Spatiotemporal Distribution Characteristics of Heavy Rainfall and Rainstorm Disaster Risk Assessment in Shanxi Province, 1957–2019 (Postprint)

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Date: 2023-06-28T00:00:00+00:00

Abstract

Utilizing daily precipitation data from 27 meteorological stations in Shanxi Province spanning 1957–2019, this study employs wavelet analysis and other methods to analyze the spatiotemporal distribution characteristics of heavy rainfall in Shanxi Province, and conducts a risk assessment of heavy rainfall disasters using the Analytic Hierarchy Process (AHP) based on natural disaster theory. The results indicate: (1) From a temporal perspective, heavy rainfall occurrence in Shanxi Province demonstrates periodicity and seasonality; interannual variations exhibit oscillations at four temporal scales of 4 a, 9 a, 14–15 a, and 27–28 a, with the oscillation periods shortening and the frequency of heavy rainfall events showing an increasing trend; seasonal distribution is uneven, concentrated primarily in summer with a higher probability of forming heavy rainfall disasters, with cumulative heavy rainfall days during June–August accounting for 85.23% of the annual total, of which July represents the largest proportion at 45.18%. (2) From a spatial perspective, heavy rainfall occurs predominantly in central-southern Shanxi and high-altitude mountainous regions, following an overall decreasing pattern from southeast to northwest with significant regional disparities; with Mount Heng as the boundary, the probability of heavy precipitation and rainfall amounts in the southern region are generally higher than in the northern region, wherein Yuanqu, Wutai Mountain, and Yangcheng exhibit annual average heavy rainfall amounts exceeding 65 mm and cumulative heavy rainfall days surpassing 60 d. (3) Through risk assessment of heavy rainfall disasters in Shanxi Province, the comprehensive risk level is found to exhibit a spatially decreasing trend from south to north, with the northeastern Yuncheng Basin classified as a high-risk area, while the northeastern and northwestern regions of Shanxi Province are classified as low-risk areas, and most remaining

areas fall into medium-risk and sub-high-risk categories.

Full Text

Spatiotemporal Distribution Characteristics of Rainstorms and Rainstorm Disaster Risk Assessment in Shanxi Province from 1957 to 2019

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Abstract: Based on daily precipitation data from 27 meteorological stations in Shanxi Province from 1957 to 2019, wavelet analysis and other methods were employed to analyze the spatiotemporal distribution characteristics of rainstorms in Shanxi Province. The decision analysis method (AHP) was used to conduct a rainstorm disaster risk assessment based on natural disaster theory. The results show that: (1) From a temporal perspective, the occurrence of rainstorms in Shanxi Province exhibits periodicity and seasonality. Interannual variations in rainstorms show oscillations at four time scales: 4 years, 9 years, 14–15 years, and 27–28 years, with the oscillation period shortening and the frequency showing an increasing trend. The seasonal distribution of rainstorms is uneven, concentrated mainly in summer with a high probability of rainstorm disasters. The cumulative number of rainstorm days from June to August accounts for 85.23% of the annual total, with July accounting for the largest proportion at 45.18%. (2) From a spatial perspective, rainstorms occur mainly in the central and southern parts of Shanxi Province and in mountainous areas with higher altitudes, showing an overall decreasing trend from southeast to northwest with obvious regional differences. With Hengshan Mountain as the boundary, the probability of heavy rainfall and the amount of rainstorms in the southern region are generally higher than those in the northern region. Among them, Yuanqu, Wutaishan, and Yangcheng have average annual rainstorm amounts exceeding 65 mm and cumulative rainstorm days exceeding 60 days. (3) Through the assessment of rainstorm disaster risk in Shanxi Province, it was found that the comprehensive risk level of rainstorm disasters in Shanxi Province shows a gradually decreasing trend from south to north spatially. The northeastern part of the Yuncheng Basin belongs to the high-risk area, while the northeastern and northwestern parts of Shanxi Province belong to the low-risk area, with most other areas belonging to medium-risk and sub-high-risk areas.

Keywords: rainstorm; wavelet analysis; spatiotemporal distribution; disaster risk assessment; Shanxi Province

1 Introduction

China is one of the countries with the highest frequency of rainstorm and flood disasters, which cause serious impacts on people's lives and socio-economic development. The disaster rate, economic losses, and casualties in some areas are much higher than those in the southeast coastal regions. How to effectively reduce the losses caused by rainstorm and flood disasters has become a topic of common concern for countries, regions, and scholars worldwide. The main characteristics of rainstorm and flood disasters in China are that they are influenced by the East Asian monsoon, with frequent rainstorm activities showing obvious interdecadal, interannual, seasonal, and intraseasonal oscillations. The distribution of annual average rainstorm amount has obvious regional characteristics, and the regional distribution of annual average rainstorm days is consistent with that of annual average rainstorm amount, but there are obvious differences in the regional distribution of annual average rainstorm days in different seasons. Precipitation amount and frequency are the main influencing factors of flood disasters. Previous studies have widely applied methods and models such as the Decision Analysis Method (AHP) and Geographic Information System (GIS) to natural disaster risk prediction and assessment. Pei Huijuan et al. combined the AHP method with natural disaster risk assessment theory to study the spatiotemporal distribution and risk assessment of rainstorms and floods in Gansu Province, mapping the comprehensive risk zoning map of rainstorm and flood disasters in Gansu Province. Yang Xing et al. conducted a risk assessment of meteorological disasters in Hanzhong City and concluded that high-risk areas for rainstorm and flood disasters are mostly located in mountainous areas, while plain areas have lower risks. Rainstorm and flood disaster risk assessment should comprehensively consider disaster-causing factors, disaster-bearing bodies, and disaster prevention capabilities. Sun Peng and Liu Hui et al. conducted comprehensive assessments of regional rainstorm and flood disaster risks based on natural disaster assessment theory, mapping rainstorm risk level maps and analyzing the spatial characteristics of rainstorm and flood disaster risks, which improved the practicality and scientificity of risk assessment. Combining remote sensing images for flood disaster risk assessment research is beneficial for the planning of flood control and disaster reduction projects. Scientific risk assessment of regional rainstorm disasters will more effectively guide regional disaster prevention and mitigation as well as industrial and agricultural production activities.

In recent years, with global climate warming, the intensity and frequency of rainstorm disasters in Shanxi Province have gradually increased, seriously affecting the province's socio-economic development. Existing relevant studies mainly focus on the short-term spatiotemporal variation patterns and influencing factors of rainstorms in Shanxi Province and some areas, which have limited guiding significance for future disaster prevention and mitigation. However, there are few studies on rainstorm disaster risk assessment in Shanxi Province. Research on historical data is conducive to better understanding recent changes in rainstorms. In response to this situation, this study combines historical precipitation data from 1957 to 2019 to conduct an in-depth analysis of the spatiotemporal distribution of rainstorm disasters in Shanxi Province. Based on natural disaster assessment theory and the AHP method, a disaster risk assessment of rainstorm disasters in Shanxi Province is conducted to provide a scientific basis for regional rainstorm flood control and disaster reduction, strengthening disaster risk management, and post-disaster reconstruction work.

2 Study Area and Methods

2.1 Study Area

Shanxi Province is located in the eastern part of the Loess Plateau, between 34°34 –40°44 N and 110°14 –114°33 E, with a total area of 15.67$×10^{4}$ km^{2}. It has a temperate monsoon climate, with an average annual precipitation of about 400–650 mm. Precipitation is unevenly distributed throughout the year, with approximately 60–80% of annual precipitation concentrated in June–September. The landform within the territory is complex and diverse, with mountainous areas accounting for about 80% of the total area, and geological disasters occur frequently. Shanxi Province governs 11 prefecture-level cities and 117 county-level administrative units. In 2019, the province's permanent population was 37.2922 million, with a gross national product of 17026.7$×10^{8}$ yuan and per capita GDP of 45,724 yuan. In 2019, the province suffered direct economic losses of 120.8$×10^{8}$ yuan from various natural disasters, with a year-on-year increase of 142.2$×10^{8}$ yuan. The affected area of crops reached 71.5$×10^{4}$ hm^{2}, of which the affected area caused by rainstorm and flood disasters reached 68.8%.

2.2 Data Sources

Meteorological data mainly came from the China Meteorological Data Network (http://data.cma.cn). Based on the principles of feasibility and objectivity of the research work and combined with reality, 27 meteorological stations were relatively evenly selected in Shanxi Province, namely Youyu, Datong, Hequ, Tianzhen, Shuozhou, Wutaishan, Lingqiu, Wuzhai, Xingxian, Yuanping, Pingding, Lishi, Taiyuan, Taigu, Yushe, Xixian, Jixian, Jiexiu, Linfen, Anze, Changzhi, Xiangyuan, Yuncheng, Houma, Yuanqu, Yangcheng, and Yongji. The obtained data have been strictly verified, with good quality and accuracy. Socioeconomic data came from the Ministry of Civil Affairs of China and the *Shanxi Statistical Yearbook*. ArcGIS 10.2, Matlab, and Origin 2018 software were used for data analysis and chart plotting.

2.3 Methods

2.3.1 Wavelet Analysis Wavelet analysis is widely used in atmospheric science and hydrology and water resources research. Wavelet analysis can detect instantaneous components and frequency components at different time scales and study variation components at multiple time scales. The Morlet wavelet has a good balance between time and frequency localization, so this paper uses the Morlet wavelet function to conduct time series analysis of rainstorms in Shanxi Province through Matlab. The calculation formula is as follows:

$$\varphi(t) = \pi^{-1/4} e^{i\omega_0 t} e^{-t^2/2}$$

where $\varphi(t)$ is the wavelet function; i is the imaginary number; t is time; c is a dimensionless constant; and ω_0 is the central frequency.

2.3.2 Decision Analysis Method (AHP) This paper uses AHP to determine the weights of multiple indicators for rainstorm disaster risk assessment. First, it is necessary to construct a judgment matrix, mainly through expert evaluation to compare each indicator element pairwise and give scores (1–9). To ensure that there are no contradictions in the importance of each element due to different expert opinions, the above matrix needs to be tested for consistency. After passing the consistency test, the final target weight is determined. The specific calculation formula is as follows:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(Aw)_i}{w_i}$$

$$CI = \frac{\lambda_{\max} - n}{n-1}$$

$$CR = \frac{CI}{RI}$$

where $\lambda_{\max}$ is the maximum eigenvalue; $(Aw)_i$ is the weight value generated after matrix A is multiplied by the weight matrix w; w_i is the weight value of the weight matrix w; CI is the maximum eigenroot value; n is the matrix dimension; RI is the random consistency index; and CR is the consistency ratio. When $CR < 0.1$, the obtained hierarchical ranking weight is considered correct and reasonable; otherwise, the judgment matrix needs to be readjusted until the consistency test is qualified. The calculation results are detailed in Tables 1–5.

2.3.3 Construction of Rainstorm Disaster Risk Assessment Index System The formation of rainstorm disasters is the result of multiple factors working together. This paper uses AHP to explore the problem of spatial rainstorm disaster risk assessment in Shanxi Province. Combined with natural disaster system theory, it mainly focuses on four aspects (criterion layer) and 11 specific indicator layers as evaluation standards. AHP is used to determine the weight of each indicator (Tables 1–6). This paper uses the Kriging interpolation method to draw the assessment grade classification map of rainstorm days and disaster risk index in Shanxi Province, using the natural breakpoint method for color classification.

Weight judgment matrix of criterion layer indices and consistency test
Weight judgment matrix of disaster factors indices layer and consistency test
Weight judgment matrix of gestational disaster environment indices layer and consistency test
Weight judgment matrix of disaster bearing body indices layer and consistency test
Weight judgment matrix of disaster prevention and mitigation capacity indices layer and consistency test
Risk assessment index system of rainstorm disaster

2.3.4 Natural Disaster Risk Assessment Model Natural disaster risk assessment quantitatively estimates and analyzes the possibility and consequences of disasters of different intensities from various aspects of disasters, especially disaster-causing factors and disaster degree. Based on natural disaster system theory and risk assessment theory, this paper selects relevant indicators and establishes a rainstorm disaster risk assessment model. The formulas are as follows:

Disaster-causing factor hazard index (S_{hazard}):

$$S_{\text{hazard}} = Z_1 \times P_1 + Z_2 \times P_2 + Z_3 \times P_3$$

where Z_1 is the standardized value of annual average rainfall; Z_2 is the standardized value of annual average rainstorm days; Z_3 is the standardized value of daily maximum rainfall; and P_1, P_2, P_3 are the corresponding indicator weight values.

Gestational environment sensitivity index ($S_{\text{sensitivity}}$):

$$S_{\text{sensitivity}} = Z_4 \times P_4 + Z_5 \times P_5 + Z_6 \times P_6$$

where Z_4 is the standardized value of elevation; Z_5 is the standardized value of terrain slope; Z_6 is the standardized value of river network density; and P_4, P_5, P_6 are the corresponding indicator weight values.

Disaster-bearing body vulnerability index ($S_{\text{vulnerability}}$):

$$S_{\text{vulnerability}} = Z_7 \times P_7 + Z_8 \times P_8$$

where Z_7 is the standardized value of population density; Z_8 is the standardized value of cultivated land area ratio; and P_7, P_8 are the corresponding indicator weight values.

Disaster prevention and mitigation capacity index (S_{capacity}):

$$S_{\text{capacity}} = Z_9 \times P_9$$

where Z_9 is the standardized value of GDP per 10^8 yuan and P_9 is the corresponding weight value.

Comprehensive rainstorm disaster risk index ($S_{\text{comprehensive}}$):

$$S_{\text{comprehensive}} = S_{\text{hazard}} \times P_{\text{hazard}} + S_{\text{sensitivity}} \times P_{\text{sensitivity}} + S_{\text{vulnerability}} \times P_{\text{vulnerability}} + (1 - S_{\text{capacity}}) \times P_{\text{capacity}}$$

where S_{hazard} is the disaster-causing factor hazard index; $S_{\text{sensitivity}}$ is the gestational environment sensitivity index; $S_{\text{vulnerability}}$ is the disaster-bearing body vulnerability index; S_{capacity} is the disaster prevention and mitigation capacity index; and $P_{\text{hazard}}, P_{\text{sensitivity}}, P_{\text{vulnerability}}, P_{\text{capacity}}$ are the corresponding indicator weights.

3 Results

3.1 Temporal Variation Characteristics of Rainstorms

3.1.1 Interannual Variation of Rainstorms Based on the daily precipitation data from 27 meteorological stations in Shanxi Province from 1957 to 2019, the interannual variation trends of cumulative rainstorm days and annual average rainstorm amount in Shanxi Province were plotted [Figure 2: see original paper]. The variation trend of rainstorm days is roughly consistent with that of annual average rainstorm amount. The interannual variation of cumulative rainstorm days is large, and its variation follows certain patterns. It can be seen that after 1980, the cumulative rainstorm days showed an increasing trend with shortened intervals. Among them, the cumulative rainstorm days in 2018 reached 52 days, the highest in recent years. The fluctuation range of annual average rainstorm amount is generally stable, showing a slight decline over time, but the frequency of rainstorm occurrence has increased. The annual average rainstorm amount over the years is about 67 mm.

3.1.2 Intra-annual Variation of Rainstorms Rainstorms in Shanxi Province are mainly concentrated in June–September, with July as the peak month, when the cumulative rainstorm days reach 78.63% of the annual total. The proportions of rainstorm days in June, July, August, and September are 3.39%, 45.18%, 33.45%, and 6.60%, respectively. July has the most rainstorm days, accounting for 45.18% of the annual total, followed by August at 33.45%. This indicates that summer is the high-incidence period of rainstorms in Shanxi Province, with concentrated precipitation, and also reflects the fact that uneven temporal distribution of precipitation and frequent extreme precipitation events coexist in Shanxi Province [Figure 3: see original paper].

3.1.3 Periodic Analysis of Rainstorms The interannual variation of rainstorm days in Shanxi Province from 1957 to 2019 has multiple periodic variation characteristics, namely 4-year, 9-year, 14–15-year, and 27–28-year time scales [Figure 4: see original paper]. Among them, the 27–28-year time scale shows a quasi-27–28-year periodic oscillation of rainstorm abundance and scarcity alternation. The 14–15-year time scale shows a periodic variation of rainstorm abundance and scarcity alternation. The above four time scales show stable and global periodic variations. However, the 14–15-year time scale did not show significant periodic oscillation before 1990, but became more stable afterward. The 27–28-year periodic oscillation signal has continued throughout, while the 14–15-year periodic oscillation signal has been relatively stable after 1990 [Figure 5: see original paper].

3.2 Spatial Distribution Characteristics of Rainstorms

The spatial distribution of rainstorm days in Shanxi Province overall shows a decreasing trend from southeast to northwest [Figure 6: see original paper]. The areas with the most rainstorm days are Yuanqu County and Yangcheng County in southern Shanxi, with cumulative rainstorm days of 77.53 days and 71.5 days, respectively, followed by the Wutaishan area with high altitude, with cumulative rainstorm days of 65 days. In contrast, northern Shanxi areas such as Datong City, Tianzhen County, and Youyu County have fewer rainstorm days, with cumulative rainstorm days between 20–30 days. Central Shanxi areas have cumulative rainstorm days between these extremes. Rainstorm events occur mostly in areas south of Hengshan Mountain, with average rainstorm days basically above 40 days, more than in northern areas. As shown in [Figure 7: see original paper], the differences in annual average rainstorm amount among all regions are not large, with the provincial average being 67.48 mm. The area with the largest rainstorm amount is Yuanqu at 77.53 mm, and the smallest is Datong at 58.27 mm. The differences in rainstorm days among different regions are obvious, with Yuanqu having a maximum cumulative rainstorm days of 77.53 days, while Tianzhen has only 20.52 days. This reflects the uneven spatial distribution of precipitation in Shanxi Province. Generally, areas with large precipitation amounts also have high frequencies of extreme precipitation events, especially Yuanqu, Wutaishan, and Yangcheng, where the annual average rainstorm amount exceeds 65 mm and cumulative rainstorm days exceed 60 days. These areas have a high probability of suffering from rainstorm disasters.

3.3 Rainstorm Disaster Risk Assessment

3.3.1 Hazard Assessment of Disaster-causing Factors The hazard level of rainstorm disaster-causing factors in Shanxi Province [Figure 8: see original paper] is divided into low hazard, sub-low hazard, medium hazard, sub-high hazard, and high hazard areas. The hazard index of disaster-causing factors in southern Shanxi is overall higher than that in northern areas. High hazard areas include Yuanqu, Yangcheng, Anze, and the high-altitude Wutaishan area. Low hazard areas include Youyu, Datong, Tianzhen, and Lingqiu. Sub-low hazard areas mainly include Hequ, Wuzhai, Shuozhou, Taigu, and Yongji. Medium hazard areas include Taiyuan, Lishi, Jiexiu, Xingxian, Pingding, Yuanping, Xixian, and Changzhi. Sub-high hazard areas include Jixian, Linfen, Yuncheng, Houma, Yushe, and Xiangyuan.

3.3.2 Sensitivity Assessment of Gestational Environment The sensitivity level of the gestational environment for rainstorm disasters in Shanxi Province [Figure 9: see original paper] is divided into low sensitivity, sub-low sensitivity, medium sensitivity, sub-high sensitivity, and high sensitivity areas. High sensitivity areas are mainly distributed in Taiyuan, Taigu, Yushe, Pingding, Xiangyuan, and Yuncheng. Sub-high sensitivity areas are mainly distributed in Xingxian, Changzhi, and Houma. Medium sensitivity areas are mainly distributed in Datong, Hequ, Wuzhai, Lishi, Anze, Jixian, Yuanqu, and Yongji. Sub-low sensitivity areas are mainly distributed in Youyu, Yuanping, Lingqiu, Tianzhen, Jiexiu, Xixian, Linfen, and Yangcheng. Low sensitivity areas are mainly distributed in Wutaishan and Shuozhou.

3.3.3 Vulnerability Assessment of Disaster-bearing Bodies The vulnerability level of rainstorm disaster-bearing bodies in Shanxi Province [Figure 10: see original paper] is divided into low vulnerability, sub-low vulnerability, medium vulnerability, sub-high vulnerability, and high vulnerability areas. High vulnerability and sub-high vulnerability areas are mainly distributed in Datong, Changzhi, and Tianzhen. Medium vulnerability areas are mainly distributed in Houma, Yuncheng, Yongji, Linfen, Yuanqu, Yangcheng, and Xiangyuan. Sub-low vulnerability areas are mainly distributed in Jiexiu, Taiyuan, Taigu, Yushe, Anze, Pingding, Hequ, Shuozhou, Wutaishan, and Lingqiu. Low vulnerability areas are mainly distributed in Wuzhai, Yuanping, Xingxian, Lishi, Xixian, and Jixian. Areas with a cultivated land ratio above 0.4 all belong to low vulnerability or sub-low vulnerability areas. High vulnerability occurs in Datong, which has a large proportion of cultivated land and high population density, while sub-high vulnerability areas are Changzhi and Tianzhen.

3.3.4 Assessment of Disaster Prevention and Mitigation Capacity Disaster prevention and mitigation capacity refers to the ability of a disaster risk area to prevent disasters before they occur and to repair losses after they occur. The more mature the urban development, the stronger the disaster prevention and mitigation capacity. The disaster prevention and mitigation capacity level in Shanxi Province [Figure 11: see original paper] is divided into low capacity, sub-low capacity, medium capacity, sub-high capacity, and high capacity areas. High capacity areas include Taiyuan, Xiangyuan, Anze, and Hequ. Sub-high capacity areas include Changzhi, Yangcheng, Jiexiu, Youyu, and Shuozhou. Medium capacity areas include Houma. Sub-low capacity areas include Datong, Xingxian, Yuanping, Lishi, Pingding, Taigu, Linfen, Yongji, and Yuncheng. Low capacity areas include Tianzhen, Lingqiu, Wutaishan, Wuzhai, Yushe, Xixian, Jixian, and Yuanqu. The overall distribution characteristic shows a decreasing trend from the central region to the northeast and southwest, with urban areas generally higher than county areas.

3.3.5 Comprehensive Assessment of Rainstorm Disaster Risk Based on the comprehensive risk level classification of rainstorm disasters in Shanxi Province [Figure 12: see original paper], the spatial distribution generally shows a gradually decreasing trend from south to north. The high-risk area is the northeastern part of the Yuncheng Basin, while low-risk areas are located in the northeastern and northwestern parts of Shanxi Province, with most other areas belonging to medium-risk and sub-high-risk areas. According to statistics, 21 rainstorm events occurred in the Fenhe River Basin in southern Shanxi during 1957–2019, 15 events occurred in the Yellow River Basin, 8 events occurred in the Zhangshan River Basin, while only 3 events occurred in the Yongding River and Daqing River basins in the north. The characteristics of rainstorms in Shanxi Province show a pattern of more in the south and less in the north, and more in mountainous areas than in basins. Yuanqu County is a high-incidence area of rainstorm disasters, with 21 rainstorm disaster events during 1957–2019. The results show that Yuanqu County's disaster-causing factor hazard level, gestational environment sensitivity level, disaster-bearing body vulnerability level, and disaster prevention and mitigation capacity level belong to high hazard, medium sensitivity, medium vulnerability, and low capacity areas, respectively. After comprehensive superposition according to weights, they all belong to high-risk areas of rainstorm disaster risk index level. This is determined by the climate and topographic characteristics of Shanxi Province, where mountainous areas account for a large proportion, soil erosion is serious, and mountain floods are easily caused when rainstorms occur.

4 Discussion

Rainstorm activities are frequent in Shanxi Province, mainly concentrated in summer, with obvious interannual and intra-annual variation characteristics, which is consistent with the main characteristics of rainstorm activities in China. According to the variation patterns of annual cumulative rainstorm days and annual average rainstorm amount, it can be predicted that the next few years will be a stage of frequent rainstorm activities with a high probability of rainstorm disasters. The number of rainstorms in Shanxi Province shows an increasing trend with a shortened cycle, but there are still 14–15-year and 27–28-year oscillation cycles, and it is currently still in a period of high rainstorm incidence. This is consistent with the increase in frequency of extreme weather events under the background of global climate change. The spatial distribution of rainstorms in Shanxi Province generally shows a decreasing trend from southeast to northwest, mainly influenced by weather systems and topographic factors, among which the influence mechanism of weather systems needs further exploration. In rainstorm disaster risk assessment, the main influencing factors are rainfall amount, rainstorm days, etc. Shanxi Province has numerous mountains and basins, with low and flat terrain in the south and located on the windward slope, resulting in abundant and concentrated precipitation, while in the northern region, water vapor is weakened and difficult to reach due to the blocking effect of high mountains, resulting in less precipitation.

5 Conclusions

Through the analysis of the spatiotemporal distribution characteristics and disaster risk assessment of rainstorms in Shanxi Province from 1957 to 2019, the following conclusions are drawn:

1. From a temporal perspective, the seasonal variation of rainstorms in Shanxi Province is obvious, mainly concentrated in summer. The rainstorm amount from June to August accounts for 85.23% of the annual total, with July accounting for 45.18%. The annual average rainstorm amount does not vary much between years, but the interannual variation of cumulative rainstorm days is large, showing an increasing trend with shortened intervals.
2. From a spatial perspective, with Hengshan Mountain as the boundary, the probability of heavy rainfall and rainstorm amount in the area south of the boundary are higher than those in the northern region. Affected by geographical location and topography, the average rainstorm amounts in Yuanqu, Wutaishan, and Yangcheng all exceed 65 mm, with cumulative rainstorm days exceeding 60 days, making them high-incidence areas of rainstorm events. These three areas are more vulnerable to rainstorm disasters.
3. According to wavelet analysis, the interannual variation of rainstorm days in Shanxi Province has oscillation cycles at four time scales: 4 years, 9 years, 14–15 years, and 27–28 years.
4. The comprehensive risk level of rainstorm disasters in Shanxi Province shows a decreasing trend from south to north, with the central and southern parts belonging to high-risk areas of rainstorm disasters. Wutaishan, Yuanqu, Yangcheng, and Anze are high-hazard areas for disaster-causing factors; Taiyuan, Taigu, Yushe, Pingding, Xiangyuan, and Yuncheng are high-sensitivity areas for the gestational environment; Datong is a high-vulnerability area for disaster-bearing bodies; Hequ, Taiyuan, Anze, and Xiangyuan belong to high-capacity areas for disaster prevention and mitigation. In the comprehensive risk level assessment of rainstorm disasters, Yuanqu belongs to the high-risk area of rainstorm disasters, while Tianzhen, Lingqiu, Youyu, and Shuozhou are low-risk areas.

These conclusions not only reveal the spatiotemporal distribution characteristics and recurrence patterns of rainstorm events in Shanxi but also provide a scientific assessment and zoning of rainstorm disaster risks, which basically conforms to the actual situation. Based on this study, further exploration should be conducted to establish and improve rainstorm disaster monitoring, early warning, and emergency response mechanisms. In combination with the spatiotemporal patterns of rainstorms in Shanxi Province, relevant departments should focus on improving the accuracy of rainstorm disaster forecasting, rationally plan disaster prevention and mitigation according to regional natural and human geographical environments, and conduct post-disaster reconstruction and recovery work.

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