Study on the variation characteristics of annual rainfall and runoff in Oujiang River Basin of Zhejiang Province

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Abstract. In this paper, Mann-Kendall method and wavelet analysis method are used to analyze the annual rainfall and runoff data in Oujiang River Basin of Zhejiang Province, and the following conclusions are obtained: in the past 50 years, the annual average rainfall series increase and the annual runoff series decrease in Oujiang River Basin. The reason for this is that in 1960s, many hydraulic structures were built near Xuren station, such as river dams, which led to the rapid decline of runoff in the flood season. The results of Morlet wavelet analysis show that there is significant multi-time scale variation characteristic in the annual average rainfall and runoff series. The periodicity of the annual rainfall series exhibits three types of variation trends for different time-scales, i.e. 22-to 30-year scale, 10-to 22-year scale, and 3-to 10-year scale. While the periodicity of the annual runoff time series exhibits three types of variation trends for different time-scales, i.e. 15-to 25-year scale, 8-to 15-year scale, and 3-to 8-year scale.

1. Introduction

Due to the increasing intervention ability of modern human activities, coupled with the change of various climate factors, the contradiction between supply and demand of water resources in China is increasingly intensified, the distribution of drought and flood is uneven, and extreme climate occurs frequently. More and more attention has been paid to the study of the characteristics of rainstorm and flood [1-5].

Oujiang River is located in the south of Zhejiang Province. The water flows from the west to the East. Its main stream is 390 kilometers long, and the drainage area reaches 18030 square kilometers. The annual distribution of runoff in Oujiang River is very uneven. From May to September, the runoff accounts for about 2 / 3 of the whole year. In this paper, the precipitation and runoff of Oujiang River Basin in Zhejiang Province are analyzed in detail by using various analysis methods, such as linear trend analysis, Mann–Kendall rank trend test and Wavelet periodic analysis.

2. Data and Methods

2.1. Data

According to the characteristics of the basin, the rainfall data of seven rainfall stations are selected in this paper in the past 50 years. The names of the seven hydrological stations are Chuanliao, Hongfu'an,
Jingning, Panshan, Shawan, Shuiduiji and Xuren, respectively. The water level and discharge data of Xuren station are also selected.

2.2. Methodology

The statistical methods of linear trend analysis, Mann–Kendall rank trend test, Wavelet periodic analysis are used in this study to analyze the rainfall and runoff data [6-7]. A simple method to detect long-term trends in time series is linear regression analysis. The Mann–Kendall rank trend test method is a nonparametric hypothesis test for assessing the significance of monotonic trends in hydro-meteorological time series. Mann-Kendall test can test trends in a time series without requiring normality or linearity, and is therefore highly recommended to be an excellent tool for trend detection by other scholars in similar applications.

Wavelet analysis is useful for the investigation of multiple-scale periodic phenomenon in temporal variability processes. The key of this temporal-frequency method is the wavelet transformation, which is powerful to characterize the frequency, intensity, time position, and duration of the variations in a climate data series.

The continuous wavelet transformation of a discrete signal, \( f(t) \), with a Morlet wavelet, \( \psi(t) \), is given as

\[
W_f(a, b) = |a|^{-1/2} \int f(t) \psi\left(\frac{t-b}{a}\right) dt
\]

(1)

Where \( W_f(a, b) \) is the transformation coefficient, \( a \) is a scale parameter, \( b \) is a translation parameter, \( t \) is the time scale, and \( \psi'(t) \) is the complex conjugate function of \( \psi(t) \). The wavelet variance, \( \text{Var}(a) \), can be expressed as

\[
\text{Var}(a) = \int_{-\infty}^{\infty} |W_f(a, b)|^2 db
\]

(2)

The peak values in the graph of \( \text{Var}(a) \) correspond to the main periods of various time scales. In wavelet analysis, errors usually occur at the beginning and the end of a time series with finite length. Consequently, a symmetry extension is implemented at both the beginning and the end of the time series before wavelet transform. Otherwise, the 1-year natural period would be eliminated, and an annual time series anomaly would be used in the wavelet analysis.

3. Result

3.1. Trend analysis

3.1.1. Trend analysis of annual rainfall and runoff data According to the measured data, the annual average rainfall and runoff in Oujiang basin are analyzed. The results are shown in Figure 1, Figure 2 and Figure 3.

It can be seen from Figure 1 that the annual rainfall of each rainfall station is roughly coincident, with similar distribution rules, showing an upward trend. In addition, it can be seen from Figure 2 that the annual average rainfall in the basin also shows an upward trend. Further, it can be seen from Figure 3 that the total runoff of the drainage basin decreases.

The result indicate that the annual rainfall is accompanied by a slight increase, while the annual runoff is in a relatively rapid downward trend. The possible reasons are that many hydraulic structures, such as river dams, have been built near Xuren station, which cause the runoff to drop too fast in flood season and keep the water in dry season.

3.1.2. Mann Kendall trend test Based on the measured annual rainfall and runoff data of the hydrological stations in Oujiang River Basin, the change trend of the annual rainfall and runoff are analyzed by Mann Kendall trend test method. The test statistics value of Z for annual rainfall and runoff are 1.454 and -2.417, respectively. The results show that the annual rainfall shows an upward trend, and
the upward trend is significant. The annual runoff decreased with the increase of time, with a significant downward trend. The results are consistent with the above analysis.

Figure 1. Change trend of annual rainfall in each rainfall station

Figure 2. Change trend of annual average rainfall in the basin

Figure 3. Change trend of annual runoff
3.2. Periodicity analysis

Figure 4 shows the contour map of the wavelet coefficients for the deviation variations of annual average rainfall in the basin. A positive or negative value of the wavelet coefficients indicates the concentration or dilution of annual rainfall series, respectively. It is shown that the periodicity of the annual rainfall series exhibits three types of variation trends for different time-scales, i.e. 22-to 30-year scale, 10-to 22-year scale, and 3-to 10-year scale. The 22-to 28-year time scale is the dominant one. For the 22-to 28-year time cycle, there are three shocks of alternating high and low.

![Figure 4. The contour map of the wavelet coefficients for the deviation variations of annual rainfall](image1)

The contour maps of the wavelet coefficients for annual runoff series are shown in Figure 5. It is shown that the periodicity of the annual runoff time series exhibits three types of variation trends for different time-scales, i.e. 15-to 25-year scale, 8-to 15-year scale, and 3-to 8-year scale. The 15-to 25-year time scale is the dominant one. For the 15-to 25-year time cycle, there are five shocks of alternating high and low.

![Figure 5. The contour map of the wavelet coefficients for the deviation variations of annual runoff](image2)
4. Discussion
In this paper, the change characteristic of precipitation and runoff under annual scale of Oujiang River Basin in Zhejiang Province are analyzed in detail by using a variety of analytical methods. Some conclusions are obtained as follows: The annual average rainfall increases, and the annual runoff decreases in the past 50 years. The reason for this is that in 1960s, many hydraulic structures were built near Xuren station, such as river dams, which led to the rapid decline of runoff in the flood season, and the water was retained in the dry season. The results of Morlet wavelet analysis show that there is significant multi-time scale variation characteristic in the annual average rainfall and runoff sequences.

Acknowledgments
This study was supported by the National Natural Sciences Foundation of China (Grant number:51209096) and the Fundamental Research Funds for the Central Universities, South China University of Technology (Grant number: 2018MS62).

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