Climatic Characteristics of Rainstorms in the Eastern Foothills of Helan Mountain and Disaster Prevention Countermeasures: Postprint

Authors: Li Xiaohong

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Abstract

Using hourly precipitation data from 9 conventional stations and 287 automatic weather stations during the flood season (May–September) in the eastern foothills of Helan Mountain, and applying methods such as linear trend coefficient, Kriging interpolation, and Morlet wavelet transform, the spatiotemporal characteristics and oscillation periods of rainstorms in this region were analyzed. The results indicate: (1) The number of rainstorm days in the eastern foothills of Helan Mountain was highest in the 1960s, rainstorm intensity was strongest in the 1970s, and rainstorm contribution rate was greatest during 2011–2019. (2) The annual average number of rainstorm days during 1961–2019 was 2.1 d, with a rainstorm intensity of 46.6 $\text{mm} \cdot \text{d}^{-1}$. (3) During 1961–2019, the number of rainstorm days exhibited a decreasing trend of 2.1 $\text{d} \cdot (10\text{a})^{-1}$, rainstorm intensity showed little change, and the rainstorm contribution rate displayed a weak increasing trend of $1\% \cdot (10\text{a})^{-1}$. (4) Rainstorms occurred mainly in July and August, concentrated from mid-July to mid-August. (5) A total of 810 short-duration heavy precipitation events occurred at various stations in the eastern foothills of Helan Mountain during different time periods, mainly appearing at night from 21:00–22:00 and during the day at 16:00, with nighttime rainstorms accounting for 57.8%. (6) The number of rainstorm days exhibited periodic variations of 2–6 a and 7–15 a, with the primary period of variation being 3 a; rainstorm intensity showed periodic variations of 2–4 a and 5–16 a, with the primary period of variation being 9 a. (7) The areas with the most frequent occurrence, strongest intensity, and greatest magnitude of rainstorms were mainly distributed in the mountain-adjacent regions along the Yinchuan to Shizuishan section of Helan Mountain. (8) Flood disasters were characterized by high frequency, extensive coverage, obvious seasonality, regional concentration, strong destructiveness, and substantial losses.

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Full Text

Climate Characteristics of Rainstorms and Disaster Prevention Countermeasures along the Eastern Helan Mountain

LI Xiaohong[1,2,3], SU Zhansheng[1,2,4], NA Li[1,2,4], CHEN Yuying[1,2], CHEN Yanhu[3], WU Baoguo[4]

[1]Key Laboratory for Meteorological Disaster Monitoring and Early Warning and Risk Management of Characteristic Agriculture in Arid Regions, CMA, Yinchuan 750000, Ningxia, China

[2]Ningxia Key Lab of Meteorological Disaster Prevention and Reduction, Yinchuan 750000, Ningxia, China

[3]Shizuishan Meteorological Observatory of Ningxia, Shizuishan 753000, Ningxia, China

[4]Ningxia Meteorological Service Center, Yinchuan 750000, Ningxia, China

Abstract

Using hourly precipitation data from nine conventional meteorological stations and 287 automatic weather stations during the flood season (May–September) along the eastern Helan Mountain, this study analyzes the spatiotemporal characteristics and oscillation periods of rainstorms through linear trend coefficient, Kriging interpolation, and Morlet wavelet transform. The results indicate: (1) The 1960s recorded the highest number of rainstorm days, the 1970s exhibited the strongest rainstorm intensity, and the period 2011–2019 showed the maximum rainstorm contribution rate. (2) The average annual rainstorm days along the eastern Helan Mountain from 1961 to 2019 was 2.1 d, with a rainstorm intensity of 46.6 $\mathrm{mm \cdot d^{-1}}$. (3) Rainstorm days displayed a decreasing trend of 2.1 $\mathrm{d \cdot (10a)^{-1}}$, while rainstorm intensity remained relatively stable with minimal change; the rainstorm contribution rate exhibited a weak upward trend of $1\% \cdot \mathrm{(10a)^{-1}}$. (4) Rainstorms primarily occurred in July and August, concentrated from mid-July to mid-August. (5) A total of 810 short-duration heavy precipitation events were recorded across stations, predominantly occurring at night (57.8%), with the peak frequency at 21:00–22:00. (6) Rainstorm days showed periodic variations of 2–6 a and 7–15 a, with the first dominant period at 3 a; rainstorm intensity displayed periodic variations of 2–4 a and 5–16 a, with the first dominant period at 9 a. (7) The region with the most frequent, strongest, and heaviest rainstorms was mainly distributed along the mountainous area from Yinchuan to Shizuishan. (8) Flood disasters were characterized by high frequency, extensive coverage, obvious seasonality, regional concentration, strong destructiveness, and substantial losses.

Keywords: rainstorm; climate characteristics; spatiotemporal characteristics; disaster prevention; eastern Helan Mountain

1 Research Area Overview

The study area is located along the eastern Helan Mountain (Fig. [Figure 1: see original paper]), situated between the Yellow River alluvial plain and the Helan Mountain alluvial fan, bordered by the Helan Mountains to the west and the Yellow River to the east. This region encompasses the western parts of Shizuishan, Yinchuan, and Wuzhong cities. Historically known as the "Jiangnan beyond the Great Wall," the eastern Helan Mountain is recognized globally as a prime zone for wine grape cultivation and wine production. By [year], the wine grape planting area reached 3.8$×10^{4}$ hm^2, with annual wine production of 1.2$×10^{8}$ bottles and output value exceeding 2$×10^{8}$ yuan, representing the largest concentrated wine grape cultivation area in China. The region features arid climate with low precipitation, high evaporation, abundant sunshine, and high accumulated temperature, providing favorable natural conditions for grape cultivation. The Helan Mountains serve as a natural barrier against cold currents in the west, while the Yellow River provides climate regulation to the east. All climatic indicators including temperature, humidity, and hydrothermal coefficient fall within the suitable range for grape cultivation.

2 Data and Methods

2.1 Data Sources

The dataset comprises: (1) Hourly precipitation observations from nine conventional meteorological stations (Qingtongxia, Yongning, Yinchuan, Helan, Dawukou, Shitanjing, Pingluo, Huinong, and Helan Mountain) and 287 automatic weather stations along the eastern Helan Mountain during the flood season (May–September) from 1961 to 2019, obtained from the Ningxia Integrated Meteorological Database with quality control applied; (2) Meteorological disaster data from the China Meteorological Disaster Yearbook (2001–2019).

2.2 Statistical Definitions

The following definitions were adopted: (1) **Rainstorm**: According to China Meteorological Administration standards, precipitation reaching $ $30 mm per hour or $ $50 mm per day; (2) **Rainstorm days**: The number of days with rainstorm occurrence during the statistical period, calculated as the average across all stations; (3) **Rainstorm precipitation**: The cumulative precipitation from rainstorm events, reflecting the magnitude; (4) **Rainstorm intensity**: The ratio of rainstorm precipitation to rainstorm days, indicating the strength; (5) **Rainstorm contribution rate**: The percentage of rainstorm precipitation relative to total precipitation, reflecting its proportion; (6) **Short-duration heavy precipitation**: Hourly precipitation $ $20 mm.

2.3 Wavelet Analysis

Wavelet analysis, particularly the Morlet wavelet transform, provides multi-resolution analysis capabilities for time series studies. This method clearly reveals hidden periodicities, reflects system trends across different temporal scales, and qualitatively estimates future development. The fundamental principle involves representing a signal using a series of wavelet functions. A wavelet function (t) is an oscillatory function that rapidly decays to zero, satisfying (t)dt = 0. Through translation and scaling, a series of sub-wavelets , (t) = $|a|^{-1\ 2}$ ((t−b)/a) is formed, where a is the scale factor representing wavelet period length and b is the translation factor representing temporal shift. For a finite signal f(t) L^2( ), the continuous wavelet transform is W_f(a,b) = $|a|^{-1\ 2}$ f(t) *((t−b)/a)dt, where* denotes the complex conjugate. In practical applications, discrete wavelet transform is used: W_f(a,b) = $|a|^{-1\ 2}$ f(kΔt) *((kΔt−b)/a). Wavelet variance, obtained by integrating the squared wavelet coefficients over the* b* domain, reflects energy distribution across scales and identifies dominant periods.

3 Results

3.1 Temporal Characteristics of Rainstorms

3.1.1 Interdecadal Variation Interdecadal analysis reveals that rainstorm days peaked in the 1960s at 2.6 $d \cdot a^{-1}$, followed by the 1970s (2.3 $d \cdot a^{-1}$) and 1980s (2.2 $d \cdot a^{-1}$). Rainstorm intensity was strongest in the 1970s at 50.2 $mm \cdot d^{-1}$, followed by the 1960s. The rainstorm contribution rate reached its maximum during 2011-2019 at 34.8%, indicating that although rainstorm frequency was not highest in recent decades, both intensity and contribution rate increased significantly (Table).

3.1.2 Interannual Variation From 1961 to 2019, the average annual rainstorm days was 2.1 d, exhibiting a decreasing trend of 2.1 $d \cdot (10a)^{-1}$ (Fig. [Figure 2: see original paper]). The average rainstorm intensity was 46.6 $mm \cdot d^{-1}$, with minimal change over time (0.3 $mm \cdot d^{-1}$). The average rainstorm contribution rate was 32.6%, showing a weak upward trend. These trends suggest that while rainstorm frequency declined, the proportion of rainstorm precipitation in total precipitation increased.

3.1.3 Monthly Variation Rainstorms occurred between May and September, with the earliest on May 26 (2018, Helan Mountain station) and the latest on September 23 (1976, Pingluo station). July and August accounted for 76.8% of annual rainstorm days, with average rainstorm days of 1.6 $d \cdot a^{-1}$. July exhibited the highest intensity at 54.3 $mm \cdot d^{-1}$, followed by August at 53.5 $mm \cdot d^{-1}$ (Table).

3.1.4 Ten-day Variation Rainstorms concentrated in mid-to-late July, with early and mid-July accounting for 59.2% of monthly rainstorm days. Early July showed the strongest intensity at 57.8 $\mathrm{mm \cdot d^{-1}}$ (Fig. [Figure 3: see original paper]).

3.1.5 Diurnal Variation Analysis of hourly data from 287 automatic stations identified 810 short-duration heavy precipitation events, predominantly occurring at night (57.8%). The peak frequency occurred at 21:00–22:00 (16.4% of total events), followed by 16:00 (14.2%). The lowest frequency occurred at 09:00–10:00 (1.8%). Nocturnal rainstorms likely relate to favorable convective development conditions in the evening (Fig. [Figure 4: see original paper]).

3.2 Spatial Distribution Characteristics

Using ArcGIS-based Kriging interpolation of rainstorm days, precipitation, intensity, and contribution rate from all stations, the spatial distribution pattern was obtained. All parameters decreased sharply from northwest to southeast, showing marked spatial differentiation. The area with the most frequent, strongest, and heaviest rainstorms was primarily distributed along the mountainous region from Yinchuan to Shizuishan. Heavy rainstorms occurred exclusively in this area, with the storm center along the Helan Mountain foothills. The maximum cumulative precipitation was recorded at Helan Mountain Ski Resort (239.5 mm and 297.4 mm in two events), causing direct economic losses of 2.9$×10^{8}$ yuan. High-intensity areas also included southeastern Qingtongxia and western Huinong, while high contribution rate areas included Qingtongxia city, northwestern Yongning, Yinchuan urban area, and southeastern Pingluo (Fig. [Figure 5: see original paper]).

3.3 Periodic Variation Characteristics

Wavelet analysis of 1961–2019 rainstorm days revealed two periodic scales: a stable 7–15 a oscillation showing multiple strong-weak alternations with global characteristics, and a less stable 2–6 a oscillation. The wavelet variance diagram showed three significant peaks corresponding to 2–6 a, 7–15 a, and 18–22 a scales, with the maximum peak at 8–15 a, indicating the first dominant period of approximately 3 years (Fig. [Figure 6: see original paper]).

Rainstorm intensity showed periodic variations at 2–4 a and 5–16 a scales. The 5–16 a oscillation remained stable throughout, while the 2–4 a scale became stable after 1995. The variance diagram exhibited two peaks at 2–4 a and 5–16 a, with the maximum at 2–4 a, identifying this as the first dominant period for intensity changes (Fig. [Figure 6: see original paper]).

3.4 Flood Disaster Characteristics and Prevention Countermeasures

3.4.1 Flood Disaster Characteristics Analysis of 2001–2019 meteorological disaster data revealed three main characteristics: (1) **High frequency**

and extensive coverage: 43 flood events occurred, affecting 3–5 counties in 16 cases and >5 counties in 5 cases (Table). (2) **Obvious seasonality and regional concentration**: 74.4% of events occurred in summer, particularly July–August, concentrated in the mountainous areas of Dawukou, Pingluo, Qingtongxia, and Helan counties. The terrain creates a "pipeline effect," rapidly forming flood peaks during rainstorms. These areas are also prone to geological disasters like debris flows and collapses, triggered by heavy rain. (3) **Strong destructiveness and substantial losses**: Floods feature short confluence time, violent onset, and rapid rise/fall. The August 21, 2016 extreme rainstorm (50–200 year return period) caused traffic disruption, affected 1.7×10^{4} people, inundated 9,802 hm^2 of crops, and inflicted 1.8×10^{8} yuan in direct losses.

3.4.2 Rainstorm Flood Disaster Prevention Countermeasures Given the marked spatial differences in rainstorm parameters and the concentration of high-risk areas along the Yinchuan–Shizuishan mountainous region—also a hub for wine industries and tourism—enhanced disaster prevention is critical. (1) **Strengthen disaster-bearing capacity**: Systematically plan and construct flood prevention engineering based on local conditions. Industrial and tourism development should consider spatial rainstorm patterns to avoid high-risk zones and reduce disaster costs. (2) **Improve forecast accuracy and timeliness**: Deepen understanding of rainstorm mechanisms, refine forecasting systems, and utilize advanced remote sensing technologies (satellite, radar) to enhance prediction accuracy, focusing on high-incidence periods. (3) **Enhance emergency response**: Strengthen disaster preparedness for key industries, vineyards, tourist sites, and communities through publicity and education to raise public awareness and reduce losses. (4) **Promote ecological protection**: Implement flood storage projects to rationally utilize rainstorm water resources for ecological restoration while mitigating flash floods.

4 Conclusions

This study analyzed spatiotemporal variation characteristics of rainstorms and flood disaster features along the eastern Helan Mountain, yielding five key conclusions: (1) Rainstorm days peaked in the 1960s ($2.6\ d \cdot a^{-1}$), with an average of 2.1 d from 1961–2019, showing a decreasing trend of $2.1\ d \cdot (10a)^{-1}$. (2) Rainstorm intensity was strongest in the 1970s ($50.2\ mm \cdot d^{-1}$), with an average of $46.6\ mm \cdot d^{-1}$, remaining stable with minimal change; the contribution rate showed a weak upward trend, reaching 34.8% during 2011–2019. (3) Rainstorms concentrated in July–August, particularly mid-July to mid-August, with 810 short-duration heavy precipitation events occurring mainly at night (57.8%), peaking at 21:00–22:00. (4) Spatially, the Yinchuan–Shizuishan mountainous region experienced the most frequent, intense, and heavy rainstorms. (5) Periodic analysis revealed two scales for rainstorm days (2–6 a and 7–15 a, first dominant period 3 a) and intensity (2–4 a and 5–16 a, first dominant period 9 a). (6) Flood disasters exhibited high frequency, wide coverage, seasonal patterns, regional concentration, strong destructiveness, and substantial losses, primarily in summer months.

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