The Runoff Changes and Influential Factors Analysis of Wulanmulun River

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Abstract: In the past 60 years, climate change and increasingly extensive human activities have greatly altered the runoff in Wulanmulun River basin. Based on the climate and hydrological data in Wangdaohengta station during 1959 - 2015, runoff variation characteristics and the influencing factors were studied. Mann - Kendall trend analysis, statistic analysis, R / S analysis, and double mass curve were used comprehensively in the study. The results indicated that the multi - year change of runoff had a decreased tendency in all, and this trend was the most evident since the end of the twentieth century. The runoff affected by rainfall and human activities appeared three change periods in which the turning years were 1980 and 1995 respectively. The effect of precipitation on runoff decreased, and the influence rate reduced from 18.77% in 1980 - 1995 to 8.48% in 1995 - 2015. The influence of human activities on runoff gradually increased, the influence rate increased from 81.23% in 1980 - 1995 to 91.52% in 1995 - 2015. The Hurst index was 0.3533 for the Wangdaohengta station which indicates that the runoff of Wulanmulun River will have a raise trend in the future.

Key words: Runoff change; Precipitation; Human activities; Wulanmulun watershed; Hurst index

1. Introduction

Stream runoff is an important part of the hydrological cycle. The change of runoff plays a leading role in the evolution of the entire hydrological system, and has a significant impact on the environment and the regional economy [1]. Runoff that affected by natural conditions and human activities, has some regularity and strong randomness in its evolution process[2]. In recent years, under the influence of global warming and human activities, there have been significant temporal and spatial changes in river runoff, which have a direct impact on the allocation, development and utilization of water resources and the physical, chemical and biological processes of river ecosystems [3]. Wulanmulun River is a tributary of the Kuye River. With the development of agriculture and industry and the increase of domestic water consumption, especially the large-scale mining of coal resources in the river basins, the runoff of rivers is decreasing. The contradiction between the supply and demand of local water resources aggravates and the ecological environment deterioration. At present, there are many researches on the runoff variation in the Kuye River [4-6], while the runoff analysis of Wulanmulun River is rare. Therefore, it is of great significance to carry out the planning, management, development and utilization of the water resources in the Wulanmulun River basin by analyzing the characteristics and influencing factors of the runoff change.

2. Materials and research methods.

2.1. Basic information.

Wulanmulun River is the superior river of Kuye River, it originated from the desert area of Yikezhao League in southern Inner Mongolia, with a total length of 132.5 kilometers and a catchment area of 3837.27km^2. The Wulanmulun River mainly flows through the topography of the broken Loess Hilly Region [7]. It belongs to the arid and semi-arid continental climate, with less drought and precipitation in spring, abundant rainfall in summer and lower frost in autumn and frost and snowfall in winter. The average annual temperature is 7.9℃, precipitation 413.5 mm, annual runoff 167.3 million m^3.Precipitation and melting snow and ice is the main source of River runoff supplies. The confluence of the Wulanmulun River and Beiniuchuan River, it was injected into the Kuye River in Shenmu county. The Wangdaohengta is the nearest hydrological station to the junction of Wulanmulun River and Beiniuchuan River. The paper analyzes the monthly mean runoff data and precipitation data of Wangdaohengta hydrological station from 1959 to 2015. The data come from the actual observation of the hydrological station.

2.2. Research methods.

The trends of runoff series were analyzed by linear trend analysis and moving average method [8].The cumulative interval method was used to analyze the stages of inter-annual variation of runoff , description of methods in literature[9];Mann-Kendall nonparametric statistics The test method is used to determine the location of the sudden change in runoff and precipitation series [10-12]. The Hurst index is used to judge the persistence of the trend of runoff variation. The literature made a further introduction [13-15]. Double cumulative curve method was used to analyze the influence of natural and human activities on runoff evolution in different stages [16].

3. Results and analysis

3.1. Characteristics of runoff changes.

3.1.1. Runoff inter-annual changes.

The coefficient of variation is one of the most important indicators to measure the inter-annual variation of runoff. The greater the value, the more severe the change of annual runoff and abundance, and the other is that the inter-annual variation of runoff is even. The annual extreme value ratio can show the uneven degree of runoff, and the greater the value is, the more uneven the annual variation of runoff is [17]. From Table 1, it can be seen that the maximum runoff of the Wulanmulun River is 5.25 × 10^8m^3 over the years, the minimum runoff is 0.38×10^8m^3, the annual mean is 1.67 × 10^8m^3, the runoff extremum ratio is 13.78, the variation coefficient is 0.59, The coefficient of variation and inter-annual extremum ratio are relatively large, indicating that the change of runoff abundance in Wulanmulun River is more severe and the inter-annual variation of runoff is not uniform.

Table 1 The inter-annual variation eigenvalues of runoff in Wulanmulun River Basins

Site name	Years mean （10^8 m^3）	Cv	Annual mean ratio			Minimum annual runoff			Inter-annual extreme value ratio
			Years	Runoff （10^8m^3）	Annual mean ratio	Years	Runoff （10^8m^3）	Annual mean ratio	
Wang daohengta	1.67	0.59	1961	5.25	3.14	2000	0.38	0.23	13.78

In order to further explain the inter-annual variability of the Wulanmulun River runoff, Table 2 shows the average runoff and the mean annual runoff of Wangdaohengta station in different years. As can be seen from the table, before 2010, the change of runoff showed a decreasing trend, and the runoff in different years decreased by 4.7%, 24%, 29% and 49% respectively, compared with the previous generation. The runoff from 2000 to 2009 was only 26% and 28% of the 1960s and 1970s, 40% of the multi-year average. After 2010, the runoff showed an increasing trend, increasing from 0.67 × 10^8m^3 in 2000-2010 to 0.86 × 10^8m^3, an increase of 28%.

Table 2 Inter-annual average runoff in Wulanmulun River（10^8m^3）

Years	1959-1969	1970-1979	1980-1989	1990-1999	2000-2009	2010-2015	Average
Wangdaohengta	2.54	2.42	1.84	1.31	0.67	0.86	1.67

3.1.2. Annual runoff trend.

In the recent 60 years, the runoff of the Wulanmulun River has shown a trend of decreasing year by year (Figure 1) except for the normal fluctuation in the inter-annual period. The linear trend coefficient of annual runoff of Wangdaohengta Station is -0.00416.By plotting the accumulated runoff curve from Wangdaohengta Station from 1959 to 2015 (Figure 2), the stage of inter-annual variability of runoff can be discerned more clearly. The annual runoff of Wulanmulun River mainly experienced three stages of change: the runoff was generally increasing from 1959 to 1979; the runoff decreased greatly from 1980 to 1994; after 1995, the annual runoff decreased somewhat.

3.1.3. The continuous characteristics of annual runoff.

To illustrate the future trend of the runoff series (Figure 3), the R / S analysis method is used to analyze the annual runoff series of the Wulanmulun River. The Hurst index of the station is $H = 0.3533$, $H < 0.5$, which indicates that the runoff series has negative effects, that is the trend of the future is opposite to that of the past. If the climate change and human activities still have the current development trend in the future, the annual runoff of the Wulanmulun River will have an increasing trend.

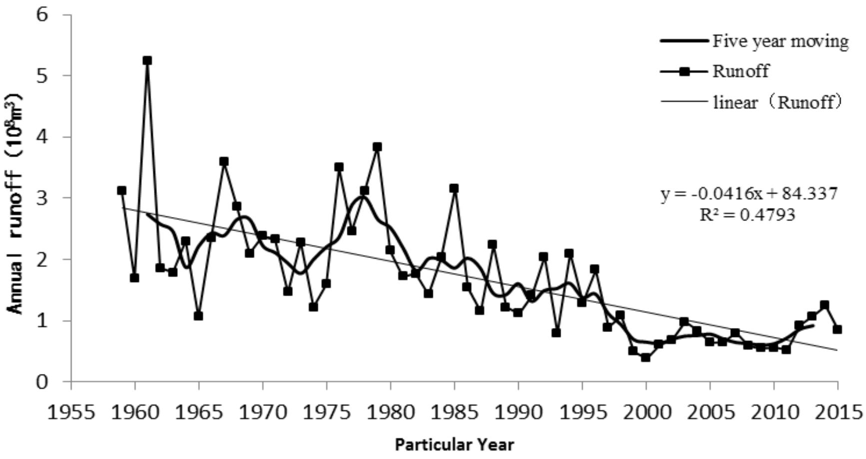

Figure 1 Annual runoff trend in Wangdaohengta station

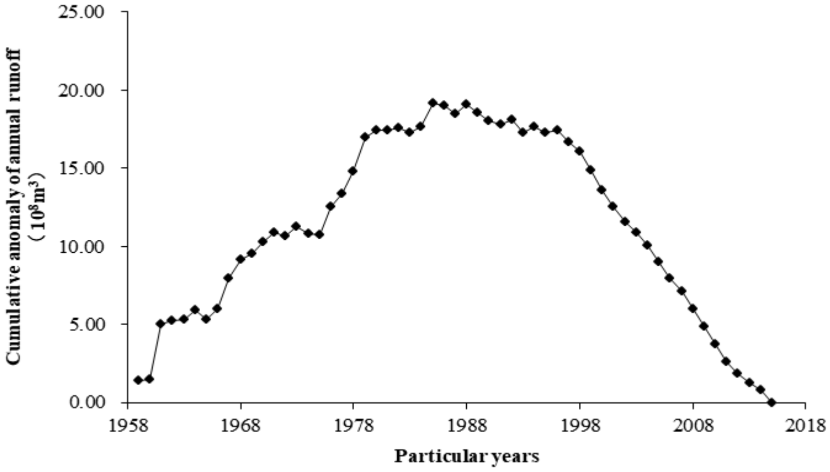

Figure 2 The accumulation anomaly curve of runoff series in Wangdaohengta station

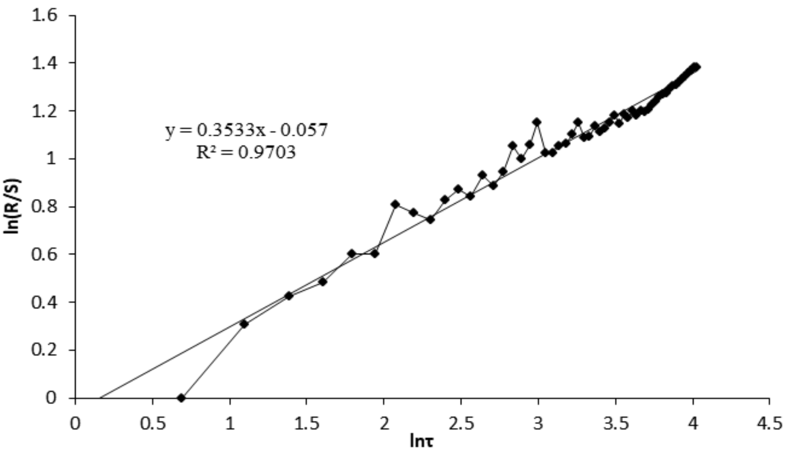

Figure 3 R/S Analysis results of the runoff series in Wulanmulun River

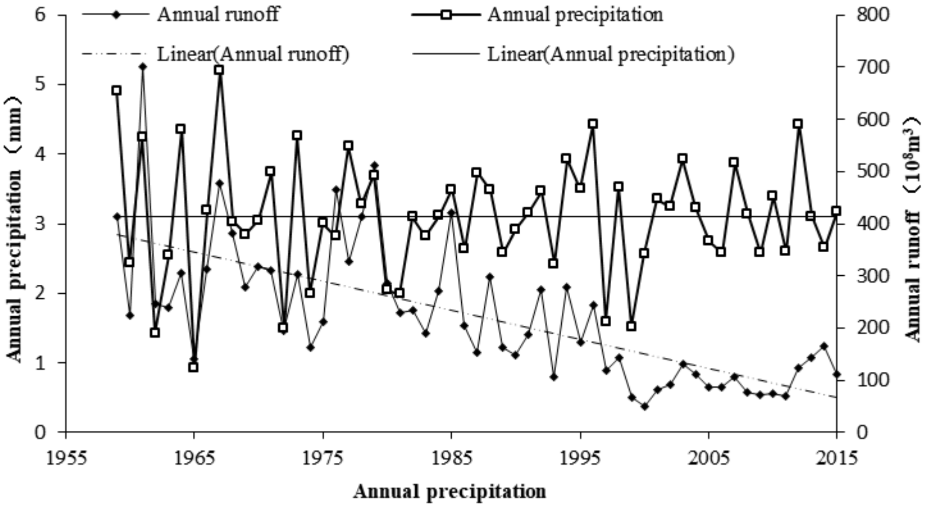

Figure 4 The inter-annual variations of annual runoff and precipitation in Wangdaohengta station

3.2. Influencing Factors of Runoff Changes

3.2.1. Precipitation on the impact of runoff changes

Throughout the study period, the mean annual precipitation of the Wulanmulun River basins was 413 mm, the maximum annual rainfall was 694.1 mm, the minimum was 124 mm, the annual precipitation extrema ratio was 5.59, and the annual precipitation did not change much. This shows that the change of precipitation in Wulanmulun River is not severe and relatively uniform. Comparing the annual runoff and precipitation curve (Figure. 4), the annual runoff and precipitation trends were basically consistent before the end of the 20th century. At the beginning of the 21st century, annual runoff decreased significantly, although the precipitation did not change much. M - K rank correlation test was conducted on annual runoff and precipitation in different periods (Table 3). At the level of $\alpha = 0.05$, annual runoff and precipitation both showed a certain increase from 1959 to 1979 , none of their Zc values passed the significance test, indicating that the decreasing state is not significant; From 1980 to 1994, the annual precipitation continued to increase while the runoff decreased, and their Zc values did not pass the significance test. It indicates that both the increase of precipitation and the decrease of runoff are insignificant. The results show that both the increase of precipitation and the trend of decrease of runoff are insignificant. From 1980 to 2015, the annual precipitation shows an increasing trend, the Zc value does not pass the significant test and the annual runoff further decreases, and the Zc value passes the significant test, indicating that the runoff shows a significant decreasing trend under the condition of not obvious increase of precipitation. The above analysis shows that precipitation was the main influencing factor of runoff change before 1980. From 1980 to 2015, the influence of precipitation on runoff gradually decreased, and precipitation was no longer the dominant factor of runoff change.

Table 3 M-K Test of the annual runoff and precipitation series in Wangdaohengta station

Years	Sequence length	Runoff		Precipitation	
		Zc	Saliency	Zc	Saliency
1959-1979	21	0.5737	Not significant	0.151	Not significant
1980-1994	15	-1.0887	Not significant	1.4846	Not significant
1995-2015	21	-0.5737	Not significant	-0.2114	Not significant
1980-2015	36	-4.2089	Saliency	0.8036	Not significant

3.2.2. Human activities on the impact of changes in runoff

Double cumulative curve method is a common method of time series analysis. The basic idea is that two variables at the same time length gradually accumulate, a variable as the abscissa, another variable as the vertical axis. The inflection point can be used as the basis for analyzing the periodic change of the analysis variable. When there is only a change in precipitation without other factors, the double cumulative curve is a straight line, and the curve will be offset when influenced by other factors such as human activities. The precipitation-runoff double cumulative curve can reveal the periodic changes in the impact of human activities on runoff.

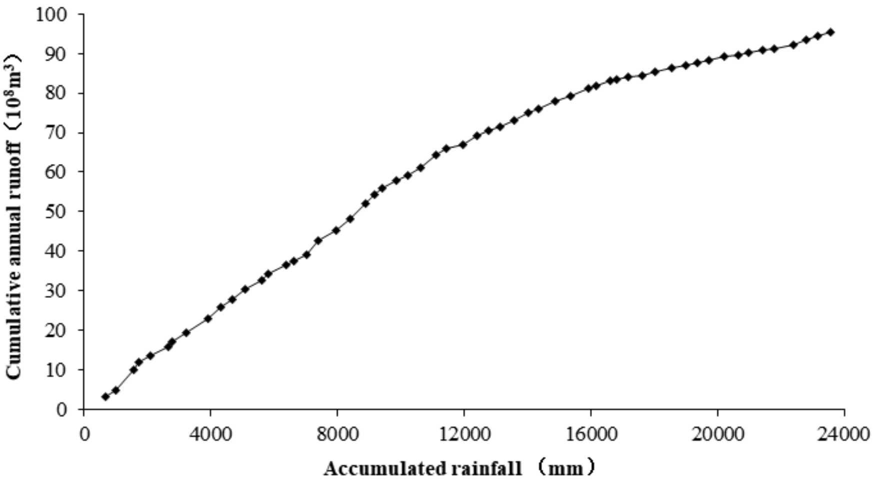

Figure 5 Double mass curve for annual rainfall stream flow in Wangdaohengta station

Figure 5 shows the precipitation-runoff double cumulative curve of Wangdaohengta station. The curve was obviously deflected towards the precipitation since 1980. Therefore, from 1959 to 1979 as the reference period of Wangdaohengta station, the runoff sequence station was divided into three stages according to the inflection point of the precipitation - runoff double cumulative curve (table 4). Based on the regression analysis of accumulated precipitation and accumulated runoff during the reference period, the correlation equations of accumulated annual precipitation (Σ P) and accumulated annual runoff (Σ R) series were established: Cumulative precipitation - Cumulative runoff: $\Sigma R=0.0057\Sigma P+0.9209(R^2=0.9968)$.

Based on the data of annual precipitation and annual runoff in the reference period, the correlation equations of precipitation series and runoff series in the baseline period are established: precipitation - runoff: $R=0.04P^{0.6793}$ Calculate the theoretical average runoff of Wangdaohengta at different periods according to the correlation equation of precipitation - runoff, and using it as an approximation of natural runoff. The difference between the measured value of the reference period and the calculated value of each time period is the effect of precipitation change on the runoff during this period. The difference between the measured value of the benchmark period and the measured value of each period minus the influence value of the change of precipitation is the influence value of human activities on the change of runoff; the percentage of impact and total reduction is the impact rate.

It can be seen that the impact of human activities on runoff has increased in the past 1980-2015 years. During the periods of 1980-1994 and 1995-2015, the impacts of human activities on the annual runoff changes were $0.6165 \times 10^8m^3$ and $1.5667 \times 10^8m^3$, the influence rates were 81.23% and 94.94% respectively. From 1980 to 2015, the influence of human activities on runoff was significantly higher than that of the corresponding 1980-1994. From the entire study period, the impact of human activities on runoff was 91.52%, which was the main influence factor of runoff reduction.

Table 4 Influences of precipitation and human activities on the Wulanmulun River runoff

Time	rainfall（mm）	Runoff(10^8m^3)			rainfall		Human activity	
		Calculated	Measured value	Total decrease	Influence value(10^8m^3)	Influence rate(%)	Influence value(10^8m^3)	Influence rate(%)
1959-1979	422.9		2.481					
1980-1994	399.4	2.339	1.723	0.759	0.142	18.77	0.617	81.23
1995-2015	414.1	2.398	0.831	1.650	0.083	5.06	1.567	94.94
1980-2015	407.9	2.373	1.203	1.279	0.108	8.48	1.170	91.52

4. Discussion

(1) The comprehensive management of soil and water conservation in the 1970s was vigorously carried out. Therefore, the annual runoff of Wulanmulun Basin changed significantly in 1979. In 1980-1994, the implementation of water conservation measures and the increase in water use for industrial and urban expansion resulted in another significant change in annual runoff in 1997 [18]. The soil and water conservation measures in the Kuye River basins mainly include terrace, afforestation, grass-planting and construction of silt dams. Compared with the 1970s, the area of afforestation and grass planting in the 1980s increased by 4.47×10^4 hm^2 and 1.5 23×10^4 hm^2 respectively[5]. The large-scale implementation of the project of returning farmland to forestry and natural forest protection and large-scale coal mining started in 1999 led to a further significant

decrease of runoff. Wulanmulun River basin is an important coal energy base in China, which contains abundant coal resources. The exploitation of coal resources along the river basin is increasing year by year, leading to the formation of a large number of water flowing fractures, and changing the underlying surface conditions of the basin, which has a significant impact on the river runoff.

(2) The combined effect of climate change and human activities resulted in a significant reduction of runoff in Wulanmulun River. In the past 60 years of precipitation series, the impact of climate change on runoff within a short time scale is relatively small and relatively slow. However, human activities have a large impact on runoff within a short time scale and the effect is faster. Therefore, for development and management of water resources in river basin, we must strengthen the management of human activities and make them develop in a favorable direction.

(3) The double cumulative curve was used to study the effects of precipitation and human activities on runoff. There was no data on temperature and evaporation. The method give the influence of total human activities on runoff but cannot separate the effects of different human activities, which is the focus and difficulty of future research.

(4) Wulanmulun basin is arid and semi-arid continental climate. The shortage of water resources is the main problem that limits the economic development and environmental improvement in this area. In the past few decades, the decrease of runoff because of climate change and human activity has put enormous pressure on water management in the basin. In the future, we should strengthen research on a reasonable model of human activities to promote the sustainable use of water resources in the basin and provide the basic support for the economic development and ecological environment in the basin.

5. Conclusion

(1) In recent 60 years, the change of runoff abundance in Wulanmulun has been quite dramatic, and the inter-annual variation of runoff has been uneven. The average inter-decadal runoff is decreasing. Especially at the end of the 20th century, the annual runoff showed a significant downward trend. Annual runoff mainly experienced three stages of change, inflection point respectively in 1980 and 1995.

(2) The decrease of runoff in Wulanmulun is the result of natural factors and human activities. Before 1980, there was a good consistency between the change of runoff and precipitation. During the period of soil and water conservation in 1980-1994, the impact of climate change on runoff is still relatively large. After 1995, the change of runoff was mainly affected by human activities. During this period, the consistency between the change of runoff and the change of precipitation was decreased, and the impact of human activities on the decrease of runoff reached 8.23 million m^3. Throughout the study period, the impact of precipitation on runoff decreased gradually from 18.77% in 1980-1994 to 5.06% in 1995-2015. The impact of human activities on runoff increased significantly, and the influence rate increased from 81.23% in 1980-1994 to 91.52% in 1980-2015. It has become the most important factor affecting the change of runoff.

(3) The runoff sequence of Wulanmulun has strong anti-persistence characteristics. If climate change and human activities are still in accordance with the current trends, the Wulanmulun river runoff will have an increasing trend in the future.

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