Study on the variation characteristics of rainstorm and flood in Puyang River Basin

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Abstract. Based on the measured rainfall and runoff data of 6 hydrological stations in the Puyang River Basin for many years, the trend of rainfall and runoff series are analyzed by using the methods of the regression analysis and the Mann-Kendall test in Puyang River Basin. The main conclusions are as follows: The trend analysis results show that the annual maximum 1-hour, 3-hour and 24-hour rainfall series in the Puyang River Basin is basically on the rise, but the flood and runoff series show a downward trend. It reflects that the main reason for the decrease of runoff in the Puyang River Basin is not the climate change. It is likely to be related to the impact of human activities. In summary, under the influence of climate change and human activities, human activities are the main reason for the decrease of runoff in the Puyang River Basin.

1. Introduction
Global climate change is a topical issue for the international scientific community. According to the IPCC fourth assessment report, the global air temperature rose by 0.74 °C in the past 100 years. The rise of air temperature has led to accelerated water circulation, increased precipitation and widened the extent of flooding. The change of precipitation and runoff in a variety of spatial and temporal scales has been of great concern in hydrology [1-8].

In the study, the Puyang River Basin is selected as the research region. Puyang River, originated in Jinhua City, is a major tributary of Qiantang River. The total length of Puyang river is 150km, and the drainage area is 3452km². The flood disaster in Puyang river basin is very frequent. In recent years, human activities are frequent in Puyang River Basin, such as reclamation, water resource utilization, construction of various water conservancy construction projects, etc. Human activities have changed the original topography of Puyang River Basin, resulting in the change of underlying surface conditions of the basin, and finally the conditions of runoff generation and concentration have changed. Coupled with global climate change, the characteristics of rainstorm and flood in Puyang River Basin become more complicated. Therefore, it is of great significance to study the impact of climate change and human activities on the runoff of Puyang river basin for the economic development, social stability and effective utilization of water resources along the Bank of Puyang River Basin. In this paper, the Puyang River Basin in Zhejiang Province is taken as the research object, and the precipitation and runoff sequence are analyzed by various analysis methods.
2. Data and Methods

2.1. Data

In this paper, six hydrometric stations, Anhua station, Chencai station, Henglingding station, Jieting station, Shibi reservoir station and Zhuji station, are selected as research objects. The data of these hydrometric stations used in the research includes rainfall and runoff data.

2.2. Methodology

There are many statistical methods available to detect trends within the time series such as linear regression, moving average, Mann–Kendall trend test, filtering technology, etc. Two statistical methods are used in this study to analyze the rainfall and runoff data: (1) The Mann-Kendall test. 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. (2) A simple linear regression method. It is used to test the long-term linear trends.

The nonparametric Mann–Kendall (MK) trend test has been considered to be the most appropriate tool for climate change analysis and has been commonly used for hydrologic time series data analysis such as water quality, stream flow, precipitation, and so on [9].

For a time series $x_1, x_2, \ldots, x_n$, in which $n>10$, the standard normal statistic $Z_c$ is estimated as follows:

$$Z_c = \begin{cases} \frac{(S-1)}{\sqrt{\text{var}(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{(S+1)}{\sqrt{\text{var}(S)}}, & S < 0 \end{cases}$$

(1)

Where

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} \text{sgn}(x_k - x_i)$$

(2)

$$\text{sgn} (\theta) = \begin{cases} 1, & \theta > 0 \\ 0, & \theta = 0 \\ -1, & \theta < 0 \end{cases}$$

(3)

Under the null hypothesis of no trend, and the assumption that the series are independent and identically distributed, the variance of the $S$ denoted by $\text{var}(S)$ is computed as:

$$\text{var}(S) = \frac{n(n-1)(2n+5)}{18}$$

(4)

If $Z_c > 0$, the series increase. In the other hand, if $Z_c < 0$, the series decrease. When $Z_c$ belongs to $-1.96 < Z_c \leq 1.96$, the null hypothesis is accepted. This indicates that there is no obvious variation trend in the samples. The trend is significant at the 95% confidence level if $|Z_c| > 1.96$.

3. Result

3.1. Trend analysis of annual maximum rainfall of 1-hour, 3-hour and 24-hour in the basin

According to the measured rainfall data of six hydrometric stations in Puyang River Basin, using linear trend regression analysis method, the change trend of the maximum 1-hour, 3-hour and 24-hour rainfall series in the basin is analyzed. The results are shown in Figure 1, 2 and 3.
Figure 1. Linear regression analysis result of annual maximum 1-hour rainfall in Puyang River Basin from 1963 to 2007.

y = 0.1487x - 258.99
R² = 0.0721

Figure 2. Linear regression analysis results of annual maximum 3-hour rainfall in Puyang River Basin from 1963 to 2007.

y = 0.0823x - 112.96
R² = 0.0109

Figure 3. Linear regression analysis results of annual maximum 24-hour rainfall in Puyang River Basin from 1963 to 2007.

y = 0.4112x - 731.3
R² = 0.0354

It can be seen from Figure 1, Figure 2 and Figure 3 that the annual maximum 1-hour, 3-hour and 24-hour rainfall series in Puyang river basin all show an upward trend. The test statistics of the annual
maximum 1-hour, 3-hour and 24-hour rainfall series fail to pass the test of 95% significance level, and the upward trend is not significant. The results are shown in Table 1.

Table 1. Test results of linear regression analysis for the annual maximum rainfall of 1-hour, 3-hour and 24-hour in Puyang River Basin.

| Variable                      | Test statistics value | Trend | Significant characteristic |
|-------------------------------|-----------------------|-------|----------------------------|
| Annual maximum 1-hour rainfall | 0.0721                | upward| not significant            |
| Annual maximum 3-hour rainfall | 0.0109                | upward| not significant            |
| Annual maximum 24-hour rainfall | 0.0354               | upward| not significant            |

Based on the measured rainfall data of six hydrological stations in Puyang River Basin from 1963 to 2007, the change trend of the annual maximum 1-hour, 3-hour and 24-hour rainfall in Puyang River Basin was analyzed by Mann Kendall trend test method. The Mann Kendall test results at the significance level of $\alpha = 0.05$, are shown in Table 2.

Table 2. Results of Mann Kendall test for the annual maximum rainfall of 1-hour, 3-hour and 24-hour in Puyang River Basin.

| Variable                      | S   | Z     | Critical value | Trend | Significant characteristic |
|-------------------------------|-----|-------|----------------|-------|----------------------------|
| Annual maximum 1-hour rainfall | 172 | 1.6728| 1.64           | upward| not significant            |
| Annual maximum 3-hour rainfall | 77  | 0.7435| 1.64           | upward| not significant            |
| Annual maximum 24-hour rainfall | 152 | 1.4771| 1.64           | upward| not significant            |

It can be seen from table 2 that the annual maximum 1-hour, 3-hour and 24-hour rainfall series of Puyang River Basin show an upward trend; the upward trend of its hydrological series is not significant excepting the annual maximum 1-hour rainfall.

3.2. Trend analysis of runoff change in River Basin

The linear regression analysis results of the annual runoff series of the basin are shown in Figure 4. It can be seen from Figure 4 that the annual runoff series of Zhuji station in Puyang River Basin shows a downward trend, and the change trend passes the 99% significance level test, and the downward trend is very significant.

Figure 4. Linear regression analysis results of annual runoff series of Zhuji station from 1953 to 2008.
According to the measured runoff data of Zhuji Hydrometric Station in Puyang River Basin, the change trend of its hydrological time series is analyzed by Mann Kendall trend test method. Mann Kendall test results at the significance level of $\alpha = 0.01$, are shown in Table 3.

Table 3. Mann Kendall test results of annual runoff series of Zhuji station in Puyang River Basin

| Variable           | S     | Z       | Critical value | Trend      | Significant characteristic |
|--------------------|-------|---------|----------------|------------|---------------------------|
| Annual runoff      | -474  | -3.3429 | 2.32           | downward   | significant               |

It can be seen from table 3 that the annual runoff series of Zhuji Hydrometric Station in Puyang River Basin shows a downward trend, which has passed the significance level test of 99%, and the downward trend is very significant (significance level of $\alpha = 0.01$).

The change trend of flood series is analyzed by Mann Kendall trend test method, shown in table 4. It can be seen from table 4 that the annual maximum discharge, the annual maximum 1-day flood volume and the annual maximum 3-days flood volume series of Zhuji Hydrometric Station in Puyang river basin all show a downward trend, and the trend fails to pass the 95% significance level test (significance level $\alpha = 0.05$).

Table 4. Results of Mann Kendall test for flood data series of Zhuji station.

| Variable             | S     | Z       | Critical value | Trend      | Significant characteristic |
|----------------------|-------|---------|----------------|------------|---------------------------|
| Annual maximum discharge | -70   | -0.4877 | 1.64           | downward   | not significant            |
| Annual maximum 1-day flood volume | -104  | -0.7280 | 1.64           | downward   | not significant            |
| Annual maximum 3-day flood volume | -186  | -1.3075 | 1.64           | downward   | not significant            |

4. Discussion

In this paper, the change characteristic of precipitation and runoff under different time scale of Puyang River Basin in Zhejiang Province are analyzed in detail by using a variety of analytical methods. Some conclusions are obtained as follows: On the whole, the short duration precipitation series shows an upward trend, but the flood series and annual runoff series show a downward trend. It indicates that climate change is not the main cause of the change of flood trend characteristics, and it is likely to be related to the change of underlying surface conditions and the impact of human activities, such as the construction of water conservancy construction projects, reclamation and farmland, which change the underlying surface conditions and runoff conditions of the basin, thus further affecting the runoff characteristics of the basin.

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