Extreme Precipitation Variability in the Qinling Mountains and Surrounding Areas over the Past 40 Years: Postprint

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Abstract

Using daily precipitation data from 337 meteorological monitoring stations in the Qinling Mountains and surrounding areas from 1980 to 2021, the spatiotemporal variation characteristics of extreme precipitation were analyzed, and methods such as the generalized extreme value distribution and climate statistics were employed to compare the differential changes in extreme precipitation years and the spring, summer, and autumn seasons between the first stage (1980–2000) and the second stage (2001–2021). The results indicate: (1) Extreme precipitation in the Qinling Mountains and surrounding areas is mainly concentrated from April to November, with July having the highest number of extreme precipitation days, and extreme precipitation has shown an overall increasing trend over the past 40 years. The spatial distribution of daily extreme precipitation thresholds and maximum daily precipitation exhibits higher values in the southeast than in the northwest, while the number of extreme precipitation days shows a pattern of more in the south and less in the north, with the Qinling Mountains serving as the boundary. (2) From an annual perspective, the period 2001–2021 experienced more extreme precipitation events with greater intensity compared to 1980–2000. The spatial trends in daily extreme precipitation thresholds, number of extreme precipitation days, and maximum daily precipitation also demonstrate that the number of stations with increasing trends exceeds those with decreasing trends. (3) Seasonal differences in extreme precipitation are significant, with spring showing distinct differences from summer and autumn. Both in terms of extreme precipitation probability and frequency, spring overall exhibited higher extremes during 1980–2000, while summer and autumn showed stronger extremes during 2001–2021. Seasonal differences in spatial distribution are also evident; in spring, daily extreme precipitation thresholds and the number of extreme precipitation days generally show increases in the west and decreases in the east, displaying a transition from positive to negative trends from west to east, with more stations exhibiting negative trends than positive ones.

In contrast, the number of stations with increasing trends in daily extreme precipitation thresholds and number of extreme precipitation days exceeds those with decreasing trends in summer and autumn, particularly in autumn where the proportion of stations with increasing trends is higher.

Full Text

Variation Characteristics of Extreme Precipitation in the Qinling Mountains and Surrounding Areas Over the Past 40 Years

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Abstract: Based on daily precipitation data from 337 meteorological monitoring stations in the Qinling Mountains and surrounding areas during 1980-2021, this study analyzes the spatiotemporal variation characteristics of extreme precipitation. Using generalized extreme value distribution and climate statistical methods, we compare differences in extreme precipitation between two phases—the first phase (1980-2000) and the second phase (2001-2021)—for annual totals and for spring, summer, and autumn seasons. The results show that: (1) Extreme precipitation in the Qinling region and its surroundings occurs mainly from April to November, with July having the highest number of extreme precipitation days. Over the past 40 years, extreme precipitation has shown an overall increasing trend. The spatial distribution of daily extreme precipitation thresholds and maximum daily precipitation exhibits higher values in the southeast than in the northwest, while the number of extreme precipitation days shows a pattern of more occurrences south of the Qinling Mountains and fewer to the north. (2) From an annual perspective, the 2001-2021 period experienced more extreme precipitation events with greater intensity compared with 1980-2000. Spatial trends in daily extreme precipitation thresholds, extreme precipitation days, and maximum daily precipitation also show an overall increase, with more stations exhibiting upward trends than downward trends. (3) Seasonal differences in extreme precipitation are pronounced, with spring showing distinctly different patterns from summer and autumn. In terms of both probability and frequency, spring extreme precipitation was more extreme during 1980-2000, whereas summer and autumn extreme precipitation was more extreme during 2001-2021. Spatial distribution patterns also vary seasonally. In spring, daily extreme precipitation thresholds and the number of extreme precipitation days generally increase in the west and decrease in the east, transitioning from positive to negative trends from west to east, with more stations showing decreasing trends than increasing trends. In contrast, during summer and autumn, the number of stations with increasing trends in daily extreme precipitation thresholds and extreme precipitation days exceeds those with decreasing trends, particularly in autumn where the proportion of stations with

increasing trends is highest.

Keywords: daily extreme precipitation threshold; maximum daily precipitation; number of extreme precipitation days; temporal variation

Introduction

Under the background of global warming, extreme precipitation events have shown an increasing trend across most land areas worldwide, a phenomenon confirmed by studies in the United Kingdom, United States, Japan, and other regions. China' s extreme precipitation characteristics are generally consistent with this global trend but exhibit distinct regional features. Most regions of China have observed increases in the frequency and intensity of heavy and extreme precipitation events, characterized by decreasing light rain and increasing heavy rainstorms. This trend is particularly pronounced in Northwest China, the middle and lower reaches of the Yangtze River, and the southeastern coastal areas.

The Qinling Mountains serve as a natural barrier for warm, moist air from the south moving northward and dry, cold air from the north moving southward. The unique topography and climatic characteristics make the northern and southern foothills of the Qinling particularly vulnerable to extreme precipitation, often resulting in severe flood disasters. According to data from the National Disaster Management System, direct economic losses in Shaanxi Province due to rainstorms and flooding reached 248.9×10^{8} yuan in 2021, the highest in recent years. Under the broader context of climate warming and increasing global extreme precipitation, recent precipitation in the Qinling region has also shown an overall increasing trend, with decreasing precipitation days and a shift toward more extreme precipitation patterns.

Previous studies have revealed that extreme precipitation in most areas of the Qinling and its surroundings is increasing, but these studies have typically treated the past several decades as a single period. Few have investigated whether extreme precipitation has become more intense in recent years compared with earlier periods, and research on seasonal and spatial variations in extreme precipitation and their interrelationships remains limited. To address these gaps, this paper divides the study period into two phases (1980–2000 and 2001–2021) to comprehensively analyze spatial and seasonal variations in extreme precipitation thresholds, extreme precipitation days, and maximum daily precipitation in the Qinling Mountains and surrounding areas. This work will provide decision-making support for monitoring, assessment, zoning, and disaster prevention and mitigation meteorological services for extreme precipitation events in the region, while also offering a theoretical basis for improving climate adaptation capacity.

1.1 Study Area Overview

The Qinling Mountains, an east-west oriented mountain range in central China, extend from the Funiu Mountains in Henan Province in the east to the Die Mountains in Gansu Province in the west, with a length of approximately 800 km and a north-south span of about 200 km. The southern slope is gentle while the northern slope is steep, forming a natural barrier for warm, moist air from the south and dry, cold air from the north. The climate north of the Qinling belongs to the warm temperate semi-humid zone, while the area to the south falls within the north subtropical humid zone. This study focuses on the Qinling Mountains and surrounding areas (103°-113°E, 31°-40°N), including parts of Shaanxi, Ningxia, Inner Mongolia, Shanxi, Henan, Hubei, Sichuan, and Gansu provinces (Fig. 1).

1.2 Data Sources

Considering data length, station density, and missing data issues, daily precipitation data were selected from 337 meteorological monitoring stations across the Qinling Mountains and surrounding areas from the China Meteorological Administration' s meteorological dataset for 1980–2021.

1.3 Definition and Statistics of Extreme Precipitation

This study employs the percentile threshold method to define extreme precipitation, where precipitation events exceeding the threshold are identified as extreme precipitation events. The method involves: first, sorting all valid daily precipitation values ($ $0.1 mm) for a given station and year in ascending order; the 95th percentile value is defined as the daily extreme precipitation threshold for that station and year. The multi-year average threshold is then calculated as the station' s daily extreme precipitation threshold. If a station' s daily precipitation equals or exceeds this threshold, it is considered an extreme precipitation event and counted as one occurrence. To analyze seasonal characteristics, meteorological seasons are used: spring (March–May), summer (June–August), and autumn (September–November).

Linear regression is used to analyze trends in extreme precipitation, with significance tested using the Kendall non-parametric method. The generalized extreme value (GEV) distribution is employed for extreme precipitation probability distribution. This method is a highly applicable probability distribution model widely used in meteorology and hydrology. Because the GEV distribution can effectively fit the skewed distribution of precipitation, it is suitable for modeling extreme weather and climate events such as heavy precipitation and drought. Depending on the shape parameter, the GEV distribution includes three types: Weibull ($k < 0$), Gumbel ($k = 0$), and Fréchet ($k > 0$) distributions, with the distribution function as follows:

$$F(x) = \exp\left\{-\left[1 + k\left(\frac{x-\beta}{\alpha}\right)\right]^{-1/k}\right\}$$

where $F(x)$ is the distribution function and α, β, and k are the scale, location, and shape parameters, respectively.

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2 Results and Analysis

2.1 Spatial Distribution and Trends of Extreme Precipitation

2.1.1 Spatial Distribution of Extreme Precipitation The spatial distribution of extreme precipitation in the Qinling Mountains and surrounding areas during 1980–2021 (Fig. 2) shows that daily extreme precipitation thresholds and maximum daily precipitation are generally higher in the southeast than in the northwest, while the number of extreme precipitation days shows a pattern of more occurrences south of the Qinling and fewer to the north. Daily extreme precipitation thresholds in eastern Gansu, Ningxia, and southern Inner Mongolia range between 20–40 mm, with the minimum value of 19.4 mm at Jilantai Station in Inner Mongolia. Thresholds in Shaanxi, western Shanxi, and northwestern Hubei range from 40–60 mm, while thresholds in the Sichuan Basin and parts of Henan exceed 80 mm, reaching a maximum of 100.9 mm at Nanzhao Station in Henan.

The spatial distribution of extreme precipitation days reveals a clear north-south boundary along the Qinling Mountains, separating high-value areas in the south from low-value areas in the north. Regions with more than 70 extreme precipitation days are concentrated in the Sichuan Basin, Hanzhong City, and Ankang City in Shaanxi. Fewer extreme precipitation days occur along the Yellow River, in western Shanxi, and at the border between Henan and Shanxi, where the number of days is only 20–40. Unlike the threshold distribution, the eastern Tibetan Plateau also shows a relatively high number of extreme precipitation days, indicating that while precipitation amounts are not large in this region, the frequency of extreme events is high.

Maximum daily precipitation ranges from 41.6 mm to 423.8 mm. The minimum values ($ $50 mm) are distributed in Gansu, Sichuan, and Inner Mongolia on the eastern Tibetan Plateau. Nine stations recorded maximum daily precipitation exceeding 300 mm, including Dujiangyan, Beichuan, and Mianzhu in Sichuan; Gongyi, Yanshi, and Nanzhao in Henan; Yunxi in Hubei; and Ningshan in Shaanxi.

2.1.2 Trends in Extreme Precipitation From 1980 to 2021, the annual extreme precipitation threshold ranged from 40.2 mm to 65.0 mm, with most thresholds concentrated between 45-60 mm. The linear trend of the 11-year moving average shows that the annual extreme precipitation threshold increased at a rate of 1.5 mm · $(10a)^{-1}$. The trend in extreme precipitation frequency is similar to that of the threshold, increasing at a rate of 0.3 times · $(10a)^{-1}$. Maximum daily precipitation ranged from 133–423 mm, with the highest value reaching 423.9 mm. Overall, maximum daily precipitation shows a fluctuating increasing trend at a rate of 5 mm · $(10a)^{-1}$.

Thus, the annual extreme precipitation threshold, frequency, and maximum daily precipitation all show increasing trends, with more pronounced increases in recent years.

2.2 Comparison of Extreme Precipitation Between 1980-2000 and 2001-2021

2.2.1 Annual Extreme Precipitation Comparison In operational weather forecasting in China, rainfall $ $50 mm at a single station is defined as a rainstorm, and $ $100 mm as a heavy rainstorm. Using fixed thresholds of 50 mm, 100 mm, and 150 mm, we further examine changes in extreme precipitation. The number of precipitation events is defined as the count of days when daily precipitation reaches or exceeds the specified threshold.

During 1980–2000, the study area averaged 109.6 events per year with daily precipitation $ $50 mm, increasing to 119.6 events per year during 2001–2021, representing an increase of 10 events per year (9.1%). For the $ $100 mm threshold, the average increased from 28.4 to 32.8 events per year (15.5% increase), and for $ $150 mm, from 9.8 to 13.6 events per year (38.8% increase). Notably, events with daily precipitation $ $220 mm increased from 9 to 19 occurrences, and those $ $250 mm increased from 3 to 8 occurrences, clearly indicating increases in both the frequency and magnitude of extreme precipitation events (Fig. 4).

Analyzing spatial variation characteristics by examining trend directions (positive or negative) at each station (Fig. 6), we find that 62.3% of stations show increasing trends in daily extreme precipitation thresholds, with significantly increasing stations located in western and northern Guanzhong (Shaanxi), Pingliang and Qingyang (Gansu), Bazhong and Guangyuan (Sichuan), Luoyang (Henan), and Taiyuan, Xinzhou, and Lüliang (central-western Shanxi). These results are consistent with previous research. Among these increasing stations, 13 passed significance tests. Decreasing trends are observed at 36.5% of stations, primarily in southern Shaanxi and Xiangyang (Hubei), though none passed significance tests.

For extreme precipitation days, only 53.7% of stations show increasing trends, with 11 stations passing significance tests, mainly in northern Shaanxi, Shangluo (Shaanxi), and southwestern Shanxi. The spatial distribution of maximum daily precipitation trends is similar to that of daily extreme precipitation thresholds, with 62.3% of stations showing increasing trends (13 passing significance tests) and 36.5% showing decreasing trends.

2.2.2 Seasonal Extreme Precipitation Comparison The warm season is the primary period for precipitation concentration in the Qinling region and its surroundings, and extreme precipitation also shows clear seasonality. Understanding the temporal distribution of extreme precipitation provides valuable reference for local forecasting and early warning. To determine the main occurrence period, we analyzed events exceeding the regional average daily extreme precipitation threshold ($ $52.5 mm). Results show that extreme precipitation begins at some stations as early as April (2 events, both in 2021) and continues through November, with the latest event occurring on November 9. Therefore, the following analysis focuses on spring, summer, and autumn.

The average daily extreme precipitation thresholds for the study area are 25.6 mm in spring, 55.3 mm in summer, and 32.0 mm in autumn. Based on these thresholds, the maximum daily precipitation values for the two phases are 173.3 mm (spring), 340.9 mm (summer), and 281.2 mm (autumn), all occurring in July. The probability density curves from the GEV distribution fit the sample histograms well, indicating good model performance.

In spring, as precipitation increases, the extreme precipitation probability is initially higher in 1980–2000 than in 2001–2021, but this relationship reverses at higher precipitation amounts. In summer, the probability distributions for the two phases alternate with relatively small differences. In autumn, the probability of extreme precipitation is higher in 2001–2021 than in 1980–2000.

For precipitation events $ $50 mm, spring shows 15 events in 1980–2000 and 18 in 2001–2021. Summer shows the most events: 340 in the first phase and 378 in the second phase. Autumn shows 283 events in the first phase and 312 in the second phase. All seasons except spring (where events between 180–190 mm were fewer) show higher frequencies in 2001–2021, particularly for events $ $250 mm.

Spatial distribution differences are pronounced across seasons, with spring showing the smallest changes and summer the largest. In spring, 51.9% of stations show decreasing trends in daily extreme precipitation thresholds (mainly in southeastern Shaanxi, southwestern Shanxi, northwestern Hubei, and northeastern Sichuan), while 46.0% show increasing trends (mainly in western Gansu, central Shanxi, Guangyuan in Sichuan, and Yan'an in Shaanxi). Only 4 stations passed significance tests: Hezheng and Heshui in Gansu, Kongtong in Gansu, and Jiuzhaigou in Sichuan.

In summer, 57.0% of stations show increasing trends in daily extreme precipitation thresholds, with 12 stations passing significance tests, concentrated in the Loess Plateau region (northern Guanzhong, Gansu, Ningxia, and Shanxi) and the Sichuan Basin. Decreasing trends occur at 39.8% of stations in southern Shaanxi, southern Gansu, western Henan, and northwestern Hubei.

In autumn, 58.5% of stations show increasing trends, with 14 stations reaching significance—more than in spring and summer. Significantly increasing stations are concentrated in two regions: the Loess Plateau (northern Shaanxi, Qingyang in Gansu, Ningxia, and Shanxi) and the Sichuan Basin. Decreasing trends occur at 37.4% of stations. The spatial distribution of extreme precipitation days in autumn is consistent with threshold patterns, with 58.5% of stations showing increasing trends (14 significant) and 34.1% showing decreasing trends.

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3 Discussion

Extreme precipitation events frequently cause severe economic and human losses worldwide, attracting widespread attention from all sectors of society. The Qinling Mountains and surrounding areas have complex climate variations, uneven precipitation distribution, and are prone to rainstorm and flood disasters during the flood season. Therefore, studying the anomalous characteristics of extreme precipitation is crucial for scientifically understanding the spatiotemporal changes of flood and drought disasters and reducing disaster losses.

This study reveals that extreme precipitation in the Qinling region and its surroundings shows an overall increasing trend, consistent with both China' s general extreme precipitation trends and previous research on this region. However, earlier studies have primarily focused on annual and warm-season extreme precipitation characteristics, with limited research on seasonal variations. Although extreme precipitation mainly occurs in the warm season, variations in other seasons are also critical. Through detailed comparative analysis of spring, summer, and autumn extreme precipitation, this study finds pronounced seasonal characteristics, with spring showing clear differences from summer and autumn. The overall annual increasing trend in extreme precipitation is mainly contributed by summer and autumn. Understanding these seasonal variations provides valuable reference for local extreme precipitation forecasting and early warning.

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4 Conclusions

1) Spatially, daily extreme precipitation thresholds and maximum daily precipitation show a pattern of higher values in the southeast and lower values in the northwest. The number of extreme precipitation days exhibits a north-south boundary along the Qinling Mountains, with more occurrences in the south and fewer in the north. Southern Shaanxi, the Sichuan Basin, and northwestern Hubei have high thresholds, numerous events, and high intensity, while the eastern Tibetan Plateau has low thresholds, low intensity, and high frequency.

2) Temporally, interannual variations in extreme precipitation thresholds, frequency, and maximum daily precipitation are substantial. Over the past 40 years, extreme precipitation has shown an overall increasing trend.

Based on 11-year moving average linear trends, annual extreme precipitation thresholds, frequency, and maximum daily precipitation have increased at rates of 1.5 mm$\cdot$(10a)$^{-1}$, 0.3 times$\cdot$(10a)$^{-1}$, and 5 mm$\cdot$(10a)$^{-1}$, respectively.

3) From an annual perspective, comparing precipitation events \$ \$50 mm clearly shows more extreme precipitation events in 2001–2021 than in 1980–2000. Events with daily precipitation \$ \$50 mm, \$ \$100 mm, and \$ \$150 mm increased by 9.1%, 15.5%, and 38.8%, respectively. Spatially, the patterns of change in daily extreme precipitation thresholds and maximum daily precipitation are similar, with most stations showing increasing trends. Significantly increasing stations are located in western and northern Guanzhong (Shaanxi), Pingliang and Qingyang (Gansu), Bazhong and Guangyuan (Sichuan), Luoyang (Henan), and Taiyuan, Xinzhou, and Lüliang (central-western Shanxi). Although more stations show increasing than decreasing trends in extreme precipitation days, a considerable proportion of stations show no clear trend.

4) Seasonal variations in extreme precipitation are substantial, with spring differing markedly from summer and autumn. In spring, both the frequency and probability of \$ \$50 mm precipitation events were higher in 1980–2000 than in 2001–2021. In contrast, summer and autumn events were more frequent and intense in 2001–2021, with autumn also showing higher precipitation probabilities. Spatial distribution differences are also evident. In spring, daily extreme precipitation thresholds and extreme precipitation days generally increase in the west and decrease in the east, transitioning from positive to negative trends, with more stations showing decreasing trends. In summer and autumn, however, the number of stations with increasing trends exceeds those with decreasing trends, particularly in autumn where the proportion of stations with increasing trends is highest.

References

[1] Goswami B N, Venugopal V, Sengupta D, et al. Increasing trend of extreme rain events over India in a warming environment[J]. Science, 2006, 314(5804): 1442-1445.

[2] Osborn T J, Hulme M, Jones P D, et al. Observed trends in the daily intensity of United Kingdom precipitation[J]. International Journal of Climatology, 2000, 20(4): 347-364.

[3] Howarth M E, Thorncroft C D, Bosart L F. Changes in extreme precipitation in the northeast United States: 1979—2014[J]. Journal of Hydrometeorology, 2019, 20(4): 673-689.

[4] Yamamoto R, Sakurai Y. Long term intensification of extremely heavy rainfall intensity in recent 100 years[J]. World Resource Review, 1999, 11(2): 271-281.

[5] IPCC. IPCC Sixth Assessment Report Working Group I Report: Main conclusions interpretation and suggestions[J]. Environmental Conservation, 2021, 49(suppl. 2): 437-444.

[6] Jiang X M, Yuan H L, Xue M, et al. Analysis of a heavy rainfall event over Beijing during 21-22 July 2012 based on high resolution model analyses and forecasts[J]. Journal of Meteorological Research, 2014, 28(2): 199-212.

[7] Zhen Zuofang, Wang Zaiwen, Gao Hua. Characteristics of extreme precipitation events in summer and its effect on urbanization in Beijing area[J]. Meteorogical Monthly, 2013, 39(12): 1635-1641.

[8] Bueh Cholaw, Zhuge Anran, Xie Zuowei, et al. Water vapor transportation features and key synoptic scale systems of the rainstorm in Henan Province in 2021[J]. Chinese Journal of Atmospheric Sciences, 2022, 46(3): 725-744.

[9] Chen Haishan, Zhu Yuejia, Liu Lei. Relationship of synoptic-scale transient eddies and extreme winter precipitation events in the middle and lower reaches of the Yangtze River[J]. Chinese Journal of Atmospheric Sciences, 2013, 37(4): 801-814.

[10] Li W, Chen Y. Detectability of the trend in precipitation characteristics over China from 1961 to 2017[J]. International Journal of Climatology, 2021, 41(suppl. 1): E1980−E1991.

[11] Ma S M, Zhou T J, Stone D A, et al. Detectable anthropogenic shift toward heavy precipitation over eastern China[J]. Journal of Climate, 2017, 30(4): 1381-1396.

[12] Wang Zhao, Luo Hui, Li Yali, et al. Effects of urbanization on temperatures over the Qinling Mountains in the past 50 years[J]. Journal of Applied Meteorological Science, 2016, 27(1): 85-94.

[13] He Bingrui, Zhai Panmao. Characteristics of the persistent and non-persistent extreme precipitation in China from 1961 to 2016[J]. Climate Change Research, 2018, 14(5): 437-444.

[14] Zhai P M, Zhang X B, Wan H, et al. Trends in total precipitation and frequency of daily precipitation extremes over China[J]. Journal of Climate, 2005, 18(7): 1096-1108.

[15] Yang Wei, Cheng Zhi. Variation characteristics of extreme precipitation during meiyu flood period over Yangtze Huaihe Basin in recent 53 years[J]. Meteorogical Monthly, 2015, 41(9): 1126-1133.

[16] Wang Nan, Zhao Qiang, Jing Yu, et al. Causation analysis of a short time strong rainfall triggered by cold front at the northern piedmont of Qinling Mountains[J]. Plateau Meteorology, 2018, 37(5): 1277-1288.

[17] Zhang Ming, Li Guosheng. Trend analysis and statistical distribution of extreme rainfall in Guanzhong area[J]. Yellow River, 2021, 343(11): 59-64.

[18] Tian Fuyou, Yang Shunan, Zheng Yongguang, et al. Comparison of short duration heavy rainfall environmental conditions during two extreme torrential rainfall events over Beijing area[J]. Journal of Arid Meteorology, 2017, 35(2): 239-249.

[19] Yang Hanwei, Gong Zhiqiang, Wang Xiaojuan, et al. Analysis of the characteristics and causes of interdecadal changes in the summer extreme precipitation over eastern China[J]. Chinese Journal of Atmospheric Sciences, 2021, 45(3): 683-696.

[20] Li Xiangrui, Fan Ke, Xu Zhiqing. Decrease in extreme precipitation in summer over east northern China and the water vapor transport characteristics after year 2000[J]. Chinese Journal of Atmospheric Sciences, 2019, 43(5): 1109-1124.

[21] Chen Hongzhuan. Climatic characteristics and weather system classification of extreme precipitation in Hunan Province[J]. Meteorogical Monthly, 2021, 47(10): 1219-1232.

[22] Song Xiaomeng, Zhang Jianyun, Kong Fanzhe, et al. Probability distribution of extreme precipitation in Beijing based on extreme value theory[J]. Scientia Sinica Technologica, 2018, 48(6): 639-650.

[23] Zhang Hongfang, Pan Liujie, Chen Haoming, et al. Diurnal variations and causes of warm season precipitation in Qinling and surrounding areas[J]. Plateau Meteorology, 2020, 39(5): 935-946.

[24] Shi Weiliang, Che Luyang, Li Tao. Probability distribution and comprehensive risk assessment of extreme precipitation in flood season in Shaanxi Province[J]. Arid Land Geography, 2023, 46(9): 1407-1417.

[25] Li Jian, Yu Rucong, Sun Wei. Duration and seasonality of the hourly extreme rainfall in the central eastern part of China[J]. Acta Meteorologica Sinica, 2013, 71(4): 652-659.

[26] Huang Xin, Jiao Li, Ma Xiaofei, et al. Application of generalized extreme value distribution model to short duration extreme precipitation in Chongqing[J]. Meteorogical Monthly, 2019, 45(6): 820-830.

[27] Wang Ying, Liu Xiaoran, Cheng Bingyan, et al. Change characteristics of extreme precipitation events in Central Asia in recent 60 years based on RClimDex model[J]. Arid Land Geography, 2023, 46(7): 1039-1051.

Note: Figure translations are in progress. See original paper for figures.