



# Coupling relationship between meteorological factors and precipitation: an empirical study from Xinjiang Province, China

Yuhu Zhang<sup>1</sup> · Pei Xie<sup>2</sup> · Yanru Pu<sup>3</sup> · Peng Wang<sup>3</sup>

Received: 31 July 2019 / Accepted: 28 April 2022 / Published online: 12 May 2022  
© The Author(s), under exclusive licence to Springer-Verlag GmbH Austria, part of Springer Nature 2022

## Abstract

The present study examines the spatio-temporal trend analysis of rainfall and temperature over time (annual, warm season, and cold season) from 1981 to 2010 in Xinjiang Province, China. The Mann–Kendall test, least square linear regression, and Spearman rank correlation were used to detect the direction and magnitude of change in rainfall and temperature. A panel data set of 8 meteorological factors during 1981–2010 was used to detect the statistical relationship between rainfall and other meteorological factors in Sect. 4.4. The results showed that annual rainfall and seasonal rainfall increased steadily, and the increasing rainfall trend during the cold season was more significant compared to the warm season. For temperature, average, high, and low temperatures increased on the annual and seasonal scales. Spatially, the northern parts of Xinjiang received more rainfall and showed higher variability. Based on the rainfall trend, the province was clustered into three parts using the K-means method. Based on this clustering, the statistical relationships between rainfall and other meteorological factors were investigated. The results showed that temperature and relative humidity were significantly correlated with rainfall in the three clusters, whereas sunshine, wind speed, and cloud cover had small influences on rainfall.

## 1 Introduction

Rainfall and temperature are frequently analyzed to demonstrate the climate characteristics of a region and thereby, assess climate change (Almazroui et al., 2012). Rainfall determines the amount of water available in an area to meet various demands such as agriculture, industrial, hydroelectric power generation, and others (Jain and Kumar, 2012). Especially with global climate constantly warming in recent years, some extreme climate events have occurred frequently (Hao et al., 2013; Leonard et al., 2014), resulting in a clear increase in the occurrence of meteorological disasters and socioeconomic losses (Bouwer, 2010). For instance, drought, flood, agricultural production, and loss

of biodiversity depend largely on rainfall and temperature (Sharma et al., 2011).

It is obvious that the characteristics of rainfall and temperature vary distinctively in different regions (Zhang et al., 2013). The assessment of the historical trends and future projections on local scale is of immense significance for climate analysts and local water resources planners. China has witnessed significant changes in climate (IPCC, 2007; IPCC, 2013), especially in Xinjiang Province, a typical arid and semi-arid land that has witnessed considerable changes in rainfall and temperature trends. Increasing number of studies have so far focused on the analysis of rainfall and temperature trends in Xinjiang Province on a local scale (Jiang et al., 2013; Zhang et al., 2012). It was revealed that both temperature and rainfall trends increased steadily during 1960–2010, but varied substantially between annual and seasonal periods. Furthermore, extreme weather conditions are also becoming increasingly evident in this region. Increasing trends in the precipitation amount, number of rainy days, and the intensity of the extreme precipitation have been identified in more than 70% of the total rainfall monitoring stations (Jiang et al., 2013). Therefore, it is urgent to reduce the intensity and frequency of the changes in these trends to avoid extreme weather conditions.

✉ Peng Wang  
upeswp@ujls.edu.cn

<sup>1</sup> College of Resource Environment & Tourism,  
Capital Normal University, Beijing 100048,  
People's Republic of China

<sup>2</sup> Chinese Research Academy of Environmental  
Sciences, No.8, Dayangfang, Beiyuan, Beijing 100012,  
People's Republic of China

<sup>3</sup> Faculty of Civil Engineering and Mechanics, Jiangsu  
University, Zhenjiang 212013, People's Republic of China

In the more severe context of climate change, exploring the reasons behind the rainfall trend has become a prominent issue. A large number of statistical researches has been conducted to investigate the relationship between rainfall and meteorological factors such as El Niño-southern oscillation (Nicholls et al., 1997; Ogutu et al., 2008; Kane R P., 1997) and monsoon (Sun et al., 2017). In Xinjiang Province, several researches were conducted to investigate the reasons of rainfall trend as well. Zhou et al. (2015) explores the relationship between the sea surface temperature over the Indian Ocean (IOSST) in March and the summer rainfall in Xinjiang, and the results demonstrated that the warm (cold) IOSST in March tends to cause the increase (decrease) of the summer rainfall over Xinjiang, especially in the Tian Shan and Kunlun Mountains. Wei et al. (2003) detected that response relationship of rainy season precipitation in northern Xinjiang to ENSO, and found that the rainy season precipitation in northern Xinjiang has response to the southern oscillation index from May of the previous year to April of the same year. Moreover, the correlation between rainfall and temperature was also significant. Nicholls N (1997) has proven that variations in rainfall are closely related to variations in the diurnal temperature range, on both interannual and decadal time-scales. Gardner (2009) confirmed that rising mean temperature enhances evaporation due to the warming of ocean, thereby increasing precipitation. Trenberth et al. (2011) proved that improving the water holding capacity of the atmosphere can alter moisture transport and lead more rainfall. And in Xinjiang Province, Wei et al. (2003) has found that precipitation in northern Xinjiang to had a sustained and significant response to the Sea surface temperatures of the equatorial eastern Pacific. Researches on the relationship between mean rainfall and temperature ranged from local scale to global scale (Kharin et al., 2013) and regional scale (Angélil et al., 2016). However, the relationships between rainfall and meteorological factors, such as sunshine, wind speed, and relative humidity, have been scarcely investigated. In fact, these relationships can be complex and variable, and can contribute to the understanding of the rainfall mechanism. The latter aspect can help deal with climate change and reduce climate-related disasters. Hence, it is of great significance to investigate the relationships between rainfall and other meteorological factors.

The main aim of this study is to explore the climate change in Xinjiang Province by analyzing rainfall and temperature trends, and evaluate the statistical relationships between rainfall and other meteorological factors in Sect. 4.4, using the panel data mode.

### 1.1 Study area

The Xinjiang region (73°40′–96°18′E and 34°25′–48°10′N), located in Central Asia, holds an important strategic

position: the core area of the “One Belt One Road” (abbreviated as B&R). It shares borders with eight countries: India, Russia, Kazakhstan, Kyrgyzstan, Tajikistan, Pakistan, Mongolia, and Afghanistan, and covers a total area 1.6 million km<sup>2</sup>. This region exhibits large variations in elevations ranging from –155 m (Aydingkol Lake in Turpan) to 8611 m (the peak of Mount Qogir, located at the border between China and Pakistan). The Tianshan Mountains spread across Xinjiang, one of the seven mountains in the world, dividing Xinjiang into two major parts. The extensive development of inland rivers forms its unique landscape – “mountain-oasis-desert system” that is typically found in the global arid region (Zhu et al., 2015). Xinjiang is a typical semiarid and arid area. It generally has a temperate continental climate with little rainfall (Fig. 1).

### 1.2 Methodology and data sources

The MK (Mann–Kendall) non-parametric statistical test, Spearman’s Rank (SR) test, and least square linear regression (LSLR) method were utilized to analyze the trends of rainfall and temperature. Besides, the K-means clustering method was used to cluster areas based on the varied rainfall trend. The statistical relationships between rainfall and meteorological factors such as average temperature (TA), high temperature (TH), least temperature (TL), sunshine (S), relative humidity (RH), wind speed (WS), and cloud cover (CA) were analyzed using the random effects panel data model.

### 1.3 Mann–Kendall (MK) non-parametric statistical test

The Mann–Kendall non-parametric statistical test (Kendall, 1948; Mann, 1945) was applied in this study to determine the trend test and the occurrence of change points. This method does not require data to be normally distributed and has low sensitivity to outliers or abrupt breaks in a time series. This tool is widely used for trend detection, and many researchers have used this test to evaluate the significance of trends.

### 1.4 Spearman’s rank (SR) test

The Spearman’s Rank test is a simple method with uniform power for linear and nonlinear trends. It is widely used to verify the absence of trends (Mergenthaler, 1979; Sneyers, 1991). The null hypothesis for these tests was that all data in the time series are distributed independently, while the alternative hypothesis refers to the increasing or decreasing trend were existing in the dataset. The statistical indicator  $D$  can be written as

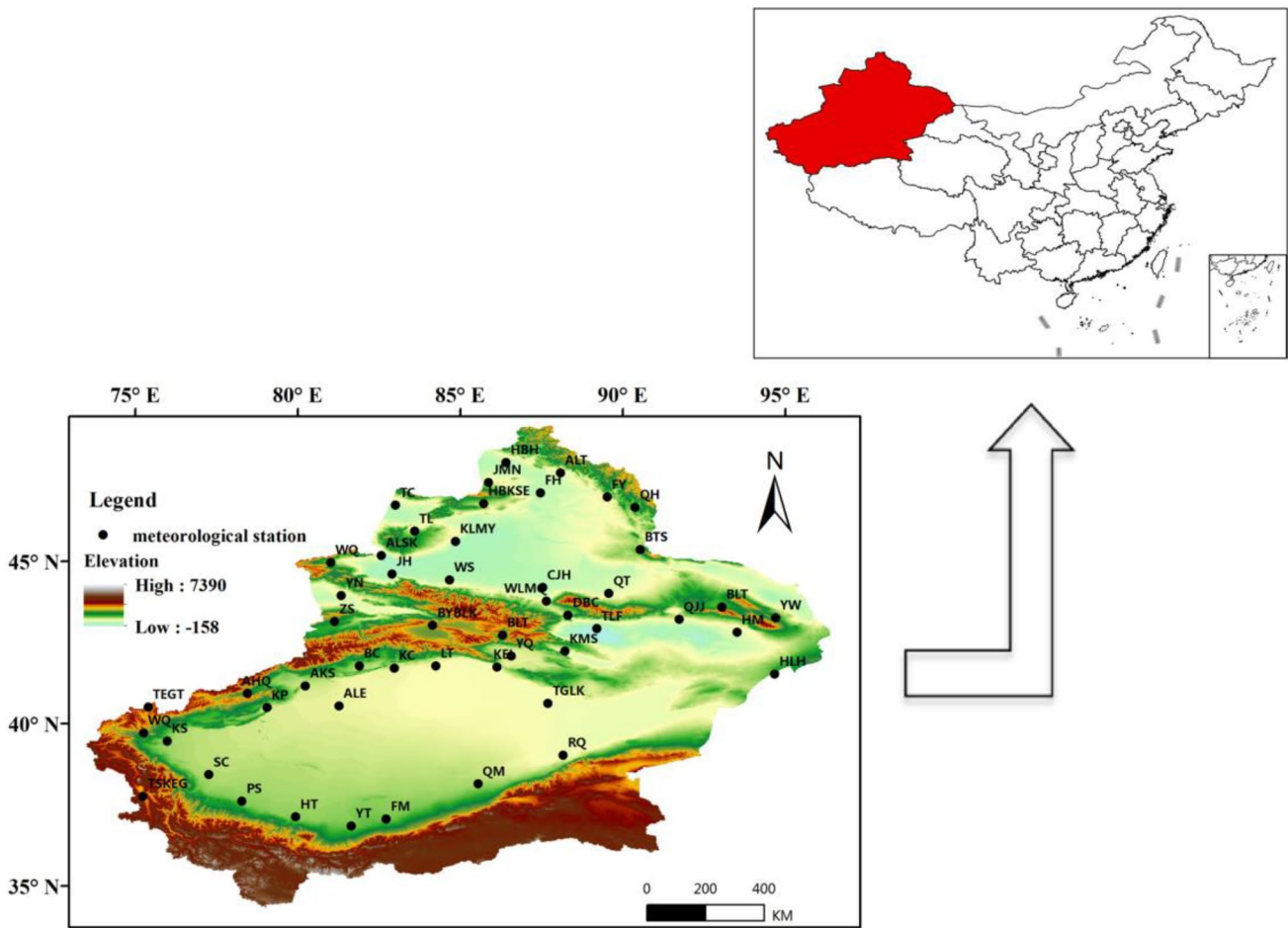


Fig. 1 Location of the Xinjiang Province and meteorological stations considered

$$D = 1 - \frac{6 \sum_{i=1}^n (R(x_i) - i)^2}{n(n^2 - 1)} \tag{1}$$

$$Z_{SR} = D \sqrt{\frac{n-2}{1-D^2}}$$

where  $R(x_i)$  is the rank of  $i$ -th observation  $x_i$  in the time series,  $n$  is the length of the time series,  $Z_{SR}$  reflects the changing trend of time series data. When  $|Z_{SR}| > t_{(n-2, 1-\alpha/2)}$ , the null hypothesis is rejected and shows a significant trend.

### 1.5 Least square linear regression (LSLR) method

The least square linear regression method is a parametric test used to describe the presence of a linear trend. In the LSLR test statistics,  $T$  is defined as follows:

$$T = \frac{\hat{b}}{se(\hat{b})} \tag{2}$$

where  $\hat{b}$  stands for the estimated slope of regression line between time series and observed values, and  $se(\hat{b})$  is the standard error of the estimated slope.

### 1.6 K-means clustering method

The K-means clustering method is a widely used algorithm for clustering, which can achieve minimal difference within groups and maximized difference between groups. On the basis of the K-means clustering method, stations with similar characteristics can be clustered into one group. Thus, K-means was utilized in this study to figure out clusters with similar rainfall trends.

### 1.7 Random effects panel data model

All variables need to be detected prior to the analysis to avoid spurious regression. The results are detailed as follows. First, all variables in the panel data model must be stationary. In this study, several traditional unit root tests, including Levin, Lin and Chut, and Fisher Chi-square, were chosen to test stationarity. The empirical results are shown in Table 1. These results implied that all variables are stationary in the level. Based on the stationary panel data sets, the Hausman test was used to determine the panel data model type (fixed effects model or

**Table 1** Unit root test results

Variable	Levin, Lin and Chut		Fisher Chi-square	
	Adjusted t*	P value	Modified chi-squared	p value
MAP	-2.8510***	-0.0022	11.2754***	0.0000
TA	0.2779***	-0.0095	11.0179***	0.0000
TH	0.7299*	-0.0673	9.0933***	0.0000
TL	-0.7909	-0.2145	15.1181***	0.0000
S	-7.8357***	0.0000	24.6871***	0.0000
RH	-4.2060***	0.0000	26.2340***	0.0000
WS	-9.2098***	0.0000	26.7243***	0.0000
CA	1.4506**	-0.0266	12.0704***	0.0000

random effects model), and results (Table 2) indicated that *p* value was 0.4031 that refuted the original assumption, and hence, the random effects model (REM) was employed in this study. REM is established by the following Eq. (7):

$$Y_{it} = \beta_1 + \sum_{k=2}^K \beta_k X_{kit} + \rho Y_{it-1} + \varepsilon_{it} \tag{3}$$

where *i* indicates the *i*-th individual, *t* indicates year *t*, *Y<sub>it</sub>* is the of *i*-th individual in year *t*; *X<sub>kit</sub>* is the explanatory variable, which represents the observed value of the *k*-th explanatory variable of *i*-th individual in year *t*; *β<sub>k</sub>* is the parameter of the *k*-th explanatory variable, to be estimated; the *ε<sub>it</sub>* represents random error.

**Table 2** Hausman test results

Variables	Coefficients			
	(b) FE	(B) RE	(b-B) Difference	Sqrt(diag(v_b = v_B)) S.E
TA	-101.1079	-107.0461	5.938167	4.636299
TH	32.67599	35.1766	-2.500603	2.004137
TL	57.39436	60.63596	-3.241596	2.421701
SH	-0.0890305	-0.0860673	-0.0029632	0.0047987
RH	6.871635	6.693593	0.178042	0.1634731
WS	-4.857843	-4.26069	-0.5971533	0.4305948
CA	0.9251362	0.7356998	0.1894365	0.6153442

(1) b = consistent under Ho and Ha; obtained from xtreg.

(2) B = inconsistent under Ha, efficient under Ho; obtained from xtreg.

Test: Ho: difference in coefficients not systematic.

chi2(7) = (b - B) [(v\_b = v\_B) \ (-1)] (b - B) = 7.25.

Prob > chi2 = 0.4031.

**Table 3** Annual trends of rainfall and temperature

Variables	Average	Linear trend (10a)	Interdecadal variation		
			1981–1990	1991–2000	2001–2010
Rainfall (mm)	142.8	9.4	132.2	144.9	151.4
Temperature (°C)	7.7	0.49	7.3	7.7	8.2

## 2 Results and discussion

Generally, more rainfall and higher temperature are observed over the Xinjiang Province on the annual scale as shown in Table 3. Spatio-temporal characteristics results of rainfall and temperature are detailed in the following Sects. 4.1 and 4.2, respectively. Both annual and seasonal rainfall and temperature trends are discussed in each section.

### 2.1 Rainfall trend analysis

#### 2.1.1 Annual rainfall trend

Using the ordinary kriging method, the results demonstrated that the distribution of annual average rainfall and its standard deviation were similar. The annual average rainfall and its variability were observed to be the highest in the northern parts of Xinjiang, especially in the northern border area (Fig. 2). Besides, the standard deviation of annual rainfall was high both in the northern and southern areas. It also showed that areas receiving high rainfall had higher spatial variability than areas receiving low rainfall.

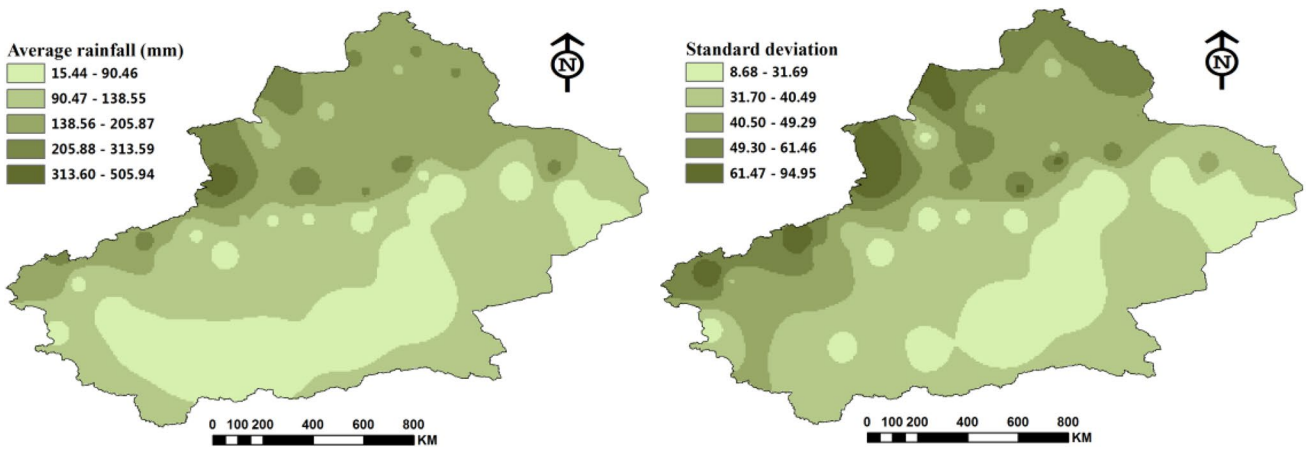


Fig. 2 Spatial distribution of annual average rainfall and its standard deviation

### 2.1.2 Seasonal rainfall trend

## 3 Temporal varying seasonal rainfall

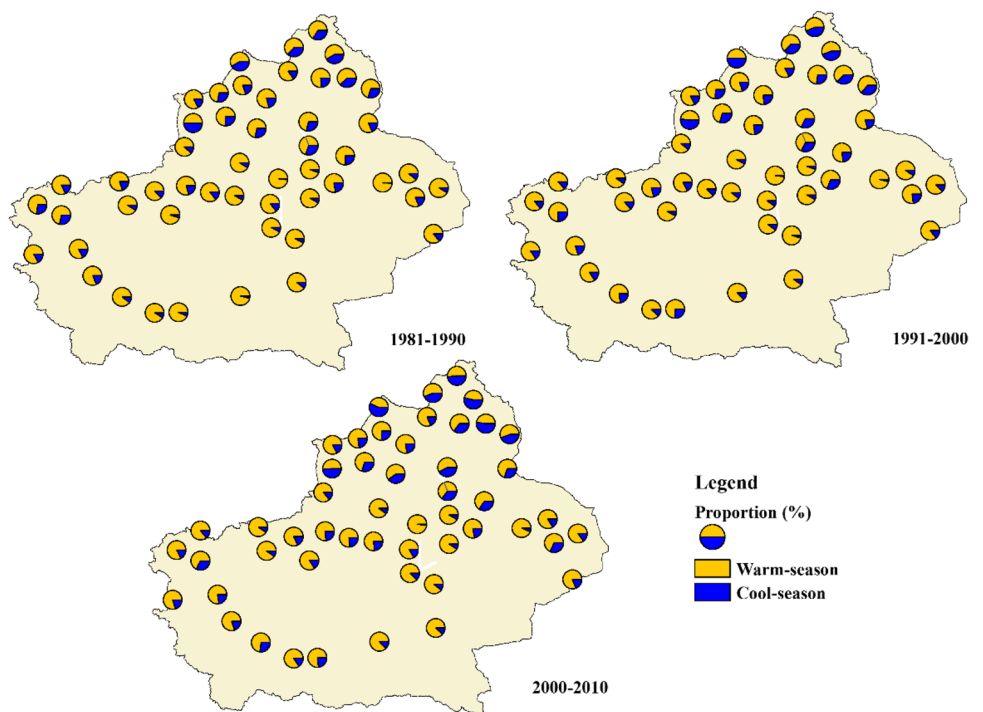
Clearly, rainfall increased significantly during the cold season. Considering the period 1981–1990 as the standard, a comparison was made between 1991–2000 and 2000–2010. Consequently, 80% sites increased during 1991–2000 and 94% sites increased during 2000–2010. In addition, 22% sites showed rainfall increased by about half or more on the basis of the standard during 1991–2000, whereas 49% sites

were detected during 2000–2010. There was also an increasing trend during the warm season, but less pronounced. Only 3% sites showed increased rainfall by half or more on the basis of the standard during both periods (Fig. 3).

## 4 Significance of seasonal rainfall trend

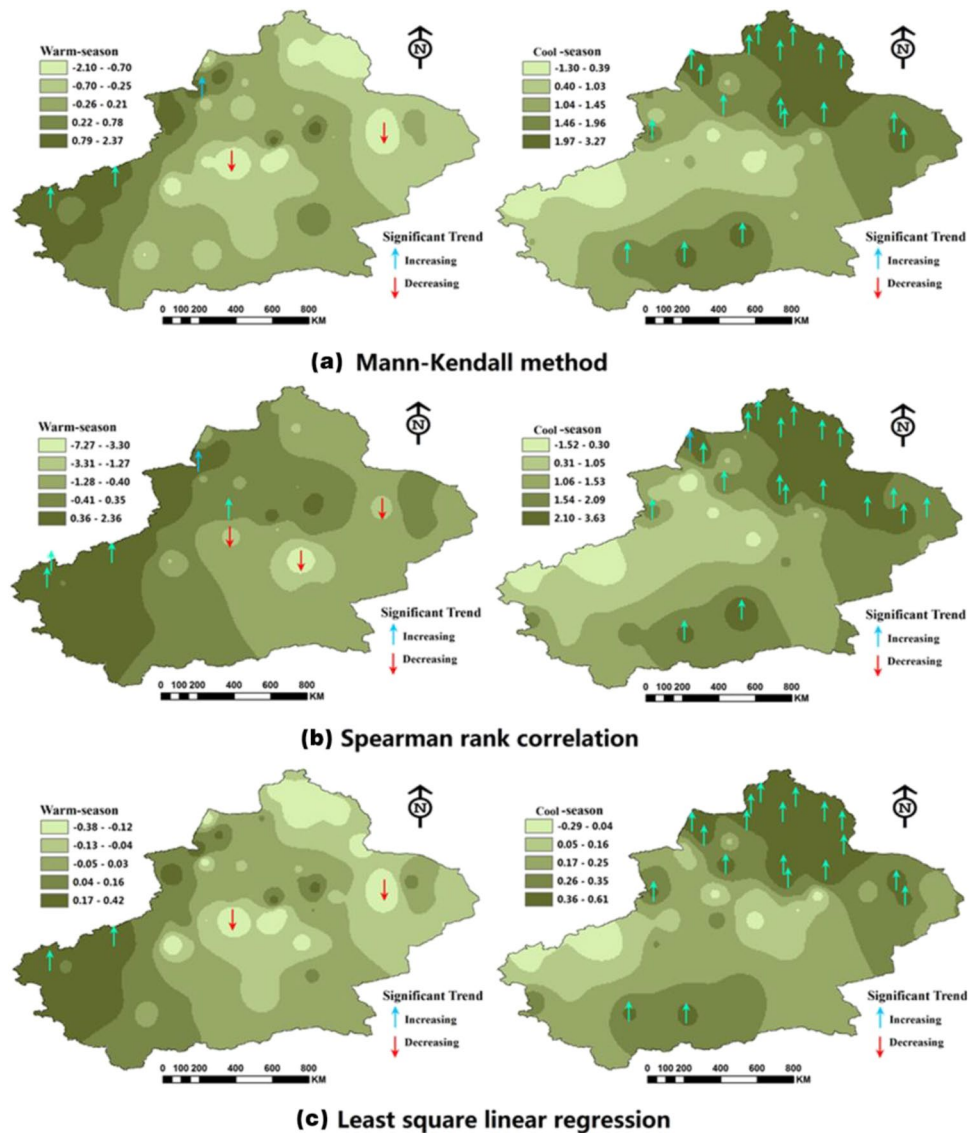
The trend analysis of the seasonal rainfall test (Fig. 4) performed using different methods generally indicated similar seasonal trend across the entire Xinjiang Province. Based on the calculated data, a significant increasing trend was found both during warm and cold seasons,

Fig. 3 Trends of rainfall of warm and cold seasons at the meteorological stations





**Fig. 4** Significant seasonal trend of rainfall in warm (left column) and cool (right column) season. Mann–Kendall method (a); Spearman rank correlation (b); Least square linear regression (c)



especially during the cold season, whereas a significant decreasing trend was found only during the warm season. The cold-season trends obtained from different methods were compared, and showed similar trends with MK, SR, and LSLR tests varying from 1.3 to 3.28,  $-1.52$  to  $3.64$ , and  $-0.3$  to  $0.61$ . An increasing trend was observed in the majority of the north and a small part of the south. During the warm season, increasing trend was observed in the western part, whereas decreasing trend was observed in the eastern and central parts. Almost similar spatial trends were observed using MK (2.1 to 2.6), SR ( $-2.1$  to  $2.6$ ), and LSLR ( $-0.39$  to  $0.42$ ) tests. The region experiencing a significant decrease in rainfall trend indicates that droughts may become more recurrent. In contrast, the region experiencing a significant increase in rainfall trend indicates that floods may become more intense.

### 4.1 Rainfall clustering

The rainfall trend varied significantly in different regions. The features of rainfall in Xinjiang Province were represented using rainfall clusters, shown in Table 4. Based on the historical rainfall situation, Xinjiang Province was clustered

**Table 4** Features of rainfall clusters

Cluster	Number of stations	Average rainfall/mm
Cluster 1	22	49.5
Cluster 2	10	131.7
Cluster 3	19	291.6
Entire area	51	163.1

into three parts using the K-means clustering method. There were 22 meteorological stations in cluster 1, and 74% of them were located in the Tarim Basin of southern Xinjiang; cluster 2 contained 10 meteorological stations, and 78% of them were located in the Junggar Basin of northern Xinjiang; cluster 3 contained 19 meteorological stations, and 80% of them were located in higher mountains such as the Altai Mountain, west Pamirs Plateau, and Tianshan Mountain (Fig. 5).

## 4.2 Temperature trend analysis

### 4.2.1 Annual temperature trend analysis

In the case of temperature (Fig. 5), the average temperature, high temperature, and low temperature were found to be higher in the south than in the north. A large difference was detected between the northern and southern parts, and the maximum difference showed that the high temperature, average temperature, and low temperatures were 24.97 °C, 19.33 °C, and 19.81 °C, respectively, whereas the standard deviation was not apparent throughout Xinjiang, indicating that three types of temperature showed similar increasing trends throughout Xinjiang (Fig. 6).

### 4.2.2 Seasonal temperature trend analysis

Variations in maximum, minimum, and mean temperatures were observed to increase significantly during both warm and cold seasons, as shown in Table 5. With the global climate change, significant increasing trends in mean, maximum, and minimum temperatures during warm and cold seasons were observed for the majority of urban and suburban districts in the study area. The warming trend for TA (warm season: 0.40 °C/decade, cold season: 0.60 °C/decade) is also supported by other studies in Xinjiang (Zhang et al., 2012; Jiang et al., 2013). In addition, linear trend during the

warm season was found to be maximum for TH (0.37 °C/decade) and minimum for TL (0.56 °C/decade). The significant increasing trends during the cold season were observed with the linear trend at more than 0.5 °C/decade. From the warming trend, the increasing rate presented a special phenomenon:  $TL > TA > TH$ , whether during the warm season or the cold season.

## 4.3 Covariation of rainfall with meteorological factors

Xinjiang Province is the biggest Province in China with a vast territory. As such, it is essential to conduct research locally on meteorological factors. Based on three rainfall clusters in Xinjiang Province, the random effect GLS model was utilized to explore the statistical relationships between rainfall and other meteorological factors, including average temperature (TA), maximum temperature (TH), minimum temperature (TL), sunshine (SH), relative humidity (RH), wind speed (WS), and cloud cover (CA), locally. The meteorological factors that influence rainfall the most in different clusters were investigated, and also the impact of each factor on rainfall in three clusters was compared to identify the reasons for the distribution of three rainfall clusters.

### 4.3.1 Data description

This study constructed an unbalanced panel data set for 3 rainfall clusters for the period 1961–2010. Table 6 shows all variables for each rainfall cluster. In terms of MAP, rainfall in cluster 3 was the highest, followed by cluster 2 with mean temperature almost half of cluster 3. Rainfall in cluster 1 was the lowest with value 48.74933. In terms of temperature, clusters can be ranked as follows: cluster 1 > cluster 2 > cluster 3, in TA, TH, and TL. A few differences existed between the sunshine, relative humidity, wind speed, and cloud cover in three clusters.

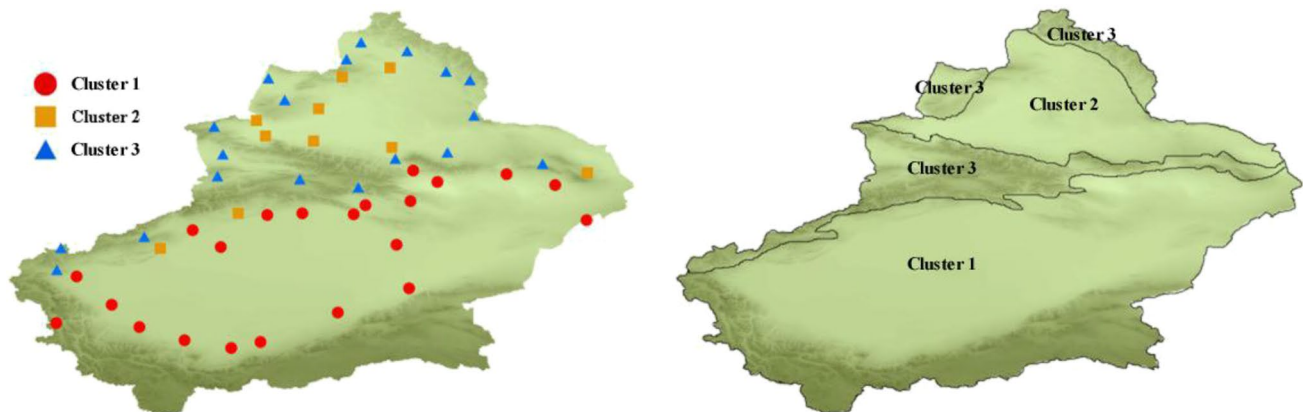
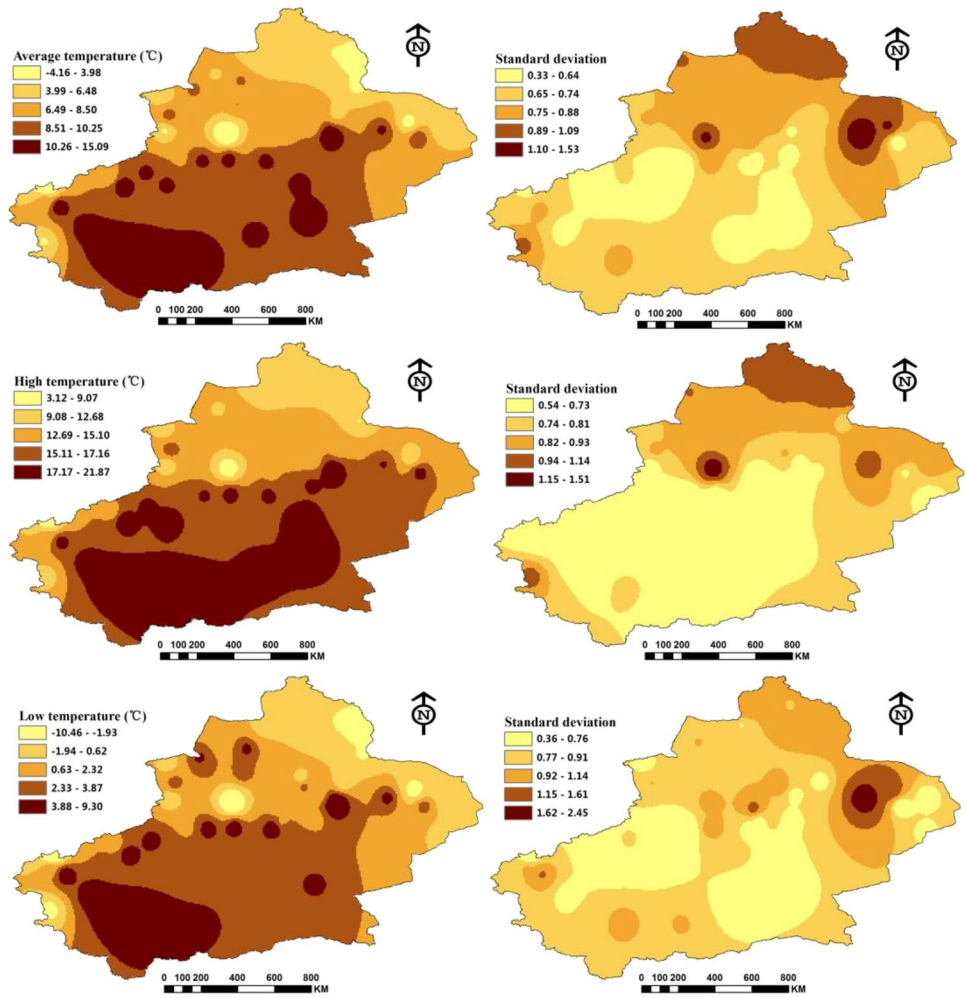


Fig. 5 Rainfall clusters of Xinjiang Province

**Fig. 6** Spatial distribution of annual average/high/low temperatures (left column) and their standard deviation (right column)



**Table 5** Temporal trends of temperature during warm and cold seasons

	Mean value (°C)		Linear trend (°C/decade)		Significance	
	Warm-season	Cool-season	Warm-season	Cool-season	Warm-season	Cool-season
TA	19.8	-5.0	0.40	0.60	3.39***	2.57***
TH	27.1	1.4	0.37	0.54	2.85***	2.14**
TL	13.1	-10.4	0.56	0.74	4.5***	3.39***

\*, \*\*, \*\*\* is for the significance test of confidence level 90%, 95%, and 99% respectively.

**4.3.2 Spatially varying associations**

As shown in Table 7 and Fig. 7, temperature demonstrates strong statistical relationships with rainfall in three clusters. For TA, it exerted significantly huge negative impact on rainfall in all three clusters, among which, the influence of TA in cluster 3 was up to -71.0541 within 90% confidence interval ( $P=0.052$ ), -49.5542 in cluster 1 within 99% confidence interval ( $P=0.002$ ), and -24.3884 in cluster 2 within 90% confidence interval ( $P=0.084$ ). It was an interesting found that the impacts of TH in three clusters were all without at least 90% confidence interval. In terms of TL, it exerted

considerable influences on rainfall in cluster 1 ( $P=0.003$ ) and cluster 3 ( $P=0.008$ ), both in 99% confidence interval. However, TH's effect in cluster 2 was not significant. Hence, except temperature, influences of S, RH, WS, and CA on rainfall were all weak. Considering S, it had negative impacts on rainfall in cluster 2 ( $P=0.000$ ) and cluster 3 ( $P=0.018$ ), although the effects were small. RH was positively correlated with rainfall in cluster 1 and cluster 3, but separately huge in cluster 3 with a coefficient of 17.6740 ( $P=0.000$ ) and weak in cluster 1 with a coefficient of 3.3340 ( $P=0.000$ ). For WS and CA, it was indicated that WS was separately positively correlated with rainfall in cluster 1



**Table 6** Statistical description

			MAP	TA	TH	TL	S	RH	WS	CA
Cluster 1	Mean	Overall	48.74933	12.16514	19.27556	5.852371	2797.167	26.51228	3.692318	12.58851
	Std. Dev	Overall	36.85059	1.678362	1.533912	2.102752	167.4147	4.389039	1.640875	13.80678
		Between	18.29871	0.5758	0.625956	0.672021	79.4564	2.369867	0.470879	13.20392
		Within	32.1265	1.579321	1.404131	1.995514	147.9319	3.714588	1.573752	4.57866
Cluster 2	Mean	Overall	139.4127	5.530516	11.89498	-0.2643	2916.093	34.77521	3.766868	17.50202
	Std. Dev	Overall	49.82782	2.298768	2.24722	2.702063	257.5699	6.824437	4.66769	12.45703
		Between	27.82837	0.788502	0.778378	0.797386	81.82072	1.965241	1.106958	11.55003
		Within	41.58345	2.163167	2.111964	2.585032	244.5963	6.543275	4.538158	5.035425
Cluster 3	Mean	Overall	306.216	3.363475	9.466643	-1.80669	2728.259	39.2686	4.469315	25.05612
	Std. Dev	Overall	125.6728	3.529984	3.439002	3.741876	419.2757	4.86407	2.226947	12.54236
		Between	52.91617	0.652448	0.694405	0.665104	165.9719	2.31179	0.920291	10.0219
		Within	114.3184	3.470811	3.370086	3.683904	385.9857	4.29631	2.033493	7.718072

**Table 7** Random effects of GLS regression results

	Cluster 1	Cluster 2	Cluster 3
TA	-49.5542*** (0.002)	-24.3884* (0.084)	-71.0541* (0.052)
TH	11.8591 (0.108)	2.2123 (0.777)	9.9597 (0.640)
TL	26.4748*** (0.003)	9.5618 (0.201)	51.3693*** (0.008)
S	0.0136 (0.272)	-0.1725*** (0.000)	-0.04452** (0.018)
RH	3.3340*** (0.000)	-0.1671 (0.827)	17.6740*** (0.000)
WS	2.4811* (0.079)	-5.5797*** (0.000)	1.7176 (0.630)
CA	0.1614 (0.406)	0.2972 (0.363)	1.4958** (0.035)
Cons	130.4864 (0.136)	775.2114*** (0.000)	-74.00921 (0.600)
N	150	150	150
R-squared	0.6203	0.5004	0.6072
P	0.000	0.000	0.000

t statistics in parentheses. \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ .

(0.079) and negatively in cluster 2 ( $P=0.000$ ). Besides, CA had a positive relationship only with rainfall in cluster 3 ( $P=0.035$ ).

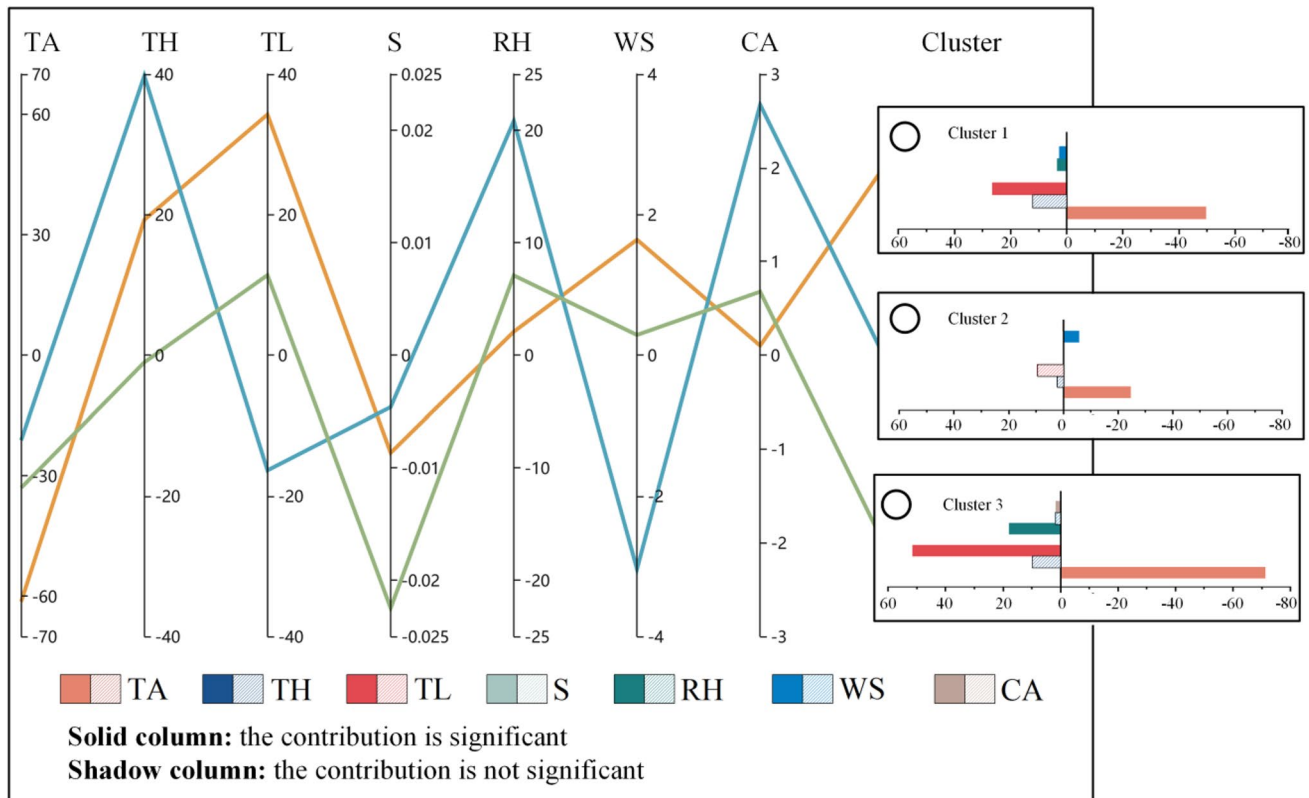
From the perspective of three clusters, TA, TH, TL, and RH can be concluded as the most crucial factors affecting rainfall in Xinjiang Province, without considering the weak impacts of each factor. It is detailed as follows: 1) In cluster 1, TA contributed most to rainfall with a huge negative impact, followed by TL, whose impact was also enormous; 2) In cluster 2, TA performed as the most vital contributor for rainfall, which exerted a considerable negative impact on rainfall; 3) In cluster 3, TA, TL, and RH contributed much to rainfall, among which TA contributed the most, followed by TL.

Temperature plays a vital role in rainfall variation. Interestingly, this study found that average temperature was negatively correlated with rainfall in all three clusters, and it also weighed the most among all indicators in each cluster. This implied that the climate in Xinjiang Province tended to be warm and dry, which can greatly harm the agriculture

in the region. The results also showed that the least temperature contributed to increasing rainfall in cluster 1 and cluster 3, whereas its impact was not significant in cluster 2. It is proved that low temperature can help hold the water in the atmosphere to alter moisture transport. The increasing least temperature can enhance the surface evaporation and vegetation transpiration, thus increasing rainfall. The relative humidity in cluster 3 was also positively correlated with rainfall. In this study, the reasons behind the results were not further researched, but crucial suggestions have been provided for further investigations.

## 5 Discussion and conclusions

Climate change has become the biggest global environmental problem faced by human beings. In order to better respond to climate change and contribute to climate change mitigation, this study investigated the spatio-temporal distribution of temperature and rainfall in Xinjiang Province,



**Fig. 7** Covariations of rainfall with other 7 meteorological factors in three rainfall clusters

China. Three clusters were divided based on the spatial variations in the rainfall trends in the province. Furthermore, the meteorological factors influencing rainfall were investigated based on the three rainfall clusters.

It was observed that annual average rainfall increased temporally in the entire province, and was the highest in the northern Xinjiang, especially in the northern border area. An increasing trend was observed in rainfall during both cold and warm seasons, especially during the former, while the decreasing trend was observed only during the warm season. Spatially, an increasing trend was observed in the majority of the north and a small part of the south of the study area during the cold season.

Annual average temperature, high temperature, and low temperature showed similar increasing trends in the entire province. Spatially, the temperature (in all three categories) was high in the south than in the north. Furthermore, significant increasing trends were found for average, high, and low temperatures during the warm and cold seasons in the entire study area. Particularly during the warm and cold seasons, the increasing rate presented a special phenomenon:  $TL > TA > TH$ .

Based on the rainfall trend in Xinjiang, the entire area was divided into three clusters. The majority of cluster 1 was in the southern areas of Xinjiang, cluster 2 was in the northern areas, and the majority of cluster 3 was in the middle areas. Based on three rainfall clusters, the statistical relationships between rainfall and other meteorological factors were analyzed. It was found that temperature and relative humidity were significantly correlated with rainfall in three clusters, whereas sunshine and wind speed had small influence on rainfall in all three clusters. TA was the biggest contributor to rainfall in all three clusters.

**Author contribution** Yuhu Zhang: Conceptualization, Methodology, Formal Analysis. Pei Xie: Writing- Original draft preparation, Data curation, Software. Yanru Pu: Validation, Writing-Reviewing and Editing. Peng Wang: Visualization, Investigation.

**Funding** This work was supported by the National Natural Science Foundation of China [Grant No. 51908249], the Natural Science Foundation of the Jiangsu Higher Education Institutions of China [Grant No. 19KIB560012], the High-level Scientific Research Foundation for the introduction of talent for Jiangsu University [Grant No. 18JDG038], and the Innovative Approaches Special Project of the Ministry of Science and Technology of China [Grant No. 2020IM020300].

**Data availability** Data will be made available on reasonable request.

## Declarations

**Competing interests** The authors declare no competing interests.

## References

- Almazroui M, Islam MN, Jones PD, Athar H, Rahman MA (2012) Recent climate change in the Arabian Peninsula: Seasonal rainfall and temperature climatology of Saudi Arabia for 1979–2009. *Atmos Res* 111:29–45. <https://doi.org/10.1016/J.ATMOSRES.2012.02.013>
- Angéilil O, Perkins-Kirkpatrick S, Alexander LV, Stone D, Donat MG, Wehner M, Shiogama H, Ciavarella A, Christidis N (2016) Comparing regional precipitation and temperature extremes in climate model and reanalysis products. *Weather Clim Extremes* 13:35–43. <https://doi.org/10.1016/J.WACE.2016.07.001>
- Bouwer LM (2010) Have Disaster Losses Increased Due to Anthropogenic Climate Change? *Bull Am Meteor Soc* 92:39–46. <https://doi.org/10.1175/2010BAMS3092.1>
- Chen juying, Wei xiang., 2003. The response relationship of the rainy season precipitation in northern Xinjiang to ENSO and period analysis[J]. *Acta Oceanologica Sinica (Chinese version)*,2003,25(1):120–127.<https://doi.org/10.3321/j.issn:0253-4193.2003.01.014>.
- D’Abrera HJM, Lehmann EL (1975) Nonparametrics: statistical methods based on ranks. Holden-Day
- Gardner LR (2009) Assessing the effect of climate change on mean annual runoff. *J Hydrol* 379:351–359. <https://doi.org/10.1016/J.JHYDROL.2009.10.021>
- Hao Z, AghaKouchak A, Phillips TJ (2013) Changes in concurrent monthly precipitation and temperature extremes. *Environ Res Lett* 8:34014. <https://doi.org/10.1088/1748-9326/8/3/034014>
- IPCC, 2007. *Climate Change 2007: The Physical Science Basis*. Solomon S, Qin D, Manning M et al. eds. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.
- IPCC (2013) *Climate Change 2013: The Physical Science Basis*. In: Stocker TF et al (eds) Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York, pp 1–1535
- Jain, S., Kumar, V., 2012. Trend analysis of rainfall and temperature data for India SK Jain, V Kumar *Current Science(Bangalore)* 102 (1), 37–49, *Current Science*.
- Jiang F, Hu R-J, Wang S-P, Zhang Y-W, Tong L (2013) Trends of precipitation extremes during 1960–2008 in Xinjiang, the Northwest China. *Theoret Appl Climatol* 111:133–148. <https://doi.org/10.1007/s00704-012-0657-3>
- Kendall, M.G., 1948. Rank correlation methods., Rank correlation methods. Griffin, Oxford, England.
- Kharin VV, Zwiers FW, Zhang X, Wehner M (2013) Changes in temperature and precipitation extremes in the CMIP5 ensemble. *Clim Change* 119:345–357. <https://doi.org/10.1007/s10584-013-0705-8>
- Leonard M, Westra S, Phatak A, Lambert M, van den Hurk B, McInnes K, Risbey J, Schuster S, Jakob D, Stafford-Smith M (2014) A compound event framework for understanding extreme impacts. *Wiley Interdiscip Rev Clim Change* 5:113–128. <https://doi.org/10.1002/wcc.252>
- Mann HB (1945) Nonparametric Tests Against Trend. *Econometrica* 13:245–259. <https://doi.org/10.2307/1907187>
- Nicholls N, Drosowsky W, Lavery B (1997) Australian rainfall variability and change. *Weather* 52:66–72. <https://doi.org/10.1002/j.1477-8696.1997.tb06274.x>
- Ogutu JO, Piepho H-P, Dublin HT, Bhola N, Reid RS (2008) El Niño–Southern Oscillation, rainfall, temperature and Normalized Difference Vegetation Index fluctuations in the Mara–Serengeti ecosystem. *Afr J Ecol* 46:132–143. <https://doi.org/10.1111/j.1365-2028.2007.00821.x>
- Sharma CS, Behera MD, Mishra A, Panda SN (2011) Assessing Flood Induced Land-Cover Changes Using Remote Sensing and Fuzzy Approach in Eastern Gujarat (India). *Water Resour Manage* 25:3219. <https://doi.org/10.1007/s11269-011-9853-7>
- Sun L, Shen B, Sui B, Huang B (2017) The influences of East Asian Monsoon on summer precipitation in Northeast China. *Clim Dyn* 48:1647–1659. <https://doi.org/10.1007/s00382-016-3165-9>
- Sneyers, R. 1991. On the statistical analysis of series of observations (No. 143).
- Trenberth KE, Fasullo JT, Mackaro J (2011) Atmospheric Moisture Transports from Ocean to Land and Global Energy Flows in Reanalyses. *J Clim* 24:4907–4924. <https://doi.org/10.1175/2011JCLI4171.1>
- Zhang Q, Li J, Singh VP, Xiao M (2013) Spatio-temporal relations between temperature and precipitation regimes: Implications for temperature-induced changes in the hydrological cycle. *Global Planet Change* 111:57–76. <https://doi.org/10.1016/J.GLOPLACHA.2013.08.012>
- Zhang Y, Wei W, Jiang F, Liu M, Wang W, Bai L, Li K (2012) Brief communication “Assessment of change in temperature and precipitation over Xinjiang, China.” *Nat Hazards Earth Syst Sci* 12:1327–1331. <https://doi.org/10.5194/nhess-12-1327-2012>
- Zhou Y, Huang A, Zhao Y, Yang Q, Jiang J, La M (2015) Influence of the sea surface temperature anomaly over the Indian Ocean in March on the summer rainfall in Xinjiang. *Theoret Appl Climatol* 119:781–789. <https://doi.org/10.1007/s00704-014-1149-4>
- Zhu X, Zhang M, Wang S, Qiang F, Zeng T, Ren Z, Dong L (2015) Comparison of monthly precipitation derived from high-resolution gridded datasets in arid Xinjiang, central Asia. *Quatern Int* 358:160–170. <https://doi.org/10.1016/J.QUAINT.2014.12.027>

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.