Analysis of runoff characteristics and contribution rate in Xiying River Basin in the Eastern Qilian Mountains

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Abstract. The impact of climate change on the basin is extensive and long-lasting, which will have a profound impact on the natural ecosystems, water resources, agriculture, and human production and life throughout the basin. An in-depth understanding of the impacts of climate change on watersheds and quantitative assessments will help to scientifically plan and manage water resources and protect the integrity of natural ecosystems. In this paper, temperature, precipitation and potential evapotranspiration data were used to analyze the response of Xiying River runoff to climatic factors in the Qilian Mountains by sliding correlation and wavelet analysis. M-K test and cumulative anomaly (CA) were used to analyze the climatic factors and runoff in the basin and use the pettitt method to test. Finally, the cumulative rate slope change rate comparison method was used to analyze the change of precipitation, potential evapotranspiration and snow-melt water contribution to runoff in this area. The results showed that temperature, precipitation and potential evapotranspiration had obvious mutations from 1961 to 2012 in this region. Compared with temperature and potential evapotranspiration, the precipitation showed greater impact on runoff. In addition, the contribution rate of ice and snow melt water to runoff was relatively larger in 1990 - 2002 compared to 1961-1989, followed by precipitation and evapotranspiration; the increase of the precipitation contribution rate became the main factor to runoff, followed by ice and snow melting and evapotranspiration compared to 1990-2002 in 2003-2017.

1 Introduction

Global climate change has a profound impact on the terrestrial hydrological cycle, and the rate of climatic factors change was accelerating. Many scholars have begun to pay attention to its impact on the water cycle mechanism [1]. In the context of global warming, the average daily precipitation and extreme daily precipitation were continuously increased in many regions, which provided strong supports for the view that the water cycle was increasing [2-3]. The IPCC's first assessment report that the global warming in the past 100 years was estimated to be 0.45 °C, which rose to 0.85~0.89 °C in the fifth assessment report, and the global warming trend was obvious [4-5]. The impact of climate change on river basins was mainly reflected in changes of watershed area and runoff [6-7]. As an important part of the water cycle process in the basin, runoff was sensitive to climate change [8]. Chen et al [9] found that surface runoff in Canada showed an increasing trend in 2081-2100 through quantifying the prediction of the climate change effects on runoff, while Radchenko [10] found the summer runoff will reduced but the winter and spring runoff will increased from 2071 to 2100 in the Fergana Gorge in Central Asia through the HBV-light model, compared with 1971-2000. The study of predicted the change in the Amazon basin area found that the increase in temperature and precipitation would cause same change in the flood area in one third of the basin, especially, the precipitation time may increase by about 3 months in the eastern part of the Amazon [11]. Therefore, although the global average precipitation shows an increasing trend, the trend of different regional runoffs is different considering the regional temperature, evapotranspiration and other factors, [6].

The runoff changes was deeply affected by factors such as temperature, precipitation, evapotranspiration, ice and snow melt water, and changes in land use types [12-13]. The study of climate and human factors for global ocean emissions had found that the flow trends of many rivers was mainly reflect the change of precipitation due to the influence of atmospheric-ocean circulation, showing that the runoff in mid-latitude regions were reduced and increased at high latitudes [14]. A study in different regions of the Nile River Basin found that a 10% increase in precipitation would increase runoff in the tropical regions of the basin, while the arid regions had opposite changes [15]. In the Great Plains of North America, the contribution rate of spring rainfall to rainfall runoff increased by 51%, and the snow and ice melt water to runoff decreased by 59% during the same period [16]. But in the observation of glacial runoff had found that glacial runoff will show a steady decline in the context of global climate change in high latitudes [17]. In the climate-ridden Central Asia region, climate warming would lead to an increase in the annual total

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evapotranspiration, which will bring greater changes to the form of river recharge in the area. And the overall runoff of the river would decrease, and the recharge time would be advanced [18]. A study on the runoff variation of rivers with different supply sources found that temperature rise was the main factor of river runoff change in this region and human activities have gradually became an important factor causing river runoff changes in northwestern China [19].

More and more studies have shown that in the context of global warming climate, the rate of temperature increase would rise with the altitude adding, and the temperature change of alpine climate was more significant than that of low altitude [20]. Elevated dependence warming (EDW) was obvious in the Qinghai-Tibet Plateau, so the region had become one of the most sensitive regions to respond to global climate change [21-22]. Located in the northeastern part of the Qinghai-Tibet Plateau, Qilian Mountain is an ecologically fragile cold and arid zone and a monsoon-affected marginal zone. It is an important ecological barrier in northwestern China [23]. According to the research on runoff variation in Qilian Mountainous Area, the runoff change in this area was less affected by human factors, and the climate had greater impact [24]. In addition, there was a big difference in the trend of runoff change between the eastern and western regions and the central region [25]. Furthermore, the study on runoff variation in Qilian Mountain area was mainly focused on the overall analysis of the three main domains of Heihe River, Shule River and Shiyang River, but the micro-level analysis of river source areas involves less [26-27]. Therefore, in this paper, we used the cumulative slope change rate comparison method proposed by Wang Suiji [28] to quantitatively analyze the characteristics of the Xiying River Basin runoff variation in the climate change background, which is the maximum primary tributary of the Shiyang River Basin. This method was widely used in quantitative research on runoff variation in arid and semi-arid areas of Northwest China [29]. The aim of this paper was to solving the following three problems: 1) Understand the climate and runoff variation characteristics of the river basin. 2) Confirmed the main factors causing the change of runoff in different time periods; 3) Quantitative analyzed the contribution rate of various factors causing changes in runoff at different time periods.

2 Formatting the title, authors and affiliations

2.1 Study Area

Xiying River is located in the northeastern part of the Qilian Mountains in northwestern China (101°39′-102°24′E and 37°28′-38°2′N). It is the largest primary tributary of the Shiyang River Basin, one of the three inland river basins in the Hexi Corridor, originating from the LengLongling Peak in the eastern section of the Qilian Mountains, flows southwest to the northeast and flows into the Xiying Reservoir after exiting the

mountain (Figure 1). The basin is located in a temperate continental arid climate zone. The climatic characteristics are cold and rare precipitation in winter, many high-temperature precipitations in summer in this area. The altitude is about 1873-4911 m, the drainage area are 1727.5 km^2, and there has JiuTiaoling hydrological stations (102°3′E and 37°52 ′N). During the period of 1961-2017, the average annual temperature was -0.63 °C, the annual precipitation was 489.13 mm, and the runoff was 3.16×10^8 m^3.

2.2 Data Sets

2.2.1 Meteorological Data. The meteorological data was come from the China Meteorological Data Sharing Service Network. The daily data includes daily average temperature, daily minimum temperature, daily maximum temperature, daily precipitation, sunshine hours, daily average relative humidity and daily average wind speed. Monthly data includes China's surface temperature monthly value of 0.5 ° × 0.5 ° grid data set (V2.0) and China's ground precipitation monthly value of 0.5 ° × 0.5 ° grid data set (V2.0), length of time was 1961-2017 year.

2.2.2 Runoff Data. The runoff data was derived from monthly measured runoff data from the JiuTiaoling Hydrological Station (Figure 1) in the Xiying River Basin provided by the Shiyang River Basin Authority. The length of time was 1961 - 2017.
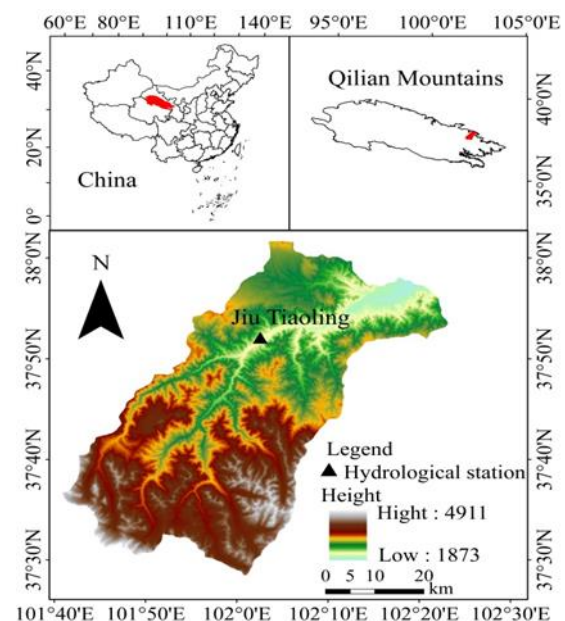

Figure 1. Overview of the study area.

2.3 Methods

2.3.1 Mutation analysis. The regression analysis and sliding mean method were used to analyze the trend of temperature precipitation and runoff in the Xiying River Basin, and the periodic characteristics of precipitation

and runoff in the basin were analyzed by wavelet transform and wavelet variance test. Although the Mann-Kendall mutation test has the advantage that the outliers have less interference to the results, the detection results may have drift and pseudo-mutation points [30-31], the results of the Mann-Kendall mutation test and cumulative anomaly (CA) mutation test for climatic factors and runoff were verified by the Pettitt test[32-33], in which the significance level of the M-K method and the Pettitt method was set to 0.05, the critical value of M-K is U=±1.96.

2.3.2 *Mann-Kendall mutation test:*

First, for the time series X (containing n samples), construct the order column:

$$s_k = \sum_{i=1}^{k} r_i \qquad (k = 2,3, \dots, n) \qquad (1)$$

In the formula

$$r_i = \begin{cases} +1 & x_i > x_j \\ 0 & \text{else} \end{cases} \qquad (j = 1,2, \dots, i) \qquad (2)$$

In the order column, S_k indicates that the value of the i-th time is greater than the value of j times, and the number of values is accumulated.

Define the statistic under the assumption that the time series is random:

$$UF_k = \frac{[s_k - E(s_k)]}{\sqrt{Var(s_k)}} \qquad (k = 1,2, \dots, n) \qquad (3)$$

In the formula, $UF_1=0$, $E(s_k)$ and $Var(s_k)$ s_k are the mean and variance of S_k, when x_1, x_2, …, x_n are independent of each other, according to their same continuous distribution, can be calculated The following formula:

$$E(s_k) = \frac{n(n+1)}{4} \qquad (2 \le k \le n) \qquad (4)$$

$$Var(s_k) = \frac{n(n-1)(2n+5)}{72} \qquad (2 \le k \le n) \qquad (5)$$

UF_k represents a standard normal distribution, which is a statistic sequence calculated in the order of time series X ($x_1, x_2, \dots, x_n$). Given the significance level α, according to the normal distribution table, if $UF_i > U_\alpha$, it indicates that there is a significant trend change in the sequence. Repeat the above process in the reverse order of time series X, (x_n, x_{n-1}, …, x_1), and let $UB_k = UF_k(k = n, n-1, \dots, 1)$, $UB_1 = 0$

2.3.2 *The Slope Changing Ratio of Cumulative Quantity.* The slope changing ratio of cumulative quantity (SCRCQ) was proposed by Wang Suiji et al to study the contribution rate of runoff variation in the HuangFuchuan watershed in 2012. The method overcomes the fitting defect of the original precipitation-runoff double accumulation curve in the inflection point

year, and significantly improves the correlation of the fitting [28]. The principle was to divide the study period by accumulating the anomaly inflection point. It was assumed that the slope of the linear relationship of the cumulative precipitation before and after the mutation point is recorded as K_{Pa} and K_{Pb} (unit: mm·a⁻¹), and the of change is the difference between the slope before and after the change and the slope before the change recorded as S_P; Similarly, the rate of change in runoff and evapotranspiration is recorded as S_R and S_{ET}. The Xiying River Basin has a high altitude and low human activities, which has little impact on runoff. The runoff changes are mainly affected by natural factors such as precipitation, evapotranspiration and melting of snow and ice. According to the definition of the slope changing ratio of cumulative quantity:

Cumulative precipitation slope changing ratio (S_P) is:

$$S_P = \frac{K_{Pb} - K_{Pa}}{K_{Pa}} \times 100 \qquad (6)$$

The contribution ratio of precipitation to runoff changes (C_P) is:

$$C_P = \frac{S_P}{S_R} \times 100 \qquad (7)$$

The contribution ratio of potential evapotranspiration to runoff changes (C_{ET}) is:

$$C_{ET} = \frac{S_{ET}}{S_R} \times 100 \qquad (8)$$

The contribution ratio of snowmelt to runoff changes (C_S) is:

$$C_S = 100 - C_P - C_{ET} \qquad (9)$$

In the formula: the subscript *P* indicates precipitation; *R* indicates runoff; *ET* indicates evapotranspiration; and *S* indicates ice and snowmelt water.

3 Results

3.1 Characteristics of climatic factors change in the Xiying River Basin

3.1.1 The interannual variation characteristics of climatic factors. The change trend of temperature, precipitation and evapotranspiration in the Xiying River Basin was analyzed with five years as a unit (Figure 2). The results showed that the overall trend of warm and wet changes in the Xiying River Basin was related to the predecessors against Qilian Mountain. The results of the regional studies were basically similar [34-35]. From 1961 to 2017, the temperature showed a temperature increase trend of 0.033 °C·a⁻¹ in this basin, and the annual average anomaly temperature changed from negative to positive in 1987, which was from -0.026 °C·a⁻¹ to 0.039 °C·a⁻¹ (Figure 2a). The precipitation showed an upward trend of 0.813 mm·a⁻¹ from 1961 to 2017, and this trend became more apparent in the 21st century (Figure 2b). Combined with the changes of annual precipitation and temperature, it can be seen that the Xiying River Basin had a tendency

toward cold and wet in 1961-1986, then the tendency changed toward warm and wet after 1987. In addition, the potential evapotranspiration showed a trend of 0.773 mm·a^{-1} from 1961 to 2017. Compared with the

temperature change, the time of annual average anomalous evapotranspiration changed from negative to positive value was later and the change range of each unit was small (Figure 2c).
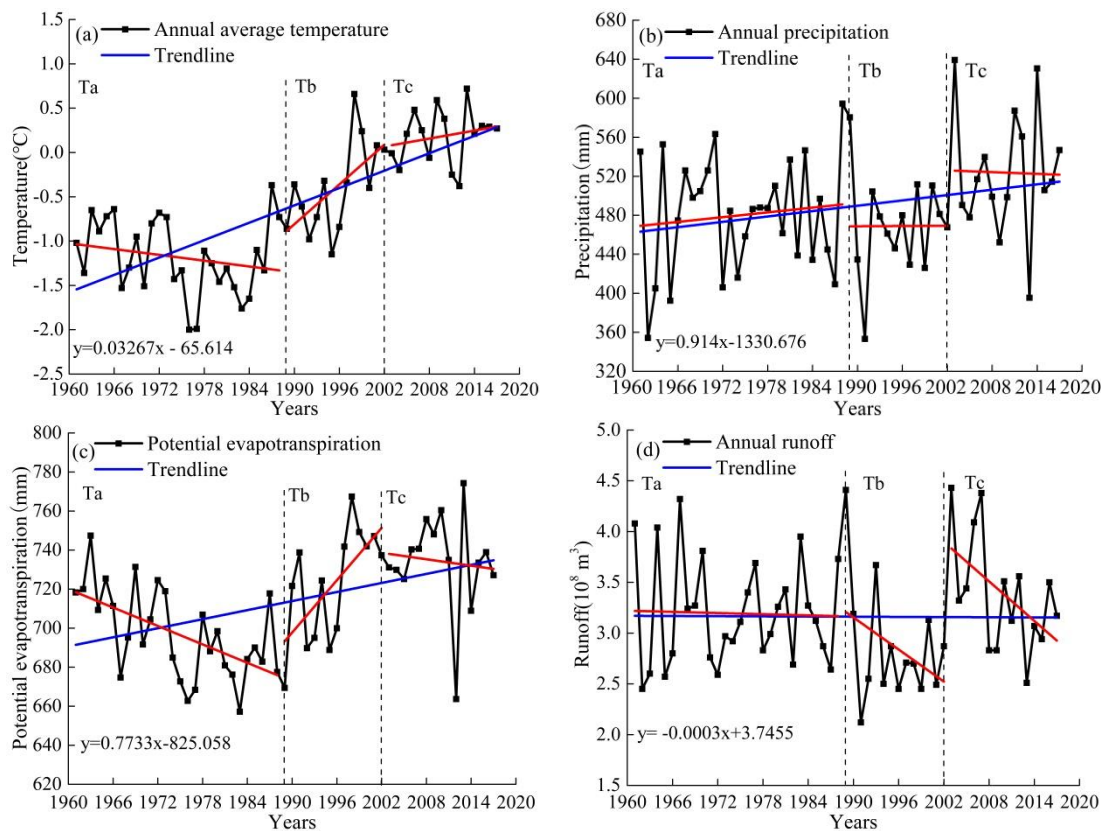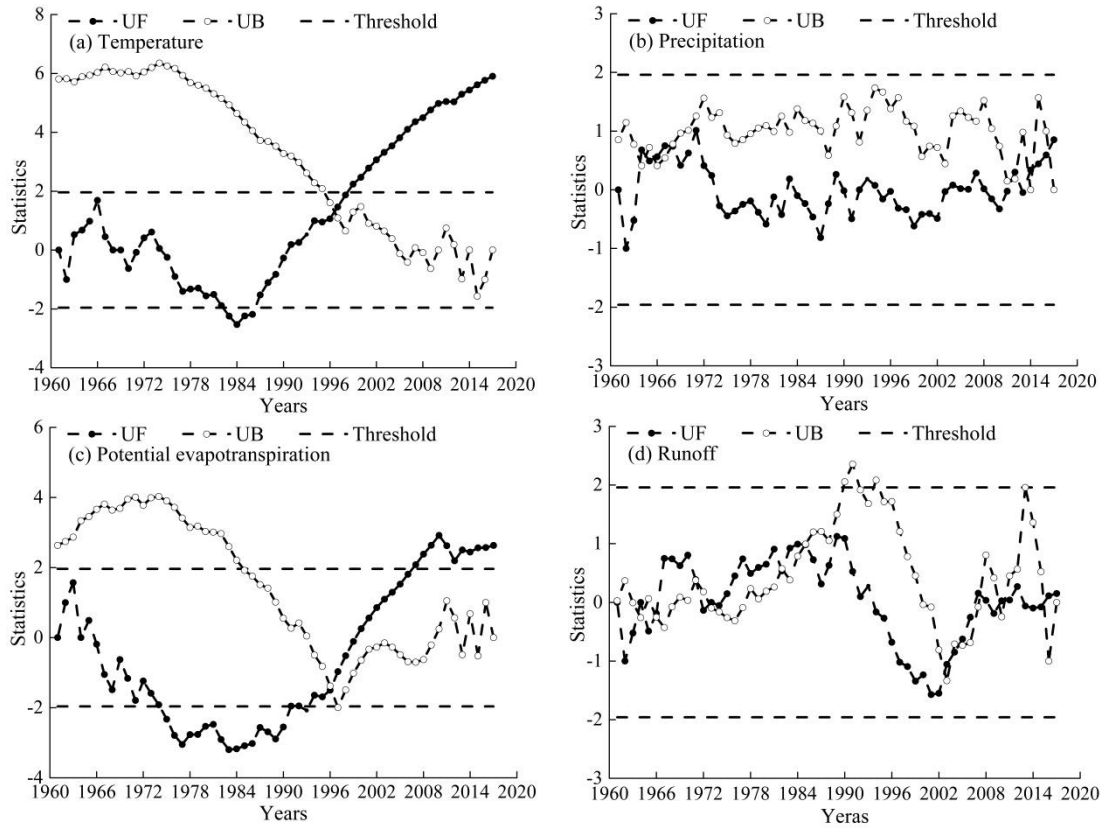

Figure 2. These Average temperature (a), precipitation (b), potential evapotranspiration (c), and Xiying River runoff (d) interannual variation. T_a: 1961-1989 years, T_b: 1990-2002years, T_c: 2003-2017years; blue line: overall trend line, red line: segmentation trend line.

3.1.2 Climatic factor mutation characteristics.
According to the mutation analysis (Figure 3a), the temperature of the Xiying River Basin in the M-K test showed an intersection point in 1996 and was tested by the significance level of P=0.05. The UF value began to be greater than the critical value of 1.96 in 1998, indicating that the temperature began to show a more obvious trend. At the same time, from the change of the cumulative anomaly value (Figure 4a), it can be seen that the cumulative anomaly temperature reached a minimum in 1996. After that, the annual average temperature rises and the trend increases, which was same as the results verified by the Pettitt method. The results of the sudden change in precipitation (Figure 3b) indicated that UF and

UB have multiple fluctuation intersections, but they have not passed the P=0.05 significance level test; In the analysis of cumulative anomaly variation, the cumulative anomaly of precipitation (Figure 4b) decreased sharply after 1989 and reached a minimum in 2002, followed by an upward trend. The results verified by the Pettitt method showed that the precipitation had mutation occurred in 2002. The change of potential evapotranspiration in this basin was similar to the suddenly change in temperature. UF and UB intersected in 1996 and passed the significance level test of P=0.05 (Figure 3c). The cumulative anomaly reached the minimum value in 1996 (Figure 4c) and the Pettitt method determined that evapotranspiration's mutation occurred in 1996.

Figure 3. Annual average temperature (a), precipitation (b), potential evapotranspiration (c), and runoff sequence (d) mutation point M-K analysis of the Xiying River Basin.
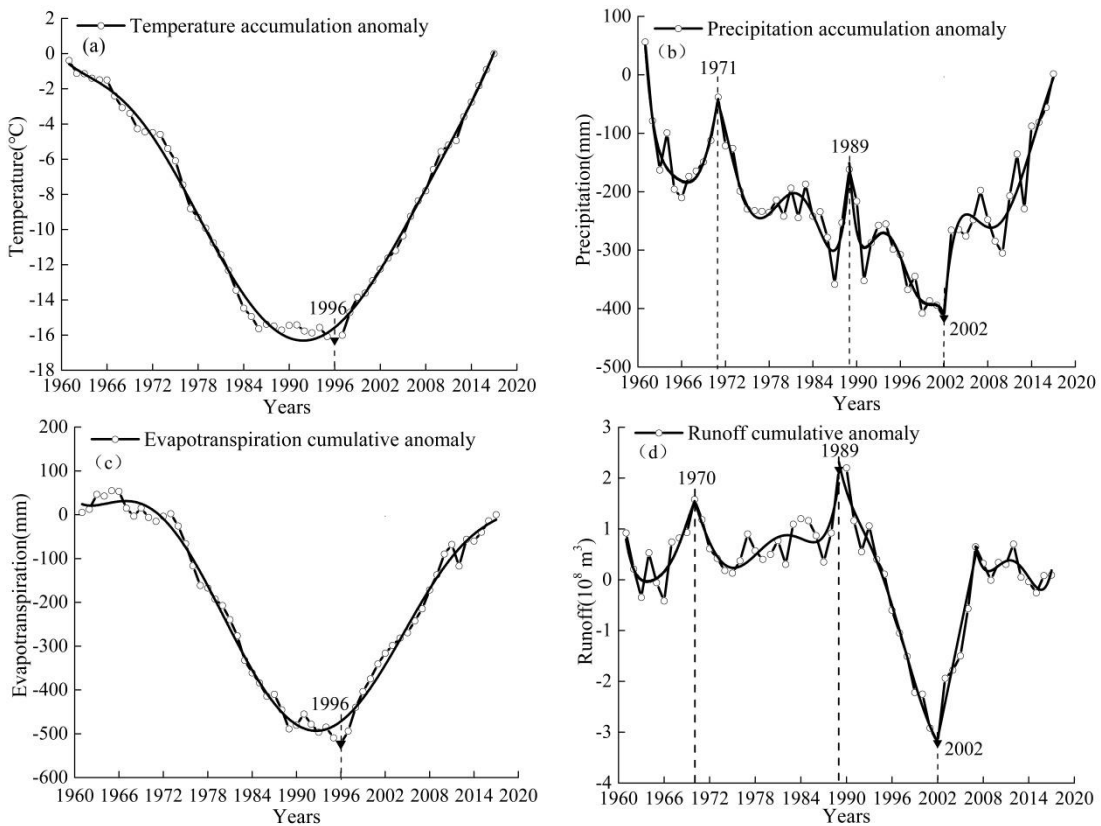
Figure 4. Annual average temperature (a), precipitation (b), potential evapotranspiration (c) and runoff (d) cumulative anomalies in the Xiying River Basin.

3.2   Characteristics of runoff variation in the Xiying River Basin

3.2.1 Interannual trends. The runoff of the Xiying River showed a weak downward trend during the period from 1961 to 2017, which was similar to the previous study on the runoff of the Shiyang River Basin [36], and its rate of change was -0.0003×10^8 m·a^{-1}, but Changes in runoff in the basin have large changes in different time periods (Figure 2d). It can be seen from the five-year sliding mean of the annual runoff that the annual runoff of the Xiying River fluctuated less before the 1990s, and then the fluctuation range became larger and the lowest and highest values of annual runoff appeared. At the same time, we found that the runoff of Xiying River in 1961-2017 showed a trend of decline-rise-rise-rise-rise-fall combined with polynomial regression analysis.

3.2.2 The mutation characteristics of runoff. Used M-K and cumulative anomaly method to analyze the runoff variation in the Xiying River Basin, it had found that there were multiple fluctuation intersections in the runoff of the M-K test, so there may be pseudo-mutation points (Figure 3d). It can be seen from the cumulative

runoff anomaly map (Figure 4d) that the runoff had an inflection point in 1989 (maximum value) and 2002(minimum value), and the cumulative runoff anomaly was divided into three segments, thus showing an increase - Decline-rise trend. At the same time, the Pettitt test determined that the runoff of the Xiying River was mutated in 1989 and 2002. Combined with Figure 2d, the runoff of the basin showed a trend of 0.0067 °C·a^{-1} from 1961 to 1989; in 1990 - 2002, there was a trend of -0.0064 °C·a^{-1} , and showed a trends of -0.0649 °C·a^{-1} in 2003-2017. The runoff had obvious trend before and after the mutation.

3.2.3 River periodicity. In the wavelet analysis of the inter-annual variation of the runoff in the Xiying River, it was found a relatively obvious periodicity (Figure 5). According to the wavelet transform and the variance test, the Xiying River runoff showed the first main cycle change of 15 years, followed by   sub-period change of 24 years and 3 years. The results were similar to the conclusions of the Shiyang River runoff cycle [37], which indicates that the Xiying River had similar runoff changes with the Shiyang River as the largest tributary of the Shiyang River source area. Their runoff changes were closely related.
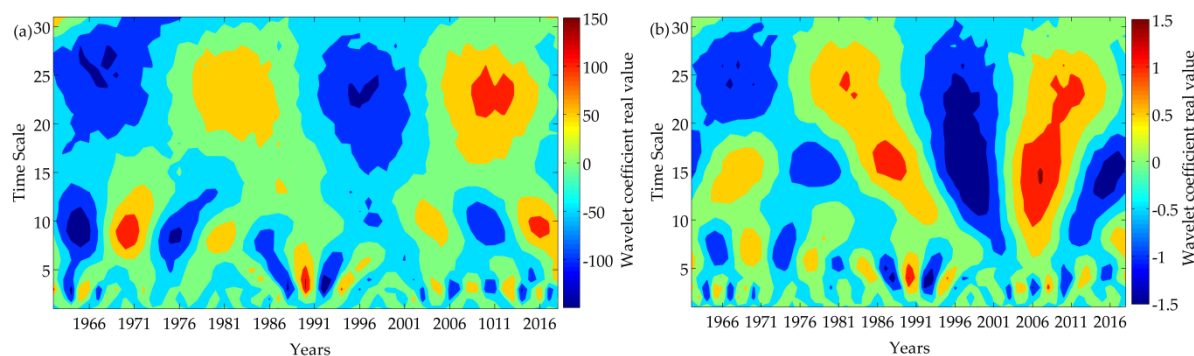

Figure 5. Precipitation (a) and runoff (b) wavelet analysis of Xiying River Basin.

3.3   The response characteristics of runoff and climatic factor

The runoff was related to the climatic factors (temperature, precipitation, potential evapotranspiration). After several attempts, the results of the 28-year sliding window were best. From the sliding correlation results (Figure 6), it can be seen that between 1961 and 2017, precipitation has always been significantly positively correlated with runoff ($P<0.01$, $0.564<R<0.772$), while the correlation between temperature and potential evapotranspiration and runoff changed significantly between 1975-2002 and 1978-2005. In 1975-2002, there was a significant negative correlation between temperature and runoff in 14 periods ($P<0.05$). After this period, the negative correlation between temperature and

runoff began to become insignificant and gradually changed to a positive correlation trend. The potential evapotranspiration and runoff were significantly negatively correlated before the period from 1978 to 2005 ($P<0.05$), and the correlation became insignificant after this period. Combined with the analysis of the climatic factors, it can be seen that before the early 21st century, temperature and evapotranspiration have a greater impact on the runoff of the Xiying River, but then the temperature and potential evapotranspiration were caused by a sudden change in the climatic factors in the region. The impact of runoff was reduced. At the same time, the used wavelet analysis also found that the precipitation and runoff cycles had a good consistency (Figure 5), although the main cycle was different, the secondary cycle were 24 years and 3 years.
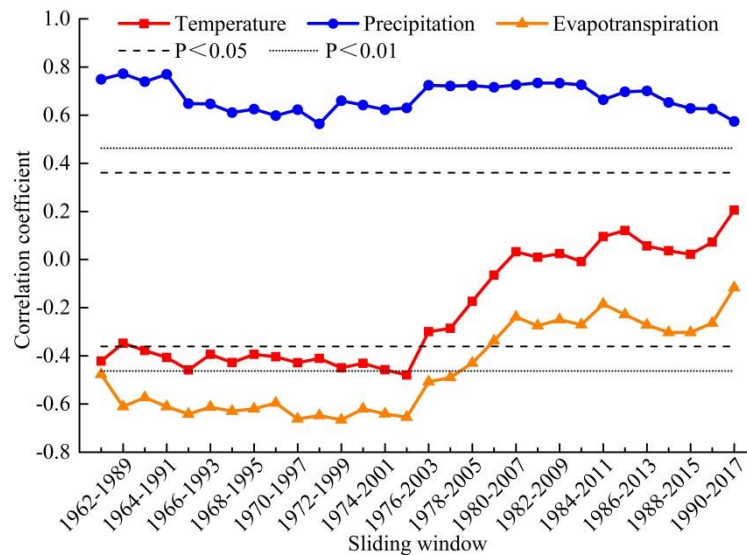
Figure 6. 28-year sliding correlation coefficient of climate factors in Xiying River Basin.

3.4 Studied on Contribution Rate of Runoff Change in Xiying River Basin

Xiying River Basin had a high altitude and a small population. Human activities had little impact on the ecological environment of the basin. The changed of runoff was mainly affected by natural factors such as precipitation, potential evapotranspiration and melting of snow and ice [38]. According to the previous two inflection points (1989 and 2002), the changed in the annual runoff of the Xiying River Basin was divided into three periods (T_a: 1961-1989, T_b: 1990-2002, T_c: 2003-2017), where the T_a period was the reference period for the change of the basin runoff. According to formula (6), the sag slope changed of runoff, precipitation and potential evapotranspiration at different time periods were calculated (Table 1).

Table 1. The slope variation of runoff meteorological and hydrological factors in the Xiying River Basin.

Period	The slope of Cumulative runoff (10^8 m³·a⁻¹)	The cumulative slope (Compared with Ta period)		The cumulative slope (Compared with Tb period)	
		Slope change (10^8 m³·a⁻¹)	Rate of change(%)	Slope change (10^8 m³·a⁻¹)	Rate of change(%)
T_a: 1961-1989	3.19	-	-	-	-
T_b: 1990-2002	2.73	-0.46	-14.42	-	-
T_c: 2003-2017	3.28	0.09	2.82	0.55	20.15

Period	The slope of precipitation (mm·a⁻¹)	The cumulative slope (Compared with Ta period)		The cumulative slope (Compared with Tb period)	
		Slope change (mm·a⁻¹)	Rate of change(%)	Slope change (mm·a⁻¹)	Rate of change(%)
T_a: 1961-1989	482.61	-	-	-	-
T_b: 1990-2002	466.04	-16.57	-3.43	-	-
T_c: 2003-2017	516.27	33.66	6.97	50.23	10.78

Period	The slope of potential evapotranspiration (mm·a⁻¹)	The cumulative slope (Compared with Ta period)		The cumulative slope (Compared with Tb period)	
		Slope change (mm·a⁻¹)	Rate of change(%)	Slope change (mm·a⁻¹)	Rate of change(%)
T_a: 1961-1989	716.56	-	-	-	-
T_b: 1990-2002	705.51	-11.05	-1.54	-	-
T_c: 2003-2017	735.33	18.77	2.62	29.82	4.23

It can be seen from Table 1 that the cumulative runoff slopes in the three periods of T_a, T_b and T_c were $3.19×10^8$ m³·a⁻¹, $2.73×10^8$ m³·a⁻¹ and $3.28×10^8$ m³·a⁻¹, respectively and experienced the process of falling and rising again. Compared with T_a, the cumulative runoff slope of the T_b period shows a decreasing change of - $0.46×10^8$ m³·a⁻¹, and the change ratio was 14.42%. The slope of cumulative amount of precipitation and potential evapotranspiration in the same period was -16.27 mm·a⁻¹ and -11.05 mm·a⁻¹, downward trend was 3.43% and 1.54%, respectively. According to formula (7) and formula (8), the influence of precipitation and potential

evapotranspiration on runoff variation was calculated. Compared with T_a period, the contribution rate of precipitation and potential evapotranspiration to runoff variation in T_b period was 23.79% and 10.68% respectively. Without considering the influence of temperature and other factors, according to formula (9), the contribution rate of snow and ice melt water to the runoff change in the T_b period was 65.53%.

Compared the T_c period with the T_b period, it can be found that the cumulative runoff slope change shows an increase of 0.55×10^8 m$^3 \cdot$a^{-1} with a change rate of 20.15%. The cumulative precipitation and evapotranspiration slope at the same time show 50.23 mm$\cdot$a^{-1} and 29.82 mm$\cdot$a^{-1}, respectively. The ratio was 10.78% and 4.23%, respectively. Compared with the T_b period, the contribution rate of precipitation and evapotranspiration to the runoff change in the T_c period was 53.5% and 20.99%, respectively, and the contribution rate of the snow melt water to the runoff change was 25.52%.

Comparing the three periods, it can be seen that the contribution rate of precipitation to the runoff variation of Xiying River increased from 23.79% in the T_b period to 53.5% in the T_c period, an increase of 29.71%. The contribution of potential evapotranspiration to the change of runoff in the same period, the rate increased from 10.68% to 20.99%, an increase of 10.31%. The contribution rate of ice and snow melt water to runoff change decreased from 65.53% to 25.52%, a decrease of 40.01%. In the three research periods, the contribution rate of precipitation and potential evapotranspiration to the runoff change in the Xiying River Basin was increase, with the largest increased in precipitation, while the contribution rate of ice and snow melt water to the change of runoff. The downward trend was similar to the results of previous studies on the snow cover area in the Qilian Shandong section [39-40]. Based on the above analysis, it can be seen that since 1961, the influence of precipitation, potential evapotranspiration and snow-melting water on the runoff variation of the Xiying River Basin had changed greatly. The influence of precipitation on runoff had gradually increased and became the main factor of influence.

4 Discussion

4.1 Response analysis of runoff changes in Xiying River to climatic factors

In this paper, we analyzed the climate and runoff characteristics of the Xiying River Basin from 1961 to 2017. Although the temperature, precipitation and evapotranspiration in the basin show an increasing trend, the climate factors in the Xiying River Basin were related to runoff sliding. In the results, the correlation between temperature, precipitation, evapotranspiration and runoff during this period has a large difference (Figure 6).

Throughout the study period, the runoff and precipitation in this area maintained a significant positive correlation. At the same time, combined with the analysis of watershed precipitation and runoff, it can be

seen that the runoff variation in the Xiying River Basin was closely related to the precipitation. Such results have also been confirmed in previous studies of the basin [41]. In addition, many studies indicate that river runoff was highly dependent on precipitation in small watersheds [42-44]. As the tributary of the source of the Shiyang River, the Xiying River has a small drainage area, so the runoff was significantly affected by precipitation.

The correlation between temperature and potential evapotranspiration and runoff showed significant changes in the early 21st century, both from significant negative correlation to insignificant (Figure 6). Which indicated that the runoff of the Xiying River was less affected by temperature and evapotranspiration, which may be due to a decrease in the rate of temperature rise and a decrease in potential evapotranspiration (Figure 2a and Figure 2c). This increased difficulty in converting glaciers and snow into surface runoff [39-40]. In addition, previous studies have shown that the temperature of glacial snowmelt may lead to an increase in seasonal runoff in the short term, but it would lead to the reduction of subsequent runoff in the medium and long term [45]. Therefore, after half a century of climate warming and a sudden change in climate in the early 21st century, the negative correlation between runoff in Xiying River Basin and temperature and potential evapotranspiration was greatly reduced.

4.2 Analysis of the variation of the runoff rate of the Xiying River

In this paper, the study on the change of the runoff contribution rate in the Xiying River Basin showed that the main contribution rate of the runoff in this region was changed from ice and snow melt to precipitation in the T_c period (2003-2017) compared with the T_b period (1990-2002). The precipitation contribution rate of in the Xiying River Basin increased significantly during the T_c period, and the contribution rate of evapotranspiration also increased, but the contribution rate of ice and snow melted water decreased significantly. This change may be related to sudden changes in temperature, precipitation, and potential evapotranspiration. Between 1990 and 2002, precipitation in this area decreased significantly, while temperature and evapotranspiration increased significantly during this period (Figure 2), so glaciers and snow were favored to be converted into ice and snow melted under the influence of temperature and other factors [46], which made it more important to contribute to the change of runoff. Analyzed glaciers and runoffs in the Nalin River Basin in Central Asia found that snow and ice melt water was significantly affected by temperature changes. Since global warming, the shrinkage of large glaciers and glaciers had accelerated, and snow and ice melt water had become an important source of runoff [47]. In 2002, the precipitation and runoff in the Xiying River Basin showed a sudden change. After 2002, the precipitation became the main factor affecting the change of runoff. Using the CMIP5 model to simulate and analyzed the uncertain effects of climate change on rivers, it had found that the change of

precipitation had more obvious effect on runoff than temperature. In the RCP4.5 scenario, the annual average runoff would decrease from 13.3% to 27.7% [48]. In addition, when analyzed the change of runoff in the ADR river basin in Central Asia, it was also found that the dominant factor causing the decline of runoff in the basin was precipitation rather than temperature. The decrease in precipitation reduces the runoff by 15.5%. The increase in temperature only increases the runoff by 0.2% [49].

5　Conclusions

In 1961-2017, the temperature in the Xiying River basin showed a trend of 0.033 °C·a^{-1}, and the mutation occurred in 1996; the precipitation showed a trend of 0.915 mm·a^{-1}, and the mutation occurred in 2002; the evapotranspiration showed a change trend of 0.336 mm·a^{-1} occurred in 1996. The runoff in the Xiying River Basin showed a weak downward trend of -0.0003×10^8 m^3·a^{-1}, and it was mutated in 1989 and 2002. The cumulative anomaly trend before and after the mutation changed significantly. At the same time, the runoff of the basin presents the first main cycle of 15 years and the secondary cycle of 24 years and 3 years.

In 1961-2017, precipitation and runoff in the Xiying River Basin have remained extremely positively correlated. The correlation between annual average temperature and runoff has changed from significant negative correlation to insignificant after 1975-2002. The potential evapotranspiration and runoff also changed from a significant negative correlation to insignificant after the period from 1978 to 2005.

Compared with the T_a period, the cumulative runoff slope showed a downward trend in the T_b period, and the contribution rates of precipitation, evapotranspiration and snow-melt water to runoff were 23.79%, 10.68% and 65.53%, respectively. The contribution rate of runoff variation during this period was mainly snow and ice melt water; while the cumulative runoff slope was still decreasing compared with T_b in T_c period, the contribution rate of precipitation, evapotranspiration and snow-melt water to runoff change was 53.5%, 20.99% and 25.52%, and the contribution rate of runoff change during this period was mainly precipitation. Compared with the T_c period and the T_b period, the contribution rate of precipitation to runoff change was increased by 29.71%, the evapotranspiration increased by 10.31%, and the ice and snow melt water decreased by 40.01%.

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