Spatiotemporal Characteristics of Extreme Precipitation in Shaanxi Province Based on the Regional L-Moment Method: A Postprint

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Abstract

Based on daily precipitation data from 58 meteorological stations with complete measurements and relatively uniform distribution in Shaanxi Province from 1971 to 2015, using maximum 1-day, 3-day, 5-day, and 7-day precipitation amounts to represent extreme precipitation, the regional linear moment method was applied to investigate the spatiotemporal characteristics of regional extreme precipitation. The results indicate: (1) Shaanxi Province can be divided into 6 hydrometeorologically homogeneous regions, among which the Generalized Extreme Value (GEV) distribution provides the best simulation performance in each homogeneous region, and the optimal frequency estimates for each homogeneous region show good agreement with observed values at the same frequency. (2) The extreme precipitation frequency estimates calculated by the regional analysis method exhibit better robustness and accuracy compared to the single-site analysis method, particularly when computing extreme precipitation over longer durations. (3) At a 2-year return period, the regional growth factor in southern Shaanxi is greater than that in northern Shaanxi; the opposite is true when the return period reaches 5 years, and as the return period increases, both the regional growth factor and its difference between southern and northern Shaanxi also increase. (4) Under 100-year and 50-year return periods, extreme precipitation is relatively large in southern Shaanxi Province, moderate in the eastern region, and relatively small in the central Xianyang-Shangluo area, northwestern Yan' an in the western region, and western Yulin; the distribution characteristics of extreme precipitation are related to the unique geographical features of Shaanxi Province, particularly the east-west oriented Qinling Mountains which block moisture transport northward, creating north-south differences in extreme precipitation.

Full Text

Spatiotemporal Characteristics of Extreme Precipitation in Shaanxi Province Based on the Regional L-moments Method

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Abstract

Based on daily precipitation data from 58 meteorological stations in Shaanxi Province from 1971 to 2015 with no missing observations and relatively uniform distribution, this study uses the maximum precipitation on the 1st, 3rd, 5th, and 7th day to represent extreme precipitation. The regional L-moments method is applied to investigate the spatiotemporal characteristics of regional extreme precipitation. The results show that: (1) Shaanxi Province can be divided into six hydrometeorological homogeneous regions, among which the Generalized Extreme Value (GEV) distribution provides the best simulation performance in each region, and the optimal frequency estimates for each region are in good agreement with the observed values at the same frequency. (2) The extreme precipitation frequency estimates calculated by the regional analysis method demonstrate better robustness and accuracy compared with the single-site analysis method, particularly for longer-duration extreme precipitation events. (3) When the return period is 2 years, the regional growth factor in southern Shaanxi is greater than that in northern Shaanxi; when the return period reaches 5 years, the opposite occurs, and with increasing return period, the regional growth factor and its difference between southern and northern Shaanxi also increase. (4) Under 50-year and 100-year return periods, extreme precipitation is relatively large in southern Shaanxi, moderate in the eastern region, and relatively small in the central Xianyang-Shangluo region, the northwestern part of Yan’ an in the west, and western Yulin. The distribution characteristics of extreme precipitation are related to the unique geographical features of Shaanxi Province, particularly the east-west oriented Qinling Mountains, which block moisture transport northward, causing north-south differences in extreme

precipitation.

Keywords: Shaanxi Province; extreme precipitation; spatiotemporal characteristics; regional L-moment method

Introduction

Under the background of global warming, the frequency of extreme precipitation events has increased significantly, causing severe impacts on agricultural production, socio-economics, life safety, and ecological environments. In recent years, many scholars have explored regional extreme precipitation characteristics. Zhai et al. [?] analyzed extreme precipitation events in China over recent decades and pointed out that both the average intensity and frequency of extreme precipitation show increasing trends. For regional extreme precipitation characteristics, numerous scholars have investigated their causes. For example, Yang et al. [?] found that the abnormal warming of the Western Pacific Warm Pool, which reduces the land-sea temperature difference, is an important driving factor for the shift in summer extreme precipitation in eastern China around the 1990s. Long et al. [?] noted that the strength of the plateau summer monsoon can cause increases or decreases in summer extreme precipitation in different regions of China, with the physical mechanism involving characteristics of mid-to-high level circulation, mid-to-low level wind fields, water vapor transport, and moist potential vorticity.

Many scholars have also conducted research on extreme precipitation events in Shaanxi Province. Zheng et al. [?] found that both annual maximum precipitation and the frequency of heavy precipitation events in Shaanxi show increasing trends, with abrupt changes occurring in the mid-1990s. Wang [?] discovered that the first mode of extreme precipitation frequency during the flood season in Shaanxi shows an opposite phase between the north and other regions, while the second mode shows a north-south opposite pattern with the Qinling Mountains as the boundary. Li et al. [?] analyzed the spatiotemporal variation characteristics of four types of extreme precipitation in the Qinling region and pointed out that as temperature rises, persistent extreme precipitation shows a decreasing trend while single-day extreme precipitation shows an increasing trend. Xiao et al. [?] analyzed the causes from the perspective of circulation and sea temperature anomalies, identifying the reasons for extreme summer rainfall in Shaanxi in 2010. It is evident that meteorologists have conducted in-depth research on extreme precipitation in Shaanxi Province from aspects of type, intensity, frequency, and causes, drawing some important conclusions.

Shaanxi Province is located in the inland 腹地 of China, with mountainous terrain in the south and the Loess Plateau in the north, spanning humid, semi-humid, and arid, semi-arid zones. Its climate characteristics are transitional, making it a typical region for studying climate change. Research on extreme precipitation characteristics in Shaanxi can provide a theoretical basis for global warming and water cycle variation features. For frequency analysis of extreme precipitation, linear fitting and parameter estimation are typically performed to obtain extreme precipitation frequency estimates, with methods including conventional moments, probability weighted moments, L-moments, and regional analysis. The regional L-moments method, based on L-moments, divides the study area into homogeneous regions and further estimates precipitation frequency design values at each station. This method is currently widely used for regional extreme precipitation frequency analysis, significantly improving the accuracy of parameter estimation and frequency estimates, while homogeneous region division comprehensively considers hydrometeorological and geographical conditions (latitude, longitude, elevation, topography, etc.). This method has been applied by many domestic scholars to analyze regional extreme precipitation [?]. Currently, in frequency analysis of extreme precipitation in Shaanxi Province, Niu [?] conducted an in-depth analysis of extreme precipitation frequency in the Guanzhong Plain based on L-moments, with frequency estimates showing good consistency with observed values. However, there has been no corresponding regional frequency study for extreme precipitation across the entire Shaanxi Province. Therefore, this study, based on recent daily precipitation data from the study area, uses the regional L-moments method to analyze the return period and spatiotemporal distribution characteristics of extreme precipitation in Shaanxi Province, providing a comprehensive analysis of extreme precipitation frequency in different climate zones of the province, which has certain reference significance for regional disaster prevention and mitigation.

1. Data and Methods

1.1 Data

This study selected daily precipitation data from 58 meteorological stations in Shaanxi Province. The meteorological data are daily precipitation records provided by the National Meteorological Information Center, with a sequence length of 1971-2015. DEM data were obtained from the Geospatial Data Cloud. The spatial distribution of the meteorological stations is shown in Figure 1. Using the daily precipitation data from Shaanxi Province from 1971 to 2015, we extracted the annual maximum 1-day precipitation (AMP1), annual maximum 3-day precipitation (AMP3), annual maximum 5-day precipitation (AMP5), and annual maximum 7-day precipitation (AMP7) for each station, and based on this, studied the spatiotemporal characteristics of extreme precipitation in Shaanxi Province.

1.2.1 Regional L-moments Method

The regional L-moments method includes the L-moments method and regional analysis method. The L-moments method is a new parameter estimation method with good unbiasedness and robustness. The regional analysis method is based on historical precipitation data from all stations in the study area, with the basic idea of "trading space for time" to overcome the shortage of short observation sequences. By analyzing the frequency distribution curves of meteorological stations within a homogeneous region, the precipitation frequency estimates at each station can be calculated. The regional L-moments method combines the advantages of both and has been successfully applied in many regions domestically and internationally [**?**]. For detailed introduction to the method, refer to Hosking et al. [**?**].

The concept of L-moments was proposed by Hosking [**?**], with the basic idea of calculating the expected values of order statistics from a distribution function and performing linear combinations on them. Assuming X follows a certain distribution function, let $X_{1:n} \leq X_{2:n} \leq ... \leq X_{n:n}$ be the order statistics from a sample of size n. The r-th L-moment is defined as:

$$\lambda_r = \frac{1}{r}\sum_{k=0}^{r-1}(-1)^k \binom{r-1}{k} E[X_{r-k:r}]$$

where $X_{r:n}$ is the r-th order statistic; $E[X_{r:n}]$ is the expected value of the r-th order statistic in a sample of size n; and $\binom{r-1}{k}$ is the binomial coefficient.

The first four L-moments of X are:

$$\lambda_1 = E[X_{1:1}]$$
$$\lambda_2 = \frac{1}{2}E[X_{2:2} - X_{1:2}]$$
$$\lambda_3 = \frac{1}{3}E[X_{3:3} - 2X_{2:3} + X_{1:3}]$$
$$\lambda_4 = \frac{1}{4}E[X_{4:4} - 3X_{3:4} + 3X_{2:4} - X_{1:4}]$$

where n is the sample size and $X_{i:n}$ are the sample order statistics. Based on the first four sample L-moments, statistical characteristic parameters can be derived, including the L-coefficient of variation (L-CV), L-coefficient of skewness (L-CS), and L-coefficient of kurtosis (L-CK), calculated as follows:

$$\tau = \frac{\lambda_2}{\lambda_1}$$
$$\tau_3 = \frac{\lambda_3}{\lambda_2}$$
$$\tau_4 = \frac{\lambda_4}{\lambda_2}$$

1.2.2 Hydrometeorological Homogeneous Region Classification

To ensure that stations within a homogeneous region have the same hydrometeorological background, this paper divides stations into homogeneous regions based on the following criteria: (1) Meteorological determination, i.e., stations within the same homogeneous region should have the same background conditions such as moisture inflow and physical causes, which are typically comprehensively determined using elevation, landform, and circulation characteristics. (2) Hydrological determination, i.e., the extreme value series of stations within a homogeneous region should follow the same distribution, meaning that the coefficients of variation, skewness, and kurtosis of each station should be consistent within a certain tolerance. Whether stations belong to the same homogeneous region is usually determined using heterogeneity tests, and when $H < 1$, the homogeneous region is considered acceptable. After meteorological and hydrological determination, the hydrometeorological homogeneous region can be preliminarily established. Then, the discordancy measure D_i for each station within the region is calculated. If all discordancy measures D_i are less than the critical value, the homogeneous region is considered reasonably delineated. If individual stations have discordancy measures D_i exceeding the critical value, these discordant stations need to be moved to surrounding regions or even removed.

The Kendall trend test and first-order autocorrelation coefficient test were applied to the extreme precipitation series at 58 meteorological stations in Shaanxi Province. As shown in Figure 2, in the Mann-Kendall trend test for Shaanxi Province, several stations show an upward trend, mainly located in northern Ankang, Xianyang, northern Baoji, eastern Yulin, and the southwestern corner of Yulin. The Dingbian station in the southwestern corner of Yulin shows the most significant upward trend, while the Xunyang station in Ankang shows the most significant downward trend. Among all stations, a small proportion of individual extreme precipitation series passed the significance test at the 0.1 level. The remaining meteorological stations show no significant trends in their extreme precipitation series. Therefore, the extreme precipitation series in Shaanxi Province can be considered stationary. As shown in Figure 2, for the first-order autocorrelation coefficient, only a few series passed the significance test at the 0.1 level, while other stations show no significant autocorrelation. Therefore, the extreme precipitation series in Shaanxi Province can be considered independent.

1.2.3 Determination of Optimal Distribution

In hydrology, distribution models with three parameters are typically used for frequency calculation, as they are both accurate and flexible for simulating extreme precipitation distributions. In the regional L-moments method, three-parameter distributions are most commonly used. The research object of the regional analysis method must belong to a hydrometeorological homogeneous region with the same climate background and statistical characteristics in terms of extreme precipitation properties. This method decomposes the precipitation series into two components: the local component reflecting the precipitation characteristics of the individual site, and the regional component reflecting the common regional precipitation characteristics. When calculating the frequency estimate for a station, both components are considered, making the results more reliable. The frequency estimate is calculated as:

$$Q_T(i,j) = q_T(i) \times x_j(i)$$

where T is the return period of extreme precipitation to be estimated; i represents each homogeneous region; j represents stations within the corresponding homogeneous region; $q_T(i)$ is the regional frequency factor reflecting the common extreme precipitation characteristics of all stations in the region, known as the regional growth factor, which can be obtained from the optimal distribution curve and parameters of the region; and $x_j(i)$ is the local component factor, representing the multi-year average of extreme precipitation at station j in region i. According to formula (4), after removing the mean from the station frequency estimate, the regional component reflecting common extreme precipitation characteristics can be obtained, i.e., the regional growth factor.

The most commonly used three-parameter distributions include the Generalized Logistic (GLO), Generalized Extreme Value (GEV), Generalized Pareto (GPA), Generalized Normal (GNO), and Pearson Type III (PE3) distributions [**?**]. This study selects these five distributions for simulating extreme precipitation in Shaanxi Province. First, Monte Carlo simulation is used to determine the optimal distribution for each homogeneous region. Second, the goodness-of-fit is evaluated by comparing the average L-kurtosis coefficient of stations in the homogeneous region with the L-kurtosis coefficient of the selected distribution. In practice, the statistic Z^{DIST} is typically used for judgment. When $|Z^{DIST}| \leq 1.64$, the fit is considered acceptable; the smaller the $|Z^{DIST}|$ value, the better the fit. The threshold of 1.64 is selected because Z^{DIST} follows a standard normal distribution at significance level $\alpha = 0.1$.

2. Results and Analysis

2.1 Data Statistical Tests

The regional L-moments method requires comprehensive statistical tests of data series, such as stationarity and independence, to ensure the reliability of frequency estimates. In fact, stationarity and independence are two fundamental assumptions in hydrological frequency analysis. The Mann-Kendall test can be used to test the stationarity of data series, while the first-order autocorrelation coefficient can test the independence of data series. This study uses these two methods to test the extreme precipitation series in Shaanxi Province.

2.2 Hydrometeorological Homogeneous Region Classification

The process of hydrometeorological homogeneous region classification is as follows: First, the K-means method (based on station latitude, longitude, elevation, and annual precipitation) is used for cluster analysis to divide Shaanxi Province into several regions. Then, considering the unique climate and topographic features of Shaanxi Province, combined with discordancy test index D and heterogeneity test index H, the clusters obtained from the analysis are appropriately adjusted so that stations in each region are located under the same climate and topographic conditions as much as possible. Finally, heterogeneity tests and discordancy tests are performed on the extreme precipitation series in each adjusted homogeneous region. During the adjustment process, if any region fails these tests, discordant stations are moved to adjacent regions, or the region is divided into sub-regions, or the station is removed, and the process is repeated for all regions in the study area.

After multiple adjustments, this study finally divides Shaanxi Province into six hydrometeorological homogeneous regions. Table 1 shows the heterogeneity test results for stations in each homogeneous region. As shown in Table 1, the extreme precipitation series in all six regions passed the heterogeneity test (i.e., $H < 1$). Meanwhile, except for one station' s series (with D_i slightly exceeding the critical value), all stations' extreme precipitation series passed the discordancy test. Figure 3 shows the final division results of the six hydrometeorological homogeneous regions based on extreme precipitation in Shaanxi Province. Comparing with Figure 1, the homogeneous region division corresponds well with the topographic distribution of Shaanxi Province. Region 1 is mainly located in the Qinling Mountains with mountainous terrain and the highest elevation. Region 2 is located on the eastern side of the southern Qinling area, mainly featuring hills and mountains. Region 3 is located in the southern Qinling area, also mainly featuring hills and mountains. Region 4 is primarily in the Wei River Basin, featuring plain and terrace terrain with relatively low elevation. Region 5 is located in the Loess Plateau, featuring plateau terrain. Region 6 is in the northernmost part, also featuring plateau terrain.

2.3 Determination of Optimal Distribution

To determine the optimal distribution, we first use the plotting position formula to calculate the empirical frequency corresponding to the measured values of each station' s AMP1 series, then determine the regional analysis method estimate at that empirical frequency, and compare the two to indirectly reflect the accuracy of the estimates. The plotting position formula used is:

$$p_i = \frac{i - A}{n + 1 - 2A}$$

where i is the rank of the sorted series; n is the length of the series; A is a parameter of the plotting position formula, which is taken as 0.38 in this study.

Based on this formula, the empirical frequency of each station' s AMP1 series measured values is calculated, and the frequency estimate corresponding to that empirical frequency is derived based on the optimal distribution. Figure 4 shows scatter plots of measured values versus frequency estimates for each homogeneous region, demonstrating good linear correlation with coefficients of determination (R^2) all exceeding 0.9 at the 0.1 significance level. Additionally, when measured values are small (i.e., short return periods), frequency estimates are more accurate (points are close to the diagonal line). The measured values in Region 1 are around 50 mm, while in Region 6 they are around 75 mm.

In this study, the data series length is 45 years, so the maximum value of the extreme series can be approximated as the true value for a 50-year return period. Comparing this with the frequency estimates can indirectly reflect the accuracy of the estimates. In the previous regional division, Regions 1, 4, and 6 are located in northern, central, and southern Shaanxi, respectively, belonging to the Loess Plateau, Guanzhong Plain, and Qinba Mountains, reflecting precipitation characteristics under different landform types in Shaanxi. Table 3 compares the measured maximum values of AMP1 series at each station with the 50-year return period frequency estimates and their relative errors. It can be found that relative errors are mainly concentrated between 0-30%, with a few stations having relative errors exceeding 30%. Among them, the Ningshan station has the largest relative error of 52.4%, with its measured maximum exceeding the multi-year average by a factor of . For stations with smaller relative errors, the measured maximum is generally around 50 mm, corresponding to the most accurate frequency estimates. When measured values are large (i.e., long return periods), frequency estimates are significantly smaller than measured values, and errors increase with measured values.

2.4 Comparison of Single-Site and Regional Analysis Methods

In single-site analysis, the optimal fitting distribution for extreme precipitation at each station can be determined from extreme value plots. Taking Zizhou station in northern Shaanxi and Shanyang station in southern Shaanxi as examples (Figure 5), it can be seen that among the commonly used distributions, the Generalized Extreme Value (GEV) distribution provides the best fit for Zizhou station' s AMP1 series, while the Generalized Normal (GNO) distribution provides the best fit for Shanyang station' s AMP1 series. That is, the optimal fitting distributions for Zizhou and Shanyang stations' AMP1 series are GEV and GNO, respectively. Similarly, the optimal fitting distributions for other stations can be obtained.

Using both single-site analysis and regional analysis methods, frequency estimates for different return periods were calculated for all stations in Shaanxi Province. The relative root mean square error (RMSE) was calculated for each method, where smaller RMSE indicates better fit and higher accuracy. Figure 6 shows boxplots of relative RMSE values for 50-year return period frequency estimates from both methods. It can be found that the relative RMSE range from the regional analysis method is significantly smaller than that from the single-site analysis method (the interquartile range of regional analysis is very small because its quantiles are very close), indicating that the regional analysis method is more stable. This result is consistent with Liu et al. [**?**].

From the boxplots, for AMP1 series, the relative RMSE from regional analysis is mostly within the range of relative RMSE from single-site analysis, with small differences in mean values (except for Region 4). For AMP7 series, the relative RMSE from regional analysis is significantly smaller than that from single-site analysis, with larger differences in mean values (except for Region 4). Therefore, the regional analysis method provides higher accuracy when calculating frequency estimates for longer-duration extreme precipitation.

2.5 Regional Growth Factors

The frequency factor representing the common extreme precipitation characteristics within a homogeneous region is called the regional growth factor. Its essence is the magnitude of increase of extreme precipitation for a given return period relative to the multi-year average extreme precipitation within a homogeneous region with the same hydrometeorological conditions. Table 4 provides the regional growth factors for AMP1 series at different return periods for each homogeneous region. It can be found that when the return period is 2 years, the regional growth factor is less than 1. When the return period is 5 years, the regional growth factor is greater than 1. The regional growth factor in Region 1 is greater than that in Region 6. With increasing return period, the regional growth factor increases, and the difference between southern and northern Shaanxi also increases, which is a major factor causing differences in extreme precipitation frequency estimates between different homogeneous regions.

According to formula (4), when the return period is very small, such as 2 years, its frequency estimate is less than the multi-year average extreme precipitation. The difference between the 2-year frequency estimate and the multi-year average extreme precipitation in southern Shaanxi is smaller than that in northern Shaanxi, resulting in the regional growth factor in southern Shaanxi being greater than that in northern Shaanxi. When the return period is larger, such as greater than 5 years, the frequency estimate may exceed the multi-year average extreme precipitation, and the larger the return period, the larger the frequency estimate, and the corresponding regional growth factor also increases. Meanwhile, northern Shaanxi generally has less precipitation and thus smaller multi-year average extreme precipitation, but extreme precipitation in some years is very high, resulting in the regional growth factor in northern Shaanxi being greater than that in southern Shaanxi for long return periods.

The regional growth factor is the same for all stations within a homogeneous region, meaning that differences in extreme precipitation within a homogeneous region are caused by differences in the local component at each station. For example, under 50-year return period conditions, Zizhou station in Region 6 has a local component of 61.27 mm, while other stations in Region 6 under the same frequency have local components of 45-55 mm, which are less than Zizhou station' s local component, resulting in Zizhou station' s extreme precipitation being higher. Additionally, regional growth factors differ between different homogeneous regions. That is, with the same local component, if stations are located in different homogeneous regions, their extreme precipitation frequency estimates will differ. For example, under 50-year return period conditions, Danfeng station has a local component of 61.28 mm, similar to Zizhou station' s local component. However, because Danfeng station is located in Region 2 with a regional growth factor of , while Zizhou station is located in Region 6 with a regional growth factor of , Danfeng station' s final frequency estimate is 111.53 mm, smaller than Zizhou station' s 136.01 mm.

2.6 Spatial Distribution of Frequency Estimates

Using the regional L-moments method, frequency estimates for 50-year and 100-year return periods of extreme precipitation in Shaanxi Province were calculated and mapped using ArcGIS (Figure 7). The spatial distribution of extreme precipitation frequency estimates under these return periods is similar, showing larger extreme precipitation in southern Shaanxi, moderate in the eastern region, and smaller in the central Xianyang-Shangluo region, the northwestern corner of Yan' an in the west, and western Yulin. Overall, extreme precipitation roughly decreases from south to north. Among them, Region 1 in southern Shaanxi has the largest frequency estimates, with maximum values exceeding 270 mm. In the Loess Plateau region to the west, the minimum values are around 90 mm. It is evident that the distribution of extreme precipitation frequency values in Shaanxi Province is very uneven, which is related to the unique geographical distribution of the province (Figure 1). Southern Shaanxi has lower elevation and can receive moisture transported from the south, while the Qinling Mountains have high elevation (above 2000 m in Shaanxi), blocking moisture from moving northward and causing north-south differences in extreme precipitation.

The main conclusions are as follows: (1) The extreme precipitation series at most stations in the study area show no significant trend or autocorrelation, thus satisfying the basic assumptions of stationarity and independence for hydrological frequency analysis. (2) Using K-means clustering based on station latitude, longitude, elevation, and annual precipitation, combined with discordancy test index D_i and heterogeneity test index H_1, the study area was divided into six hydrometeorological homogeneous regions. The GEV distribution provided the best simulation performance in each region, and the optimal frequency estimates were in good agreement with measured values at the same frequency. (3) The relative RMSE confirms that the regional analysis method is more robust than the single-site analysis method, with higher accuracy for longer-duration extreme precipitation frequency estimates. (4) According to the regional analysis method, when the return period is 2 years, the regional growth factor in southern Shaanxi is greater than that in northern Shaanxi; when the return period reaches 5 years, the opposite is true. With increasing return period, the regional growth factor increases, and the difference between southern and northern Shaanxi also increases, which is a major factor causing differences in extreme precipitation frequency estimates between different homogeneous regions. (5) Under 50-year and 100-year return periods, extreme precipitation is large in southern Shaanxi, moderate in the east, and small in the central Xianyang-Shangluo region, the northwestern corner of Yan' an, and western Yulin. The maximum value exceeds 270 mm in the southern center of Region 1, while the minimum value is around 90 mm in the central and western Loess Plateau. The distribution characteristics of extreme precipitation are related to the unique geographical features of Shaanxi Province, particularly the east-west oriented Qinling Mountains blocking moisture transport northward.

Shaanxi Province has diverse topography including mountains, hills, and plateaus. Extreme precipitation can easily trigger disasters such as debris flows and landslides. Even in central and northern regions with smaller extreme precipitation frequency estimates, sudden extreme precipitation can cause great harm due to fragile geological conditions. For example, on August 12, 2015, Shangluo City (in Region 3) experienced '7.28' extreme rainstorm, with local 3-hour precipitation exceeding 100 mm, causing 65 deaths, 15 missing persons, and 122 collapsed houses. On July 26, 2017, northern Yulin experienced extreme rainstorm, with daily precipitation at Hengshan, Mizhi, and Zizhou (in Region 6) reaching 111.1 mm, 140.3 mm, and 218.7 mm respectively, all breaking historical records, and the heavy precipitation caused major disasters such as floods and debris flows threatening life and property. The regional L-moments method is robust to extreme values, and individual extreme anomalies do not affect the regional frequency curve. When calculating single-site frequency estimates, they are obtained by multiplying the multi-year average of annual maximum values by the regional growth factor. Therefore, extreme precipitation anomalies in northern Shaanxi have limited impact on the results. In summary, more attention should be paid to various hydrometeorological disasters caused by extreme precipitation in Shaanxi Province.

3. Conclusions and Discussion

Shaanxi Province spans a large latitude range from south to north, with obvious differences in topography, landform, and climate, resulting in large regional differences in extreme precipitation. The division of hydrometeorological homogeneous regions based on the regional L-moments method is well-suited to the large spatial differences in geographical features of Shaanxi Province. Meanwhile, heavy rain occurs frequently in southern Shaanxi, and the geological and geomorphological conditions in the northern Loess Plateau region are fragile. Frequency analysis of extreme precipitation is of great significance for disaster prevention and mitigation of extreme precipitation, landslides, debris flows, and other disasters. However, this study also found that the spatial distribution characteristics of extreme precipitation frequency estimates for AMP1, AMP3, AMP5, and AMP7 series are similar in Shaanxi Province. This is because extreme precipitation in Shaanxi has strong seasonality, mostly occurring in summer, so extreme precipitation of different durations overlaps in time. Therefore, the authors will conduct in-depth research on the differences in frequency estimates among different series in the next step, exploring the impacts of different time durations on extreme precipitation in Shaanxi Province.

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