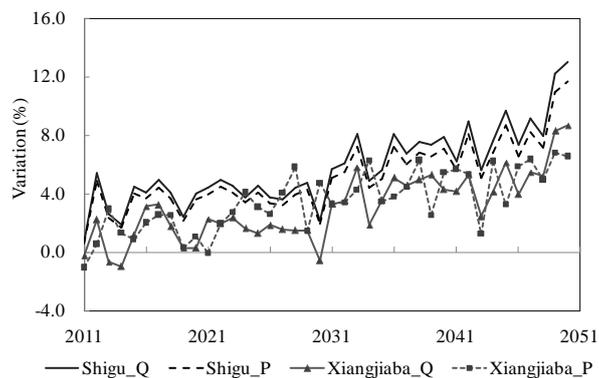


Figure 4. Changes of the projected annual river discharge and precipitation.

5.2. Changes of monthly river discharge and precipitation from 2011-2050

The monthly river discharge at the Shigu and Xiangjiaba stations in July, August and September are projected based on the established relationships with the monthly precipitation by applying the precipitation projection from 2011-2050.

For the monthly river discharge at the Shigu and Xiangjiaba stations in July, the variations from 2011-2050 under the RCP4.5 scenario become significantly large above 15%. For the monthly river discharge in August, the variations at the Shigu station are larger than at the Xiangjiaba station, which is different from July because the variations in the monthly river discharge at the two hydrological stations in July are nearly the same. For the monthly river discharge in September, the variations from 2011-2050 become smaller than those in August and July, and the extent of change ranges from -10% to 15% (Figure 5).

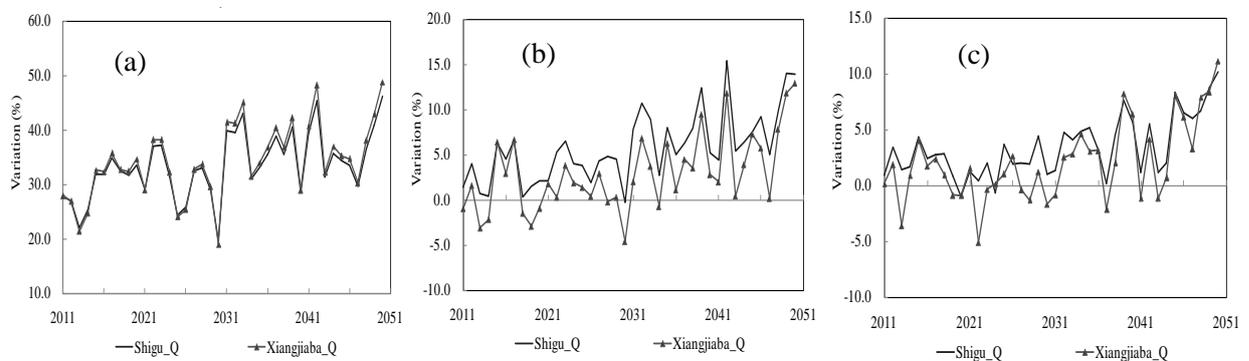


Figure 5. Changes of the projected monthly river discharge (a) July (b) August (c) September.

The monthly river discharge in July, August, and September are the most important over one year. From 2011-2050, the discharge amounts show a significantly different change under the RCP4.5

scenario, especially for July, which requires more attention due to the possible effects on floods and hydropower projects scheduling in the Jinsha River basin.

6. Conclusions

As the source area of the Yangtze River basin (the largest river basin in China), the Jinsha River basin has a drainage area accounting for 26% of the Yangtze River basin. Variations of the river discharge in this basin have significant effects on the middle and lower regions of the Yangtze River basin. The relationships between river discharge and precipitation are studied in this research. In addition, river discharge and precipitation projections are also analyzed to obtain useful information for water resources planning and management. Due to the importance of the main flood season, linear regression relationships between the monthly river discharge in July, August and September and the monthly precipitation were established for the Shigu and Xiangjiaba stations. To project the future river discharge and the precipitation, precipitation outputs of the regional climate model CCLM in the Jinsha River basin are used, including precipitation from 2011-2050 under the greenhouse gas emission scenario RCP4.5.

The monthly river discharge at the Shigu and Xiangjiaba stations in July among the three months (including July, August and September) in the main flood season showed the largest variations, and they increase obviously. The monthly river discharge in August and September does not show obvious trends, and the variations are smaller than 20%.

Generally, the temporal and spatial distributions of the monthly precipitation and river discharge could be more uneven from 2011-2050, and the hydrological cycle would become quicker in this basin. Hence, the department of water resources management should focus on the potential frequent floods and droughts in the Jinsha River basin and their possible effects on downstream watersheds.

Acknowledgement

This research has been financially supported by the National Key Research and Development Program (2016YFC0401005), and the Funds for the Central Universities, HUST (2016YXZD046, 2017KFYXJJ191).

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