The Influence of Series Length and Current Maximum Value on the Estimation of the Rainfall Return Period

JIN Shuang-yan¹  XU Jian-hua¹  Wu Xiao-shuang²
¹Yellow River Institute of Hydrology and Water Resources, Zhengzhou 450004, China;
²Ningmeng Bureau of Hydrology and Water Resources, YRCC, Baotou 014014, China
E-mail: 1178922805@qq.com.

Abstract: According to the rainfall data of Lijiahe and Dingjiagou hydrological stations from 1960 to 2017 in Wudinghe basin, the influence of series length on the variation coefficient is calculated and analyzed. Taking "7.26" rainstorm in Wudinghe as an example, using P-III distribution, rainfall frequency curve of the maximum 24h and 12h of the two stations in the following three cases were established, i.e. not considering the current rainfall, considering the current rainfall, transplanting adjacent extra-large rainfall, and the return period of rainfall at each station was calculated. The results showed that: (1) When the series length reaches 30-35 years or more, the variation coefficients of the six different time scales tend to be stable. (2) The influence of current maximum value on the rainfall recurrence period is obvious. The max 24h rainfall of the "7.26" rainstorm in Lijiahe station ranks first of the series, the return period is about 90 years when considering the value, otherwise it is about 500 years. The max 24h rainfall of the "7.26" rainstorm in Dingjiagou station doesn’t rank the first of the series, whether the value is involved in the establishment of frequency curve, return period is 20~30 years. (3) Considering the transplantation of rainstorm, it is suggested that in the analysis of rainfall return period, the current maximum value should be considered, and the adjacent extra-large value should be transplanted.

1. Introduction

1.1 Research area
Wudinghe is the primary tributary of the Yellow River, locates in the southern Maowusu desert and the northern Loess Plateau, and the basin area is 30261km². The Baijiachuan hydrological station is the controlling station entering the Yellow River, the catchment area above which is 29662km²(shown in Figure 1).
According to the landform and the soil erosion characteristics, the basin can be divided into three types: River Source Liang-Jian Region, Windy Desert Area and Loess Hilly and Gully Region. Among them, the Windy Desert Area is located in the north and northwest of the basin, occupies 54.3% of the total area (Zhang, 2003).

Dalihe is the largest primary tributary of the Wudinghe, and the basin area is 3906 km². The controlling station entering the Wudinghe is Suide hydrological station, the catchment area above which is 3893 km². The whole basin of Dalihe locates in the Loess Hilly and Gully region.

1.2 Rainstorm and flood

The rainstorm occurred in the most of the north Shanxi-Shaanxi Region of the middle Yellow River from July 25 to July 26 in 2017, and the heavy rain occurred in the tributary of Wudinghe. The rainstorm center is mainly concentrated in the Dalihe basin. The heavy rainstorm center is Zhaojiabian of Suide County, and the rainfall is 252.3mm. There are 34 rainfall stations with cumulative rainfall over than 100mm and 10 rainfall stations over than 200mm. It is 63.6mm above Baijiachuan hydrological station in Wudinghe basin. It reaches 129.8mm above Suide hydrological station in Dalihe basin (Tab.1 and Fig.2).

Tab.1 Rainfall over than 200mm at the stations from July 25 8:00 to July 26 8:00

| No. | River  | Station   | Rainfall (mm) | No. | River  | Station   | Rainfall (mm) |
|-----|--------|-----------|---------------|-----|--------|-----------|---------------|
| 1   | Wudinghe | Zhaojiabian | 252.3         | 6   | Chabagou | Xinyaozai  | 214.2         |
| 2   | Wudinghe | Sishiliu  | 247.3         | 7   | Wudinghe | Mizhi     | 214.2         |
| 3   | Dalihe  | Zizhou    | 218.7         | 8   | Chabagou | Caoping   | 212.2         |
| 4   | Xiaolihe | Lijiahe   | 218.4         | 9   | Chabagou | Zhujiayangwan | 201.2     |
| 5   | Xiaolihe | Lijiahe   | 214.8         | 10  | Chabagou | Jijiajian | 200.6         |
The flood occurred in the trunk stream and tributary of Wudinghe in succession due to the rainfall. The peak discharge of Suide hydrological station in Dalihe is 3290 m$^3$/s, the largest flood since the establishment of the station in 1959. The peak discharge of Dingjiagou hydrological station in Wudinghe is 1660 m$^3$/s, the largest flood since 1994. The peak discharge of Baijiachuan hydrological station is 4480 m$^3$/s, occurred at 9:42 on July 26, the largest flood since 1975, and ranks the second in the history (shown in Figure 3).

1.3 Proposal of the problem
The government and public have paid great attention to the rainstorm and flood. The different voices about the return period of heavy rain were given, some say less than one hundred years, some other say more than one hundred or even two hundred years.

The recurrence period refers to an average of hydrological event can occur in a number of years during long periods (Zhuang, 1995). It is a design standard widely used in the planning programming, operation and management of water conservancy and hydropower projects and civil engineering. It is mainly determined by the importance of engineering and the result of the damage to the project of hydrological events (Jin, 1964; Huang, 2011).

For "7.26" rainstorm in the Wudinghe Basin, if current rainfall of single station (referred as "7.26" rainfall) is the maximum of the series, is this value considered in establishing P-III frequency curve when analyzing rainfall recurrence? What is the difference between participating and not participating? Is this the main reason causes the different conclusions of the recurrence? How the coefficient of variation tends to be stable of the series length? Does the heavy rain in adjacent areas needs to be transplanted to participate in frequency analysis?

In order to answer these questions, the rainfall data of Lijiahe and Dingjiagou station with long
rainfall observation data in the “7.26” rainstorm area were selected as representatives, to analyze the current rainfall recurrence, and to discuss the effects of rainfall recurrence due to series length, current maximum and transplant of the adjacent heavy rainfall.

2 Data and Method

2.1 Basic data

(1) Hydrological data

The two hydrology stations of Lijiahe and Dingjiagou is established in 1959, thus the rainfall of the annual maximum 24h and 12h from 1960 to 2017 are selected. Both the rainfall of the annual maximum 24h and 12h is 214.8mm of Lijiahe station on July 26 in 2017, ranks the first in the series. While it is 139.2mm and 130.8mm in Dingjiagou station, which ranks the third and the second respectively in the series.

(2) Transplant of Zhaojiabian rainfall

According to the transplant principle of rainstorm, the rainstorm in adjacent area should be transplanted into the series of frequency analysis, under the similar weather background, water vapor source and underlying surface conditions.

Zhaojiabian locates about 33km and 12km from Lijiahe and dingjiagou station. The maximum 24h and 12h rainfall is 252.3mm and 239.4mm in Zhao Jiabian is the heavy rain measured by Yulin Meteorological Bureau in 2017. It should be transplanted into the rainfall series of Lijiahe and Dingjiagou station to establish the frequency curve.

2.2 Method

The ultimate aim of hydrological frequency calculation is to determine the design values corresponding to the given design frequency. It stipulates that the line type of frequency curve generally adopts P-III distribution in the code for calculation of design flood of water conservancy and hydropower project (Wang, 2006).

The P-III curve is an unsymmetrical single peak and positive partial curve with infinite end at one end. The probability density function is (Zhan, 2010; Guo, 1992):

\[ f(x) = \frac{\beta^\alpha}{\Gamma(\alpha)} (x - a_0)^{\alpha-1} e^{-\beta(x-a_0)} dx \]

Where: \( \Gamma(\alpha) \), Gamma Function; \( \alpha, \beta \), the shape, scale and position parameter of the P-III type distribution, \( \alpha > 0, \beta > 0 \).

After the integration, standardized transformation and simplification for formula (1), the equation for calculating the design value of the given design frequency can be deduced:

\[ x_p = \bar{x}(1 + C_p \Phi_p) = \bar{x} \left( 1 + \frac{\xi^2 \times C_s/C_V \times \text{GammaInv}(1-P, \alpha, \beta)}{\Phi_p} - \frac{2}{C_s/C_V} \right) \]

Where:

\[ \Phi_p = C_s/2 \times T_p - 2/C_s \]  \hspace{1cm} (3)

\[ T_p = \text{GammaInv}(1-P, \alpha, \beta) \]  \hspace{1cm} (4)

\[ \alpha = 4/C_s^2 \]  \hspace{1cm} (5)

\[ \beta = 1 \]

Using macro command programming in Excel to find out the mean value \( \bar{x} \), variation coefficient \( C_v \), coefficient of skew \( C_s \) and GammaInv \( (1-p, \alpha, \beta) \) of series \( x_i \) \( (i=1,2,\ldots, n) \), and draw P-III frequency curves of series \( (p, X_p) \). The parameters of mean, \( C_v \) and \( C_s/C_V \) are determined by the estimation of the fitting line method. According to the formula (2), the frequency corresponding to the rainfall or peak discharge is calculated.

3. Results and discussion

3.1 Effect of series length on variation coefficient

(1) The smaller the timescale is, the larger the coefficient of variation is.
Among the six different time scales of Lijiahe and Dingjiagou station, the variation coefficient of annual rainfall is the lowest, then followed by is which from June to September, from July to August, maximum 24h, maximum 12h and maximum 6h. Generally speaking, the smaller the time scale, the greater the coefficient of variation (Table 2).

(2) When the series length reaches 30-35 years or more, the variation coefficients of different timescales tend to be stable.

In the six different time scales of Lijiahe and Dingjiagou, the variation coefficient changes obviously when the series of rainfall data are too short. When the series length reaches 30-35 years or more, the variation coefficients basically tend to be stable (Table1, Figure 4-5).

![Fig.4 Variation coefficient of rainfall of different series length in 1960-2017 of Lijiahe](image1)

![Fig.5 Variation coefficient of rainfall of different series length in 1960-2017 of Dingjiagou](image2)
3.2 Impact on the current maximum rainfall to return period
Establishing the frequency curve of maximum 24h and 12h rainfall of Lijiahe and Dingjiagou station based on the following three cases: regardless of the current rainfall, i.e. 1960-2016 series; considering the current rainfall, i.e. 1960~2017 series; transplanting Zhaojiabian rainfall in adjacent areas, i.e. 1960~2017 series and 252.3mm or 239.4mm (Fig.6~ Fig.8). The parameters of mean, CV and Cs/CV are determined by the estimation of the fitting line method. According to the formula (2), the rainfall return period is calculated.

Fig.6 The frequency curve of the max 24h rainfall in 1960~2016 in Lijiahe station

Fig.7 The frequency curve of the max 24h rainfall in 1960~2017 in Lijiahe station

Fig.8 The frequency curve of the max 24h rainfall in 1960~2017 and transplantation data in Lijiahe station

(1) If the current rainfall is the maximum value of the series, the return period of frequency curve considering this value is obviously shorter than that of non-considering. When transplanting the adjacent heavy rain, the return period of the established frequency curve is further shortened.

Both the rainfall of the annual maximum 24h and 12h is 214.8mm of Lijiahe station on July 26 in 2017, ranks the first in the series. When establishing the frequency curve of Lijiahe maximum 24h
rainfall, if regardless of the current maximum rainfall, the return period is about 500 years. If considering this value, the return period is about 90 years. While transplanting the adjacent rainfall of Zhaojiaibian, the return period is about 40 years. Similarly, establishing the maximum 12h rainfall frequency curve of Lijiahe hydrological station, and the return period of the above three cases are about one thousand years, 80 years and 50 years (Table 3).

(2) If the current rainfall is not the maximum of series, whether the value is involved in to establish the frequency curve has little effect on the recurrence period.

The rainfall of the annual maximum 24h and 12h in Dingjiagou station is 139.2mm and 130.8mm, ranks the third and the second in the series respectively. Whether the value is involved in the establishment of the frequency curve, the recurrent period is 20-30 years, and which of maximum 12h rainfall is about 40 years. When considering the transplantation data, the recurrence period is about 10 years. Therefore, if the current rainfall is not the maximum of series, whether it is participated in to the establishment of the frequency curve, the results of return period are similar.

Tab. 3 The recurrence period of the "7.26" rainstorm in 2017 in Lijiahe and Dingjiagou station

| Hydrology station | Rainfall /mm | Series       | Parameters | Frequency /% | Return period /a | Remarks of return period/a |
|-------------------|--------------|--------------|------------|--------------|------------------|---------------------------|
| Lijiahe           | max 24h      | 1960~2016    | 57.8       | 0.53         | 3.5              | 0.187                     | 53                         | 500                        |
|                   | max 24h      | 1960~2017    | 60.5       | 0.70         | 3.5              | 1.17                      | 85.5                       | 90                         |
|                   | max 24h+ transp. | 1960~2016        | 63.7       | 0.86         | 3.5              | 2.73                      | 36.7                       | 40                         |
| Dingjiagou        | max 24h      | 1960~2016    | 50.6       | 0.55         | 3.5              | 0.091                     | 1099                       | 1000                       |
|                   | max 24h      | 1960~2017    | 53.2       | 0.82         | 3.5              | 1.26                      | 79.4                       | 80                         |
|                   | max 24h+ transp. | 1960~2016        | 56.6       | 0.89         | 3.5              | 2.05                      | 48.8                       | 50                         |
|                   | max 12h      | 1960~2016    | 64.6       | 0.52         | 3.5              | 3.90                      | 25.6                       | 20~30                      |
|                   | max 12h      | 1960~2017    | 65.9       | 0.51         | 3.5              | 4.04                      | 24.8                       | 20~30                      |
|                   | max 12h+ transp. | 1960~2016        | 69.1       | 0.70         | 3.5              | 8.36                      | 12.0                       | 10                         |
|                   | max 12h      | 1960~2016    | 56.0       | 0.49         | 3.5              | 2.22                      | 45.0                       | 40                         |
|                   | max 12h      | 1960~2017    | 57.3       | 0.49         | 3.5              | 2.49                      | 40.2                       | 40                         |
|                   | max 12h+ transp. | 1960~2016        | 60.6       | 0.54         | 3.5              | 7.12                      | 14.0                       | 10                         |

Remarks: Cs / Cv = 3.5 (Wang, Zhang, 2006).

4. Conclusions and suggestions
(1) When analyzing the return period of rainfall, data series of rainfall station should be at least 30-35 years. For the different time scales during the year, the change of variation coefficient is obvious when the series of rainfall data are too short. When the series length reaches 30-35 years or more, the variation coefficients of the six different time scales tend to be stable.

(2) The impact of current maximum on the return period of rainfall is very obvious. The maximum 24h rainfall of the "7.26" rainstorm in Lijiahe station ranks the first in the series of 1960-2017, the return period is about 90 years when considering the value to establish frequency curve, otherwise it is about 500 years.

(3) Considering the randomness of the rainstorm, it is suggested that in the analysis of rainfall recurrence period, the maximum value of the present situation should not only be considered, but also the adjacent extra-large value should be transplanted under the similar weather background, water vapor source and underlying surface conditions.

Acknowledgment
Foundation: National Key Technology R&D Program (2016YFC0402401); YRIHR Program (2018ZW019).

References
[1] Zhuang Jinglin. Yellow River Conservancy Commission, MWR. Yellow River Flood-Prevention
Dictionary [M]. Zhengzhou: Yellow River Water Conservancy Press. 1995.

[2] Jin Guangyan. The Principle and Method of Hydrology Statistics [M]. Beijing: China Industrial Press, 1964.

[3] Huang Zhenping, Chen Yuanfang. Hydrologic Statistics [M]. Beijing: China Water Power Press, 2011.

[4] Hydrology Bureau of Water Resources Ministry, Hydrology Year Book of Yellow River Basin [M]. Beijing: Hydrology Bureau of Water Resources Ministry (1960-2016).

[5] WANG Jun, CHEN Junchi, GUO Haijin al. Regulation for Calculating Design Flood of Water Resources and Hydropower Projects [M]. Beijing: China Water Power Press. 2006.

[6] ZHAN Daojiang, XU Xiangyang, CHEN Yuanfang. Engineering Hydrology [M]. Beijing: China Water Power Press. 2010.

[7] GUO Shenglian, YE Shouze. The empirical frequency formula in hydrologic calculation [J]. Journal of Wuhan Institute of Water Conservancy and Electric Power, 1992, 25(2):38-45.

[8] WANG Jiaqi, ZHANG Jianyun. Atlas of the Statistical Parameters of China's Rainstorm [M]. Beijing: China Water Power Press. 2006.