Variation and Trend Analysis of Rainfall in Qingshui River Basin of Ningxia in China

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Abstract. The study on the variation law and trend of rainfall characteristics of Qingshui River, a typical tributary of the upper Yellow River in China, is of great significance to reveal the cause of runoff and sediment change in the Yellow River. According to the daily rainfall data on 93 rainfall stations in the Qingshui River Basin from 1958 to 2015, the rainfall characteristics of the basin, such as annual rainfall, flood season rainfall, and main flood season rainfall were calculated. Using time-domain analogy, Mann-Kendall trend and abrupt change point test, coefficient of variation, etc., the variation and trend of rainfall characteristic values in the past 60 years were analyzed. The results showed that the distribution of rainfall during the periods from 1970 to 1979 and 2010 to 2015 was significantly different from other periods. There is no significant trend change in rainfall characteristic values from 1958 to 2015. From 1958 to 2015, the intensity of discrete changes in the rainfall characteristics of different series from small to large is the annual rainfall, flood season rainfall, and main flood season rainfall. The intensity of the discrete changes in main flood season rainfall gradually decreased with time.

1. Introduction

The situation of runoff and sediment in the Yellow River Basin has changed dramatically in recent years. The annual sediment load of Tongguan Hydrological Station has decreased from 1.6 billion tons in 1919-1959 to 1.5 billion tons since 2010, reduced by approximately 90.6%[1]. Although a lot of research work has been carried out on the variation of runoff and sediment in the Yellow River, the research area mostly focuses on the main stream and the typical tributaries of the middle reaches of the Yellow River, including the effects of rainfall and human activities on runoff, sediment and the relationship between runoff and sediment[2-6]. However, the study on rainfall variation and trend of typical tributaries in the upper reaches of the Yellow River is seldom involved. Since runoff mainly comes from the upper reaches and sediment mainly comes from the middle reaches, it is of great significance to study the variation law and trend of rainfall characteristics in the main tributaries of the upper reaches of the Yellow River for revealing the causes of the variation of runoff and sediment in the Yellow River.

Qingshui River is the largest and most eroded tributary of the Ningxia section of the Yellow River. The annual sediment load input to the Yellow River accounts for about 49% of the total sediment load of Ningxia[7]. Studying the variation and trend of rainfall characteristics in the Qingshui River Basin in the past 60 years can provide support for the study of situation of runoff and sediment in the Ningxia section of the Yellow River. In this paper, the daily rainfall data on 93 rainfall stations in Qingshui River Basin from 1958 to 2015 was counted, by using time-domain analogy, Mann-kendall trend and...
catastrophe test and the coefficient of variation, the variation and trend of the annual rainfall, the rainfall in flood season (June-September), and the rainfall in main flood season (July-August) of Qingshui River were analyzed.

2. Research method

2.1. Overview of the research area

The Qingshui River is 320 km long and has a basin area of 14481 km². It flows through 7 counties, including Yanzhou District, Haiyuan County, Xiji County, Tongxin County, Hongsibao District, Zhongning County, and Shapotou District, and flows into the Yellow River at Quanyuan Mountain of Zhongning County. The terrain of basin is high in the South and low in the north, with the Loess Hilly and gully area as its main geomorphology. The main tributaries on the left bank are Dongzhi River, Zhonghe River, Amandan River, Xihe River, Jinjier Valley and Changsha River, and the main tributaries on the right bank are Yangdazi Valley, Dahonggou, Shuangjingzi Valley, Zhishigou, Hongguan Valley, etc[7]. The annual rainfall in the Qingshui river basin ranges from 600 mm in the upper reaches to 200 mm in the lower reaches, with a difference of two times. The average annual rainfall in the basin is 349 mm. The southern part of Qiying and Xianma River in Guyuan is semi-arid area, and the northern part is arid area.

2.2. Data Processing

The daily rainfall data on 93 rainfall stations in Qingshui River Basin from 1958 to 2015 was counted. The annual rainfall, flood season rainfall, and main flood season rainfall were calculated by Tyson polygon method.

2.3. Analysis method

2.3.1. Mann-Kendall Trend and abrupt change point Test. Mann-Kendall test is a non-parametric statistical method to test the significance of the change trend of time series. It is widely used to assess the trend and abrupt change point of climate factors and hydrological series. In trend test, for time series $X$ with $n$ samples, the original hypothesis $H_0$ represents that the samples of data set $X$ are independently and identically distributed with no trend. Suppose $H_1$ represents a monotonic trend in data set $X$. For the Mann-Kendall statistic $Z_c$, if $-1/2 \leq Z_c \leq 1/2$, the null hypothesis $H_0$ is accepted, otherwise $H_1$ is accepted. The inclination $\beta$ can quantify the monotonic trend. When $\beta>0$, it reflects the upward trend, otherwise it reflects the downward trend. In abrupt change point test, the statistic $UF_k$ is an order normalization parameter of time series $X$ calculated in order, and $UB_k$ is a standard normal distribution. For a given significance level $a$, if the absolute value of $UF_k$ is greater than $U_a$, the sequence has a significant trend. $UB_k$ is an order normalized parameter calculated in reverse order of time series $X$. If the statistic $UF_k$ is greater than 0, it indicates that the sequence is increasing, and less than 0 indicates that it is decreasing. When $UF_k$ exceeds the critical value, it indicates that the upward or downward trend is significant, and the range exceeding the critical value is determined as the time zone where the sudden change occurs. If there is an intersection point between the two curves of $UF_k$ and $UB_k$, and the intersection point is between the critical lines, the moment corresponding to the intersection point is the moment when the sudden change starts, that is, the abrupt change point.

2.3.2. Coefficient of variation. Variation coefficient $C_v$ is an important parameter in hydrological statistics, which is used to explain the stability degree of long-term changes in hydrological variables. The larger the value of $C_v$ is, the more drastic the change of the variable is, on the contrary, the more stable it is.
3. Analysis of rainfall in three periods

From 1958 to 2015, the average of annual rainfall, flood season rainfall and main flood season rainfall were 362, 257, and 156 mm, respectively. The rainfall in flood season and main flood season accounted for 71% and 43% of annual rainfall respectively. The variation of rainfall characteristics in different periods compared with the multi-year average is shown in Figure 1, respectively.

The annual rainfall, flood season rainfall and main flood season rainfall in Qingshui River Basin maintained the same increase and decrease in 1958-1969, 1980-1989, 1990-1999 and 2000-2009, and the trend of increase or decrease of period average over multi-year average was consistent. In 1970-1979, the annual rainfall and main flood season rainfall increased, and the flood season rainfall decreased compared to the multi-year average. In 2010-2015, the annual rainfall and flood season rainfall increased, and the main flood season rainfall decreased compared to the multi-year average. There is no obvious regularity of the increase and decrease of the rainfall characteristic values in different periods.

4. Trend and abrupt change point test

The Mann-Kendall trend test statistics $Z$ and inclination $\beta$ of annual rainfall, flood season rainfall, and main flood season rainfall in Qingshui River Basin from 1958 to 2015 are shown in Tab 1. The $Z$ value and the $\beta$ value of annual rainfall and flood season rainfall are both positive, showing an increasing trend, but the trend is not significant. The increasing rate of flood season rainfall is greater than annual rainfall. The $Z$ value and $\beta$ value of main flood season rainfall are negative, showing a decreasing trend, and the trend is also not significant. In summary, there is no significant trend in the characteristic values of rainfall (significance level $\alpha=0.05$, $|Z_{0.05}|=1.64$).

| statistics | annual rainfall | flood season rainfall | main flood season rainfall |
|------------|-----------------|-----------------------|---------------------------|
| $Z$        | 0.2012          | 0.3488                | -0.644                    |
| Slope      | 0.1228          | 0.2108                | -0.2929                   |

Mann-Kendall abrupt change point tests of annual rainfall, flood season rainfall, main flood season rainfall in Qingshui River Basin from 1958 to 2015 are shown in Figure 2 to Figure 4, respectively.

Although there are some intersections between $U_F$ and $U_g$ in annual rainfall, flood season rainfall and main flood season rainfall, there is no significant change trend and abrupt change point, because $U_F$ does not exceed the critical value 1.96.
5. Variation coefficient
The variation process of $C_v$ value of annual rainfall, flood season rainfall and main flood season rainfall in Qingshui River Basin from 1958 to 2015 is shown in Figure 5. For the same period, except that the $C_v$ value of annual rainfall in 2000-2009 is slightly greater than flood season, in other periods, the $C_v$ values of annual rainfall, flood season rainfall and main flood season rainfall decrease in order. For the variation process of $C_v$ value in different periods from 1958 to 2015, the annual rainfall and flood season rainfall showed no obvious trend of fluctuation, while the main flood season rainfall showed a
decreasing trend. In terms of the long series from 1958 to 2015, the $C_v$ values from small to large are annual rainfall, flood season rainfall and main flood season rainfall. The analysis shows that for the whole period of 1958-2015 and a certain period, the dispersion of the rainfall characteristic values from small to large is the annual rainfall, flood season rainfall, and main flood season rainfall. The changes in annual rainfall, flood season rainfall and rainfall increase one by one. For each period from 1958 to 2015, the intensity of change of annual rainfall and flood season rainfall fluctuates with time and has no obvious trend. The dispersion of rainfall in the main flood season decreases with time, that is, the intensity of change decreases gradually.

![Figure 5. $C_v$ value of annual rainfall, flood season rainfall and main flood season rainfall](image)

6. Conclusions
The values of annual rainfall, flood season rainfall and main flood season rainfall in the Qingshui River Basin divided by multi-year mean have significant differences: during 1958-1969, 1980-1989, 1990-1999 and 2000-2009, all of the values keep the increase and decrease synchronized. During 1970-1979, the values of annual rainfall and main flood season rainfall increased, and the value of flood season rainfall decreased. During 2010-2015, the values of annual rainfall and flood season rainfall increased, the value of main flood season rainfall decreased. The annual distribution of rainfall varies greatly in different periods.

Mann-Kendall trend and abrupt change point test showed that there was no significant change trend of rainfall characteristic values from 1958 to 2015.

For the $C_v$ values of each rainfall characteristic value from 1958 to 2015, the intensity of discrete changes from small to large is the annual rainfall, flood season rainfall, and main flood season rainfall. For the $C_v$ values of each rainfall characteristic value at different time periods, the intensity of the discrete change of main flood season rainfall gradually decreases with time, and the other rainfall characteristic values have no obvious trend.

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