Trend analysis of monthly and annual runoff based on a segmented M-K method in Fuhe River basin, China

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Abstract. It is very important for water resource management to analyse the change rule of runoff. In this paper, a segmented Mann-Kendall trend analysis method, which is called segmented M-K method in the following, is proposed to analyse the periods of significant trend within the time series. This method fills in the gap that the changes of internal trend for long sequence are ignored in M-K trend test by finding out the significant change period within the long time series. It may be a new method for the analyse of runoff changes. Fuhe River, which is one of the main rivers of Poyang Lake in Yangtze River basin, is taken for example. Based on the runoff data of the Lijiadu section of the Fu River Basin from 1957 to 2015, the interannual variation of runoff over Lijiadu section in Fuhe River basin was quantitatively analysed by using a combined trend analysis method containing linear regression, sliding average, cumulative filter, Mann-Kendall trend test, Mann-Kendall mutation test and segmented M-K method. The results show a light interannual variety and a trend of insignificant increase in annual runoff for whole time series in Fuhe River Basin. However, an insignificant decrease trend, which might cause a shortage of water for development and utilization, is found in the period from 1997 to 2015 while a significant increase trend is found between 1963 and 1985. The annual runoff alternates frequently between abundance and drought. However, its interannual variation of monthly runoff is large, and 3 months include January, December and August show a significant increase. From the result of segmented M-K method, both significant increase trend period and significant decrease trend period could be found in flood season months, while only significant increase trend period is found in other months. In addition, the increasing period is close to the middle part of the total time series in dry season months, to the front part in flood season months, and to the rear part in months after flood season.

1. Introduction

Water resource is a clean, efficient and renewable resource. It is also one of the necessary resources for human life, grain growth and national economic development. Being greatly influenced by climate and uneven distribution in time and space are main characteristics of water resource. Surface runoff is one of the important ways to develop and utilize water resources. Exploring the trends of runoff change is of great significance for coping with floods and drought and for rational and sustainable development and utilization of water resources and the prevention of floods.
The water resources conditions that have changed significantly in the climate context and the deteriorating global water environment and ecological environment under the influence of human activities have constrained the sustainable development of social economy [1]. The global surface temperature has increased by 0.85°C in the past 100 years according to the 5th assessment report of Intergovernmental Panel on Climate Change (IPCC), and it may increase by 1.9-5.8°C in the next 100 years [2]. The increase in temperature will accelerate the circulation of the atmosphere and the hydrological cycle, leading to the redistribution of water resources at different scales around the world, which affects the ecological environment of the earth and the economic development of human society [3]. Obviously, the law of change in hydrological quantity is closely related to the scale. Hydrological phenomena vary with space and time and necessarily involve spatial and temporal scales. As far as the spatial scale is concerned, the basin as a confluence unit is the most commonly used spatial scale in hydrological analysis. The size of the basin is one of the factors affecting hydrological characteristics. The large, medium and small watersheds have hydrological characteristics that vary significantly due to different scales. As far as the time scale is concerned, the length and duration of time period are extremely important for hydrological characteristics. The hydrological quantities (daily average flow, monthly average flow, annual average flow, etc.) at different time periods exhibit different characteristics of variation [4]. Fuhe River basin (above Lijiadu section) is used as spatial scale and a 59-year period from 1957 to 2015 is considered to be temporal scale.

The hydrological runoff analysis method can be divided into theory-driven method and data-driven method. The theory-driven method is based on the hydrological basic concept and involves the entire hydrological physical process of runoff formation, which is accuracy and suitable for short-term runoff prediction. But it is difficult to implement effectively in production practice. The data-driven method is essentially a black box model. The mathematical analysis method is used to analyse a large number of measured data to obtain the law of runoff variation, so as to predict runoff. The formation of runoff is a highly complex nonlinear system. Many factors affecting runoff have progressed with the development of mathematical theory, and related model methods have been gradually improved. They have been widely used in hydrological prediction.

Scholars have done a lot of research based on time series analysis since it was recognized. In the trend analysis and evolution of hydrological time series, Mann-Kendall (M-K) trend test is a non-parametric test method recognized and actively recommended by the World Meteorological Organization. It has outstanding advantages in time series trend test, and was applied to the study of hydrology by many scholars [5-7]. Linear regression [5,8], cumulative curve method [9], student's t-test [6], Morlet wavelet analysis [10], Rescaled Range Analysis (R/S analysis) [11], ordered clustering method [12], combined analysis method theory [13,14], grey system theory [15,16], fuzzy mathematics [17,18] and other methods are also widely used in precipitation, runoff evolution trend and driving force analysis of various regions, watersheds and sections.

Among them, linear regression model, M-K trend and mutation analysis, wavelet analysis, R/S analysis are based on the analysis of time series variables, using a certain mathematical method to establish a model, so that the time series trend extends outward, thus obtaining the sequence development trends. The advantage of this kind of method is that it does not require complicated collection and processing of multiple types of factor data, and only relies on the time series itself to analyse its development trend. The accuracy of the result depends on the sequence length, and it can only be quantitatively analysed. The predicted value, fuzzy mathematics, grey theory and other methods all consider the influence of multiple forecasting factors on the forecasting object, so as to establish the mathematical relationship between the forecasting object and the forecasting factor. The predicted predictive value of the forecasting object can be obtained by quantitative calculation. Such methods involve multiple predictors, and the error of each predictor sequence, the judgment of the predictor and factor correlation, and the choice of the mathematical model will result in different degrees of prediction error.

Considering that the acquired data is limited to annual and monthly runoff series of the Lijiadu section, combined analysis method of the first type, including segmented Mann-Kendall trend analysis
method which is proposed in next section, is used to analyse and test the trend of the annual and monthly runoff at Lijiadu section of the Fuhe River Basin. Results obtained from the study would provide decision-making reference for local water resources development, utilization, management and allocation.

2. Study area and data used
Located in the eastern part of Jiangxi Province, Fuhe River is one of the main rivers of the Poyang Lake water system. The shape of the basin is rhomboid, long in the north and south, narrow in the east and west, with high altitude in the southeast, and low altitude in the northwest (figure 1). The basin is 240 km long from north to south, with an average width of 70 km, a maximum width of 140 km and a minimum width of 20 km. The elevation of the ground is between 17 and 1300 m. The total length of the main stream is 349 km. The catchment area above Lijiadu section is 15811 km$^2$ and the length of the river is 278 km. The average slope from its source to Lijiadu section is 2.09‰.

![Figure 1. Water system map of Fuhe River Basin.](image)

The Fu River Basin (above the Lijiadu section) has a runoff of 22545 million m$^3$ (abbreviated as mm$^3$) in 2015, 16170 mm$^3$ for multi-year average, 16465 mm$^3$ for guaranteed rate P=50% (normal years), 13647 mm$^3$ for P= 75% (dry years), and 10221 mm$^3$ for P=90% (extremely dry years). Its flood season is from April to July of the year, and the dry season is from October to March. According to Jiangxi Water Resources Bulletin, the length of river where the water quality is superior to Class III is 723.4 km, accounting for 82.7% of the total river channel in Fuhe as of 2015. The main polluted river section is Chongren section and Dongxiang section, mainly indicators which not up to standard are pH, permanganate index, chemical oxygen demand and dissolved oxygen. There are 38 water function zones in Fuhe (above Lijiadu section). 36 water function zones were up to standard in whole year out of 38 zones evaluated in 2015, and the compliance rate was 94.7%. The main water conservancy hubs above the Lijiadu section of Fuhe River include Hongmen Reservoir and Liaofang Reservoir. While Hongmen Reservoir with a total storage capacity of 1214 mm$^3$ focuses power generation Liaofang Reservoir (storage capacity is 364 mm$^3$) is mainly for flood control and irrigation. The water supply in the basin is mainly surface water. The water supply was 2017 mm$^3$ in total in the basin (above Lijiadu section) in 2015, of which 1936 mm$^3$ was from surface water while other 81 mm$^3$ was from ground
water. Of the 1936 mm³ surface water supply, 741 mm³ comes from storage projects, 630 mm³ comes from diversion projects, and 565 mm³ comes from lifting projects. Compared with the average annual runoff, the utilization rate of surface water resources is 11.97%. There is a large potential for development and utilization.

The runoff data of Lijiadu section from 1957 to 2015 is selected to analyze the interannual and annual variation of runoff, and to provide scientific basis for flood control, drought resistance and water resources development and utilization in this basin.

3. Data and method

3.1. Data sources
The monthly and annual runoff data from 1957 to 2015 at Lijiadu section, which is shown in table 1, was calculated from the measured daily flow data at Lijiadu Hydrological Station. Lijiadu Hydrological Station is the downstream control station of Fuhe River, with a controlled area of 15811 km². In August 1952, the Jiangxi Provincial Water Conservancy Bureau set Lijiadu water level station to observe the water level. In 1953, it was changed to a hydrological station, and the flow rate, sediment concentration, precipitation, evaporation, and meteorology were measured. The actual measured runoff data of the station is tested, collated and reorganized according to the requirements of hydrological test specifications. The data is accurate and reliable, and the accuracy of the results is high. The selected 59-year data cover dry, normal and abundant years, and is continuous and complete with good representativeness.

| Year  | 1957       | 1958       | 1959       | 1960       | 1961       | ……   | 2015       |
|-------|------------|------------|------------|------------|------------|------|------------|
| January | 221.568    | 426.432    | 246.48     | 530.928    | 465.792    | ……  | 474.144    |
| February | 921.648    | 953.712    | 1389.072   | 309.936    | 703.2      | ……  | 328.032    |
| March   | 1655.136   | 1098.528   | 1893.216   | 1228.56    | 2118.672   | ……  | 1004.688   |
| April   | 2404.608   | 1449.312   | 1785.504   | 1684.848   | 4029.744   | ……  | 711.552    |
| May     | 4199.136   | 3137.184   | 1926.528   | 3962.544   | 2986.32    | ……  | 3609.216   |
| June    | 3668.256   | 2294.304   | 8254.08    | 3007.584   | 5947.68    | ……  | 2761.392   |
| July    | 814.752    | 1417.824   | 1975.488   | 951.648    | 1401.36    | ……  | 2213.472   |
| August  | 868.992    | 656.688    | 1354.32    | 2363.472   | 3041.424   | ……  | 1551.84    |
| September | 750.096   | 768.816    | 2395.2     | 1082.976   | 6041.28    | ……  | 1376.688   |
| October  | 1101.744   | 578.112    | 680.832    | 659.04     | 1530.672   | ……  | 889.344    |
| November | 708.624    | 265.584    | 711.072    | 517.44     | 1036.512   | ……  | 2377.392   |
| December | 529.248    | 217.488    | 588.144    | 539.424    | 911.568    | ……  | 2737.584   |
| Annual  | 17843.81   | 13263.98   | 16838.4    | 30214.22   | 3007.584   | ……  | 20035.34   |

3.2. Method
Combined time series trend analysis method is used to analyze the acquired data. Anomaly map and AR linear regression analysis are firstly used to make an intuitive view of original data sequence trend. And then moving average filtering and the cumulative average filtering are used to reduce the influence of data fluctuations and carry out the second trend discrimination. After that, M-K trend test and the mutation test are used to discriminate and test the variation trend of the annual runoff and monthly runoff series in the Fu River Basin from 1957 to 2015. Finally, segmented Mann-Kendall trend analysis (segmented M-K) method was employed in the seeking for significant periods within whole time series. Observe whether the methods are consistent in the discrimination of the sequence trend, analyze the reasons and obtain conclusions finally.

- Linear regression is a statistical analysis method used to determine the quantitative relationship between two or more variables [19]. It is expressed in the time series as establishing a linear relationship between the variable and time. When the regression coefficient is greater than 0, it indicates that the time series rises, conversely, it indicates that
the time series falls when it is less than 0.

• The sliding average is equivalent to a low-pass filter, and the sequence change trend is displayed by smoothing the value [20]. The $k^{th}$ moving average means that form a new series with giving the $i^{th}$ order to the average of k values symmetrically before and after $x_i$ which is the $i^{th}$ value of initial series to reduce fluctuations.

• The accumulation filter reflects the qualitative change trend of the time series by averaging the first i values as the $i^{th}$ value of the new sequence to form a cumulative average curve [21].

• Mann-Kendall (M-K) test method is widely used in watershed annual runoff series trend and mutation point test [22] with wide practical range, less human influence and high degree of quantification. It does not require observations to obey a certain distribution, nor is it interfered with individual outliers, and the calculation is simple.

In the Mann-Kendall test, null hypothesis $H_0$ is described as time series $(x_1, ..., x_n)$ are a set of independent identically distributed samples; alternative hypothesis $H_1$ is described as time series $(x_1, ..., x_n)$ has an increasing or decreasing trend. Theoretical description of M-K test is expressed as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sgn(x_j - x_i)$$

And:

$$Sgn(x_j - x_i) = \begin{cases} 
1 & x_j > x_i \\
0 & x_j = x_i \\
-1 & x_j < x_i 
\end{cases}$$

$S$ is a normal distribution with mean $E(S)=0$, variance $\text{Var}(S)=n(n-1)(2n+5)/18$. When $n>10$, the statistical variables are normalized as:

$$Z = \begin{cases} 
\frac{S - 1}{\sqrt{\text{Var}(S)}} & s > 0 \\
0 & s = 0 \\
\frac{S + 1}{\sqrt{\text{Var}(S)}} & s < 0 
\end{cases}$$

In the bilateral test, the significance level $\alpha$ is taken. When $|Z| < Z_{1-\alpha/2}$, the null hypothesis is accepted and there is no significant trend in the sequence. Otherwise, $Z<0$ means that the sequence has a significant downward trend, and $Z>0$ indicates a significant upward trend.

The M-K test can also be used to test mutation points of sequence by changing the test statistic, constructing the order column as:

$$S_k = \sum_{i=1}^{k} \sum_{j=1}^{i-1} \alpha_{ij} \quad (k = 2, 3, 4, ..., n)$$

$$\alpha_{ij} = \begin{cases} 
1 & x_i > x_j \\
0 & x_i \leq x_j 
\end{cases}$$

Define statistical variables as:

$$UF_k = \frac{S_k - E(S_k)}{\sqrt{\text{Var}(S_k)}}$$

And $E(S_k) = k(k + 1)/4$; $\text{Var}(S_k) = k(k - 1)(2k + 5)/72$. $UF_k$ is a standard normal distribution. Given the significance level $\alpha$, if $|UF_k| < U_{1-\alpha/2}$, null hypothesis is received. Otherwise, there is a clear trend in the sequence. Then arrange x in order, and
construct $UB_k = -UF_k; k = n + 1 - k$. Plot the two curves of $UF_k$ and $UB_k$, and draw two critical lines with $\pm U_{1-\alpha/2}$. The sequence shows an upward trend when $UF_k > 0$, and $UB_k < 0$ indicates a downward trend; when $UF_k$ exceeds the critical line, it indicates that the rising or falling trend is significant. If there is an intersection point between $UF_k$ and $UB_k$, the intersection point is the moment when the mutation starts [23,24].

- The main idea of segmented Mann-Kendall trend analysis (segmented M-K ) method is to segment the long time series with suitable step length, so that inner trends rise. Suppose a time sequence of length n is divided into m periods. And the p<sup>th</sup> period step length is $r_p$. $r_p > 10$ (p=1,2,3……, m).

Calculate:

$$S_p = \sum_{i=1}^{r_p-1} \sum_{j=i+1}^{r_p} Sgn(x_{p,j} - x_{p,i})$$

$$Z_p = \begin{cases} 
\frac{S_p - 1}{\sqrt{Var(S_p)}} & S_p > 0 \\
0 & S_p = 0 \\
\frac{S_p + 1}{\sqrt{Var(S_p)}} & S_p < 0 
\end{cases}$$

The significance level $\alpha$ is taken. The p<sup>th</sup> period is an increase trend period when $Z_p > 0$. To the contrary, the p<sup>th</sup> period is a decrease trend period when $Z_p < 0$. And the trend is significant when $|Z_p| > Z_{1-\alpha/2}$. $Z_{max}$, the max value of $Z_p$ (p=1,2,3……, m), correspond the most significant increasing period if $Z_{max} > 0$. $Z_{min}$, the min value, correspond the most significant decreasing period if $Z_{min} < 0$.

There are 3 methods supplied for period division.

- Continuous uncrossed fixed step period division. Select a certain step length r according to the demand, and enter the next period immediately after the previous period is completely over. In order to ensure that the residual data at the end of the sequence can also be considered, the forward and backward direction partition method is adopted.

- Crossed fixed step period division. Select the appropriate step length r as above. And enter the next period before the end of previous period. The start points between two next periods have a fixed interval of $\Delta$. If the starting time of the i<sup>th</sup> period is $t_i$, the step length is r, and the ending time is $t_{i+r-1}$. Then the starting time of the (i +1)<sup>th</sup> period is $t_{i+\Delta}$, and the ending time is $t_{i+\Delta+r-1}$.

- Crossed period division with varied step length. M-K mutation test was performed on time series to select the mutation points. Then form periods with starting moment, ending moment, and the points. Obviously, each period may have different step length from others.

The significant trend periods obtained by calculation should be merged if they are coterminal and have codirectional trend. If the inclusion relation appears in these periods, the period with long step would be taken. If there is a crossover, period with strong significant trend would be taken and then change the start point or end point of the weak one and re-analyze it. The periods with significant trend shall be uncrossed finally.

4. Analysis

4.1. Interannual variation characteristics of annual runoff

The factors affecting runoff are complex, and interannual variations in climate, underlying surface changes and human activities could be some of them. The annual average annual runoff of Lijiadu
Hydrological Station is 16170 mm³. The interannual variation of runoff is small, the abundance and drought alternate. The maximum annual runoff of the section is 31397.47 mm³ (1963a), and the minimum annual runoff is 6516.72 mm³ (1975a). The inter-maximum ratio is 4.8, and the annual runoff variation coefficient $C_v = 0.3$.

According to the anomaly map, the 18 years annual runoff of Lijiadu section is higher than the average, 21 are below the average, and the remaining 20 years are small fluctuations around the average (figure 2). It can be seen that the number of years when the annual runoff of Lijiadu section is small is roughly equal to the number of years when it is big, and equals the number when it is normal in the 59 years. The annual runoff of Lijiadu section shows an alternating trend of abundance and drought, and the interannual variation tends to be stable.

4.2. Trend analysis of annual runoff

According to the annual runoff data of Lijiadu section, the runoff variation curve is made, as shown in figure 3. Linear regression analysis was used to analyze the linear runoff curve of the Lijiadu section. The linear trend method assumes that the runoff sequence increases or decreases at a constant rate. From the linear trend in figure 3, the annual runoff of the Lijiadu hydrological station showed a slight upward trend, with a slight increase of 10.033 mm³/a.

Use the moving average method to draw the moving average curve and select 5-year as the sliding period. After the sliding average, the cycle period shorter than the sliding length in the sequence is weakened, and the trend of change is showed [25]. According to the 5-year moving average curve (figure 4), it can be seen that: the annual runoff of the section shows a downward trend from 1957 to 1964, and a fluctuating upward trend from 1964 to 1974. There are two floods occurred in 1973 and 1975, resulting in the largest two values in the sequence and a clear upward trend. After a short-term uptrend between 1978-1983 and 1988-1995, the annual runoff of the section shows a downward trend and a steady trend from 1995 to 2015. From the sliding average curve, the overall upward trend lasts for a short time but the change is large, and the downward trend lasts for a long time, but the change is small.

The cumulative filter method can fully reflect the qualitative trend of time series. We use the cumulative filter method to plot the cumulative average curve of Lijiadu section annual runoff (figure 5). The runoff of the Lijiadu section shows an upward trend overall, with a clear upward trend from 1958 to 1962, a clear downward trend from 1962 to 1972, and a relatively flat upward trend after 1976.

In terms of M-K trend analysis method, the $Z$ value is calculated to be $0.458$. Since $Z = 0.458 > 0$, the annual runoff of the Lijiadu section has an increasing trend. When the significance level $\alpha = 0.05$, $Z_{1-\alpha/2} = 1.96$. Obviously $|Z| < Z_{1-\alpha/2}$. The result indicates that the upward trend of the Lijiadu annual runoff series is not significant.
Taking 1957 as the start point and 10-year as a fixed step length, the time series with 59 years’ data would be successively segmented into \( n = \left[ \frac{59}{10} \right] = 5 \) uncrossed and coterminous periods leaving 9 years’ data as the rest. In order to make full use of the residual data, the reverse sequence is constructed to segment other 5 periods with the same step as above, taking 2015 as the first starting year. At this point, the existing data has been fully considered, and 10 periods have been obtained in the time series with a total length of 59 years. Consider that the reverse sequence period should be opposite to normal one in the analysis. Similarly, taking 20-year and 30-year as a fixed step respectively, the annual runoff sequence was analyzed with segmented M-K method under continuous uncrossed period division. The results are shown in table 2.

### Table 2. Analysis result of Lijiadu annual runoff in segmented M-K method under continuous uncrossed period fixed step period division.

| Pace | Rank | Period      | Statistics | Trend  | Significance |
|------|------|-------------|------------|--------|--------------|
| 10   | 1    | 1957-1966   | -0.72      | Decrease | Non-significant |
| 2    | 1967-1976 | 1.43      | Increase   | Non-significant |
| 3    | 1977-1986 | 0.89      | Increase   | Non-significant |
| 4    | 1987-1996 | 0.72      | Increase   | Non-significant |
| 5    | 1997-2006 | 0.72      | Increase   | Non-significant |
| 6    | 2015-2006 | 0.18      | Increase   | Non-significant |
| 7    | 2005-1996 | 0.89      | Increase   | Non-significant |
| 8    | 1995-1986 | 1.61      | Decrease   | Non-significant |
| 9    | 1985-1976 | 1.07      | Decrease   | Non-significant |
| 10   | 1975-1966 | 1.07      | Decrease   | Non-significant |
| 20   | 1    | 1957-1976   | 0.62      | Increase   | Non-significant |
| 2    | 1977-1996 | 0.49      | Increase   | Non-significant |
| 3    | 2015-1996 | 0.68      | Increase   | Non-significant |
| 4    | 1995-1976 | 0.16      | Increase   | Non-significant |
| 30   | 1    | 1957-1986   | 0.75      | Increase   | Non-significant |
| 2    | 2015-1986 | -0.25  | Decrease   | Non-significant |

As can be seen from the table, annual runoff presented no significant change in all periods. Among them, annual runoff from 1957 to 1966 presented an insignificant decrease trend, while other positive periods presented an insignificant increase trend.

The annual runoff of Lijiadu section was analyzed in segmented M-K under crossed period fixed
step period division and interval of 1 year. The results are shown in figure 6.

Figure 6. Analysis result of the annual runoff in Lijiadu section in segmented M-K under crossed period fixed step period division.

Figure 6 indicates that the annual runoff in Lijiadu section presented a significant trend of decrease from 1983 to 1992. However, it increased significantly from 1963 to 1982, 1964 to 1983, 1965 to 1984 and 1966 to 1985. Since they have adjacent start point and end point and show the same trend, a period from 1963 to 1985 is taken as expansion of the original ones. Calculate the value of Z for the new period. \( Z = 2.33 > 1.96 \). It shows that the annual runoff series of Lijiadu section showed a significant increase trend from 1963 to 1985. No significant change trend was found in other periods.

Figure 7. M-K trend analysis diagram of the Lijiadu annual runoff.

Using the M-K mutation test method, the M-K trend analysis diagram of the Lijiadu section annual runoff series is plotted (figure 7). It can be seen from figure 5 that: from 1957 to 1982, \( UF_k < 0 \),
indicating the runoff shows a downward trend; after 1982, \( U_F k < 0 \) from 1989 to 1994 and \( U_F k > 0 \) for the rest periods, indicating that the overall runoff in this range is on the rise. The \( U_F k \) and \( U_B k \) curves have 9 intersections between 1957 and 2015, and 3 of them failed to reach the degree of mutation. The remaining 6 were evenly distributed in the middle and late stages of the sequence, reflecting the alternate appearance of runoff series and the short cycle and high frequency in alternating abundance and dry of the annual runoff in Lijiadu section. Added two points, start point and end point, the number of typical points increases to 11 from 9. All these time points form 53 periods of which the step length is no shorter than 10. We call these periods typical periods. The step lengths and start and end point is shown in table 3. Calculate the value of Z for each typical period above. The result is shown in table 4.

| start | 1970 | 1974 | 1977 | 1983 | 1990 | 1994 | 1997 | 2002 | 2011 | 2015 |
|-------|------|------|------|------|------|------|------|------|------|------|
| 1957  | 14   | 18   | 21   | 27   | 34   | 38   | 41   | 46   | 55   | 59   |
| 1962  | 13   | 16   | 22   | 29   | 33   | 36   | 41   | 50   | 54   |      |
| 1970  |      |      | 14   | 21   | 25   | 28   | 33   | 42   | 46   |      |
| 1974  | 10   | 17   | 21   | 24   | 29   | 38   | 42   |      |      |      |
| 1977  | 14   | 18   | 21   | 26   | 35   | 39   |      |      |      |      |
| 1983  |      |      | 12   | 15   | 20   | 29   | 33   |      |      |      |
| 1990  |      |      |      |      | 13   | 22   | 26   |      |      |      |
| 1994  |      |      |      |      | 18   | 22   |      |      |      |      |
| 1997  |      |      |      |      | 15   | 19   |      |      |      |      |
| 2002  |      |      |      |      | 10   | 14   |      |      |      |      |

| start | 1970 | 1974 | 1977 | 1983 | 1990 | 1994 | 1997 | 2002 | 2011 | 2015 |
|-------|------|------|------|------|------|------|------|------|------|------|
| 1957  | -0.22| -0.30| 0.51 | 1.00 | 0.42 | 0.58 | 0.98 | 1.42 | 0.29 | 0.46 |
| 1962  | 0.55 | 1.40 | 1.90 | 0.96 | 1.10 | 1.48 | 1.80 | 0.65 | 0.82 |      |
| 1970  | 0.88 | -0.39| -0.12| 0.30 | 0.76 | -0.50| -0.30|      |      |      |
| 1974  | 0.72 | -0.87| -0.39| 0.17 | 0.73 | -0.63| -0.41|      |      |      |
| 1977  |      | -0.11| 0.30 | 0.94 | 1.45 | -0.09| 0.07 |      |      |      |
| 1983  |      | -0.21| 0.30 | 0.81 | -0.69| -0.45|      |      |      |      |
| 1990  |      |      |      | 0.55 | -1.07| -0.84|      |      |      |      |
| 1994  |      |      |      |      | -1.29| -1.07|      |      |      |      |
| 1997  |      |      |      |      | -1.29| -0.77|      |      |      |      |
| 2002  |      |      |      |      | -0.54| -1.29|      |      |      |      |

It can be seen from the table that there is no significant change before and after the change point of M-K mutation test. Among them, the max statistics value is 1.90 which is linked to the period from 1962 to 1983. Therefore, an insignificant increase trend is found in the period from 1962 to 1983. As the period from 1963 to 1985 is calculated to be a significant increase trend period in segmented M-K under crossed fixed period step division, typical point division is not better than crossed fixed step period division in seeking most significant period.

4.3. Trend analysis of monthly runoff

In terms of different months, the average monthly runoff of the Lijiadu section is showed in figure 8. As can be seen from the figure, the largest runoff of the Lijiadu section in the Fuhe River Basin is from April to June, and the monthly runoff is significantly reduced after July.
The trend analysis of monthly runoff is shown in table 5. It can be seen from the table that the monthly runoff coefficient $C_v$ of the Lijiadu section ranges from 0.5 to 0.78, indicating that monthly runoff has a large interannual variation. The monthly runoffs showed a significant increase trend in January, August and December, non-significant increase trend in February, March, July, November, and non-significant decrease trend in April, June and October. Due to a flood in the early stage of the sequence, the cumulative filter method shows a wrong trend judgment in September. Because January and December are the dry seasons of the Fu River Basin, and the average monthly runoff has been turned down at the end of the flood seasons in August, it is known that the increase in the monthly runoff of the Lijiadu section in January, August and December reflects a good change in runoff’s distribution during the year in the Lijiadu section. For dry season months, there is a significant decrease trend period in the middle of the time series in December and January. For flood season months, March, April and May each have a significant increase trend period in the front part of the sequence, while a significant decrease trend period follows in April, May and June. For the months after the flood season, July, August and September show a long significant increase trend period in the total sequence.

| Month | $C_v$ | Mann-Kendall Trend Test | Significant period | Decrease period |
|-------|-------|--------------------------|--------------------|-----------------|
| 1     | 0.59  | Increase                 | 23-42              | No              |
| 2     | 0.66  | Increase                 | No                 | No              |
| 3     | 0.74  | Increase                 | 7-36               | No              |
| 4     | 0.50  | Decrease                 | 7-28               | 34-53           |
| 5     | 0.41  | Decrease                 | 7-26               | 26-53           |
| 6     | 0.51  | Decrease                 | No                 | 17-36           |
| 7     | 0.53  | Increase                 | 22-41              | No              |
| 8     | 0.56  | Increase                 | 21-52              | No              |
| 9     | 0.72  | Decrease                 | 7-46               | 2.5             |
| 10    | 0.58  | Decrease                 | No                 | No              |
| 11    | 0.64  | Increase                 | No                 | No              |
| 12    | 0.69  | Increase                 | 27-46              | No              |

*1 Here uses the rank number to refer to the year. 1 refers to 1957, 2 refers to 1958,…, and 59 refers to 2015.*

5. Conclusion

- Segmented Mann-Kendall trend analysis (segmented M-K) method is proposed to fill in the gap that the changes of internal trend for long sequence are ignored in M-K trend test, by
finding out the significant change period within the long time series. It is used in the trend analysis of monthly and annual runoff, and find the significant change period successfully in Lijiadu section. It may be a new method for the analyses of runoff changes.

- This paper uses linear regression, sliding average, cumulative filter, Mann-Kendall trend test, Mann-Kendall mutation test, and segmented Mann-Kendall trend analysis (segmented M-K) method to quantitatively analyze the interannual variation of annual runoff in the Lijiadu section of the Fuhe River Basin. It is found that the annual runoff of the Lijiadu section has a small deviation and light interannual variety. And it alternates frequently between abundance and drought. There is an insignificant increase trend of annual runoff from 1957 to 2015, an observable first rise and then change trend between 1957 and 1975 in Lijiadu section, and a slight increase trend from 1975 to 2015, reflecting that the annual runoff of the Lijiadu section is gradually stabilizing. However, an insignificant decrease trend is found in the period from 1997 to 2015 while a significant increase trend is found between 1963 and 1985. Such an insignificant downward trend deserves our attention in order to cope with the pressure of development and utilization as well as the deterioration of water quality and environment caused by the coming shortage of water resources. One of the points in the significant change period is 1963, when the Hongmen reservoir begun to store water. The relationship between reservoir regulation and annual runoff change is worth further study.

- The interannual variation of the monthly runoff in the Lijiadu section of the Fuhe River Basin uses the method of dispersion analysis, Mann-Kendall time series trend test, cumulative filter and segmented M-K method. The results obtained are as follows: the interannual variation of monthly runoff is large, and because the annual runoff changes stably, the Fu River Basin is prone to extreme drought and extreme disasters in the same year. Nine of the 12-month monthly runoffs show an increasing trend, with 3 significant growth trends and 6 non-significant growth trends. The months with significant growth trends are January, August and December. January and December are the dry seasons of the Fuhe River Basin. August follows the end of the flood season. It can be seen that the increase trend of monthly runoff of the Lijiadu section is in January, August and December reflects the gradual improvement in the distribution of monthly runoff in Lijiadu section during the year. From the result of segmented M-K, both significant increase trend period and significant decrease trend period could be found in flood season months, while only significant increase trend period is found in other months. In addition, the increasing period is close to the middle part of the total time series in dry season months, to the front part in flood season months, and to the rear part in months after flood season.

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