Trend of Annual Runoff for Major Rivers in China under Climate Change

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Abstract

In order to understand the variation of hydrological regime for major rivers in China under climate change since 1950, the series of annual runoff for those rivers were analyzed by using several methods, including M-K method, accumulation curve method, F & T test, and anomaly analysis method. The results of this study showed that the annual runoff for only a part of those rivers took on a significant trend under climate change. Additionally, the occurring frequency of both extremely low-flow years and continuous low-flow years for most of those rivers increased after 1980.

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1. Introduction

Drought disasters have frequently occurred in China during recent years, which has directly threatened the food security, and affected the water demand during national economic development [1-3]. Since water security is closely related to the change of water resources [4-5], and drought disasters mainly happen in dry seasons, the series of annual runoff for major rivers in China were selected as the research object in this study, and the response of annual runoff to climate change was analyzed based on the study on the changing trend of annual runoff and the occurring frequency of extremely low-flow events. This study will lay the foundation for further analyzing the impact of climate change on drought disasters.

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2. Data and Analytical Methods

Measured annual runoff series between 1950 and 2008 for 20 hydrologic stations were used for analyzing the trend of annual runoff. Those hydrologic stations are distributed at six major rivers in China, including Songliao River, Haihe River, Yellow River, Huaihe River, Yangtze River and Pearl River & Minjiang River. The analysis was carried out through comparing the change of annual runoff between two stages. It is generally believed that the climate change became more significant after 1980, so the period from 1950 to 2008 was divided into two stages. The earlier stage was from 1950 to 1979, and the later stage was from 1980 to 2008. In this study, several analysis methods were used, including M-K method, accumulation curve method, F & T test, and anomaly analysis method [6].

3. Changing Trend of Annual Runoff

3.1. Changing Trend of Annual Runoff for Songliao River

The trend analysis revealed that the annual runoff at three hydrologic stations along the Songliao River, Jiangqiao, Harbin and Tieling hydrologic stations, had shown a decreasing trend since 1950 [7]. The decline rate of annual runoff at those hydrologic stations was 1546 million m$^3$/10a, 3613 million m$^3$/10a and 595 million m$^3$/10a respectively.

The significance test for the changing trend of annual runoff was carried out by using both M-K method and accumulation curve method. From 1970s to 2008, the annual runoff for Songliao River decreased, and the mean M-K values for those three hydrologic stations along Songliao River were between 2.35 and 3.05, which were all greater than the critical value of 1.96. The slope of accumulation curves for annual runoff had a noticeable change during the period from 1970 to 1980, and the annual runoff reduced significantly in late 1970s. It could be inferred that the annual runoff for Songliao River took on a decreasing trend, and the changing trend was significant.

3.2. Changing Trend of Annual Runoff for Haihe River

The annual runoff at all five hydrologic stations within the Haihe River Basin took on a decreasing trend from 1950 to 2008. The decline rate of annual runoff at Guantai, Shixiali, Xiangshuibao, Zhangjiafen and Xiaohui hydrologic stations was 383 million m$^3$/10a, 217 million m$^3$/10a, 113 million m$^3$/10a, 169 million m$^3$/10a and 50 million m$^3$/10a respectively.

The significance test revealed that the decreasing trend of annual runoff for Haihe River was significant. The annual runoff for Haihe River began to decrease in 1960s, and the M-K values for all five hydrologic stations exceeded the critical value of 1.96 in 1970s. The mean M-K values for Guantai, Shixiali, Xiangshuibao and Zhangjiafen hydrologic Stations were -2.61, -4.05, 2.61 and -2.99 respectively. The M-K value for annual runoff at Xiaohui Hydrologic Station had been decreasing, and reached the significance level in 2004.

3.3. Changing Trend of Annual Runoff for Yellow River

The annual runoff at Tangnaihai, Huayuankou and Lijin hydrologic stations had been showing a decreasing trend [8]. The decline rate of annual runoff at those hydrologic stations was 601 million m$^3$/10a, 5441 million m$^3$/10a and 7969 million m$^3$/10a respectively.

The significance test for the changing trend of annual runoff at those three hydrologic stations was performed. The annual runoff at both Huayuankou and Lijin hydrologic stations passed the significance
test, showing an obviously decreasing trend, while that at Tangnaihai Hydrologic Station did not. The annual runoff at all three hydrologic stations started to decrease in 1970s, and the decline rate increased from the upstream to downstream. The M-K value for the annual runoff at Lijin Hydrologic Station located downstream exceeded the critical value in early 1970s, that for the annual runoff at Huayuankou Hydrologic Station located at the middle reaches exceeded the critical value in the middle 1990s, while that for the annual runoff at Tangnaihai Hydrologic Station located upstream had never exceeded the critical value. Therefore, it could be concluded that the decreasing trend of annual runoff for the middle reaches and downstream of Yellow River was significant.

3.4. Changing Trend of Annual Runoff for Huaihe River

The trend analysis revealed that the annual runoff at Xixian and Wujiadu hydrologic stations decreased with the decline rate of 47 million m³/10a and 880 million m³/10a respectively. However, the annual runoff at Wangjiaba Hydrologic Station took on an increasing trend with the increasing rate of 55 million m³/10a.

The significance test for the changing trend of annual runoff at those three hydrologic stations along the main stream of Huaihe River was performed, revealing that the M-K values for the annual runoff at those hydrologic stations did not exceed the critical value. The results of significance test, combined with the changing trend of accumulation curves, showed that the changing trend of annual runoff for Huaihe River was not significant.

3.5. Changing Trend of Annual Runoff for Yangtze River

The trend analysis revealed that the annual runoff at three hydrologic stations along Yangtze River took on a decreasing trend, and the decline rate for Yichang, Hankou and Datong hydrologic stations was 6679 million m³/10a, 6523 million m³/10a and 5127 million m³/10a respectively.

The significance test for the changing trend of annual runoff revealed that the annual runoff at the upstream, middle reaches or downstream did not have significant changing trend. None of the M-K values exceeded the critical values, and the slope for accumulation curves did not change obviously. It could be inferred that the annual runoff at all three hydrologic stations had a decreasing trend, but the changing trend was not significant.

3.6. Changing Trend of Annual Runoff for Pearl River & Minjiang River

It was revealed by the trend analysis that the annual runoff at Wuzhou and Zhuqi hydrologic stations showed a decreasing trend with the decline rate of 1001 million m³/10a and 666 million m³/10a respectively, while that at Shijiao Hydrologic Station took on an increasing trend with the increasing rate of 45 million m³/10a.

The significance test for the changing trend of annual runoff for Pearl River & Minjiang River revealed that the annual runoff for Pearl River & Minjiang River did not take on any significant changing trend between 1950 and 2008. None of the M-K values exceeded the critical value, and the slope for accumulation curves did not change obviously.

4. Analysis on Extremely Low-Flow Years

Extremely low-flow year is defined as the year where the annual average runoff is equal or less than the 10th percentile (the lowest 10 percent of annual average runoff). The comparison of occurring
frequency of extremely low-flow years for major rivers in China between the earlier and later stages is depicted in Fig.1.

It is shown in Fig.1 that the occurring frequency of extremely low-flow years during the later stage was higher than that during the earlier stage for Songliao River, Haihe River, Yellow River and Pearl River & Minjiang River; For Huaihe River, the occurring frequency of extremely low-flow years during the later stage was lower than that during the earlier stage at two hydrologic stations located upstream, while the reverse at Wujiadu Hydrologic Station located downstream; For Yangtze River, the occurring frequency of extremely low-flow years during the later stage was higher than that during the earlier stage at Yichang Hydrologic Station located upstream, while the reverse at two hydrologic stations located at the middle reaches and downstream.

Thus, it can be inferred that the occurring frequency of extremely low-flow years increased after 1980 for Songliao River, Haihe River, Yellow River, the downstream of Huaihe River, the upstream of Yangtze River, and Pearl River & Minjiang River, while it decreased after 1980 for the upstream of Huaihe River and the middle reaches and downstream of Yangtze River.

5. Analysis on Continuous Low-Flow Years

![Fig.2. Comparison of occurring frequency of continuous low-flow years for major rivers in China between the earlier and later stages](image)
Continuous low flow is an important factor to cause drought disasters, so understanding and analyzing the occurrence and change of continuous low-flow years for major rivers is very important in evaluating the impact of climate change on drought in China. The comparison of occurring frequency of continuous low-flow years for major rivers in China between the earlier and later stages is shown in Fig.2.

It is evident in Fig. 2 that the occurring frequency of continuous low-flow years in the later stage was higher than that in the earlier stage for Songliao River, Haihe River, Yellow River and Pearl River & Minjiang River, while the reverse for Huaihe River and Yangtze River. It revealed that the probability of occurrence of continuous low-flow years was high for Songliao River, Haihe River, Yellow River and Pearl River & Minjiang River under climate change.

6. Conclusion

Three conclusions drawn from this study are as follows:

Between 1950 and 2008, the annual runoff for Songliao River, Haihe River and the middle reaches and downstream of the Yellow River took on a significantly decreasing trend, while that for the upstream of the Yellow River, Huaihe River, Yangtze River, and Pearl River & Minjiang River did not show any significant trend.

The occurring frequency of extremely low-flow years for Songliao River, Haihe River, Yellow River, the downstream of Huaihe River, the upstream of Yangtze River, and Pearl River & Minjiang River increased after 1980. It was an important phenomenon that we need to pay attention to.

It could be inferred that the occurring frequency of continuous low-flow years for Songliao River, Haihe River, Yellow River and Pearl River & Minjiang River increased after 1980, revealing that the probability of occurrence of continuous low-flow years was high for these rivers under climate change.

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