

Changing properties and causes of the annual maximum flood in the Jialu River Basin

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Abstract: Based on the daily precipitation data from 1969 to 2015 and the flood summary data of the hydrological station in the Jialu River Basin, the annual maximum flood (AMAXF) and extreme precipitation were used to analyze the changing properties and causes of the annual maximum flood. Mann-Kendall test were used to analyze the change characteristics and the correlations between AMAXF and extreme precipitation were analyzed with cross wavelet analysis method. The changes in the NDVI were also analyzed to investigate the reasons for the changes of AMAXF. The results showed that AMAXF series had a significant decreasing trend with an abrupt change point around 1998, and there was no significant change in extreme precipitation. Cross Wavelet Analysis showed the AMAXF had statistically correlations with extreme precipitation in the Jialu River Basin. The decreasing trend in the AMAXF were mainly caused by LUCC.

1. Introduction

Under the background of global warming, the meteorological and hydrological factors have changed a lot, such as temperature, precipitation and runoff. Precipitation is the main component of water cycle, and the global temperature rise will affect the whole process of water circulation, resulting in changes in the distribution of rainfall, the surface runoff, the frequency of flood and waterlogging. The Jialu River basin is a typical basin of the Hekouzhen-Longmen section^[1]. The Hekouzhen-Longmen section is a loess hilly area with numerous tributaries, and serious soil erosion. The regional rainstorm often occurs with strong intensity and short duration. Therefore, it often forms a high sediment laden flood with large flood peak and small flood volume. Di et al.^[2] has concluded that the peak flow is closely related to the rainfall and the rainfall intensity through the analysis of the historical flood and several floods in 2012 in Fugu-Wubao Region. Ran et al.^[3] pointed out that the flood reduction of vegetation measures was significant in the Jialu River Basin and the terrace has the capability to resisting heavy rain floods. Studies on changes in floods show that the changes in extreme precipitation and land use/cover changes (LUCC) are the two main contributors to the changes in floods^[2-5]. In this study, we investigate the impacts of these two factors on the changes in the AMAXF in the Jialu River Basin, which has positive significance for flood characteristics study and flood regulation in the Jialu River Basin.



2. Study Area

The Jialu River is a primary tributary of the middle Yellow River, locates between 109°59'10"E-110°30'00"E and 37°59'18"N-38°28'25"N, with a drainage area of about 1134 km² (Figure 1). The mainly topography of the basin is loess hilly area, and there are some rocky mountainous areas in the estuary area, with bare bedrock, and deep valley. The annual average temperature of the basin is 10°C. The average annual rainfall is 395mm.

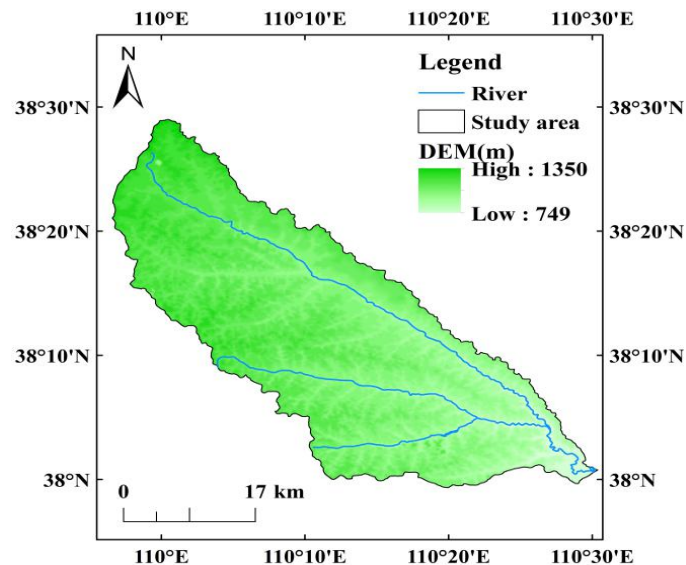


Figure 1. Location of the Jialu River Basin. The black lines represent the boundary of the study area, and the blue lines denote the river.

3. Data and Methods

3.1. Data

The daily precipitation data in 6 precipitation stations and the runoff data at Shenjiawan Station from 1969 to 2015 in the Jialu River basin used in this paper were from the hydrological yearbook. The average precipitation in the entire study area was interpolated by the Thiessen polygon method. The annual NDVI values used in the study are all annual maximum, and the data source is the third generation GIMMS NDVI dataset (NDVI3g, v1.0).

3.2. Methods

3.2.1. Mann-Kendall test. Non-parametric Mann-Kendall (MK) test is a simple and robust trend detection method. This is a rank nonparametric test developed by Mann and Kendall [6-7], and it is superior for detecting linear or non-linear trends [8-9]. The statistic Z can be used as a measure of a trend. $Z > 0$ and $Z < 0$ indicate an increasing and decreasing trend, respectively. $Z > 1.96$ and $Z < -1.96$ indicate a significant increasing and decreasing trend at 5% significant level, respectively.

3.2.2. Cross Wavelet Analysis Method. Wavelet transforms have become a useful tool for investigating local variation in time series [10] and have been widely used in hydrological and climatic time series analysis [11]. The details of cross wavelet analysis are given below. For the two time series X and Y, we can define the cross wavelet spectrum as: $W_n^{XY}(s) = W_n^X(s)W_n^{Y*}(s)$, where $W_n^X(s)$ and $W_n^Y(s)$ denote the wavelet transforms and $W_n^{Y*}(s)$ is the complex conjugate of $W_n^Y(s)$. The cross wavelet power is further

defined as $|W_n^{xy}(s)|$. The theoretical distribution of the cross wavelet power of the P_k^x and P_k^y time series with background power spectra is given in Torrence and Compo (1998) as: $D(\frac{|W_n^x(s)W_n^y(s)|}{\sigma_x\sigma_y} < p) = \frac{Z_v(p)}{v} \sqrt{P_k^x P_k^y}$ where $Z_v(p)$ is the confidence level associated with the probability p for a probability density function defined by the square root of the product of two χ^2 distributions. In this study, $Z_v(95\%) = 3.999$ is used to calculate the 5% significance level.

4. Results and Discussions

4.1. Trend analysis and abrupt change detection

Figure 2 exhibited the changes in the observed AMAXF in the Jialu River Basin. The AMAXF in the Jialu River Basin over the past 47 years exhibited a significant decreasing trend at the 5% significant level. The maximum AMAXF occurred in 1970, with a value of 5770 m³/s. The minimum AMAXF occurred in 2011, with a value of 18.6 m³/s. Abrupt change detection made by the Mann-Kendall test indicated that the change point for AMAXF was around 1998.

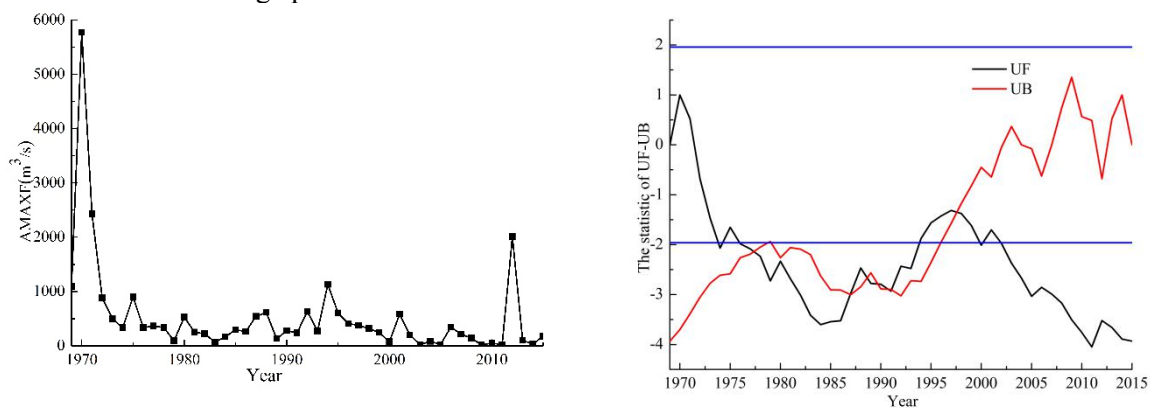


Figure 2. Changes in AMAXF and the Mann-Kendall test for AMAXF in the Jialu River Basin.

4.2. Reasons for the decrease in the AMAXF

4.2.1. Impacts of changes in extreme precipitation on AMAXF. The floods in the Jialu River Basin are almost caused by one day or several consecutive days of heavy rainfall [12]. So we chose the annual maximum 1-day precipitation (P1day) and annual maximum 3-day precipitation (P3day) as the two indices of extreme precipitation to analyze the impacts of changes in extreme precipitation on floods. The results showed that both of the P1day and P3day in the Jialu River Basin increased insignificantly at the 5% significant level during 1969–2015, and there was no abrupt change point detected in the two extreme precipitation series.

Cross Wavelet analysis was used to analyze the connections between the AMAXF and extreme precipitation indices in the Jialu River Basin (Figure 3). Figure 3a illustrated that the AMAXF had a statistically significant negative correlation with the P1day variation with a 0–1-year signal at the 95% confidence level from 1990 to 1995. In addition, the AMAXF had a statistically significant positive correlation with the P1day with a 6–8-year signal from 1969 to 1977 and a 3–8-year signal in 2005–2015 at the 95% confidence level. Figure 3b demonstrated that AMAXF had a statistically significant negative correlation with P3day variation at the 95% confidence level, with a 2–3-year signal from 1995 to 1997. In addition, AMAXF had a statistically significant positive correlation with P3day with an 8-year signal from 1975 to 1980 and a 3–7-year signal in 2005–2015 at the 95% confidence level. This shows that the AMAXF is closely related to the extreme precipitation in the Jialu River Basin.

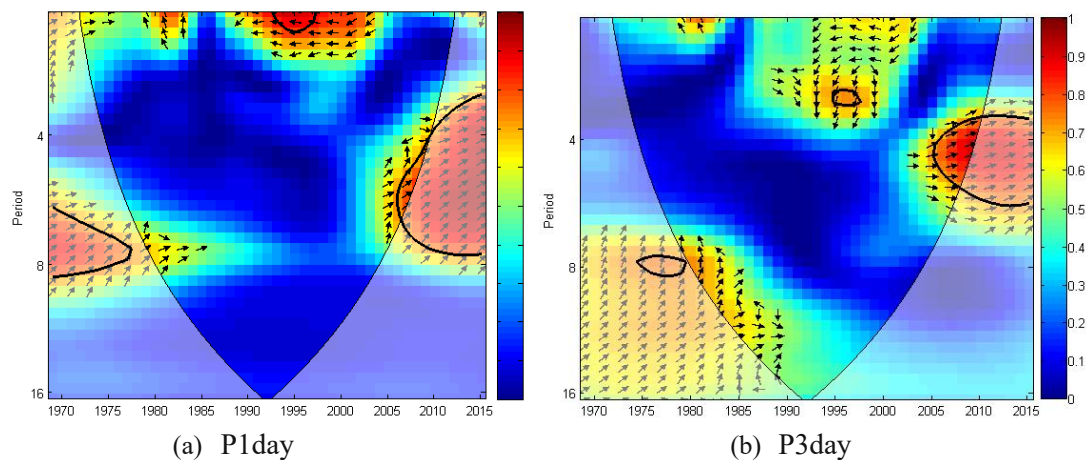


Figure 3. The cross wavelet transforms between (a) the AMAXF and P1day and (b) the AMAXF P3day in the Jialu River Basin. The thick black contour denotes the relations which are significant against the red noise at the 95% confidence level. The arrow direction the relative phase relationship (with anti-phase pointing left, in-phase pointing right). The color bar on the right represent the wavelet energy.

Although the results of the cross wavelet transforms indicated that extreme precipitation had a strong association with changes in AMAXF, as comparing the changing trends of AMAXF and extreme precipitation series over the same period, the changes in the AMAXF and extreme precipitation were inconsistent, which indicated that the decreasing trend in the AMAXF were mainly caused by LUCC rather than the extreme precipitation in the Jialu River Basin.

4.2.2. Impacts of LUCC on AMAXF. Since the implementation of the national ecological recovery program, the “Grain for GREEN Project” (GGP) in 1999, the vegetation coverage in the Loess Plateau has been greatly increased. As shown in Figure 4, the NDVI of the Jialu River Basin has increased from 0.30 in 1982 to 0.46 in 2015. The vegetation has been in the process of continuous improvement, but the improvement rate before 2005 was not significant, and the improvement after 2006 was greater. The recovery of vegetation can effectively reduce the runoff generation by intercepting more precipitation, increasing infiltration and delaying surface runoff. In 2014, the terrace area was 76.6 km² and there were 406 check dams in the Jialu River Basin [13]. All of these soil conservation practices were responsible for the peak flow reduction.

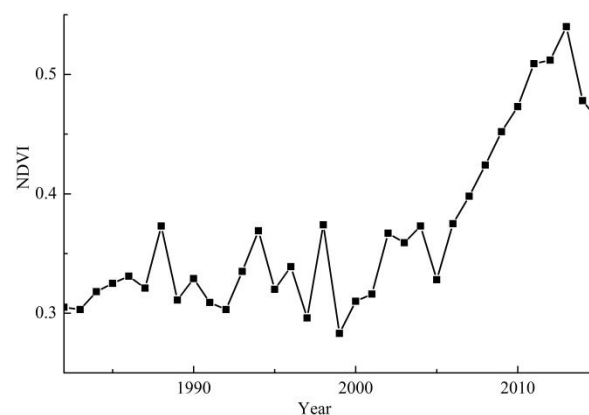


Figure 4. Changes in NDVI in the Jialu River Basin.

5. Conclusions

In this study, we investigated the changing properties of flood in the Jialu River Basin and analyzed the main causes of the flood change. The AMAXF series had a significant decreasing trend with an abrupt change point around 1998. There was no significant change in extreme precipitation in Jialu River Basin. Cross Wavelet Analysis showed the AMAXF had statistical correlations with P1day and P3day, which means the extreme precipitation indices had a strong influence on AMAXF in the Jialu River Basin. The decrease in flood was mainly caused by LUCC, for the implementation of soil conservation practices, including vegetation recovery, terraces and check dams. Further research should be performed to investigate the flood evolution mechanism to better understand the change characteristics of flood in the Jialu River Basin.

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