Flood Characteristics Analysis in the Xiying River Basin Based on GEV Distribution (Postprint)

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Abstract

Based on the annual flood hydrological element extraction tables from the Jiutiaoling Hydrological Station of the Xiying River for the period 1972–2019, three sample sequences were derived using the annual maximum sampling method: annual maximum daily discharge, spring maximum daily discharge, and summer maximum daily discharge. The Mann-Kendall (M-K) test was applied to analyze their temporal trends, and the Generalized Extreme Value (GEV) distribution was employed to fit the three sequences. The Kolmogorov-Smirnov (K-S) test and Probability Plot Correlation Coefficient (PPCC) test were used to evaluate the goodness-of-fit between the theoretical distribution and observed sequences. The results demonstrate that the GEV distribution provides a satisfactory fit to the maximum daily discharge sequences at the Jiutiaoling Hydrological Station. According to theoretical return period analysis, the frequency of spring flooding in the basin is decreasing, while the frequency of summer flooding has exhibited a decreasing-then-increasing trend since the 1980s. Mountainous runoff is significantly influenced by climate change, with a prevalent warming and drying phenomenon. The high frequency of abrupt temperature rises in spring advances the occurrence timing of spring floods, and the reduced proportion of snow and ice meltwater contribution leads to a decline in spring flood frequency in the Xiying River basin. Summer flood season precipitation largely determines the magnitude of floods within the basin, and the interannual variation trend of total annual precipitation in the basin is consistent with that of flood event frequency, both showing a fluctuating pattern of first increasing, then decreasing, and then increasing again.

Full Text

Analysis of Flood Characteristics in the Xiying River Basin Based on GEV Distribution

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Abstract

Based on the annual flood hydrological elements extract table from Jiutiaoling Hydrological Station in the Xiying River, this study employed the annual maximum sampling method to obtain three sample series: annual maximum daily discharge, spring maximum daily discharge, and summer maximum daily discharge. The basic statistical moments were calculated for each series, and trend analysis was conducted using the linear trend method. The Mann-Kendall test was applied to analyze trend significance, the Generalized Extreme Value (GEV) distribution was used for fitting analysis, and both the Kolmogorov-Smirnov test and Probability Plot Correlation Coefficient (PPCC) test were employed to evaluate the goodness-of-fit between theoretical and observed distributions. The results demonstrate that the GEV distribution provides an excellent fit to the maximum daily discharge series at Jiutiaoling Hydrological Station. According to theoretical return period analysis, the frequency of spring floods in the basin has decreased, while the frequency of summer floods has shown a pattern of initial decrease followed by increase since the 1980s. Runoff in mountainous areas is significantly affected by climate change, with a widespread phenomenon of warming-induced drying. The high frequency of abrupt spring temperature rises has advanced the timing of spring floods, while the reduced proportion of snow and ice meltwater supply has decreased the frequency of spring floods in the Xiying River Basin. Summer flood season precipitation largely determines flood magnitude, and the interannual variation trend of total annual precipitation aligns with the variation trend of flood event frequency, both showing a fluctuating pattern of increase-decrease-increase.

Keywords: generalized extreme value distribution; flood frequency; temperature surge; climate change; Xiying River Basin; Northwest China

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1 Study Area Overview

The Xiying River originates from the Lenglongling Mountains in the Qilian Mountains (Fig. [Figure 1: see original paper]) and constitutes the largest tributary of the Shiyang River Basin within Gansu Province, located between the

Dongda and Zamu rivers. Its upper reaches are formed by the confluence of the Ningchang and Shuiguan rivers, while its lower reaches receive inflow from two smaller tributaries, the Xiangshui and Ta rivers. The Xiying River Basin lies between 101°41 ~102°23 E and 37°30 ~38°00 N, covering an area of approximately 1727.5 km^2. The region features a high-altitude, cold, semi-arid climate with a temperate continental climate pattern. The mountainous area of the Xiying River Basin experiences intense solar radiation and abundant sunshine, but with large diurnal temperature variations. The multi-year average precipitation in the upper mountainous area is 542.94 mm, with evaporation ranging between 700–1200 mm. Glaciers are distributed in the upper reaches, with a mean annual temperature of -0.383°C. Runoff is primarily supplied by mountain precipitation and is concentrated in summer, with an average annual runoff of 3.88$×10^{3}$ m^3. The basin exhibits low precipitation, strong evaporation, and uneven annual runoff distribution. Influenced by snow-ice meltwater and mountain precipitation, the hydrological regime is characterized by snowmelt-induced spring floods and rainfall-induced summer floods. The Jiutiaoling Hydrological Station in Gansu, established in 1957, is a national basic hydrological station. The measurement section is located at the Jiutiaoling Coal Mine in Huajian Township, Sunan Yugur Autonomous County, Gansu Province, representing the control section at the mountain outlet of the Xiying River, with measured hydrological data covering the entire Xiying River Basin.

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2 Data and Methods

2.1 Data Sources

This study utilized the annual flood hydrological elements extract table from Jiutiaoling Hydrological Station to derive three sample series: annual maximum daily discharge, spring maximum daily discharge, and summer maximum daily discharge. Based on the runoff differential accumulation curve of Jiutiaoling Station, the data series includes at least three wet periods and three dry periods, satisfying the requirements of consistency, reliability, and representativeness. Precipitation data were obtained from the China Meteorological Administration' s daily precipitation grid dataset (0.5°$×0.5°), *andtemperaturedatafromthedailytemperaturegriddataset*(0.5°×$0.5°).

2.2.1 Flood Sequence Trend Analysis

Basic statistical moments (mean, standard deviation, coefficient of variation, and kurtosis coefficient) were calculated for the annual, spring, and summer maximum daily discharge series. Linear trend analysis was applied to examine trends in the three sample series, with the Mann-Kendall test used for significance testing at the 95% confidence level to determine whether observed trends were statistically significant.

2.2.2 Generalized Extreme Value Model and Parameter Estimation

Extreme value distributions describe the probability distribution of maximum or minimum observations. Based on extreme value theory, Coles and Jenkinson merged three types of extreme value distributions into a single distribution: the Generalized Extreme Value (GEV) distribution. The GEV distribution function is:

$$F(x) = \exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}$$

where μ is the location parameter, σ is the scale parameter, and ξ is the shape parameter. When $\xi < 0$, it corresponds to the Weibull distribution; when $\xi = 0$, the Gumbel distribution; and when $\xi > 0$, the Fréchet distribution. This study employed the maximum likelihood estimation method for parameter estimation. The likelihood function for the GEV distribution is:

$$L(\mu,\sigma,\xi) = \prod_{i=1}^{n} \frac{1}{\sigma}\left[1+\xi\left(\frac{x_i-\mu}{\sigma}\right)\right]^{-1/\xi-1} \exp\left\{-\left[1+\xi\left(\frac{x_i-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}$$

After obtaining the three parameters through maximum likelihood estimation, the Kolmogorov-Smirnov test was applied for goodness-of-fit testing, and the PPCC test was used to assess the similarity between empirical and theoretical distribution curves.

2.2.3 Calculation of Theoretical Return Period

In flood analysis, calculating the T-year flood event X_p is essential. The calculation formula is:

$$X_T = \mu + \frac{\sigma}{\xi}\left[1-(-\ln(1-1/T))^{-\xi}\right]$$

By substituting the maximum likelihood estimated parameters into this formula, the flood magnitudes corresponding to different theoretical return periods can be obtained.

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3 Results

3.1 Characteristics of Flood Sequence Trends

The GEV distribution was fitted to the three discharge series using maximum likelihood parameter estimation. Goodness-of-fit testing revealed that the annual and spring maximum daily discharge series follow the Weibull distribution, while the summer maximum daily discharge series follows the Fréchet distribution. The parameter estimates and test statistics are presented in Table . The results indicate that from 1972 to 2019, the annual, spring, and summer maximum daily discharge series in the Xiying River Basin all exhibited decreasing trends (Fig. [Figure 2: see original paper]), with summer flood discharges generally larger than spring flood discharges. This demonstrates that summer rainfall floods dominate the basin' s flood regime, and that climate warming has advanced the timing of spring floods.

The coefficients of variation (CV) for the annual, spring, and summer maximum daily discharge series were 0.35, 0.42, and 0.38, respectively, indicating relatively small variation in the annual series but greater variation in the spring flood series, which is more strongly influenced by temperature factors. Mann-Kendall trend testing yielded Z-values for all three flood series that were less than the critical value of 1.96 at the 95% significance level, indicating no statistically significant trends and supporting the assumption of stationarity for subsequent flood characteristic analysis.

The Kolmogorov-Smirnov test statistics for all three series were below the critical value, indicating good fit quality. The calculated correlation coefficients exceeded 0.95, demonstrating that the maximum daily discharge series from Jiutiaoling Hydrological Station are highly correlated with the GEV distribution, providing excellent reliability and representativeness for flood characteristic analysis in the Xiying River Basin.

3.3 Calculation of Theoretical Return Periods

By substituting the GEV distribution parameters into the return period formula, theoretical flood return periods were calculated for the Xiying River Basin. Considering the flood characteristics of the Xiying River, return periods of 5, 10, 20, 50, and 100 years were computed for annual, spring, and summer maximum daily discharges. The frequency of flood events in different decades was then determined (Table). The results show that 100-year floods primarily occurred during the 1980s, mostly as spring floods. The frequency of flood events experienced a pattern of increase-decrease-increase across decades. Spring flood frequency decreased significantly, while summer flood frequency showed a pattern of initial decrease followed by increase.

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4 Discussion

4.1 Flood Sequence Response to Temperature Changes

The mean annual temperature in the Xiying River Basin increased significantly from 1972 to 2019, exceeding 0°C for the first time in 2013. Seasonal mean temperatures all showed increasing trends, with winter warming most pronounced at a rate of $0.43°C \cdot (10a)^{-1}$, significantly higher than the national average warming rate of $0.044°C \cdot (10a)^{-1}$. The temperature trend in the Xiying River Basin is consistent with significant winter warming in Northwest China and correlates with global temperature changes.

The study also analyzed the timing of annual maximum daily temperature increases in the basin (Fig. [Figure 3: see original paper]). Temperature surges, defined as daily mean temperature increases exceeding 15.7°C within 5 days, occurred exclusively in spring and coincided temporally with the occurrence of maximum annual floods. The spring flood series showed significant positive correlation with temperature surges ($r = 0.463$, $P < 0.05$), indicating that spring floods are primarily snowmelt-driven, which explains the advancing trend in spring flood timing.

As temperatures rise, evaporation intensity increases throughout the basin. Precipitation shows a weak increasing trend but cannot compensate for increased water loss due to warming, creating a warming-induced drying phenomenon and leading to continuous runoff reduction. Significant winter warming hinders snow accumulation, corresponding to observed reductions in winter snow cover, rising snow lines, and disappearance of small glaciers in the upper Qilian Mountains of the Shiyang River Basin. Consequently, the proportion of spring runoff supplied by snowmelt is decreasing, explaining the reduced frequency of spring snowmelt floods.

4.2 Flood Sequence Response to Precipitation Changes

Floods in the Xiying River Basin are predominantly summer storm floods. Global warming increases atmospheric moisture content, leading to more frequent heavy rainfall events. Total annual precipitation in the basin showed a weak increasing trend from 1972 to 2019, but interdecadal variation exhibited a fluctuating pattern of increase-decrease-increase, consistent with the variation trend of flood event frequency (Fig. [Figure 4: see original paper]). However, the trend rate ($14.6 \text{ mm} \cdot (10a)^{-1}$, $P = 0.5954 > 0.05$) did not pass significance testing, indicating an insignificant increasing trend.

Summer precipitation, characterized by short duration and high intensity, is critical for flood generation. Analysis of maximum daily precipitation and maximum 5-day precipitation in summer revealed that flood occurrence timing is highly correlated with the timing of maximum daily or 5-day precipitation events. Maximum daily precipitation in summer showed an insignificant increasing trend ($P = 0.0623$), reaching a peak of 78 mm in 1979, after which it fluctuated and declined, consistent with the decreasing trend in annual maximum runoff and the pattern of initial decrease followed by increase in summer flood frequency. Winter precipitation is minimal (annual average of only 23.45 mm) compared to summer (annual average of 319.55 mm), and insufficient winter precipitation reduces snow cover, representing another primary cause of runoff reduction. The correlation between runoff and maximum daily precipitation is significant (r = 0.463, P < 0.05), demonstrating that summer flood season precipitation largely determines flood magnitude in the basin.

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5 Conclusions

Through fitting analysis of maximum daily discharge series in the Xiying River Basin and examination of causes for changing flood characteristics under climate change, the following conclusions are drawn:

1) Since 1972, the annual, spring, and summer maximum daily discharge series in the Xiying River Basin have shown continuous decreasing trends. The annual and spring maximum daily discharge series follow the Weibull distribution, while the summer maximum daily discharge series follows the Fréchet distribution. All three series are highly correlated with the GEV distribution, demonstrating that the GEV distribution provides a reliable and representative tool for flood characteristic analysis in the Xiying River Basin. Spring flood frequency has decreased significantly, while summer flood frequency has exhibited a pattern of initial decrease followed by increase.

2) Runoff in the Xiying River Basin mountainous area is significantly affected by climate change, with precipitation playing a key role in flood generation. Significant temperature increases have intensified evaporation, and precipitation increases cannot compensate for water loss caused by warming, resulting in a widespread warming-induced drying phenomenon. The high frequency of spring temperature surges has advanced the timing of spring snowmelt floods, while significant winter warming and low precipitation have reduced both the proportion of ice-snow meltwater supply and the frequency of spring floods.

3) With continued warming, precipitation in mountainous areas will increase somewhat, and summer flood frequency will correspondingly increase in the future. However, precipitation increases cannot meet the water supply needs for runoff and mountain snow cover, and basin water storage continues to decline, with runoff showing a slow decreasing trend. Mountain storm floods are extremely intense and can trigger debris flows and other natural disasters, while spring glacier and snowmelt will continue. Therefore, the basin must strengthen summer flood prevention and management, prepare for earlier spring snowmelt floods, and implement rational reservoir operation to ensure downstream flood safety.

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