Analysis on the variation characteristics of Wuguan River runoff in South Qinling Mountain

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Abstract. Aims at the hydrological analysis in the early stage of water conservancy project construction, studies the long series runoff and its variation law in Wuguan River, and analyzes the characteristics of annual and interannual changes in this paper, Provides basic support for the later reservoir construction. Based on the precipitation data (1959-2001) and the runoff data (1959-2014) from Wuguan hydrologic station, many methods such as statistical analysis, R/S, M-K trend test and mutation test were used to study the change rule of runoff. After that, influential factors of runoff were analyzed in the paper. Results show that the annual runoff of the Wuguan River is 1.53 million cubic meters, monthly runoff differs greatly in a year with clear period of concentration from Jul. to Oct.; Annual runoff showed a long-term decreasing trend and the mutation point appeared in 2010; Precipitation changes was the main cause of the decreasing runoff compared to human activities. Runoff forecasting showed weak increasing trend in the coming years. Overall, the runoff of the Wuguan River varies greatly between annual and interannual, but it can be used as a water source to supply water for the urban area of Danfeng County through the storage of reservoirs. The results can provide reference for the safe construction of water storage projects in the later period, and it has a reference value for the development and utilization of Wuguan River.

1. Introduction

Hydrological process is a complex natural process, and watershed runoff change process is an important basis for hydrological process research [1]. As a kind of time series data, runoff change process follows the rule of annual distribution, interannual trend and mutation change. In recent years, domestic and foreign scholars have done a lot of research in this aspect, such as the future change trend of runoff in the Yellow River is predicted by using the non-trend Wave analysis method [2]. Applying M-K trend test, wavelet and R/S, the interannual variability of runoff and responses to climate change in Dongjiang River can be discussed [3]. Based on the runoff data of the upper-middle reaches of the Yellow River, the runoff evolution process was analyzed by M-K test and double cumulative curves [4]. The trend of runoff in the upper reaches of the Miyun Reservoir and its influencing factors were analyzed [5].

Yangtze River basin is one of the most economically developed regions in China, and is also the most severe flood disaster area in China [6]. The Wuguan River originates from the main ridge of Python Ridge in southern Qinling Mountain, names by flowing through the town of Wuguan and belongs to Danjiang basin in the Yangtze River system. The length of Wuguan River is 116.7 km and the basin area is 900 km^2. It has many tributaries distributed on both sides of the main stream. The river shows the mountain stream characteristics of gully and canyons alternation, with many curved segments, large gradient and turbulent flow [7]. It is in the subtropical monsoon climate zone, and the annual average temperate is 14.4°. Wuguan hydrologic station is the control station of the Wuguan River, which is the reason why this station is selected for analysis. Figure 1 shows the location of Wuguan River in Danfeng County. At present, the research on the Wuguan River basin mainly focuses on the characteristics of water and sediment change and trend analysis. However, there are few studies on the rule of runoff process change. In view of this, a variety of methods are adopted in this paper to qualitatively and quantitatively analyze the runoff change rule in the Wuguan River Basin.

At present, Danfeng County is in a situation of water shortage, through the research on the runoff process of the Wuguan River and its influencing factors, the long-term change rule of runoff can be explored. It is beneficial to understand the change process and trend of water resources more deeply [8], and provide a basis for the new water storage project in this area, guarantee the safety construction of the project, so as to realize the economic and social sustainable development in the area.

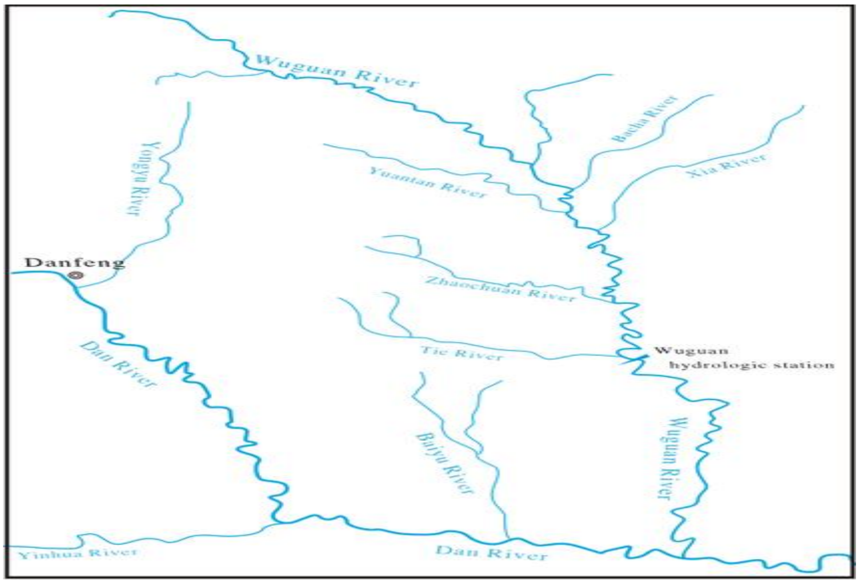

Figure 1. The map of the study area.

2. Data and methods

2.1 The source of the data

The precipitation and runoff data come from the Wuguan hydrologic station, Danfeng County of Shaanxi province, and station's data include daily, monthly precipitation (1959-2001) and daily, monthly runoff data (1959-2014). By reviewing the collected data, it can be believed that the data are reliable and representative and can be used as the basis data for the analysis of runoff laws.

2.2 Research methods

In this paper, many basic indexes such as complete adjustment coefficient, non-uniform coefficient, and concentration degree were used to study annual variation rule of runoff.

There are many methods about runoff trend analysis, including cumulative spacing, sliding averaging, R/S method, Mann-Kendall (M-K) method, etc. The R/S [9,10] method and the M-K [11] method are used in this paper, because the R/S method has some advantages in studying the statistical laws in different scale ranges, and the M-K method does not require a certain distribution of samples, nor is it disturbed by a few abnormal values. Combining these two methods can predict the future trend of runoff time series well. On this basis, M-K mutation test was used to determine the mutation point of runoff, influential rate of the driving factor on runoff can be calculated by using the double cumulative curve.

3. Results and analysis

3.1. Annual distribution of runoff

During the nearly 60 years of 1959-2014, the monthly average runoff of the Wuguan hydrologic station is shown below.

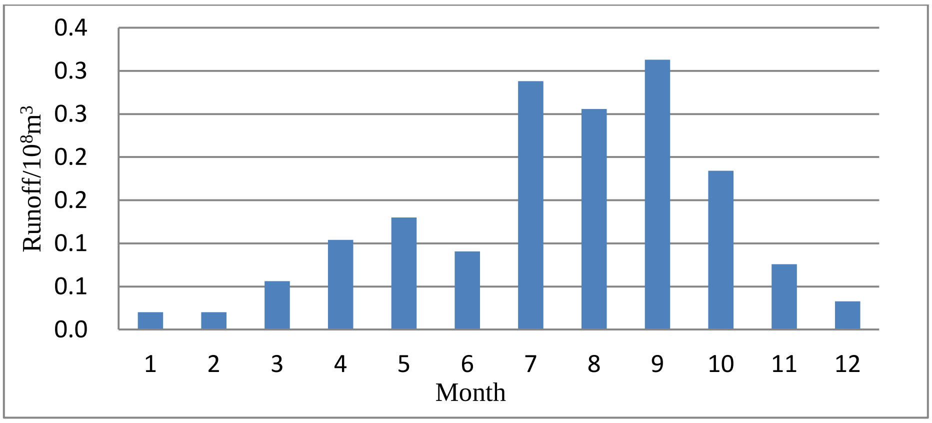

Figure 2. Monthly runoff process histogram.

It is shown from figure 2 that: the volume of monthly average runoff is mainly concentrated in Jul.-Oct. (about 66% of the total annual runoff), and the minimum volume concentration is Dec.-Feb.; Runoff has a "double peak" pattern of change in a calendar year, reflected in May and September.

Through the calculation and analysis of the precipitation data, it can be found that the volume of precipitation from June to October are maximum, accounting for 70% of the annual precipitation, which shows that the precipitation and runoff of Wuguan river have better synchronization, meanwhile the change of runoff is affected by precipitation in some degree .

The indexes such as non-uniform coefficient and concentration can be used to reflect the difference degree of annual distribution between single stations in the region, and overcome the limitation of annual runoff monthly distribution table.

Table 1. The annual runoff distribution index in chronological division.

statistics period	non-uniform coefficient	complete adjustment coefficient	concentration degree	monthly runoff ratio between the maximum and minimum value
1959-1969	0.696	0.309	0.345	13.78
1970-1979	0.733	0.312	0.435	17.25
1980-1989	0.897	0.399	0.578	24.55
1990-1999	0.794	0.316	0.488	19.08
2000-2009	0.933	0.414	0.563	17.21
2010-2014	1.191	0.437	0.561	27.73
multi-year average	0.792	0.335	0.493	16.45

From table 1, it can be seen that: (1) The following changes in the three indexes of complete adjustment coefficient, non-uniform coefficient and concentration degree are basically consistent, the main reason is that these indexes are closely related to the source of runoff recharge. From the 1860s to 80s, these three indexes values have an increasing trend, indicating that the difference in monthly runoff sequence gradually increased, the volume of runoff distribution within the year is more and more uneven, it presented a decreasing trend in the 1990s. At the beginning of 20th century, these three indicators showed an increasing trend, in terms of uniformity, manifesting that the 1990s was a turning point in the annual distribution. (2) The maximum value of runoff is much larger than the minimum during the year, especially from 2010 to 2014, which shows that the runoff varies greatly in a year with the annual distribution is uneven. (3) During the observation period in the 1960s and 1970s, the non-uniform coefficient, complete adjustment coefficient, and concentration degree is smaller than the multi-year average value, obviously the runoff distribution uneven degree is small in this period of time, indicating that the distribution of runoff within the year is relatively even during this period. The value of concentration degree in the 1880s and 20th century was distributed between 50%-60%, which showed that the distribution of runoff within the year was comparatively concentrated in this period.

3.2. Interannual trend and mutability

Adopting the R/S and M-K methods to analyze the trend of annual runoff in the Wuguan River, scientific and reasonable conclusions can be drawn. For the analysis of runoff mutation, M-K mutation test can be used to determine the mutation point of runoff.

- Analysis of runoff sequence by R/S method

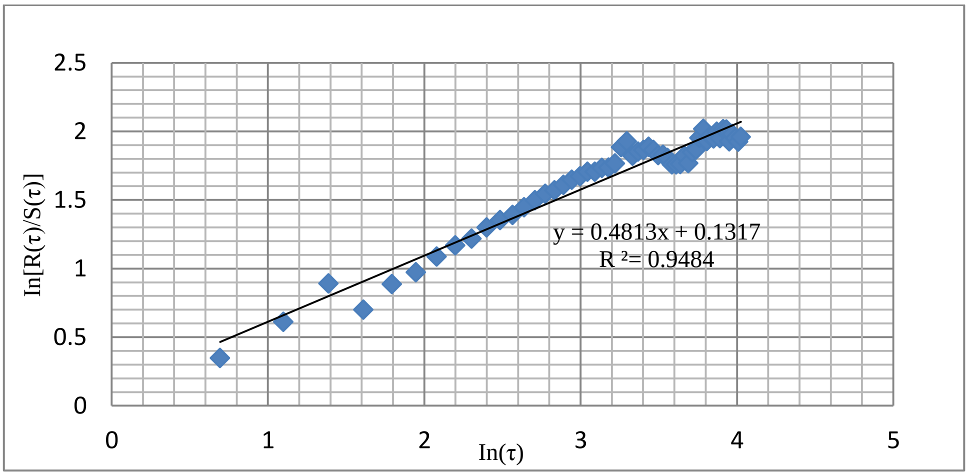

Figure 3. R/S analysis of natural runoff series.

It is shown from figure 3 that the correlation coefficient is approximately 0.95, which indicates that the natural runoff sequence fitting effect is ideal. The annual runoff Hurst index H value is 0.4813. Greater than 0, less than 0.5, manifests that the annual runoff time series of the Wuguan River has a negative persistence, that is, contrary to the original law.

- Analysis of M-K trend test

According to the statistical principle of M-K trend test, the trend of annual runoff sequence is analyzed. The calculation yields Z=-0.6007 (|-0.6007|<1.96) (the critical value at the 0.05 significance level). It can be seen that the natural annual runoff sequence of Wuguan River shows a decreasing trend, but the trend is not obvious.

Comprehensive application of two methods to analyze the trend of annual runoff changes in Wuguan River, the results are as follows: if climate change and human activities are developed accordance with current trends, annual runoff of the Wuguan River will show a weak increasing trend in the future.

- Analysis of M-K mutation test

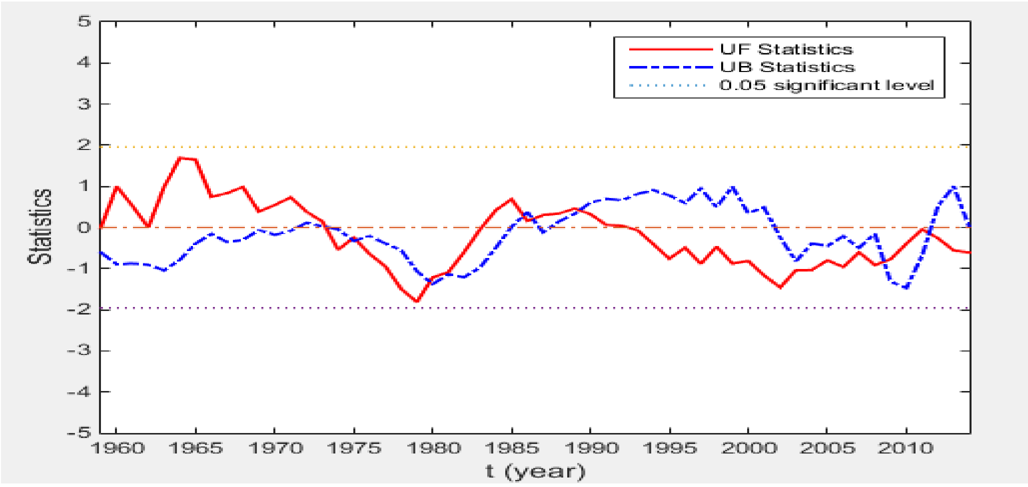

Figure 4. M-K mutation test for annual runoff.

Analysis figure 4: The annual runoff trend of the Wuguan River is more complicated, and the UF value is basically within the critical line of ±1.96, which shows that the annual runoff sequence of the Wuguan River has no obvious increase or decrease trend. Between the two critical lines, it can be seen that the UF and UB statistical curves intersect at 6 points in 1972, 1980, 1985, 1989, 2008 and 2010. During the 1959-1972, the UF statistical curve showed a fluctuation, the runoff showed a decreasing trend from 1972 to 1979. And runoff showed an increasing trend in the period of 1979-1984, it presents a trend of fluctuations from 1979 to 2008, so there was no significant mutation point, runoff gradually increased during the 2008 to 2010; However runoff has been decreasing since 2010. In the past 60 years, runoff has shown a decreasing trend as a whole, which can be inferred that 2010 was a mutation point from more to less.

Using different methods to analyze annual runoff trend and mutation of Wuguan River, it can provide basis for the rational planning and utilization of the water resources and the prevention and cure of flood and drought. On the other hand, it can provide important data support for the further study of runoff variation law, analysis of runoff change. Meanwhile it will play a certain role in protecting ecological environment and promoting social and economic development.

3.3. Driving factors analysis of runoff change

According to the driving force source, influential factors of runoff can be divided into natural factors and human activities [12]. Natural factors mainly include terrain, soil and other underlying conditions and climatic conditions; it is generally believed that the underlying surface does not changed on a certain time scale, so the natural factors are mainly considered climatic factors such as precipitation on the impact of runoff. Human activities mainly include water intake, water conservancy projects and land use. In this paper, the effects of precipitation and human activities on the runoff are analyzed by using the double cumulative curve method.

According to the double cumulative curve in figure 5, the position where the slope changes can be determined as 1975, it divides the runoff sequence is into 2 stages: 1959-1974, 1975-2001, in which the first phase as the base period. The slope of double cumulative curve drops from 0.0023 of the base period to 0.0021, with the attenuation rate is 8.7%, which indicates that human activities have little effect on runoff.

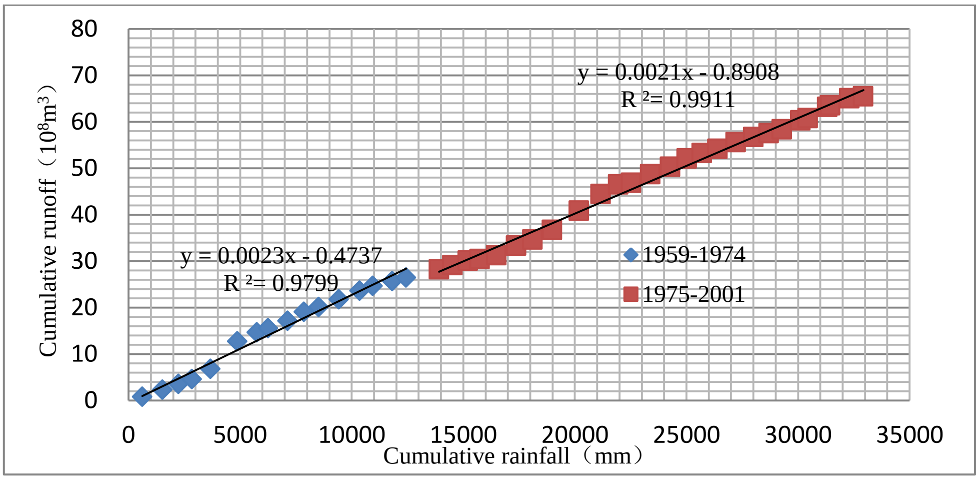

Figure 5. Double cumulative curve of Wuguan River.

Table 2. Effects of precipitation and human activities on runoff.

Hydrological station	Starting and ending year	Precipitation (mm)	Runoff			Rainfall factor		Human activity factor	
			calculated value	measured value	Total reduction	Impact amount	Impact rate	Impact amount	Impact rate
Wuguan	1959-1974	777.88		1.654					
	1975-2001	758.58	1.515	1.445	0.209	0.139	66.72	0.070	33.28

It can be seen from table 2 that during the period from 1975 to 2001, the impact of precipitation on the runoff was 66.72% at the Wuguan hydrometric station, with the impact of human activities on runoff was 33.28%.Which indicated that the reduction of runoff in the Wuguan River can mainly be attributed to precipitation, followed by human activities.

The Wuguan River Basin is mainly rainwater recharge, and the basin area is small. Therefore, precipitation is the most important and direct factor in the formation of runoff. Human activities also have a certain impact on runoff, such as water and soil conservation projects and water conservancy projects, which can increase the capacity of regulating and apportioning the river basin, thereby reducing the annual runoff of the Wuguan River.

4. Conclusions and discussion

Considering the construction demand of the water storage project in the future, this paper studies the annual distribution, interannual change trend and mutability. After that, influential factors of runoff were quantitatively analyzed. The conclusions are as follows:

- Runoff has the "double peak" type change characteristic in a calendar year. The non-uniform coefficient, complete adjustment coefficient and the concentration index have good synchronization change law. From the overall analysis of indicators, it can be seen that the river runoff distribution in a year is uneven, with the river runoff mainly concentrated in July-October.
- Using R/S and M-K trend test method to analyze the trend of annual runoff, results show that annual runoff time series of the Wuguan hydrologic station (1959-2014) exhibits negative persistence. Predicting the future natural annual runoff change of the Wuguan River basin is a weak increasing trend.
- By using M-K mutation test to analyze runoff sequence, finds that the long series of runoff with decreasing trends, runoff increased dramatically in 2010.

- Analyzing and comparing the influence rate of precipitation and human activities on runoff, it is concluded that precipitation factor is the main cause of the decreasing runoff in the Wuguan River.

This paper studies the change rule of runoff in Wuguan River, and quantitatively analyzes the influence of precipitation and human activities on runoff change, but does not take into account the effects of evaporation, temperature and other factors on runoff change, which needs further simulation analysis. In addition, there is no analysis on the construction scale of the new water storage project and the guarantee situation of the inflow to the economic and social water demand for the urban area, so it is necessary to further discussion.

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