Changing properties of extreme flood in Xiliugou River Basin, China

Suzhen Dang1*, Manfei Yao2, Huijuan Yin1 and Guotao Dong1

1Yellow River Institute of Hydraulic Research, Yellow River Conservancy Commission, Zhengzhou, 450003, China
2School of Water Conservancy, North China University of Water Resources and Electric Power, Zhengzhou, 450046, China

*Corresponding author’s e-mail: dangsz_hky@163.com

Abstract: Based on the annual maximum flood discharge sequence of the Longtouguai hydrological station in the Xiliugou River Basin from 1960 to 2015, the statistical probability characteristics of extreme flood discharge were analyzed by using generalized extreme value (GEV) distribution, generalized Pareto (GP) distribution, Pearson type III (P-III) distribution, general logistic (GLO), and Burr distribution. The parameters were estimated by the L-moments method, and the optimal distributions were selected by some of goodness-of-fit method. The results showed that the annual maximum flood discharge series decreased significantly with an abrupt change point around 2005. From the L-moments and goodness-of-fit test method, Burr distribution can better fit the annual maximum flood discharge before and after the abrupt change. Compared with the sequence before the change, the return period becomes larger and the probability of severe flood is smaller. The designed maximum flood peak discharge for the same return period of the entire sequence is smaller than that of the sequence before the change.

1. Introduction

In recent years, due to the influence of human activities and global climate change, extreme hydrological events have occurred frequently and intensified, which have seriously threatened the survival and development of human beings [1-2]. The research on the occurrence regularity and mechanism of extreme hydrological disasters have become a hot topic. Xiliugou River basin is a typical watershed in the Loess Plateau, and it is a primary tributary of the Yellow River. The flood has the characteristics of large peak flow and high sediment concentration. It not only causes flooding in the lower reaches of the basin, but also often forms sand dams in the mainstream of the Yellow River, resulting in serious siltation of the Yellow River. Many studies have contributed to the research of flood in Xiliugou River Basin [3-5]. Liu et al. [3] found out that the relationship of sediment yield and sediment concentration by one flood process could be presented as power function of runoff depth and discharge, respectively; the process of rainfall-runoff with sediment yield and transportation could be simulated based on the relationship of discharge and sediment and the regularity. Lei et al. [4] discussed the flood process caused by a rare heavy rain occurred in Xiliugou River Basin in 2016, the peak flow and runoff coefficient were all smaller than the average value of the first three floods in history, while the total rainfall, 1 h rainfall and 2 h rainfall were all larger. Studies on changes in floods show that the rainfall-runoff relationship has changed in this area [3-4], while the studies on the statistical characteristic of flood under the influence of climate change and human activities are still limited.
This research focuses on the statistical characteristic of extreme flood in Xiliugou River Basin of China, where flood is one of the most harmful natural hazards. Previous researches of flood in this region are almost concentrated on the flood events. However, studies on statistical characteristic of extreme flood are limited. In this study, statistical characteristic of extreme flood peak discharge has been analyzed by using annual maximum flood discharge series from Longtouguai station during the past 56 years (1960-2015). Five generally used extreme distributions (GEV, GP, P-III, GLO and Burr distribution) are selected to fit extreme flood series. The L-moments method is used to estimate the parameters of the selected models, and some of goodness-of-fit methods are used to select the optimal distributions. The return period values of the extreme flood series before and after the change point can be compared based on the best-fitted models.

2. Study Area and Data
Xiliugou River is a primary tributary of the Yellow River, locates between 109°24'E-110°00'E and 39°47'N-40°30'N, with a drainage area of 1180 km². The watershed is located in the semi-arid area. The main topography is loess hilly area in the upper reaches of the basin, the middle reaches are the Kubuqi desert, and the lower reaches are the alluvial fans. The annual average temperature of the basin is 6.8°C. The average annual rainfall is 260.3mm from 1960 to 2015. Intra-annual distribution of precipitation is extremely uneven, mainly concentrated from June to September, accounting for 79.8% of the total annual precipitation.

The annual maximum flood peak discharge data at Longtouguai Station from 1960 to 2015 in Xiliugou River Basin used in this paper is from the Yellow River Conservancy Commission.

3. Methods

3.1 Mann-Kendall trend analysis
Non-parametric Mann-Kendall trend method (MK) is a simple and robust test method widely used in examining trends of hydrological and meteorological series (Zheng et al., 2009; Dang et al., 2018). A positive MK statistic Z larger than 1.96 indicates a significant increasing trend under the 95% confidence level, while a negative Z less than -1.96 indicates a significant decreasing trend.

3.2 Extreme value distributions
The statistical characteristic of extreme flood peak is analyzed by five extreme value distributions, including GEV, GP, P-III, GLO and Burr distribution. The cumulative distribution functions of the selected models are given in Table 1. The L-moments method is used to estimate the parameters of these five models, and the details can be found in She et al. (2013) and it is not given herein.

Table 1 The cumulative distribution functions (CDF) of GEV, GP, P-III, GLO and Burr distributions

| Distributions | CDF | Distributions | CDF |
|---------------|-----|---------------|-----|
| GEV \( F(x) = \exp\{-[1-(k(x-\xi))/\alpha]^{1/k} \} \) | P-III \( F(x) = \frac{\alpha^k}{\Gamma(k)} \int_0^\infty (x-\xi)^{k-1} e^{-(x-\xi)/\alpha} dx \) |
| \( k \neq 0 \) | \( y = -\ln[1-(k(x-\xi))/\alpha]/k, k \neq 0 \) | GLO \( F(x) = \left[1 + \left[1 - k\left(\frac{x-\xi}{\alpha}\right)^{1/k}\right]^{-1}\right]^k \) |
| \( F(x) = 1-e^{-y} \) | \( y = -(x-\xi)/\alpha, k = 0 \) |
| GP \( y = -\ln[1-(k(x-\xi))/\alpha]/k, k \neq 0 \) | Burr \( F(x) = 1 - (1 + (\frac{x}{\alpha})^z)^{-k} \) |

3.3 Goodness-of-fit test
Optimal distributions are selected by some of goodness-of-fit methods, which are
Kolmogorov-Smirnov (K-S) test method, Akaike Information Criterion (AIC) and OLS. The test statistic of K-S test can be calculated as

\[ D_n = \max_{1 \leq i \leq n} \left| \frac{i}{n} - F_0(x_{(i)}) \right| \]

Where \( x_{(i)} \) is the empirical frequency, \( F_0(x_{(i)}) \) is the cumulative distribution function, \( n \) is the sample size. Under the significance level \( \alpha \), if \( D_n \) is calculated to be smaller than the critical value \( D_{\alpha}(n) \), then the distribution can be considered as a significantly fit model to the observed data. The probability distribution corresponding to the minimum value of \( D_n \) can be selected as the optimal distribution.

The OLS and AIC can be calculated as follows

\[ OLS = \frac{1}{n} \sum_{i=1}^{n} (P_{ei} - P_{i})^2 \]

\[ AIC = n \log(RSS/n) + 2m \]

Where \( P_{ei} \) is the empirical frequency, \( P_{i} \) is the theoretical frequency, \( RSS \) is the residual sum of squares, \( m \) is the number of parameters. The smaller the calculated OLS or AIC is, the better the function fitting effect is.

The return period values can be got from the best-fitted distribution.

4. Results

4.1 Changes in annual maximum flood peak discharge

Figure 1 exhibits the changes in the annual maximum flood peak discharge in Xiliugou River Basin. The annual maximum flood peak discharge over the past 56 years exhibits a significant decreasing trend at the significance level of 0.05. The maximum and minimum of annual maximum flood peak discharge are 6940 m³/s in 1989 and 80.6 m³/s in 1983, respectively. Abrupt change detection made by the MK test indicates that the change point for the annual maximum flood peak discharge series is around 2005.

![Figure 1 Changes in AMAXF and the Mann-Kendall test for AMAXF in the Jialu River Basin](image)

4.2 The best distributions for annual maximum flood peak discharge

Figure 2 and Table 2 present the results of goodness-of-fit methods and the best distribution for the whole series and the series before the change point. It can be seen that the both series are best fitted by the Burr distribution. It is worth noting that the test results of P-III distribution are the worst either for the whole series or the series before the change point. It can be roughly inferred that P-III distribution is not suitable for simulating flood peak series.
compared with other distributions.

Table 2 Fitting test results of maximum peak flow series

| Series | Goodness-of-fit value | GEV | GPD | P-III | GLO | Burr |
|--------|------------------------|-----|-----|-------|-----|------|
| 1960-2016 | K-S                   | 0.098 | 0.094 | 0.190 | 0.104 | 0.079 |
| AIC    | -182.058              | -201.148 | -148.301 | -155.147 | -160.381 |
| OLS    | 0.037                 | 0.026 | 0.067 | 0.039 | 0.035 | 0.048 |
| K-S    | 0.068                 | 0.063 | 0.152 | 0.053 | 0.079 |
| 1960-2004 | AIC                   | -162.229 | -158.722 | -111.836 | -139.547 | -165.851 |
| OLS    | 0.033                 | 0.026 | 0.073 | 0.024 | 0.022 |

Figure 2 The frequency distribution curves of annual maximum flood peak flow for (a) the period of 1960-2016 and (b) the series before the change point (1960-2004) in Xiliugou River Basin
Table 3 shows the designed maximum flood peak discharge corresponding to different return periods before and after the change in Xiliugou River Basin. The designed maximum flood peak discharge after the change is significantly different from that before the change. Compared with the time series before the change, the return period becomes larger and the probability of severe flood is smaller. The designed maximum flood peak discharge for the same return period of the whole series is smaller than that of the series before the change. The design maximum flood peak discharge of the entire sequence for the return period of 50a is the same as that of the sequence before the change for the 90a return period.

In Xiliugou River Basin, extreme floods occurred more frequently before the change of environment. According to the full sequence fitting analysis, there are 5 floods with the return period greater than 10a at Longtouguai station, and only 1 flood occurred after 1989.

5. Conclusions
In this study, we investigated the statistical characteristic of extreme flood peak discharge in Xiliugou River Basin. The annual maximum flood peak discharge series had a significant decreasing trend with an abrupt change point around 2005. For the whole series and the series before the change point, the Burr distribution is selected as the best fitted model to simulate the frequency of annual maximum flood peak discharge. Compared with the sequence before the change, the return period becomes larger and the probability of severe flood is smaller. The designed maximum flood peak discharge for the same return period of the entire sequence is smaller than that of the sequence before the change.

Acknowledgments
This research was financially supported by the National Key R&D Program of China (2017YFC0403600, 2016YFC0402400) and the Natural Science Foundation of China (51779099).

References
[1] Easterling D. R., Evans J L, Groisman P Y, et al. (2000) Observed Variability and Trends in Extreme Climate Events: A Brief Review. Bulletin of the American Meteorological Society, 81(3):417-426.
[2] Milly P. C. D., Wetherald R T, Dunne K A, et al. (2002) Increasing risk of great floods in a changing climate. Nature (London), 415(6871):514-517.
[3] Liu T., Zhang S. F., Liu S. X. (2007) Primary analysis of the relationship between storm runoff and sediment yield in Ten-watershed – A case study in Xiliu Brook. Journal of Water Resources & Water Engineering, 18(3): 18-21. (in Chinese)
[4] Lei C. M., Li Z., Guo S. M. (2017) Analysis of August 17, 2016 storm flood in Xiliugou River Basin of the Yellow River in 2016. Yellow River, 39(11): 63-65. (in Chinese)
[5] Yao H. F., Shi C. X., Shao W. W., et al. (2016) Changes and influencing factors of the sediment load in the Xiliugou basin of the upper Yellow River, China. CATENA, 142:1-10.
[6] She D. X., Xia J. J., Song J. Y., et al. (2013) Spatio-temporal variation and statistical characteristic of extreme dry spell in Yellow River Basin, China. Theoretical & Applied Climatology, 112(1-2): 201-213.