Analysis of runoff variation characteristics in Yishuhe River Basin

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Abstract. Yishuhe River Basin is located in the northeast of the Yishusi River Basin, with the watershed area of about 18200 km\textsuperscript{2}. It is necessary to analyze the variety characteristics of runoff in Yishuhe River Basin, and it will provide technical support for flood control and drought relief. Based on the past continuous 60 years’ data of runoff measured at 2 hydrometric stations and precipitation at 23 precipitation stations in Yishuhe River Basin, this study analyzed the monthly and annual variation characteristics of the runoff in Yishuhe River Basin using some indexes and methods such as complete regulation coefficient and non-uniformity coefficient, concentration ratio, concentration period, Man-Kendall trend test and mutation detection, and so on. The research results indicate that the distribution of annual runoff in Yishuhe River Basin is uneven, the monthly maximum precipitation occurs in August generally, and the continuous four months’ runoff even accounts for 80% of that of the year. The annual runoff shows a decreasing trend with time at Linyi station in Yihe River and Daguanzhuang station in Shuhe River, and the tendency of runoff reduction is significant in Yihe River with an abrupt point happening in 1966 and 2013.

1. Introduction
River flow is a and highly complex process [1,2] affected by natural and human factors with typical nonlinear and non-stationary characteristics, and its variation has respect to the coordination and development of a regional economy. The analysis of runoff variation helps to find the changing trend of surface water resources and provides the scientific basis for the rational and sustainable utilization of water resources.

Mahsa [3] studied the trend analysis of rainfall time series in arid and semiarid regions and found in November and December most of the stations had upward trends, while in March and May the predominant trend was downward. On the basis of Mahsa’s study, Barati and Khazaei [4] improved the analysis through the ITA technique. Hadi [5] studied monthly rainfall data over the central India for the period 1901-2010. They found most of the stations have decreasing trends in annual, summer, and monsoon seasons, while the winter and post monsoon seasons generally show increasing trend. Isioma [6] used non-parameters Mann-Kendall test to detect and estimate the magnitude of trend associated with rainfall data. Results showed a significant decreasing trend in Benin City in the coastal region of Nigeria. Gedefaw [7] studied the annual and seasonal rainfall variability in Amhara Regional State. They found the decrease in number of rainy days, leading to an increase of extreme rainfall events over the region during 1980–2016. Bigi [8] focused on past, present, and future precipitation trends for the city of Niamey through the combined assessment of WMO precipitation indices using RClimDex and the Standardized Precipitation Index. They found a precipitation recovery after the dry epoch (1968-1985), and WATCH-Forcing-Data-ERA-Interim projections that the precipitation will...
increase in the future.

Yi river and Shu river are two main tributaries of Yishusi River Basin. The uneven spatial and temporal distribution causes water shortage frequently in this basin. The local water resources become the main source for water supply [9] because of the uneven distribution of precipitation within the basin. However, the water consumption increases significantly due to the rapid development of the local economy, and the contradiction between water supply and demand becomes very prominent. In order to reveal the variety rule and changing trend of runoff in Yishuhe river basin, this paper analyses the seasonal and annual variation characteristics by use of some indexes and methods including the complete adjustment factor and non-uniform coefficient among months, centralization degree, centralization period, Man-Kendall trend test and mutation detection. During the analysis, the paper selects the continuously 60 years’ precipitation data at 23 rain-gage stations, and the runoff data at Linyi and Daguanzhuang hydrological stations which are located in the main stream of Yihe river and Shuhe river respectively.

2. General situation of Yishuhe river basin

Yishuhe river basin is located in the northeast of the Yishusi River Basin, with 117°25′～119°50′ of east longitude, 34°00′～36°20′ of north latitude, and the area of the basin is about 18,200 km². Yihe river and Shuhe river flow from north to south in parallel, through Shandong and Jiangsu province, concentrating into Luoma Lake and Xinyi River at Miao Wei town and Koutou town of Xinyi City respectively [9]. Owing to the central location in the region, Yihe River and Shuhe River make the whole region a fan alluvial plain from north to south. The basin is shown in figure 1.

![Figure 1. Location of Yishuhe River Basin.](image)

Due to its transitional climate in the temperate monsoon region, the precipitation of the basin mainly concentrates in summer, while little rain and snow in winter. The average annual precipitation
is 803.6 mm with great spatial variation, decreasing from southeast to northwest.

3. Materials and method

3.1. Data source
According to the characteristics of Yishuhe river basin, layouts of the hydrological stations and water conservancy projects, the paper selected 2 hydrological stations named Linyi and Daguanzhuang, 15 rainfall stations in Yihe river, and 8 rainfall stations in Shuhe river to support the analysis. All the Meteorological data is from the Yishusi River Basin Administration with high precision and enough length. Table 1 gives the list of the stations.

| River          | hydrometric stations | Rain-gauge stations                          | Time series            |
|---------------|----------------------|----------------------------------------------|------------------------|
| Yihe river    | Lin-yi               | Xujiazhuang, Tianzhuang reservoir, Donglidian, Xiewu, Mengyi, 1956-2015 |
|               |                      | Zhujiao, Fuwangzhuang, Gegou, Tangcun reservoir, Yangzhuang, Baiyan, Xujiaiyareservoir, Jiangzhuanghu, Linyi, Gangshang |
| Shuhe river   | Da-guan-zhuang       | Shagou Reservoir, Qingfengling reservoir, Juxian, Doushan, Shilaya, 1956-2015 |
|               |                      | Daguanzhuang, Tancheng, Xin’an               |

Data Source: Yishusi River Basin Administration.

Arithmetical average mean method is used to calculate the average precipitation in the basin considering that the geographical uniform distribution of rainfall stations and it can basically reflect the varying trend of precipitation in the whole basin.

3.2. Methodology

3.2.1. Monthly distribution of runoff. In the analysis, the complete adjustment factor and non-uniform coefficient of seasonal distribution [10] are adopted to reflect the non-uniformity of runoff, and the indexes of concentration ratio and concentration period [11] are used to analyze the runoff concentration within the year.

The annual complete poundage factor $C_v$ and the uneven distribution coefficient $C_u$ of runoff are respectively defined as follows.

$$C_v = \sum_{i=1}^{12} \phi_i (R_i - \overline{R}) \sum_{i=1}^{12} R_i$$

$$\phi_i = \begin{cases} 0, & R_i < \overline{R} \\ 1, & R_i \geq \overline{R} \end{cases}$$

$$C_u = \frac{1}{\overline{R}} \sqrt{\frac{1}{12} \sum_{i=1}^{12} (R_i - \overline{R})^2} - \overline{R} = \frac{1}{12} \sum_{i=1}^{12} R_i$$

Where: $R_i$ is the ith monthly flow of the given year; $\overline{R}$ is the average monthly flow of the year.

Normally, the larger of the monthly complete adjustment factor and the uneven distribution coefficient of runoff are, the more unevenly distributed they are.

Through calculating the monthly flow according to its vector value, and then the runoff synthesis vectors are got. Runoff concentration ratio refers to the percentage how much the runoff synthesis vector occupies the annual runoff. The date on which the concentration occurs is named concentration period, expressed by the tangent angle of the ratio of the total 12 vectors. The runoff of each period is decomposed into components in two directions, and its formula can be expressed as follows:
Runoff synthesis vector: \[ R = \sqrt{R_x^2 + R_y^2} \]; Concentration ratio: \[ CR = R / R_{\text{year}} \]; Concentration period: \[ CP = \arctan(R_y / R_x) \], where: \( R_{\text{year}} \) is annual runoff; \( r_i \) and \( \theta_i \) are the size and direction of the monthly runoff vector, \( i \) is the monthly sequence; \( R_x \) and \( R_y \) are the components of each annual vector in horizontal and vertical direction respectively.

3.2.2. Analysis method of interannual runoff variation. Methods of annual extreme value ratio, cumulative filter, Mann-kendall trend test and Mann-kendall mutation test are used to analyze the characteristics of interannual variation in Yishuhe river basin. Annual extreme value ratio is one important indicator which can reflect the runoff of the interannual fluctuation degree. The greater runoff variation which is expressed by bigger value means increases the difficulty during the utilization of water resources, flood control and drought relief within the whole basin. The principle of the cumulative filter is as follows.

\[
S = \frac{\sum_{i=1}^{n'} R_i / n'}{R}
\]

here: \( S \) is the average cumulative runoff; \( R_i \) is the \( i \)th monthly runoff; \( R \) is the average monthly runoff within the series time; \( Z \) is the series length, \( n = 1, 2, \ldots, n \).

The principle of non-parametric Man-Kendall trend test is as follows:

Define test statistics \( S \):

\[
S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} \text{sign}(X_i - X_j)
\]

here, \( \text{sign}(\cdot) \) is sign function. When \( < 0, X_i - X_j > 0 \) or \( = 0 \), \( \text{sign}(X_i - X_j) \) is -1, 0 or 1 respectively.

In the method of M-K, when \( S > 0, = 0, < 0 \), the increasing trend value \( Z \) is as follows respectively:

\[
\begin{align*}
Z &= (S - 1) / \sqrt{n(n-1)(2n+5)}/18 & S > 0 \\
Z &= 0 & S > 0 \\
Z &= (S + 1) / \sqrt{n(n-1)(2n+5)}/18 & S > 0
\end{align*}
\]

When \( Z \) is bigger than 0, it denotes an increasing trend, otherwise a decreasing trend. While the absolute value of \( Z \) is \( \geq 1.28, \geq 1.64 \) or \( \geq 2.32 \), it means passing the significance test with 90%, 95% or 99% confidence degree respectively.

The principle of non-parametric Mann-Kendall mutation detection is as follows:

Set a time sequence: \( x_2, x_3, \ldots, x_n \), construct a sequence of order \( r_i, r_i \) which express the sample accumulation of \( x_i > x_j (1 \leq j \leq i) \). Define \( S_k \) as,
\[ S_k = \sum_{i=1}^{k} r_i \quad (k = 2, 3, \ldots, n) \quad (8) \]

\[ r_i = \begin{cases} +1 & , \quad X_i > X_j \quad (j = 1, 2, \ldots, i) \\ 0 & , \quad NO \end{cases} \quad (9) \]

Define the mean value \( E(s_k) \) and the variance as follows:

\[ E(s_k) = \frac{n(n+1)}{4} \quad \text{var}(s_k) = \frac{n(n-1)(2n+5)}{72} \quad (10) \]

The statistics are defined under the assumption of the independent time series:

\[ UF_k = \frac{s_k - E(s_k)}{\sqrt{\text{var}(s_k)}} \quad (k = 1, 2, \ldots, n) \quad (11) \]

Here \( UF_1 = 0 \), and \( UF_k \) has a standardized normal distribution.

Given a significant level \( \alpha \), the threshold \( U_a \) can be got from the normal distribution table. \( |UF_k| > U_a \) indicates that there is a significant increase or decrease in the sequence.

All \( UF_k \) forms a curve \( c_1 \), and the confidence test will show whether there is a trend existing or not. The method is referenced to the inverse sequence, and the calculation process is repeated \( UB_k \), which is expressed \( c_2 \) as in the curve, can be derived through multiplying the calculated value by -1. When \( UF_k \) or \( UB_k \) in the curve is bigger than 0, the sequence shows an upward trend, and means a downward trend when the value is less than 0. When they exceed the confidence degree line, it indicates an obvious upward or downward trend; If the intersection of \( c_1 \) and \( c_2 \) is between the confidence degree lines, this point may be the start point of the mutation.

4. Varying characteristics of monthly runoff

4.1. Distribution of monthly runoff

Table 2 gives the proportion of mean monthly flow to the total annual runoff from January to December in Yishuhe river basin, and it can be seen that the annual distribution of runoff is very uneven. In Linyi station, the maximum four consecutive monthly runoff is from June to September, occupying 81.1% of the whole year; and the biggest monthly runoff occurred in July and the minimum flow in February, accounting for 32.2% and 1.41% of the whole year respectively. While in Daguanzhuang station, the maximum consecutive four monthly runoff is from July to October, occupying 77.9% of the total year; and the biggest monthly runoff occurred in July and the minimum flow in February, accounting for 30.7% and 1.57% of the whole year respectively. Runoff in Yishuhe river is affected mainly by precipitation, with the features of concentrated on flood season, great variance with seasons and large difference between maximum and minimum monthly runoff.

| Month      | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Linyi      | 1.78| 1.43| 1.53| 1.80| 2.09| 5.20| 32.20| 29.92| 13.75| 5.00| 3.12| 2.54|
| Daguanzhuang| 2.07| 1.58| 1.89| 2.07| 2.65| 5.44| 30.72| 27.31| 14.39| 5.79| 3.40| 2.85|
4.2. Characteristic value of monthly variation

The indicators of the complete adjustment factor $C_v$, the uneven distribution coefficient $C_u$, and concentration ratio $CR$ are adopted to analyze the sub-periods’ distribution characteristics of the runoff quantitatively in Yishusi river basin.

It can be seen from table 3 that the distribution of annual runoff in Yishuhe river basin is quite uneven, in which the data of Linyi station and Daguanzhuang station is used to reflect the runoff of Yihe river and Shuhe river respectively. Runoff is uneven distributed relatively in the years 1966-1965, 1966-1975 and 1986-1995, while the runoff in years 1976-1985, 1996-2005 and 2006-2015 is distributed relatively uniform. The runoff concentrates mainly in August. The value of the complete adjustment coefficient $C_v$ is consistent with the distribution inhomogeneity coefficient $C_u$ within the year, and the change trend of concentration ratio is nearly consistent with that of $C_u$.

Table 3. Characteristics of the sub-periods’ runoff distribution in Yishuhe River basin.

| Station      | Coefficients 1956-1965 | 1966-1975 | 1976-1985 | 1986-1995 | 1996-2005 | 2006-2015 | 1956-2015 |
|--------------|-------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Linyi        | $C_v$                   | 0.54      | 0.53      | 0.4       | 0.51      | 0.44      | 0.47      | 0.5       |
|              | $C_u$                   | 1.72      | 1.72      | 1.47      | 1.68      | 1.51      | 1.52      | 1.62      |
|              | $CR$                    | 0.72      | 0.77      | 0.64      | 0.75      | 0.70      | 0.69      | 0.72      |
|              | $C_P(\circ)$            | 200       | 199       | 206       | 206       | 216       | 212       | 206       |
|              | Month                   | August    | August    | August    | August    | August    | August    | August    |
| Daguanzhuang | $C_v$                   | 0.54      | 0.51      | 0.47      | 0.48      | 0.43      | 0.37      | 0.47      |
|              | $C_u$                   | 1.77      | 1.66      | 1.61      | 1.59      | 1.43      | 1.36      | 1.54      |
|              | $CR$                    | 0.74      | 0.77      | 0.71      | 0.73      | 0.68      | 0.58      | 0.67      |
|              | $C_P(\circ)$            | 197       | 202       | 202       | 206       | 222       | 214       | 207       |
|              | Month                   | August    | August    | August    | August    | August    | August    | August    |

5. Variation characteristics of annual runoff

5.1. Characteristic values of annual runoff

Table 4 describes the characteristic values of interannual runoff change in Yishuhe river basin, among which the annual runoff variation coefficient of Linyi station is 0.82, while 0.67 in Daguanzhuang station. The annual extreme ratio of maximal to minimal value is 102 for Linyi station and 21 for Daguanzhuang station.

The big variation coefficient and extreme ratio of runoff in the two stations indicates that the annual runoff varies greatly in the past 60 years, and there is great difference for annual runoff volume between wet and dry years.

Table 4. Characteristic value of the runoff variation in Yishuhe River basin.

| Station      | Mean annual runoff | Coefficient of variation | Maximum value measured Runoff volume /10^8m^3 | Minimal measured Runoff volume /10^8m^3 | Extreme ratio P |
|--------------|--------------------|--------------------------|---------------------------------------------|----------------------------------------|----------------|
| Linyi        | 19.8               | 0.82                     | 62.13                                       | 1963                                   | 2015 102       |
| Daguanzhuang | 10.8               | 0.67                     | 23.65                                       | 2005                                   | 1989 21        |

5.2. Trend analysis of annual runoff

Through the analysis of the curves of annual runoff variation in Linyi station and Daguanzhuang station (figure 2), it is found that the annual runoff of the two stations has the same variation tendency, that is, the runoff has a decreasing trend on the whole basin. While there is some difference between Linyi station and Daguanzhuang station, since the change in Linyi station is more significant than that
in Daguanzhuang station.

Figure 2. The annual runoff at the 2 stations in Yishuhe River basin.

Figure 3. Curves of the accumulative average annual runoff and precipitation in Yishuhe River basin.

Table 5. Changing tendency of annual precipitation and runoff in Yishuhe River basin.

| Index | Station                  | Time interval (Year series) | Standardized variable U | Trend       | Significance |
|-------|--------------------------|----------------------------|-------------------------|-------------|-------------|
| runoff| Linyi                    | 1956–2015                  | -2.38                   | decreasing  | significant |
|       | Daguanzhuang             | 1956–2015                  | -0.9                    | decreasing  | insignificant|
| rainfall| Multistation average | 1956–2015                  | -1.36                   | decreasing  | insignificant|
|        | in Yihe river            |                            |                         |             |             |
|       | Multistation average     | 1956–2015                  | -1.59                   | decreasing  | insignificant|
|        | in Shuhe river           |                            |                         |             |             |

Cumulative filter method is used to calculate the average annual runoff and accumulated annual rainfall, and the results are shown in figure 3. The runoff both in Linyi station and Daguanzhuang station changes with time and has a decreasing trend over the whole basin, though the change in Shuhe river seems not so obvious. Kendall rank correlation test for trend of quantitative analysis is adopted to analyze the variation characteristics of interannual runoff more reliably and scientifically. Test results are shown in table 5, it can be seen that Kendall rank correlation test has the similar result with the accumulated product filter, they all reflect the trend of change, though Kendall rank correlation test only for quantitative evaluation on the significance of trend change. In the test, when significant level
=0.05 and critical value =1.96, the runoff of Yihe river, but not Shuhe river, generally presents a very significant decreasing trend, however the precipitation reduction trend both in Yihe river and Shuhe river is not significant.

5.3. Mutation analysis of annual runoff
Runoff and rainfall mutation analysis are made for Yihe river because the annual runoff of Yihe river shows a significant decreasing trend while the reduction of runoff in Shuhe river is not so significant.
A m-k analysis diagram of annual runoff rainfall in Yihe river is drawn based on the calculation formula of m-k method, shown in figure 4. It can be seen from the figure that both the positive and negative sequence curves of Yihe river runoff and rainfall exceeded the significance level confidence line of 0.05, the two curves intersect on the confidence line, and the years corresponding to the common intersection points are 1966 and 2013 respectively. Hence it indicates that the runoff reduction mutation occurred in the whole river, which passed the significance test in 1966 and 2013.

Figure 4. The Mann-Kendall analysis of the annual runoff and precipitation in Yihe River basin.

6. Conclusion
Yishuhe River is short of water resources, and the contradiction between water demand and supply is serious. Based on the series data of precipitation and runoff, this paper analyzes the variation characteristics in Yishuhe river basin using some indexes including Cv, Cu, CR , CP and some methods, and the conclusions are drawn as follows.

- The seasonal distribution of runoff in Yishuhe river basin is very uneven. The maximum runoff for the consecutive four months accounts for 80% of the total year. The uneven distribution mainly occurred in the period from the middle of 1950s to the middle of 1970s, and from the middle of 1980s to the middle of 1990s, while in the other years, it is relatively uniform. The maximum monthly runoff occurs in August. The value of the complete adjustment factor Cv is consistent with the distribution inhomogeneity coefficient Cu within the year, and the changing trend of concentration ratio is nearly consistent with that of Cu.
- The annual runoff varies greatly, with significant difference between the wet year and the extreme dry year, and the annual runoff in Linyi station is more severe than that of Daguanzhuang station. There is a decreasing trend with time for annual runoff both at the two stations, while the decreasing degree of precipitation is less than that of runoff. According to the quantitative evaluation of runoff by Kendall rank correlation test method, the decreasing trend of runoff is much more significant in Yihe river compared to Shuhe river.
- According to the runoff mutation analysis for Yihe river by using m-k mutation test method, there was a runoff reduction mutation occurrence in 1966 and 2013, and the variation passed the significance test.

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