

Trends Analysis of Rainfall Patterns Triggering Landslide over the Gorges Reservoir Region

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Abstract. Rainfall-triggered landslides in the Three Gorges Reservoir Region are related to two rainfall patterns: rainstorm event and long-lasting moderate precipitation event. Trends of the two rainfall patterns are investigated using trend estimation and Mann-Kendall test. For this purpose, the daily rainfall data are obtained from the Yichang station, the Enshi station and the Chongqing station for the period 1952-2011. The results of the trend estimation show that annual average number of rainstorm events increase at the three stations during the period, while opposite trends in long-lasting moderate precipitation events is observed. However, the increasing and decreasing trends are not significant in the Mann-Kendall test.

1. Introduction

The Three Gorges Reservoir Region is located in the upstream of the Yangtze River at the boundary of Chongqing municipality and Hubei province with the area of 59900 km² and with the population of 16 million. The Three Gorges Reservoir Region has been affected by hundreds of destructive landslide episodes in the last century, which were responsible for significant damage and loss of life. The occurrence of landslides is often associated with intense and prolonged rainfall events (J. von Ruetten *et al*, 2014).

To reduce the number of casualties and damage to property caused by landslides, the factors that affect landslide occurrence should be understood (H. B. Wang *et al*, 2006). Many attempts have been made to establish relationships between rainfall level and landslides (Ying Ruan Chen *et al*, 2014; LIU Lei *et al*, 2016; Davide *et al*, 2016; Kyeong *et al*, 2015; M Suradi *et al*, 2016). Chen Jian *et al* (2005) divided the Three Gorges Reservoir Region into two parts, and gave probability analysis model of landslides triggered by rainfall in the two parts. Ye Dian-xiu *et al* (2014) analyzed the daily precipitation and landslides in the region during 1971-2003, the results revealed the relationship between the probability of landslides occurrence and rainfall. Ma Zhanshan *et al* (2005) identified that rainfall-triggered landslides over the Three Gorges Reservoir Region are related to two rainfall patterns: rainstorm event and long-lasting moderate precipitation event.

The idea of this study is based on the results of Ma Zhanshan *et al* (2005) concerning two rainfall patterns. The purpose is to identify their trends for the period 1952-2011.

2. Data and methods

The China meteorological administration cooperative stations provide the daily rainfall dataset used in the study. The stations data can be obtained from the China meteorological data service center web



site (<http://data.cma.cn>). There are three stations selected with daily rainfall records over the Three Gorges Reservoir Region. They are the Yichang station (latitude 30°42' N and longitude 111°05' E), the Enshi station (latitude 30°16' N and longitude 109°22' E) and the Chongqing station (latitude 29°30' N and longitude 106°33' E). The three stations are located in the eastern, central and western Three Gorges Reservoir Region. Rainfall analysis of the three stations is carried out using 60 years (01/01/1952~31/12/2011) of observed daily precipitation.

According to historical data, some landslides are triggered by intense, short duration precipitation events, while others are usually related with long-lasting rainfall episodes. We established two types of rainfall patterns following the same criteria used by Ma Zhanshan *et al* (2005): rainstorm event and long-lasting moderate precipitation event.

(1) The rainstorm event is defined as follows:

Definition 1: Within 6 days before any date, the number of rainy days (daily rainfall ≥ 50 mm) is 2 days or more.

Definition 2: Within 6 days before any date, the number of rainy days (daily rainfall ≥ 50 mm) is only one day, and within 11 days before the date, the other 10-day accumulated rainfall exceeded 35mm.

Each of these two definitions shown above belong to one rainstorm event.

(2) The long-lasting moderate precipitation event is defined as follows:

Within 6 days before any date, the daily rainfall is below 50mm, and within 11 days before the date, the number of rainy days (daily rainfall ≥ 10 mm and < 50 mm) is 4 days or more.

In this study, analysis of the two rainfall patterns consists of two parts. Firstly, Trend estimation of the two rainfall patterns for 60 years are investigated. Secondly, a Mann-Kendall test is applied to analyze whether the trends are statistically significant.

2.1. Trend estimation

Trend estimation is a statistical method to identify trend of data. When a series measurements of a process are treated as a time series, trend estimation can be used to recognize changing patterns, by relating the measurements to the times at which they occurred. In this paper, trend estimation is applied to determine if the rainstorm events and long-lasting moderate precipitation events exhibit an increasing or decreasing trends.

2.2. Mann-Kendall test

Mann-Kendall is a rank-based non-parametric test for detecting a monotonic trend in a time series (F. TOSUNOGLU *et al*, 2017). The statistical technique has been developed by Mann H.B and Kendall M.G. The magnitude of a trend in time series data can be estimated using Mann-Kendall test.

The Mann-Kendall test statistic, S is defined as follow:

$$S = \sum_{i=2}^n \sum_{j=1}^{i-1} \text{sign}(X_i - X_j)$$

If $X_i - X_j < 0$, $= 0$ or > 0 , then $\text{sign}(X_i - X_j) = -1$, 0 or 1 .

The standardized Z test statistic is given by

$$\begin{cases} Z = (S - 1) / \sqrt{n(n-1)(2n+5)/18} & S > 0 \\ Z = 0 & S = 0 \\ Z = (S + 1) / \sqrt{n(n-1)(2n+5)/18} & S < 0 \end{cases}$$

The Z statistic follows the standard normal distribution. A positive Z value indicates that there is an upward trend in data series, whereas a negative Z value indicates a downward trend.

3. Results

Analyses of rainfall patterns associated with landslides are important for reducing damage over the Three Gorges Reservoir Region. However, the rainfall patterns may be changing under changing climate.

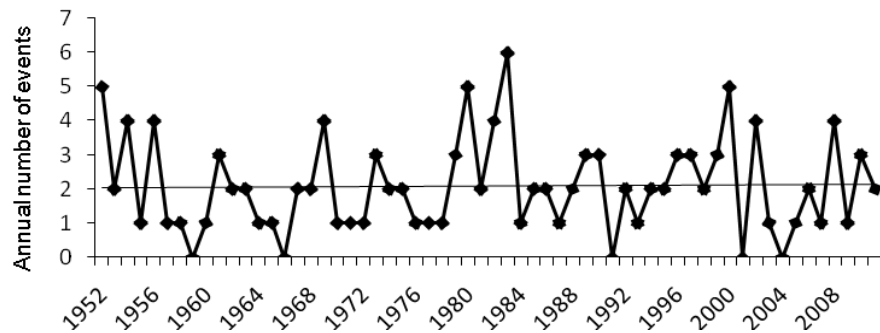


Figure 1. Rainstorm events and its trend at the Yichang station

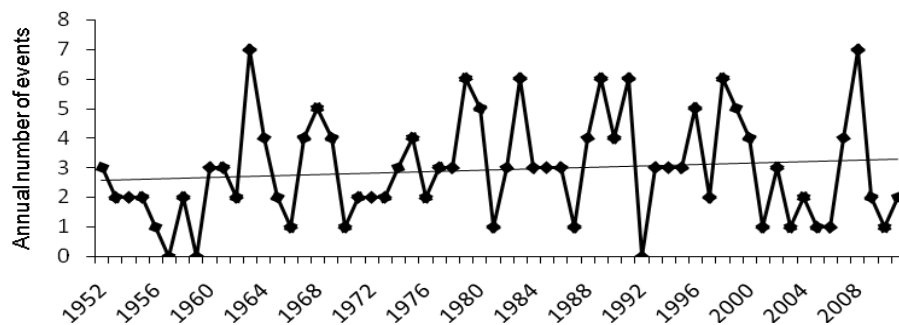


Figure 2. Rainstorm events and its trend at the Enshi station

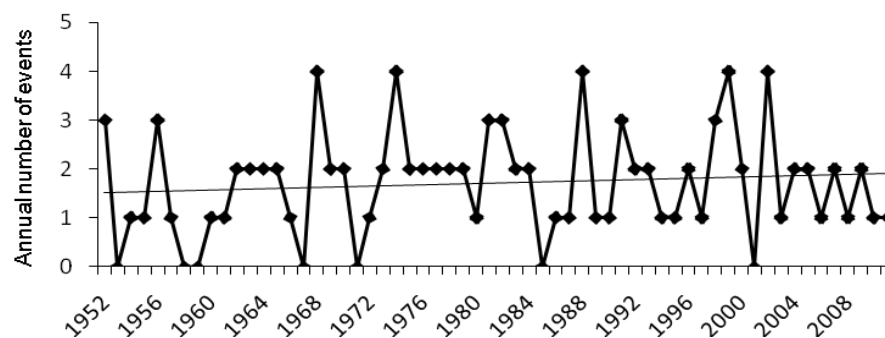


Figure 3. Rainstorm events and its trend at the Chongqing station

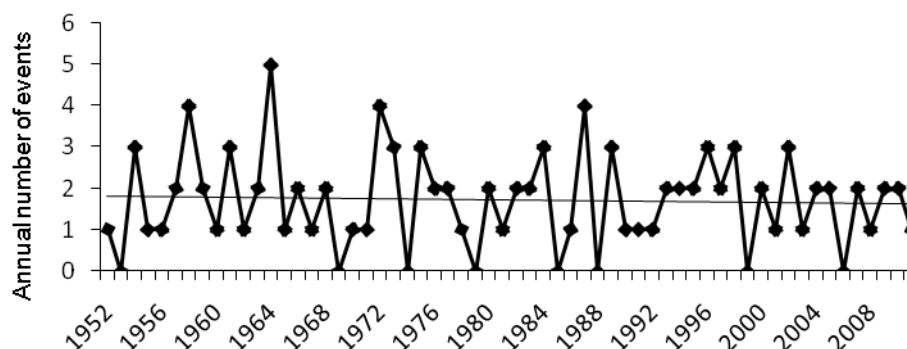


Figure 4. Long-lasting moderate precipitation events and its trend at the Yichang station

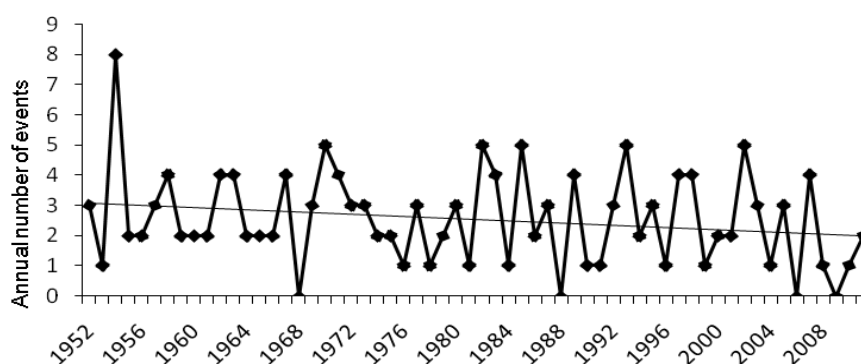


Figure 5. Long-lasting moderate precipitation events and its trend at the Enshi station

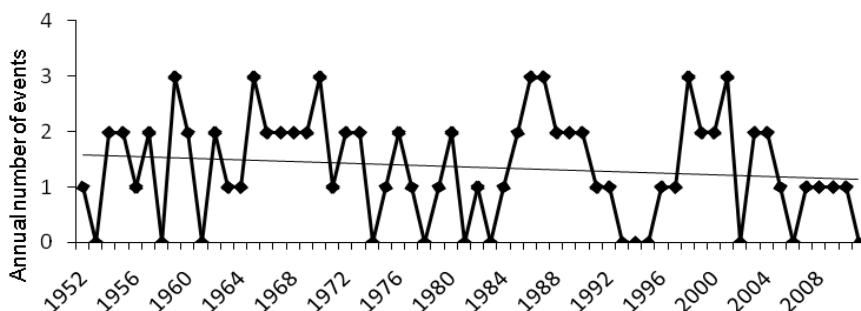


Figure 6. Long-lasting moderate precipitation events and its trend at the Chongqing station

The trends of the two rainfall patterns on each of the three stations for 60 years are calculated from the historical precipitation. Figure 1. To Figure 3. Shows the annual number of rainstorm events and their trend lines at the Yichang station, the Enshi station and the Chongqing station. Although the annual number of rainstorm events has fluctuated, the figure indicates an increase at the three stations. Annual average number of rainstorm events increase through 60 years from around 2.034 to 2.103 at the Yichang station, from around 2.557 to 3.277 at the Enshi station, from around 1.496 to 1.856 at the Chongqing station.

On the other hand, Figure 4. To Figure 6. Shows the annual number of long-lasting moderate precipitation events and their trend lines. For the period 1951-2011, however, decreasing trends are found at the three stations, from around 1.82 to 1.64 at the Yichang station, from around 3.108 to 2.028 at the Enshi station, from around 1.592 to 1.172 at the Chongqing station.

Among the three stations, the maximum rate of rainstorm events change and long-lasting moderate precipitation events change occur at the Enshi station, which is located in the central part of the Three Gorges Reservoir Region.

Table 1. The Mann-Kendall test results (1952~2011)

Station	Calculated Z value of rainstorm events	Calculated Z value of long-lasting moderate precipitation	Critical Z
Yichang	0.427	0.045	± 1.645
Enshi	0.867	-1.310	± 1.645
Chongqing	0.676	-1.090	± 1.645

The results of the Mann-Kendall analysis for the two rainfall patterns are presented in Table I. It can be seen that, for the period 1951-2011, three stations namely Yichang, Enshi and Chongqing have increasing trends in the rainstorm events data series. Two stations namely Enshi and Chongqing show decreasing trends in long-lasting moderate precipitation events data series while Yichang has an increasing trend. However, all the Z values are not greater than the critical value of the standard normal distribution at the significance level, then the decreasing and increasing trends existing in the data series are not considered to be statistically significant.

4. Conclusion

In this study, trends of rainstorm events and long-lasting moderate precipitation events, calculated from daily precipitation of the three stations over the Three Gorges Reservoir Region, are investigated by using trend estimation and Mann-Kendall test. According to the trend estimation, there are increasing trends of rainstorm events at the three stations, while decreasing trends of long-lasting moderate precipitation events are identified from 1 January 1952 to 31 December 2011.

However, the significance of their trends are assessed by Mann-Kendall test, the results do not show statistically significant.

This study presents trends of the rainfall patterns for 60 years over the Three Gorges Reservoir Region. The results should be improved in the future, and could be helpful in controlling the effects of landslides.

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