

# Quantifying the impact of mountain precipitation on runoff in Hotan River, northwestern China

Baofu LI (✉)<sup>1,2</sup>, Jili ZHENG<sup>1,2</sup>, Xun SHI<sup>3</sup>, Yaning CHEN<sup>4</sup>

<sup>1</sup> School of Geography and Tourism, Qufu Normal University, Rizhao 276826, China

<sup>2</sup> Rizhao Key Laboratory of Territory Spatial Planning and Ecological Construction, Rizhao 276826, China

<sup>3</sup> Department of Geography, Dartmouth College, Hanover, NH 03755, USA

<sup>4</sup> State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China

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**Abstract** It is of great significance to quantitatively assess the impact of mountain precipitation on inland river runoff in data scarce regions. Based on the corrected TRMM precipitation and runoff data, a variety of statistical methods were used to identify which areas of precipitation have an important impact on runoff in the Hotan River Basin, and to evaluate the effects that precipitation changes have on runoff at low, mid, high, and extremely high altitudes of mountainous areas. The results showed that: 1) From 1998 to 2015, the annual runoff showed a fluctuating upward trend with a rate of  $11.21 \times 10^8 \text{ m}^3/10 \text{ a}$  ( $P < 0.05$ ). Runoff in every season also had an increasing trend, with summer runoff the most significant at a rate of  $6.09 \times 10^8 \text{ m}^3/10 \text{ a}$ . 2) The annual runoff and precipitation changes had certain synchronization, with a correlation coefficient of 0.45 ( $P < 0.05$ ). Among them, the correlations between precipitation and runoff changes were highest at low and mid- altitudes, with coefficients of 0.62 and 0.55, respectively ( $P < 0.05$ ). 3) 65.95% of the regional precipitation at low altitudes and 48.34% at high altitudes were significantly correlated with runoff ( $P < 0.05$ ), while only 38.84% and 26.58% of regional precipitation levels at mid- and extremely high altitudes were significantly correlated with runoff. 4) The annual precipitation change in the basin was 1%, which would cause the annual runoff to change by 0.24%. In 1998–2015, the change of annual runoff caused by precipitation change at high altitudes was largest at a rate of  $-6.01\%$ ; the change rates of annual runoff caused by precipitation change in the low, mid-, and extremely high altitudes were  $-3.66\%$ ,  $-3.62\%$ , and  $-3.67\%$ , respectively. The results have significant scientific guidance for water resource

management in arid basins.

**Keywords** precipitation, mountainous areas, runoff, TRMM, arid region of northwestern China

## 1 Introduction

Precipitation in mountainous areas is one of the most significant sources of river runoff in arid regions (Chen et al., 2019). In recent years, data collected from the arid region of northwestern China has shown the impacts of global climate change (Li et al., 2016a; Wang et al., 2019; Li et al., 2020a). The response of river runoff to global climate change was inextricably linked to changes in precipitation (Deng et al., 2015; Yao et al., 2016). These changes in mountainous areas (such as total precipitation, intensity, form, and distribution) varied widely from region to region (Xu et al., 2016a; Wang et al., 2017), thus significantly impacting river water regimes, runoff, sediment, and regional water resources (Li et al., 2013; Xu et al., 2016a; Liu et al., 2018; Tian et al., 2019). Thus, research on the impact of precipitation on runoff in typical mountainous areas is of great significance to water resource management in inland river basins.

Some scholars have carried out research on these effects due to its importance (Li et al., 2013; Mo et al., 2018; Li et al., 2020b). For example, Xu et al. (2016b) simulated the annual runoff of the Kaidu River in northwestern China based on meteorological station data. Wang et al. (2017b) defined runoff indices and analyzed their relationships with associated precipitation for upper river basins in the arid region of northwestern China. The studies showed that the relationship between runoff and precipitation can be explored based on station data (Qin et al., 2016; Luo et al., 2017; Yin et al., 2017); however, given there was no

meteorological station in the high mountainous areas, the relationship between precipitation and runoff was unclear (Zhang et al., 2015; Gould et al., 2016). Furthermore, there was little research on the relationship between precipitation and runoff in the Hotan River Basin (Li et al., 2018a).

Due to the complex geographical environment in mountainous areas, there was scarce or no observation data, thus it was difficult to accurately analyze the characteristics of precipitation change (Zhu et al., 2018). The Tropical Rainfall Measuring Mission (TRMM) data had the features of high spatial and temporal resolution and long time series and could provide precipitation data for most parts of the world, which has become an important data source for studying precipitation (Kummerow et al., 1998; Rozante et al., 2018). For example, Duan and Bastiaanssen (2013) used the Geographic Ratio Analysis (GRA) method to calibrate the TRMM 3B43 V7 satellite precipitation product in Lake Tana Basin. The result indicated that the accuracy of the corrected data was improved and the GRA method was proved to be dependable and efficacious by the application in many different areas (Jongjin et al., 2016; Zhang et al., 2018). However, few studies attempted to adopt TRMM data to reveal the influence of temporal and spatial variation of precipitation in mountainous areas on runoff.

To reveal where and when precipitation change in mountainous areas significantly impacted runoff in Hotan River, we analyzed the relationship between the precipitation and runoff at low, mid-, high, and extremely high altitudes in mountainous areas based on GRA-calibrated TRMM 3B43 satellite data. We then quantitatively assessed the impact of precipitation changes on runoff

from 1998 to 2015, which can guide the simulation of hydrological processes and water resource development and utilization in the arid region.

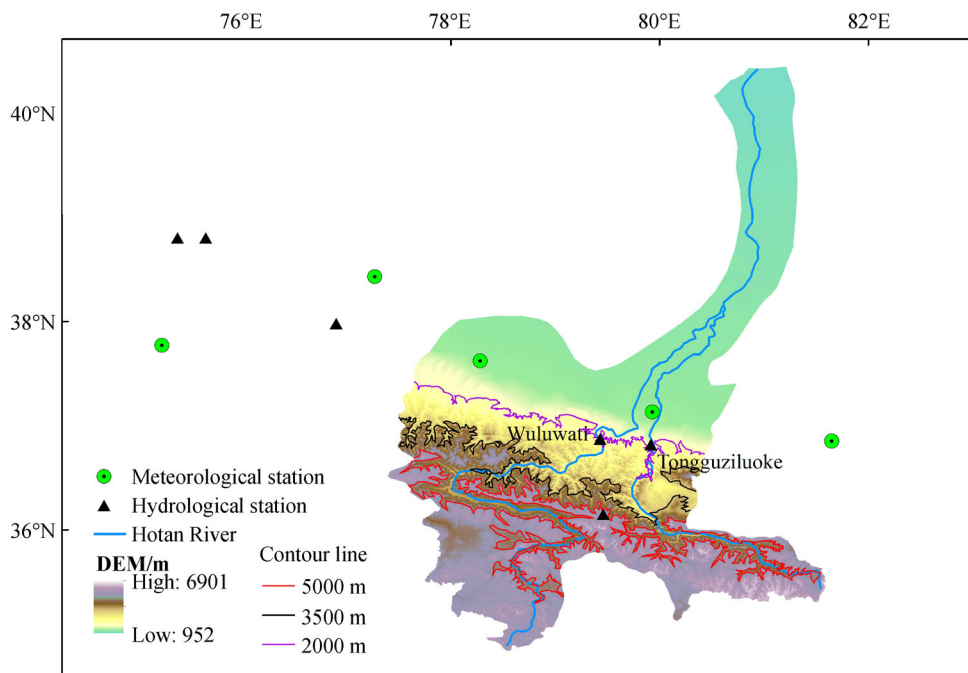
## 2 Material and method

### 2.1 Study area

The Hotan River Basin is located in the southern part of the Xinjiang Uygur Autonomous Region, China. The geographical position is between 77°41'E–81°58'E, 34°85'N–40°44'N, 117–205 km from east to west. It is 565 km long from north to south, with a drainage area of  $4.93 \times 10^4$  km<sup>2</sup> (Fig. 1). The average annual precipitation is 49 mm. The Hotan River originates from the Karakorum Mountains-west Kunlun Mountains. The Hotan River is formed by the Yulongkashi River and the Karakash River, flowing from the mountain pass and meet at the Khorshrak (38°05' N, 80°33' E). The corresponding hydrological stations are the Tongguziluoke and Wuluwati, respectively. The average altitude is about 3100 m. The weather patterns are typical for inland arid regions, with special climate, geologic, and hydrologic characteristics leading to higher temperatures, less precipitation, and strong evaporation.

### 2.2 Data

The NASA TRMM 3B43 data product (3B43 Version 7; see NASA website) was taken from the period of 1998 to 2015, with a spatial resolution of  $0.25^\circ \times 0.25^\circ$  and time resolution of 30 d. The relative error was limited at 0–



**Fig. 1** Location of the Hotan River Basin and distribution of surrounding meteorological stations and hydrological stations.

10 mm/h with the spatial range of 50°S–50°N, 180°W–180°E, covering most regions of China. The monthly product data of TRMM 3B43 precipitation was obtained by using the TRMM multi-satellite precipitation analysis method.

The TRMM data was corrected using precipitation data from 11 stations, including monthly data from 9 meteorological stations and 2 hydrological stations. The weather station data, taken from the period of 1998 to 2015, was from the China Meteorological Science Data Sharing Service Network (available at CMA website). The meteorological data of the hydrological station and the runoff data of the mountain pass were from the local hydrographic bureau.

### 2.3 Methods

#### 2.3.1 TRMM data correction

Geographic Ratio Analysis (GRA) method was employed to correct the TRMM 3B43 monthly precipitation data. The period 1998–2015 was divided into a calibration period (1998–2010) and a verification period (2011–2015) to verify the applicability of the GRA calibration method in the Hotan River Basin. The process is as follows (Duan and Bastiaanssen, 2013):

1) Calculate the ratio ( $P_{\text{Ratio}}^{\text{Point}}$ ) between the observation data ( $P^{\text{Point}}$ ) in the meteorological station from 1998 to 2015 and the corresponding TRMM precipitation data ( $P^{\text{TRMM}}$ ), that is  $P_{\text{Ratio}}^{\text{Point}} = P^{\text{Point}}/P^{\text{TRMM}}$ ;

2) IDW (Inverse Distance Weighted) interpolation method was used to interpolate  $P_{\text{Ratio}}^{\text{Point}}$  to planar data ( $P^{\text{Ratio}}$ );

3) The  $P^{\text{TRMM}}$  data multiplied by the planar interpolation data ( $P^{\text{Ratio}}$ ) to obtain the calibration precipitation data ( $P^{\text{GRA}}$ ).

The correlation coefficient ( $R$ ), relative error ( $BIAS$ ), and root-mean-square error ( $RMSE$ ) are used to judge and verify the precipitation data before and after correction.  $R$  is used to measure the linear correlation between simulated and measured values. The closer the  $R$  value is to 1, the greater the reliability of the simulation data.  $BIAS$  is used to indicate the degree of deviation between TRMM data and station measured data. The closer the  $BIAS$  is to 0, the greater the accuracy of the TRMM data. The TRMM data has overestimated the precipitation if  $BIAS$  is greater than 0, whereas an error of less than 0, indicates an under-estimation.  $RMSE$  is used to estimate the overall level of error. The smaller the  $RMSE$  value, the closer the TRMM precipitation value is to the measured value.

#### 2.3.2 Quantitative assessment of the impact of precipitation changes on runoff

The sensitivity coefficients were utilized to explore the sensitivity of hydrological elements to changes in

meteorological elements in the process of the effect of climate change on the hydrological system (Zheng et al., 2009 and 2018). We adopted the sensitivity analysis method proposed by Zheng et al. (2009) to explore the sensitivity of annual runoff to the precipitation. The formula is as follows:

$$\varepsilon = \frac{\bar{P} \sum (P_i - \bar{P})(Q_i - \bar{Q})}{\bar{Q} \sum (P_i - \bar{P})^2}, \quad (1)$$

where  $P_i$  denotes the precipitation,  $Q_i$  denotes the annual runoff,  $\varepsilon$  is the sensitivity coefficient, and  $\bar{P}$  and  $\bar{Q}$  are mean values of precipitation and runoff in many years, respectively. The physical meaning of  $\varepsilon$  means a precipitation change of 1% can induce runoff to change by  $\varepsilon\%$ .

To quantitatively identify runoff change caused by precipitation change, the following formula is used to calculate the change rate of runoff:

$$\phi = \frac{\Delta x}{\bar{P}} \times 100 \times \varepsilon, \quad (2)$$

where  $\phi$  is runoff change rate (%) caused by precipitation; and  $\Delta x$  is the change of precipitation. The Mann-Kendall-Sneyers test found that a step change point in runoff occurred in 2003, thus  $\Delta x$  refers to the change amount of the precipitation ( $P$ ) (using the comparison of the period 2004–2015 to the period 1998–2003);  $\bar{P}$  is the mean value of precipitation from 1998 to 2003; and  $\varepsilon$  is the sensitivity coefficient of annual runoff to precipitation.

#### 2.3.3 Other method

The non-parametric statistical test, called Mann-Kendall test, was used to analyze precipitation and runoff trends. This method was often employed to verify the significance test of the trend of climate time series (Wang et al., 2013; Li et al., 2018b).

To reveal the impact of precipitation on runoff in a mountainous area at different altitudes, in relation to the topographic features in the Hotan River Basin, the mountainous areas were divided into low (500–2000 m), middle (2000–3500 m), high (3500–5000 m), and extremely high (more than 5000 m).

## 3 Results

### 3.1 Runoff change

#### 3.1.1 Annual change

From 1998 to 2015, there was an increasing trend of annual runoff in the Hotan River at a rate of  $11.21 \times 10^8 \text{ m}^3/10 \text{ a}$  (Fig. 2). The results indicated that the statistical value of

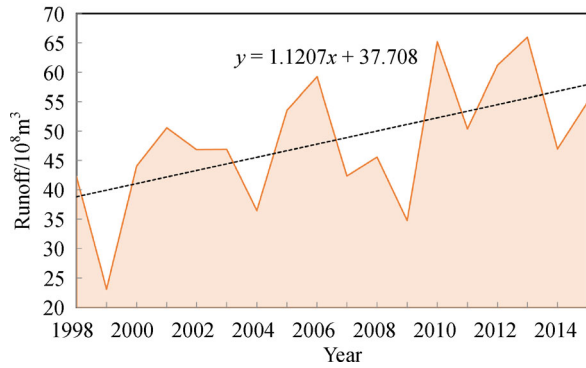


Fig. 2 Annual runoff trends of the Hotan River from 1998 to 2015.

the runoff change trend reached the significance level of  $P < 0.05$ . The runoff in 1999 was the smallest at  $23.11 \times 10^8 \text{ m}^3$ , with the greatest runoff occurring in 2013, reaching  $65.95 \times 10^8 \text{ m}^3$ ; an indication of significant fluctuation in annual runoff.

### 3.1.2 Seasonal change

From 1998 to 2015, the seasonal runoff of the Hotan River showed upward trends (Fig. 3). Among them, summer runoff showed the greatest increase of  $6.09 \times 10^8 \text{ m}^3/10 \text{ a}$ , followed by the rate for spring ( $2.11 \times 10^8 \text{ m}^3/10 \text{ a}$ ) and autumn ( $1.67 \times 10^8 \text{ m}^3/10 \text{ a}$ ), while the runoff change was

the most stable in winter, only  $0.60 \times 10^8 \text{ m}^3/10 \text{ a}$ .

From 1998 to 2015, the average annual runoff of the Hotan River in summer was  $34.11 \times 10^8 \text{ m}^3$  and the proportion of runoff for an entire year was as high as 70.54%. The runoff in August experienced the largest increase of  $14.08 \times 10^8 \text{ m}^3$ , followed by spring ( $5.01 \times 10^8 \text{ m}^3$ ) and autumn ( $6.53 \times 10^8 \text{ m}^3$ ), accounting for 10.37% and 13.50%, respectively. In winter, due to less precipitation and lower temperature, river runoff is typically dependent on groundwater recharge. The runoff ( $2.70 \times 10^8 \text{ m}^3$ ) in winter accounts for the smallest proportion, only 5.59%.

## 3.2 Precipitation change

### 3.2.1 TRMM data correction

From 1998 to 2010, there was a general overestimation of TRMM annual precipitation data before correction, which was consistent with previous research results (Zhang et al., 2017; Xu et al., 2019) (Fig. 4(a)). The TRMM data after GRA correction was basically consistent with the measured station data. The correlation coefficient between the pre-correction TRMM data and the measured precipitation was 0.56 ( $P < 0.001$ ), and was as high as 0.94 ( $P < 0.001$ ) between the correction TRMM data and measured precipitation. Meanwhile, the  $|BIAS|$  and  $RMSE$  values were reduced by 50% and 16.79%, respectively (Table 1).

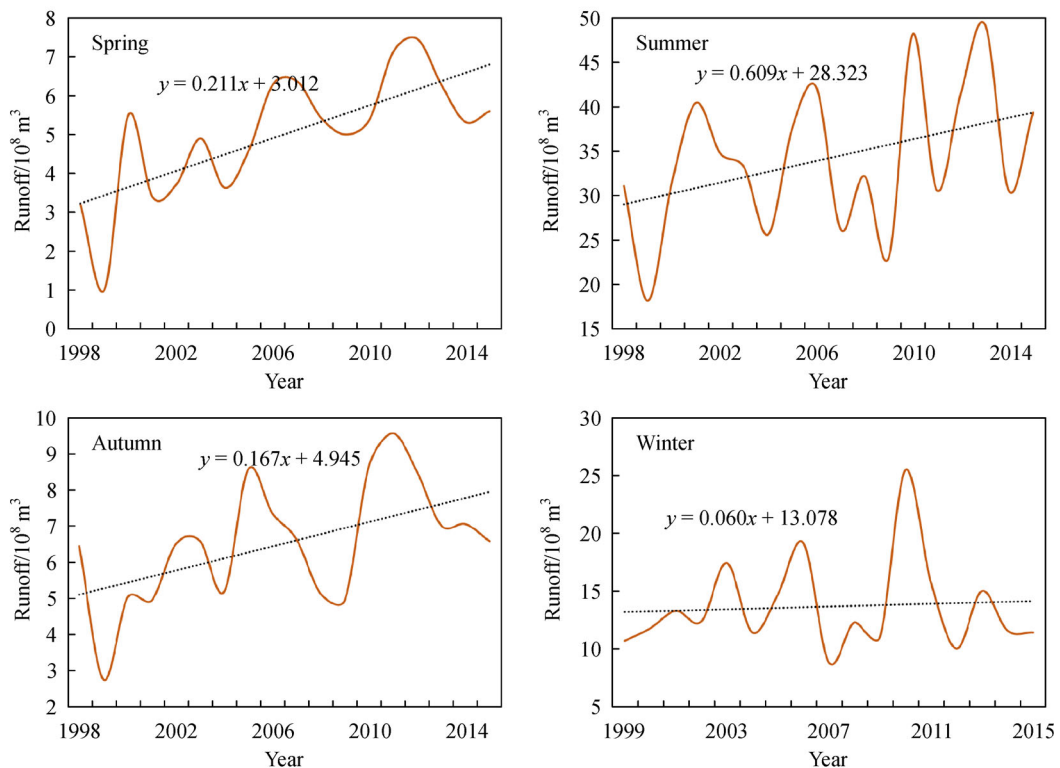
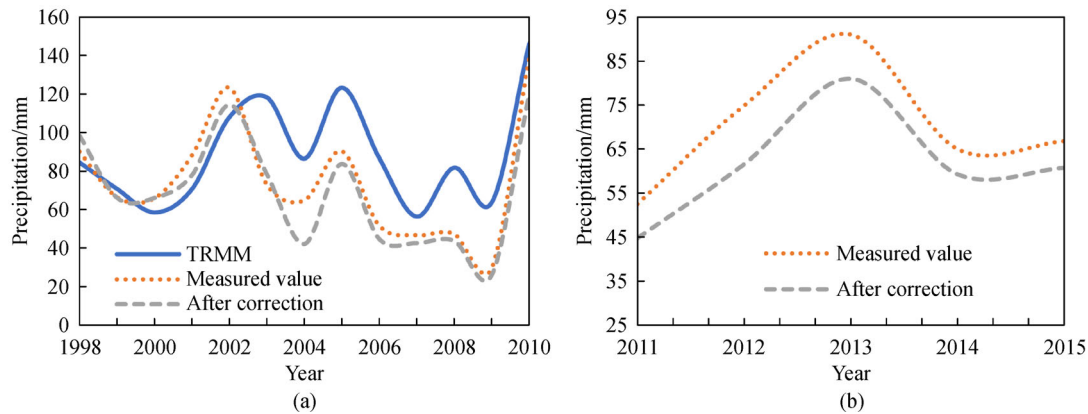


Fig. 3 Seasonal runoff trends in the Hotan River from 1998 to 2015.



**Fig. 4** In calibration period (a: 1998–2010) and verification period (b: 2011–2015), the trends in precipitation based on TRMM and stations in the Hotan River Basin.

**Table 1** Relationship between TRMM data and measured precipitation data in Hotan River basin during calibration period (1998–2010)

Correction	<i>R</i>	<i>BIAS</i>	<i>RMSE</i>
Before correction	0.56***	0.10	57.66
After correction	0.94***	-0.05	47.98

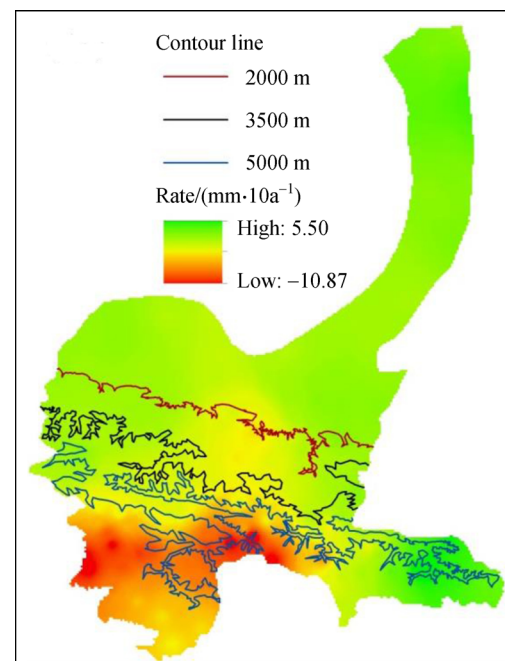
Note: \*\*\* indicates that the correlation between them reached  $P < 0.001$  significance level.

During the verification period (2011–2015), there was a slight deviation between the TRMM data and the measured site data after GRA correction, but the trend was basically the same, and the correlation coefficient reached 0.95 ( $P < 0.001$ ) (Fig. 4(b)). Overall, the accuracy of TRMM data after GRA calibration has greatly improved, indicating that the method was suitable for the correction of TRMM data in the study area. Therefore, based on the measured precipitation data from 11 meteorological and hydrological stations in the Hotan River Basin from 1998 to 2015, the GRA method was used to correct TRMM 3B43 monthly precipitation data.

### 3.2.2 Precipitation change

The average annual precipitation in the Hotan River Basin from 1998 to 2015 was 49.44 mm, with the most significant amount observed in 2001, reaching 88.21 mm and the least in 2009 at only 17.72 mm (Fig. 5). These observed amounts are an indication of the significant interannual fluctuations in precipitation. From the perspective of spatial distribution, the annual precipitation at low and middle altitudes in mountainous areas was minimal at 67.31 mm and 112.88 mm, respectively. Alternatively, annual precipitation was significant at high and extremely high areas altitudes, at 167.56 mm and 197.98 mm, respectively. The spatial distribution gradually decreased from south to north.

The trend of annual precipitation in the Hotan River



**Fig. 5** Spatial variation of annual precipitation in the Hotan River Basin from 1998 to 2015 based on correction TRMM data.

Basin showed an overall reduction from 1998 to 2015, at a rate of  $-2.25$  mm/10 a, but this trend did not pass the significance test. The precipitation trends at different elevations in the river basin were not significant. Precipitation in low mountainous areas increased while other areas exhibited decreasing trends. The precipitation change at middle altitudes was the most stable, with a rate of only  $-0.25$  mm/10 a. The change rates of precipitation at low and high altitudes were similar, at  $0.62$  mm/10 a and  $-0.88$  mm/10 a, respectively. The precipitation at extremely high altitudes was the most obvious, reaching  $-1.74$  mm/10 a.

### 3.3 Relationship between precipitation and runoff

#### 3.3.1 Change

From 1998 to 2015, the average annual runoff and precipitation in the Hotan River Basin had a certain degree of synchronization, especially after 2004 (Fig. 6(a)). The peaks and valleys of the two curves also showed good synchronization. It can be seen that precipitation changes had a clear impact on runoff.

Precipitation was relatively concentrated in June and July while the runoff was concentrated in July and August. It can be found that the distribution and concentration of precipitation and runoff were different during the year. The concentration period of runoff occurred after the precipitation concentration period and the change in precipitation was similar with that in runoff. It indicates that runoff from the Hotan River Basin may have a hysteresis effect on precipitation (Fig. 6(b)). Runoff was affected by many factors, such as climate, underlying surface conditions, and human activities (Li et al., 2016b; Liu et al., 2017). The runoff caused by precipitation passes through three stages: stoppage, flooding, and river channel collection. Therefore, each precipitation occurrence requires time to flow to the hydrological station; that is, the hydrological change corresponding to the precipitation at the hydrological station has a specific time difference.

#### 3.3.2 Relationship between precipitation and runoff at different altitudes

From 1998 to 2015, there was a significant ( $P < 0.05$ ) correlation between annual runoff and precipitation in the Hotan River Basin, with a correlation coefficient of 0.45 (Table 2). The correlation between precipitation and runoff at low altitudes was greatest, with a coefficient of 0.62 ( $P < 0.05$ ). This correlation was significant in 68.95% of the region (Figs. 7 and 8). At mid-altitudes, the correlation coefficient was 0.55 ( $P < 0.05$ ), with a significant correlation observed in 38.84% of the area. Even though the correlation coefficient between average precipitation and runoff at high altitudes (0.42) did not pass the significance test, the correlation was significant ( $P < 0.05$ ) in 48.34% of the area. The correlation coefficient at extremely high altitudes was the smallest at only 0.25, with 26.58% of the area showing a significant correlation. This primarily due to the weak correlation between precipitation and runoff in the southwestern region of the area.

In the Hotan River Basin, a high correlation between precipitation and runoff (up to 0.39) was only observed in summer, and the distribution of the correlation coefficient was similar to annual distribution. The correlation coefficient between precipitation and runoff at low altitudes was as high as 0.59 ( $P < 0.05$ ) with 63.90% of the area showing a significant correlation. The correlation

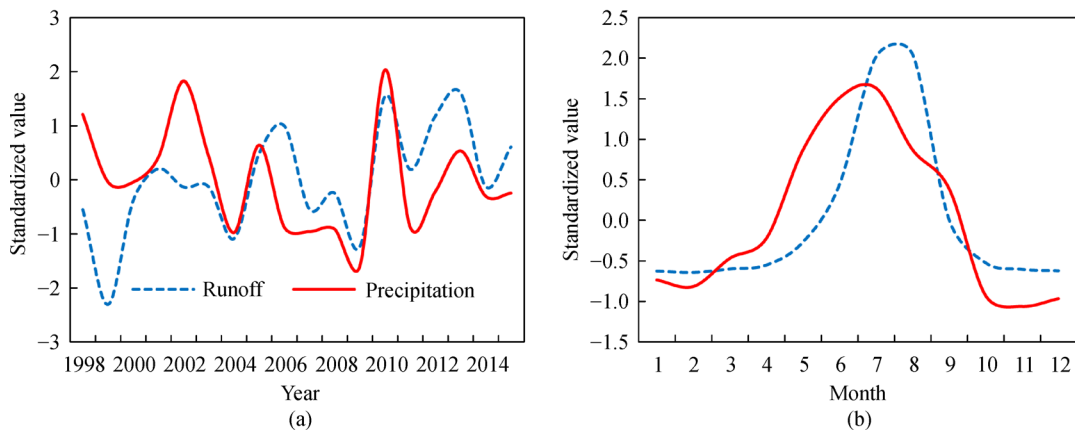
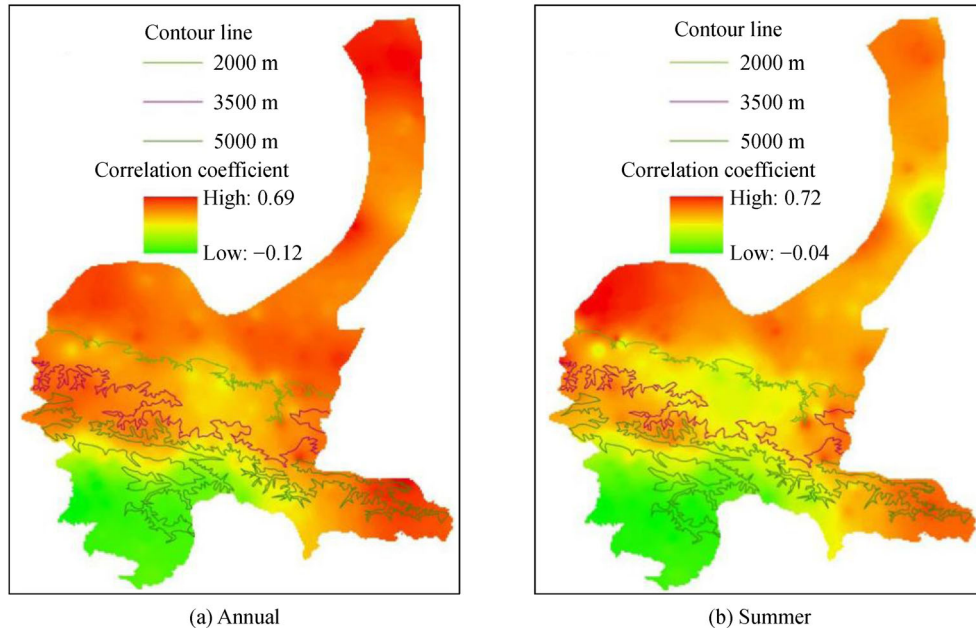


Fig. 6 (a) Annual and (b) monthly runoff and precipitation changes in the Hotan River Basin.

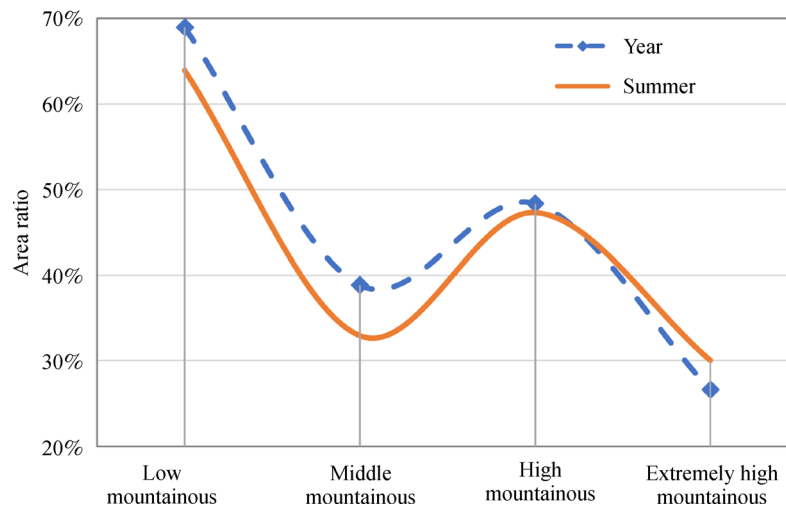
**Table 2** Pearson correlation coefficient between precipitation and runoff in Hotan River Basin from 1998 to 2015

Period	Low altitude	Mid- altitude	High altitude	Extremely high altitude	Hotan River Basin
Year	0.62*	0.55*	0.42	0.25	0.45*
Spring	0.05	0.04	0.01	-0.02	0.01
Summer	0.59*	0.39	0.38	0.27	0.39
Autumn	0.13	0.09	-0.06	-0.11	-0.03
Winter	0.00	0.13	0.08	0.05	0.07

Note: \* indicates that the correlation coefficient reached  $P < 0.05$  significant level.



**Fig. 7** Spatial distribution of correlation coefficient between (a) annual, (b) summer runoff and precipitation in the Hotan River Basin from 1998 to 2015.



**Fig. 8** The area ratio of significant ( $P < 0.05$ ) correlation between annual, summer runoff and precipitation in the Hotan River Basin from 1998 to 2015.

coefficient in other seasons was less than 0.15. This was due to the occurrence of the highest levels of rainfall in the Basin during the summer, resulting in a greater proportion of precipitation to runoff than in other seasons, and thus, a higher correlation between summer precipitation and runoff.

### 3.4 Quantitative assessment of the impact of precipitation changes on runoff

The sensitivity coefficient of annual runoff to precipitation change was 0.24, which means that a 1% change in annual precipitation would result in a 0.24% change in average

annual runoff (Fig. 9). The runoff was the most sensitive to the change of precipitation at low altitudes with a coefficient of 0.33; the river runoff had similar sensitivity to the precipitation at both mid- and high altitudes, with sensitivity coefficients at 0.26 and 0.23, respectively. The runoff was less sensitive to the change in precipitation at extremely high altitudes with a coefficient of only 0.11. The results indicated that the annual runoff was more sensitive to the change in precipitation at lower altitudes than at higher altitudes. This was primarily related to the proportion of precipitation to river runoff, indicating that the proportion of precipitation at lower altitudes was greater than that in other areas.

Using Eq. (2), this study showed the change of precipitation at high altitudes resulted in the largest annual change in runoff at the rate of  $-6.01\%$ . The change rate of annual runoff of rivers caused by precipitation changes at low, mid-, and extremely high altitudes was  $-3.66\%$ ,  $-3.62\%$  and  $-3.67\%$ , respectively, indicating that the change in runoff caused by precipitation at different elevations was inconsistent. There is a variance in the sensitivity of river runoff to precipitation changes at different elevations.

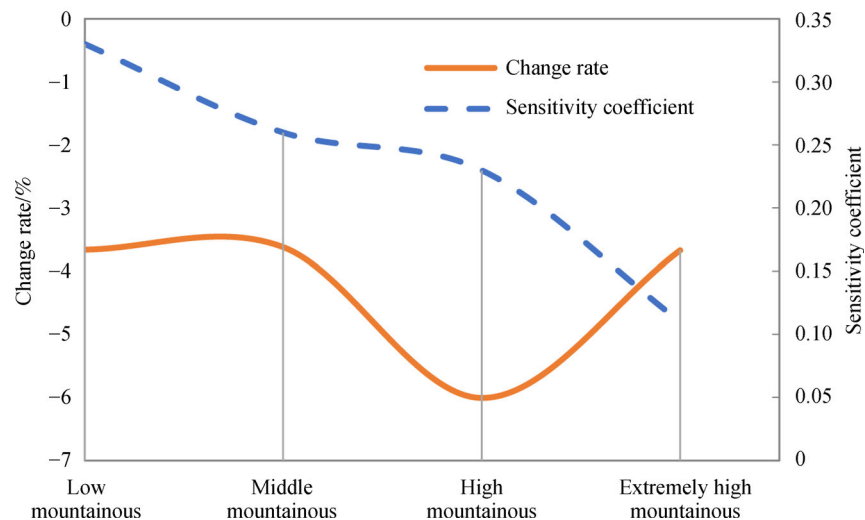
#### 4 Discussion

The glacial melting of the Yulongkashi River was about  $14.8 \times 10^8 \text{ m}^3$ , accounting for 66.4% of annual runoff; annual glacial melting in the Karakash River was about  $10.01 \times 10^8 \text{ m}^3$ , accounting for 46.6% of it (Yang, 1991). In addition, 18.3% and 24.3% of the runoff in the Yulongkashi River and the Karakash River, respectively, were replenished by groundwater in the mountains, which in turn was formed after water from melting glaciers and

snow was infiltrated into the ground (Luo et al., 2013). It can be seen that the runoff in the Hotan River Basin was dominated by the water from glacial melting at high and extremely high altitudes. Temperature was an important factor affecting the runoff in the Hotan River (Li et al., 2018a). Li et al. (2012) showed that the relationship between runoff and temperature was more significant than the relationship between temperature and precipitation in the north slope of Kunlun Mountains, yet different results were observed for other rivers. Therefore, despite reduced precipitation in the basin, there was an increase in temperature due to global warming, which also led to an increase in water levels due to melting glaciers and snow, and thus, an increase in runoff (Li et al., 2018a), which varied from other research results. For example, Qin et al. (2016) found that headwater runoff in the rivers of Xinjiang had increased over the past 50 years, primarily due to an increase in precipitation and water levels from melting of glaciers and snow caused by global warming. Thus, the increase in runoff of Hotan River was not sustainable. Glacial melt and decreases in precipitation present a risk to adequate water resources in the future; thus, it is necessary that preventative measures be taken to ensure water resources are not impacted.

Many studies have shown that the accuracy of climatic factors was an influencing factor for the simulation of climatic hydrological processes in mountainous areas (Luo et al., 2013). Our research showed that the corrected TRMM data basically reflects the characteristics of precipitation changes in mountainous areas at different altitudes. Therefore, when simulating the hydrological process of the Hotan River, the precipitation data can be considered to improve the simulation accuracy of the model in runoff.

Some studies have shown that the climate in the arid



**Fig. 9** Sensitivity coefficient of annual runoff in Hotan River Basin to precipitation changes in mountainous areas and the change rate of annual runoff caused by precipitation changes

regions of northwestern China was warming and increasing in humidity (Li et al., 2016a; Yang et al., 2017). This study indicated that the precipitation in the mountainous areas of Hotan River had decreased, which was significantly different from the climate trend of northwestern China. The changes in precipitation were affected by many factors such as topography, elevation, and regional circulation. We will carry out further study to reveal the reasons for the change in precipitation in future research.

Runoff data were taken from the mountain pass hydrology station. It is worth noting that although the results showed a significant correlation between runoff in Hotan River and precipitation at a low altitude, it cannot be concluded that precipitation at low altitudes yet above the mountain pass significantly impacted runoff. Studies have also shown (Chen et al., 2016) that precipitation in at mid- and high altitudes has a greater impact on runoff in arid areas.

## 5 Conclusions

1) From 1998 to 2015, the annual runoff showed a fluctuating upward trend with a rate of change of  $11.21 \times 10^8 \text{ m}^3/10 \text{ a}$  ( $P < 0.05$ ) in the Hotan River. The runoff in all seasons showed an upward trend. The average runoff in summer was the largest with  $34.11 \times 10^8 \text{ m}^3$ , accounting for 70.54% during the entire year. It can be seen that the distribution of runoff in the Hotan River Basin was extremely uneven.

2) From 1998 to 2015, the annual runoff and precipitation in the Hotan River Basin had a certain synchronization, with a correlation coefficient of 0.45 ( $P < 0.05$ ). The correlation between precipitation and runoff at low and mid-altitudes was highest, with correlation coefficients at 0.62 and 0.55, respectively ( $P < 0.05$ ). High correlation between precipitation and runoff (0.39) only occurred in summer, with a correlation coefficient at low altitudes at 0.59 ( $P < 0.05$ ).

3) From 1998 to 2015, the sensitivity coefficient of annual runoff to precipitation change was 0.24, which means that a 1% change in precipitation would result in a 0.24% change in average annual runoff. The river runoff was most sensitive to the change of precipitation at low altitudes with a coefficient of 0.33. The river runoff had a similar sensitivity to precipitation at mid- and high altitudes, with sensitivity coefficients at 0.26 and 0.23, respectively. The sensitivity of annual runoff to precipitation change extremely high altitudes was the lowest with a sensitivity coefficient of only 0.11.

4) From 1998 to 2015, the change in precipitation at high altitudes in mountainous areas contributed to the largest change in annual runoff, at a rate of  $-6.01\%$ . The change rates of annual runoff caused by precipitation changes at low, mid-, and extremely high altitudes were  $-3.66\%$ ,  $-3.62\%$ , and  $-3.67\%$ , respectively.

**Acknowledgements** This research is supported by the National Natural Science Foundation of China (Grant Nos. U1903208 and 41501211). We are grateful to anonymous reviewers for their helpful comments on improving the manuscript.

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