

Study on the rainfall-flood relationship and related occurrence probability in Tongzhou Area

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ABSTRACT: More and more people are concerned about flood control and disaster mitigation. Beiyun River, as one of five river systems in Beijing, its flood control capacity play a critical role in urban flood control and disaster mitigation. Hence, the research on the relationship between the Beiyun River's rainfall and floods occurring has significance for flood control and disaster mitigation in Tongzhou area, Beijing. In this paper, Beiyun River (Tongzhou area basin) was selected as the research object, the rainfall-flood relationship, the occurrence probability of heavy rainfall and lager flood were studied with the method of mathematical statistics and theoretical analysis. The results showed based on the SPSS analysis, while the 24-hour rainfall was larger than 50 mm, the occurrence probability that flow rate $>150 \text{ m}^3/\text{s}$ was 0.30. Among them, the occurrence probability that flow rate ranged $150\text{-}500 \text{ m}^3/\text{s}$, $500\text{-}1000 \text{ m}^3/\text{s}$ and $>1000 \text{ m}^3/\text{s}$ was 0.26, 0.09 and 0.30, respectively. While the flow rate was larger than $150 \text{ m}^3/\text{s}$, the occurrence probability that 24-hour rainfall $>50 \text{ mm}$ was 0.34. Among them, the occurrence probability that 24-hour rainfall ranged $50\text{-}100 \text{ mm}$, $100\text{-}200 \text{ mm}$ and $>200 \text{ mm}$ was 0.20, 0.13, 0.02, respectively. Based on R statistical programing, while flood peak flow rate was larger than $150 \text{ m}^3/\text{s}$, the occurrence probability that 24-hour rainfall $>50 \text{ mm}$ ranged from 0.28 to 0.45; while flood peak flow rate was larger than $150 \text{ m}^3/\text{s}$, the occurrence probability that 24-hour rainfall $<50 \text{ mm}$ ranged from 0.54 to 0.70; while flood peak flow rate was less than $150 \text{ m}^3/\text{s}$, the occurrence probability that 24-hour rainfall $>50 \text{ mm}$ ranged from 0.45 to 0.68..

INTRODUCTION

The flood control and disaster mitigation is a hot issue for the contemporary society, academia. The Floods not only cause huge losses of the social economy, but also threaten the people life and health (Lu et al. 2010). In recent years, the flood disasters occurred frequently by rain in the national regional. As an international metropolis, Beijing is also face to the crisis. During the 2004-2012 years, the extreme rainfall weather occurred 42 times in Beijing, which took place 29 times in the city. The flood affected by many factors, the rainfall is the main factor. Due to heavy rains caused flooding events frequently during the Beijing flood season, how to reduce the flood and water-logging events have become the key problem need to be solved.

The existing researches mainly concentrated on urban rainstorm partition and rainstorm center variation (Mou. 2011), flood generation mechanism and risk assessment (Zhang et al. 2010; Hu et al. 2013; Yin et al, 2010), heavy rains flood trend analysis (Fan. 2011; Guan et al. 2006), rainfall - runoff relation (Li et al. 2012; Yang, 2007), etc. The researches about the relationship and probability between for regional rainfall and flood were relative lacking. Hence, in order to solve this situation. Therefore, this paper aiming at the problem of frequent heavy rains caused flooding events during flood season. Taking the Beiyun River basin in Tongzhou area as the research object, the rainfall-flood relationship and the flood occurring probability were analyzed based on the measured data of hydrological stations (1919-2012) in Tongzhou area. It could provide technical supports for the urban flood control and disaster mitigation.

GENERAL SITUATION

The Beiyun River basin is located on $115^{\circ} 55' - 117^{\circ} 11' 29.1'' 29.1'' E$, $40^{\circ} 12' 40.7'' - 39^{\circ} 8' 55.9'' N$, which originated from Hezjian village, Liucun town, Changping district, Beijing. Inflows into the next higher level in Hebei district of Tianjin. The total river length is 244 km, the total basin area is 4247 km^2 , which includes Beiyun River and Wenyu River. The Wenyu River originated from Hezjian village, Liucun town. The river length is 97.5 km, the basin area is 2518 km^2 . The Beiyun river originated from Xinjian village, Tongzhou town, The river length is 40.49 km, the basin area is 1729 km^2 .

The Tongzhou hydrological station located in Beiguanzha, Tongzhou district, which is the controlling station For Beiyun River and Yunchaojian River. The river basin area is 2815 km^2 . As one of important hydrological stations in our country which undertakes the water level, flow, precipitation, evaporation, water quality, sediment, water temperature and other 14 observation items. During the period of observation, the history largest measured peak flow is $2200 \text{ m}^3/\text{s}$ (July 27, 1939), The largest annual rainfall is 1177.3 mm (1955).

RAINFALL-FLOOD ANALYSIS

Historic precipitation analysis

The historic precipitation of Tongzhou area was analyzed based on the actual measured precipitation data from 1919 to 2012 of Tongzhou hydrological stations, as shown in Figure 1. The results showed that annual average rainfall was 604 mm and little bigger than the annual average rainfall in Beijing (585 mm). Among them, the biggest precipitation was 1177mm occurred in 1955, and greater than 1170 mm encountered in 100 years. The minimum value occurred in 1999 which value is 263 mm. Trend analysis was carried out on the precipitation series for many years, as shown in figure 2. During 94 years, the precipitation presented abundant-withered alternative variations. The annual precipitation for years showed the slow decreasing tendency. Among them, the precipitation during 1999 to 2010 was less than the annual average rainfall for years, occurring hemiplegia phenomenon for the 12 years period.

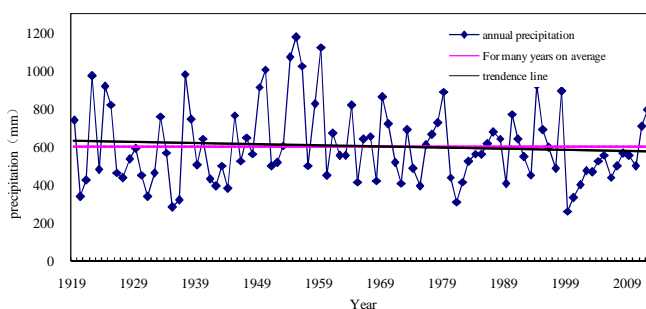


Figure1. The precipitation analysis between 1919 and 2012

The correlation analysis of rainfall-flood for many years

Based on the actual measurement data for 94 years (from 1919 to 2012), the correlation analysis of rainfall-flood was analyzed by Statistical software SPSS. The rainfall- flow linear relationship for many years was analyzed, as shown in Figure 2. The results showed that the linear relationship model is $y=0.881x-126.05$. But the data points distribution around the linear model was relative sparse. The calculated correlation coefficient R^2 was just 0.187. It further explained that the linear relationship between rainfall-flood was not obvious.

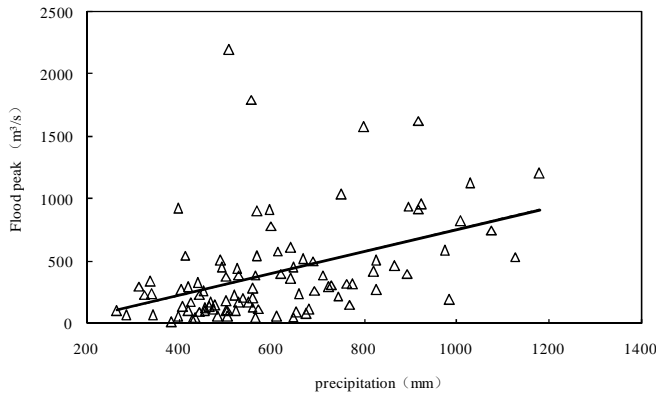


Figure2. The relationship of precipitation and flood peak for many years

The correlation analysis of typical session rainfall-flood

The rainfall-flood correlation analysis was studied from two aspects, the sample data was selected from two parts. One part of the sample data was selected from the precipitation data. In accordance with “the flood control manual” (Yang. 2014), as the cumulative rainfall of 24 hours was more than 50 mm, it could be defend as the heavy rain. Hence, selected the rainfall of 24 h that more than 50 mm during 94 years as sample data, and the corresponding flow was also collected at the same time. The other part of the sample data was selected according to the experience method. Session flow more than 150 m³/s was selected as sample data, and the corresponding flow also selected.

(1) SPSS statistical analysis

Using SPSS software, the selected two groups of sample data were studied by correlation analysis respectively, the results showed in the Figure 3-4, the session precipitation more than 50 mm corresponding flow relation model was $y=2.629x+0.292$, the correlation coefficient R^2 is 0.0987. The results showed that the 24 h precipitation more than 50 mm corresponding flow relation was not obvious. Session flow rate more than 150 m³/s corresponding rainfall relationship model was $y=0.003x+50.930$. The correlation coefficient R^2 was 0.0002. The relationship was more irrelevant.

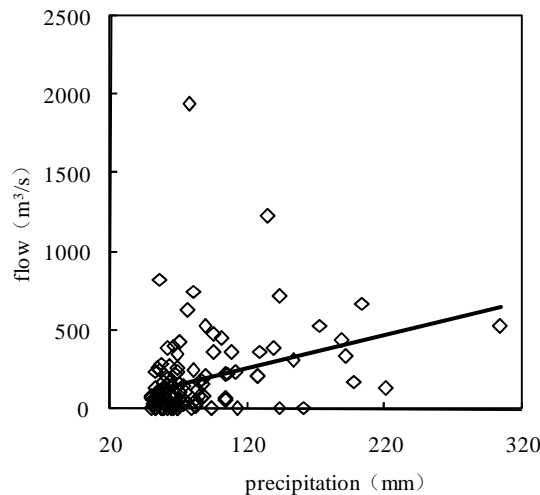


Figure3. The relationship of precipitation and flow (Precipitation more than 50mm)

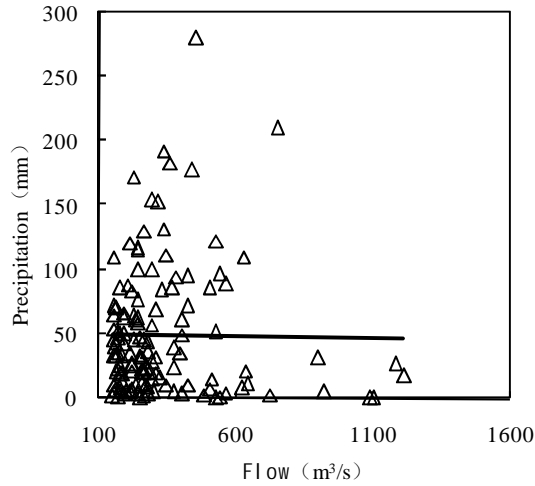


Figure4. The relationship of precipitation and flow
(Flow more than 150m³/s)

(2) R statistical analysis

In order to further prove the relationship between rainfall and flow of Beiyun basin in Tongzhou area, the sample data is divided into four categories:

- Peak flow > 150 m³/s, Precipitation > 50 mm, defined as PF_{>150}P_{>50};
- Peak flow > 150 m³/s, Precipitation < 50 mm, defined as PF_{>150}P_{<50};
- Peak flow < 150 m³/s, Precipitation > 50 mm, defined as PF_{<150}P_{>50};
- Peak flow < 150 m³/s, Precipitation < 50 mm, defined as PF_{<150}P_{<50};

Due to the amount of data was only one for category d, which did not have repeatability. So data of PF_{<150}P_{<50} exclusion. Strives for the corresponding correlation coefficient for other types of sorting data.

The correlation coefficient was defined as follows:

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \sum_{i=1}^n (y_i - \bar{y})^2}} \quad (1)$$

The correlation coefficient values between -1 to 1, $|r|=0$ showed the X, Y was uncorrelated; $|r|=1$ showed the X, Y was correlated A with linear function relationship between X and Y; As $|r|<1$, Changes in the X caused part of Y variation, the absolute value of $|r|$ was the greater, Changes in the X caused the greater changes in Y. $|r| \geq 0.8$ was known as highly correlated, $0.5 \leq |r| < 0.8$ was known as the significant correlation, $0.3 \leq |r| < 0.5$ was known as low-grade related, $|r| < 0.3$ was known as no relevant.

From the correlation coefficient analysis table 1, which can be showed: As the peak flow was small (<150 m³/s), the precipitation (< 50 mm) and peak flow (> 150 m³/s) correlation coefficient was negative, and the value was low. Hence, the quantity of rainfall had no obvious correlation. As the precipitation (> 50 mm) and peak flow (> 150 m³/s), the correlation coefficient was positive, but belonged to the low correlation.

Table 1. Correlation coefficient of different category

precipitation	>50mm	<50mm
Flood peak		
>150 m ³ /s	0.4	-0.25
<150 m ³ /s	0.045	-

PRECIPITATION, FLOOD FREQUENCY ANALYSIS

SPSS statistical analysis

Based on the above analysis, the relationship between rainfall and flow rate was not obvious for Tongzhou area. In this paper, the history long series data analyzed by classification. Mainly divided into the following three categories:

- (1) Rainfall is heavier corresponding higher flow;
- (2) Rainfall is heavier corresponding lower flow;
- (3) Rainfall is lower corresponding higher flow. Each type of probability were discussed and research separately.

The Figure 5- 6 showed that when the 24 h precipitation was greater than 50 mm, the flow (<150 m³/s) occurring probability was less than the occurring probability of flow production (>150 m³/s). When the flow rate was more than 150 m³/s, The occurring probability of precipitation(< 50 mm) was more than the occurring probability of precipitation(>50 mm).

Through the 24 h precipitation (>50 mm) sample data analysis calculation, the 24 h precipitation (>50 mm) caused the occurring probability of flow (>150 m³/s) was 0.37, which was less than 0.63 occurring probability of flow (<150 m³/s). According to the experience method, the more than 150 m³/s peak flow was divided into three kinds of situation: 150-500m³/s, 500-1000m³/s, >1000m³/s. The more than 50 mm precipitation are calculated respectively in the 24 h which happened three flow interval probability, the probability calculation results were 0.26, 0.09 and 0.30 respectively.

Through the flow rate (> 150 m³/s) sample data analysis calculation, when flow rate was more than 150 m³/s ,the occurring probability of 24 h rainfall (>50 mm) was 0.34, the occurring probability of rainfall (<50 mm) was 0.66. The 24 h precipitation of more than 50 mm was divided into three kinds: 50-100mm, 100-200mm, >200mm. Calculated three kinds respectively when the flow rate was more than 150 m³/s, the occurring probability of the three kinds of precipitation was 0.20, 0.13and 0.02 respectively.

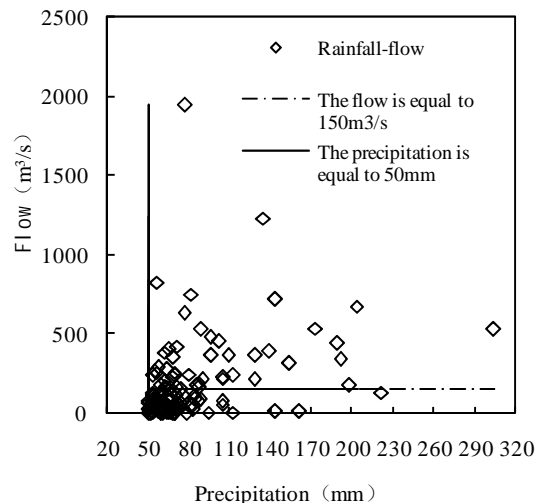


Figure5. The flood occurrence probability (Precipitation more than 50mm)

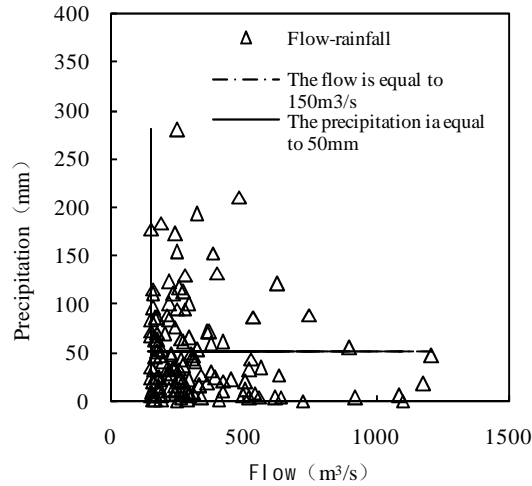


Figure6. The flood occurrence probability (Flow more than 150m³/s)

R statistical analysis

Based on the measured data in the long history series, the two sample data points were analyzed by Chi square test (the original hypothesis is 0.5). They were also divided into three kinds. The three kinds were: (1) Peak flow > 150 m³/s, Precipitation > 50 mm, defined as PF_{>150}P_{>50}; (2) Peak flow > 150 m³/s, Precipitation < 50 mm, defined as PF_{>150}P_{<50}; (3) Peak flow < 150 m³/s, Precipitation > 50 mm, defined as PF_{<150}P_{>50}.

The flow of more than 150 m³/s and the rainfall of more than 50 mm were defined as two samples respectively (sample A and sample B). First, the sample A was divided into two kinds: (1) Peak flow > 150 m³/s, Precipitation > 50 mm; (2) Peak flow > 150 m³/s, Precipitation < 50 mm. At the same time, the two kinds were defined respectively. The definition codes were 1 and 0. Using the above method defined sample B data, the Peak flow < 150 m³/s, Precipitation > 50 mm is defined as code 1.

According to the definition of sample A, B data, the occurring probability was analyzed by using R statistical. The original assume their respective probability was 0.5, then the data were analyzed by the binomial test, the results as follows:

(1) PF > 150, P > 50

The source codes were input in the R statistical, the occurring probability was calculated and analyzed under the condition of the credibility 95% which got a confidence interval for [0.28, 0.45]. It illustrated there are 95% sure real probability between 0.28 and 0.45. So, it concluded that the occurring probability of PF > 150, P > 50 was between 0.28 and 0.45 in Tongzhou area.

(2) PF > 150, P < 50

The source codes were input in the R statistical, the occurring probability was calculated and analyzed under the condition of the credibility 95% which got a confidence interval for [0.54, 0.70]. It illustrated there are 95% sure real probability between 0.54 and 0.70. So, it concluded that the occurring probability of PF > 150, P < 50 was between 0.54 and 0.70 in Tongzhou area.

(3) PF < 150, P > 50

The source codes were input in the R statistical, the occurring probability was calculated and analyzed under the condition of the credibility 95% which got a confidence interval for [0.45, 0.68]. It illustrated there are 95% sure real probability between 0.45 and 0.68. So, it concluded that the occurring probability of PF < 150, P > 50 was between 0.45 and 0.68 in Tongzhou area.

CONCLUSION

Through the long history series data of rainfall and peak flow analysis (1919-2012) in the Tongzhou, the relationship and the occurrence probability of rainfall and flow for Tongzhou area were studied. The main draw the following conclusions:

(1) Analyzed the relationship of the history long series data of rainfall and peak flow by two kinds of mathematical statistical, the relationship between rainfall and flood peak was not obvious.

(2) Through studying the occurrence probability of rainfall and flood peak flow that showed when 24 h rainfall was more than 50 mm the occurrence probability of flow ($>150 \text{ m}^3/\text{s}$) was 0.3 by statistical analysis. When flow rate is more than $150 \text{ m}^3/\text{s}$, the occurrence probability of flow ($150\text{-}500 \text{ m}^3/\text{s}$, $500\text{-}1000 \text{ m}^3/\text{s}$ and $>1000 \text{ m}^3/\text{s}$) was 0.26, 0.09 and 0.30 respectively. The probability of 24-hour rainfall of more than 50 mm was 0.34. The precipitation occurrence probability of 50 ~ 100 mm, 100 ~ 200 mm, more than 200 mm was 0.20, 0.13 and 0.02 respectively.

3. By the R mathematical statistical, in the Tongzhou area the occurrence probability of Peak flow $>150 \text{ m}^3/\text{s}$, precipitation $>50 \text{ mm}$ was between 0.28 and 0.45; the occurrence probability of Peak flow $>150 \text{ m}^3/\text{s}$, precipitation $<50 \text{ mm}$ was between 0.54 and 0.70; the occurrence probability of Peak flow $<150 \text{ m}^3/\text{s}$, precipitation $>50 \text{ mm}$ was between 0.45 and 0.68.

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