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Spatio-Temporal Change of Drought and Flood in northern Henan Province During 1961-2015 Based on Standardized Precipitation Evapotranspiration Index

Xin-Meng SHAN[1,2,a],Zhi-Guo LI[2,b,*] and Jia-Hong WEN[1,c]

1 Department of Geography, Shanghai Normal University, Shanghai 200234, China
2 Department of Surveying and Planning, Shangqiu Normal University, Shangqiu, Henan 476000, China
E-mail: [a] mxshan_123@163.com, [b] lizhiguo999999@163.com ,[c]jhwen@shnu.edu.cn,
[*]Corresponding author

Abstract. The spatial-temporal evolution of drought and flood events and their occurrence frequency in northern Henan Province, China are quantitatively analyzed during 1961~2015, based on temperature and precipitation data, by using Standardized Precipitation Evapotranspiration Index (SPEI) and indicators of drought and flood. The results show that there are significant differences in the periodicity and fluctuation of SPEI value at different time scales in the north of Henan Province during the study period. Firstly, at monthly scale, the monthly frequency of drought in the northern part of Henan Province shows a decreasing trend, but that of flood shows an increasing trend. Secondly, at seasonal scale, Autumn droughts have the highest occurrence frequency, followed by Summer droughts and Winter droughts. But for flood events, Summer floods have the highest frequency. Finally, as to the inter-annual variability of droughts and floods, serious droughts are occurred in northern Henan Province in the 1980s, 2000s and 2011-2015, but serious floods occur in the 1960s and 1970s.

1. Introduction

IPCC (Intergovernmental Panel on Climate Change) reports show that the temperature of global land surface has risen by 0.56-0.92℃ in recent 100 years. The global warming will increase the frequency and intensity of extreme weather disasters and has a great impact on agro-ecosystems[1]. Floods and droughts are among the most severe natural disasters in China, affecting a wide range of areas and causing serious losses. Since 1995, floods have accounted for 47% of all weather related disasters, affecting 2.3 billion people. The number of floods per year rises to an average of 171 in the period 2005-2014, up from an annual average of 127 in the previous decade[2]. In general, droughts last for months or even years [3-4]. Droughts are associated with agricultural failures, loss of livestock, drinking water supply shortages and outbreaks of epidemic diseases[5]. Therefore, quantitative study of temporal and spatial changes in floods and droughts explain its formation mechanism, which have great significance to disaster prevention and mitigation.

In recent years, Vicente-Serrano[6] and others propose the SPEI(Standardized Precipitation Evapotranspiration Index)[7-8]. Based on the SPI(Standardized Precipitation Index), SPEI further considers the amount of evapotranspiration which reflects the degree of drought and flood and becomes an important indicator system for measuring drought and flood [9-10]. In recent years, domestic researchers began to apply the SPEI index for scientific research. However, to our knowledge, few

studies use SPEI to study and analyze the spatial and temporal variations of drought and flood systematically at small geographical scale such as the north of Henan Province.
This paper used the Standardized Precipitation Evapotranspiration Index (SPEI) to analyze the frequency of droughts and floods in northern Henan Province in recent 55 years. In the research, it contains the analysis of the successive drought and flood events and the average temperature and precipitation data of surface meteorological stations in the northern part of Henan Province from 1961 to 2015. Based on the monthly, seasonal, semi-annual and annual scale, the spatio-temporal variations of monthly drought and flood events and their occurrence frequency in northern Henan Province are studied in order to provide useful information for drought and flood disaster reduction decision-making and climate change in this region.

2. Study Region and Analysis Methods

2.1. Study Region

Northern Henan Province refers to the area north of the Yellow River in Henan Province, within the latitude of 34°47′N-36°20′N and longitude of 112°00′E-116°4′E [11]. It includes Xinxiang, Anyang, Jiaozuo, Puyang, Hebi five prefecture-level cities in total, and Jiyuan, the provincial-level cities [12] (Figure 1). The north of Henan Province has a population of 20 million people in 2015, covering an area of 28,000 km^2. The climate belongs to the warm temperate continental monsoon climate, the four seasons are distinct, the annual average temperature is 14℃, annual average rainfall amount is 650mm, mostly concentrated in Summer and Autumn[13].

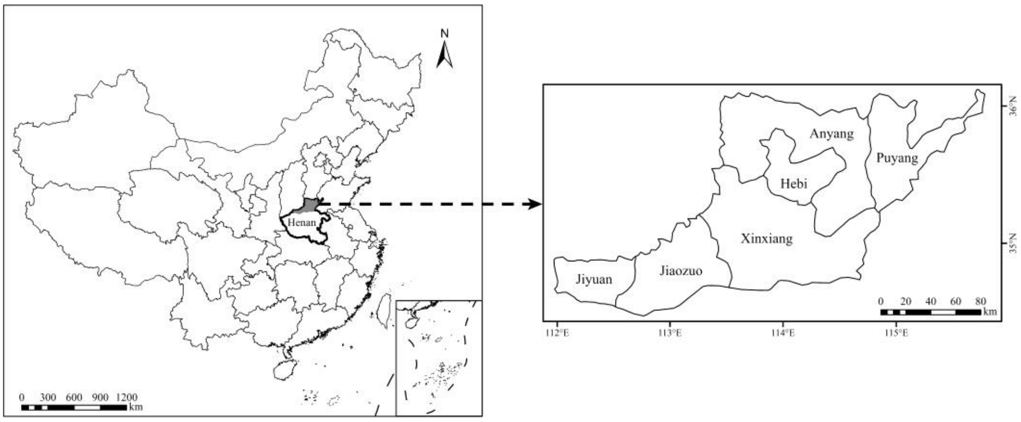


Figure 1. Distribution of weather station in the study

2.2. Data source

In this paper, monthly average air temperature and precipitation data of surface meteorological stations in Anyang and Xinxiang from 1961 to 2015 are used to calculate the standardized evapotranspiration index. The research scale of this paper is divided into four parts: monthly scale (SPEI-12), seasonal scale (SPEI-3), semi-annual scale (SPEI-6) and annual scale (SPEI-12). The monthly scale (SPEI-1) uses data from January to December each year, with a total of 660 sets of data. Special attention is payed to the seasonal scale (SPEI-3) in this work, except in 1961 February is used as the Spring season, March to May used as Spring for the remaining years, June to August as Summer, September to November as Autumn, December to February as Winter, a total of 220 data sets is used in analysis at season scale. The semi-annual scale (SPEI-6) is based on August as a proxy for the Summer-half year, February represents the Winter-half year, a total of 110 sets of data is used. The annual scale (SPEI-12) is based on the average of December each year, a total of 55 sets of data is used.

2.3. Analysis Methods

2.3.1. SPEI Index. The SPEI [9] is a standardized precipitation evapotranspiration index. The calculation methodis to characterize the degree of drought (flood) in a certain area by using the

deviation of the difference between precipitation and evapotranspiration from the mean state. The calculation steps of the index are as follows [6]:
Calculating the potential evapotranspiration (PET) with the Thornthwaite method:

$$PET_i = 16.0 \times \left(\frac{10T_i}{H} \right)^A \quad (1)$$

where: A is a constant; H is the annual calorific value; T_i is the average temperature of 30d. Calculation of constant A and annual heat index H. The formulae are expressed as follows:

$$A = 6.75 \times 10^{-7} H^3 - 7.71 \times 10^{-5} H^2 + 1.792 \times 10^{-2} H + 10^{-2} H + 0.49 \quad (2)$$

$$H_i = \left(\frac{T_i}{5} \right)^{1.514} \quad (3)$$

$$H = \sum_{i=1}^{12} H_i = \sum_{i=1}^{12} \frac{T_i}{5}^{1.514} \quad (4)$$

(2) Calculating the difference between monthly precipitation and evapotranspiration, the specific formula is as follows [9]:

$$D_i = P_i - PET_i \quad (5)$$

where: D_i is the difference between precipitation and evapotranspiration; P_i is the monthly precipitate-on; PET_i is the monthly evapotranspiration.

(3) D_i data sequence normalization. D_i is fitted by log-logistic probability distribution $F(x)$ to calculate the SPEI value corresponding to each D_i value.

when the cumulative probability $P \le 0.5$, the following formula is used to calculate $SPEI$.

$$W = \sqrt{-2\ln(P)} \quad (6)$$

$$SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \quad (7)$$

Where: $d_1 = 1.432788$, $d_2 = 0.189269$, $d_3 = 0.001308$, $C_0 = 2.515517$, $C_1 = 0.802853$, $C_2 = 0.01032$.

When $P > 0.5$, using (8) to calculate $SPEI$.

$$SPEI = -\left(W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \right) \quad (8)$$

SPEI is characterized by multiple time scales. In this study, we mainly analyze the SPEI values at 1, 3, 6 and 12 months, which are respectively represented by SPEI-1, SPEI-3, SPEI-6 and SPEI-12 [7].

2.3.2. Drought and flood Evaluation Index. The spatio-temporal distribution characteristics of drought and flood are analyzed in northern Henan Province from 1961 to 2015, using the frequency and intensity of drought and flood. The specific cau-
lation steps are as follows [10]:
(1) drought (flood) frequency (P_i):
Calculating the frequency of occurrence of drought (flood) according to the number of occurrences of drought (flood) in a station. The calculation formula is as follows:

$$P_i = n / N \times 100\%$$

Where, N is the total number of years of study, n is the total number of years when a site is droughts (floods), $N = 55$. The frequency P_i is used to evaluate the frequency of droughts and floods in a station in the study area over the past 55 years.

Table 1. Standardized precipitation evapotranspiration index of drought and flood grade

Serial number	SPEI value	grade
1	$-1 < SPEI \leq -0.5$	light drought
2	$-1.5 < SPEI \leq -1$	middle drought
3	$-2 < SPEI \leq -1.5$	heavy drought
4	$SPEI \leq -2$	very heavy drought
5	$-0.5 < SPEI \leq 0.5$	normal
6	$0.5 < SPEI \leq 1$	light flood
7	$1 < SPEI \leq 1.5$	middle flood
8	$1.5 < SPEI \leq 2$	heavy flood
9	$SPEI \geq 2$	very heavy flood

(2) drought and flood intensity:
Drought and flood intensities are classified into four levels including light, middle, heavy and very heavy drought or flood. The SPEI value can reflect the drought and flood intensity at a certain weather station in a certain period of time. Table 1 shows the international drought and flood classification. However, because the occurrence of droughts and floods in northern Henan Province is less frequent, we combine the frequency of very heavy droughts and floods into the heavy droughts and floods frequency.

3. Results and Discussion

3.1. Analysis of Continuous Drought (Flood) events

The results of continuous drought and flood times and drought and flood duration in different sites in our study region from 1960 to 2015 are shown in table 2 and table 3. As far as drought events are concerned, the number of drought times at Xinxiang station are more than those at Anyang station. In addition, in 1960s, 1970s, 1980s, 1990s and 2000s, the number of consecutive drought in 2000s is the highest, which are five times higher and the longest duration is 16.5 months. In the case of flood events, the number of flood times at Anyang station are more than those at Xinxiang station. In addition, the number of consecutive flood with six times in 2000s is the highest, and the longest duration lasts 20.5 months.

Table 2. Continuous drought times and drought duration in different sites in northern Henan Province

Site/ Decade	1960s	1970s	1980s	1990s	2000s	2011-2015	Subtotal
Anyang	3T/12M	——	7T/23M	3T/10M	2T/7M	5T/16M	20T/68M
Xinxiang	2T/8M	1T/4M	2T/6M	4T/15M	8T/26M	3T/13M	20T/72M
Average annual	2.5T/10M	0.5T/2M	4.5T/14.5M	3.5T/12.5M	5T/16.5M	4T/14.5M	20T/70M

Note: T indicates the number of times, M indicates the number of months, — indicates no continuous drought (flood) event

Table 3. Continuous flood times and flood duration in different sites in northern Henan Province

Site/Decade	1960s	1970s	1980s	1990s	2000s	2011-2015	Subtotal
Anyang	4T/17M	3T/10M	2T/7M	2T/6M	3T/10M	2T/6M	16T/56M
Xinxiang	6T/24M	3T/12M	3T/11M	——	1T/5M	1T/3M	14T/55M
Average annual	5T/20.5M	3T/11M	2.5T/9M	1T/3M	2T/7.5M	1.5T/4.5M	15T/55.5M

Note: T, M meaning see table 2 note

IOP Conf. Series: Earth and Environmental Science **182** (2018) 012008 doi:10.1088/1755-1315/182/1/012008

3.2. Drought/Flood Features are Characterized by Fluctuation of SPEI Values at Different Time Scales

SPEI values have multi-time scale features, which can be divided into SPEI-1, SPEI-3, SPEI-6 and SPEI-12. The shorter the scale, the more elaborate the situation of drought and flood in northern Henan Province. The longer the scale, the more it can capture the trend of drought and flood in the north of Henan Province. There are obvious differences in the period and fluctuation of SPEI value in different time scales in the northern part of Henan Province (Figure 2). By analyzing the fluctuation of SPEI value at each time scale, we can draw the following conclusions: the fluctuation amplitude of SPEI is most obvious on the monthly scale; the volatility of the SPEI value on the seasonal scale is more gentler than the SPEI value on the monthly scale; Annual scale SPEI value fluctuations are most stable, reflecting the inter-annual variation of drought and flood.

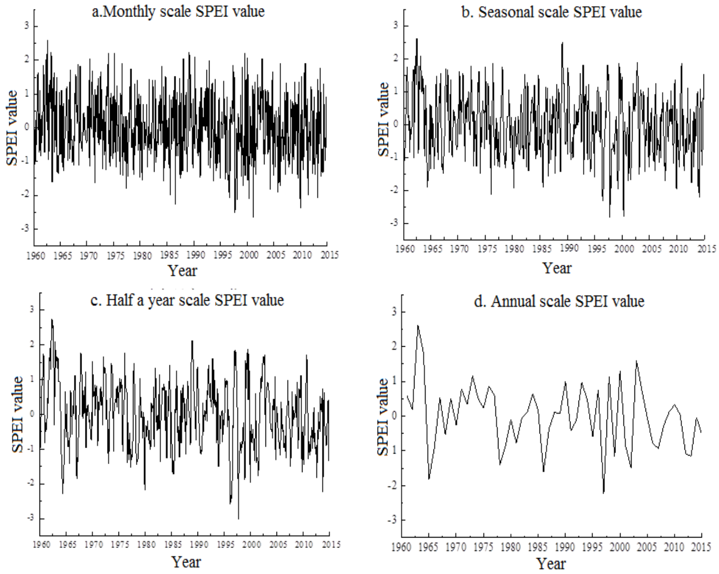


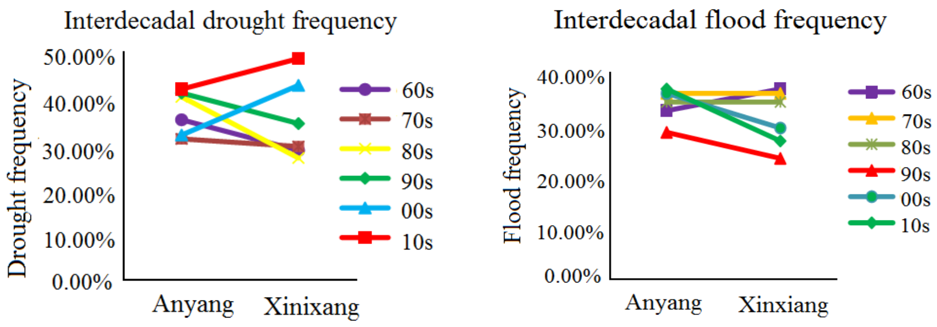
Figure 2. The annual SPEI values at different time scales in northern Henan province from 1960 to 2015

3.3. Drought and Flood Frequency Analysis

3.3.1. Drought and Flood Frequency Changes with Time. Figure 3a presents the inter-decadal drought frequency distribution of each site based on monthly values. The frequency of drought occurs at Xinxiang station in 2010s, and the frequency of drought is 48.33%.The frequency of drought at Xinxiang station in 1980s is 26.67%. The average of inter-decadal drought frequency is ranked as follows:2010s(45.00%)>1990s(37.50%)>2000s(37.09%)>1980s(33.34%)>1960s(31.67%)>1970s (30.00%).

Figure 3b presents the inter-decadal flood frequency distribution of each site based on monthly values. It indicates that the maximum frequency of flood occurs at Anyang station in 2010s and Xinxiang station in 1960s, and the frequency of flood is 36.67%. The minimum frequency of flood occurs at Xinxiang station in 1990s, the frequency of flood is 23.33%. The average of inter-decadal flood frequency is ranked as follows: 1970s(35.83%)>1960s(34.59%)>1980s(34.17%)>2000s(32.50%)>2010s(31.67%)>1990s (25.83%).

In general, the frequency of inter-decadal drought presents an increasing trend, and the decadal flood frequency presents a slight decreasing trend.



(3a) (3b)

Figure (3a). Interdecadal characteristics of light drought, moderate drought and heavy drought; **(3b).** Interdecadal characteristics of light flood, moderate flood and heavy flood.

3.3.2. Temporal Variation of Drought and Flood Frequency. From table 4, it can be seen that droughts occur most frequently in January and December, with the least frequency of drought in March and September; the most frequency of flood in April and May, and the lowest frequency of floods in March, September and November. Monthly drought at Anyang station occurs more frequently than that at Xinxiang station. Monthly flood at Xinxiang station occur more frequently than Anyang. The frequency of monthly drought in the northern part of Henan Province presents a decreasing trend, while the monthly frequency of floods presents an increasing trend.

Table 4. Drought and flood frequency distribution at month scale in northern Henan Province

	Anyang drought	Xinxiang drought	Anyang flood	Xinxiang flood
January	43.64%	41.82%	32.73%	32.73%
February	40.00%	30.91%	34.55%	27.27%
March	29.09%	30.91%	30.91%	30.91%
April	32.73%	36.36%	36.36%	36.36%
May	38.18%	34.55%	36.36%	32.73%
June	36.36%	30.91%	32.73%	32.73%
July	30.91%	27.27%	38.18%	29.09%
August	34.55%	30.91%	36.36%	30.91%
September	32.73%	34.55%	30.91%	29.09%
October	38.18%	36.36%	32.73%	30.91%
November	34.55%	36.36%	30.91%	30.91%
December	43.64%	34.55%	30.91%	32.73%
Average value	36.21%	33.79%	33.64%	31.36%

As shown in table 5, it is the droughts and floods frequency at seasonal scale in northern Henan Province. Generally speaking, at the seasonal scale, the frequency of Summer drought is the highest in the north of Henan Province, follows by the Autumn drought, while the Spring drought and Winter drought are relatively low. The frequency of Autumn flood is the highest in the northern part of Henan Province, followed by the Summer flood and Winter flood, and lowest in Spring flood.

Table 5. Drought and flood frequency distribution at season scale in northern Henan Province

	Anyang drought	Xinxiang drought	Anyang flood	Xinxiang flood
Spring	30.91%	27.27%	29.09%	23.64%
Summer	34.55%	38.18%	34.55%	34.55%
Autumn	34.55%	34.55%	38.18%	34.55%
Winter	29.09%	30.91%	34.55%	34.55%

Table 6. Decadal drought and flood frequency distribution in northern Henan Province

IOP Conf. Series: Earth and Environmental Science **182** (2018) 012008 doi:10.1088/1755-1315/182/1/012008

	Anyang drought	Xinxiang drought	Anyang flood	Xinxiang flood
1961-1970	35.00%	28.33%	32.50%	36.67%
1971-1980	30.83%	29.17%	35.83%	35.83%
1981-1990	40.00%	26.67%	34.17%	34.17%
1991-2000	40.83%	34.17%	28.33%	23.33%
2001-2010	31.67%	42.50%	35.83%	29.17%
2011-2015	41.67%	48.33%	36.67%	26.67%

The decadal drought and flood frequency distribution in northern Henan Province is shown in table 6. The frequency of droughts at the two stations decreases in the 1970s compared with the 1960s, but the frequency of floods increases. In the 1980s, the frequency of droughts at both sites indicates an increasing trend, and the frequency of floods demonstrates a slightly decreasing trend. However, in the 1990s, the frequency of droughts still illustrates an increasing trend, and the frequency of floods shows a dramatic decrease. In the 2000s, the frequency of droughts at two stations changes little and the frequency of floods displays an increasing trend. In particular, the frequency of droughts in 2011-2015 is higher than all previous years.

It has increased by 15 percentage compared with previous decade, while the frequency of floods has only dropped by 2 percentage. In short, the frequency of drought in northern Henan Province shows an increasing trend at decadal scale, and the frequency of floods shows a decreasing trend.

3.3.3. Spatial Variation of Drought and Flood Frequency. Based on SPEI-1 drought and flood statistics at each site, the frequency of drought and flood in Henan Province over the past 55 years and the distribution of drought and flood frequencies at all levels are shown in Figure 4(a) and 4(b).

For Henan Province, the maximum frequency of drought occurred at Xinyang and Xixia station(36.36%), which was higher than the average drought frequency in the whole province (32.34%); the minimum occurred at Zhengzhou station (25.45%). The frequency of drought in northern Henan Province gradually decreased to the east, and the minimum value of drought occurred at Anyang station (29.09%). The frequency of light drought in northern Henan Province decreased from west to east, the minimum frequency of light drought was Anyang station (10.91%), the maximum frequency was located in Xinxiang (16.36%), and the frequency of middle drought is around 10.91%; the heavy drought frequency is stable at 7.27%.

In the past 55 years, the maximum flood frequency in Henan Province is located in Nanyang (47.27%), which is higher than the average flood frequency in the whole province (34.63%). The frequency of flooding in northern Henan Province remained unchanged at 32.73%. For northern Henan Province, the maximum frequency is Xinxiang station , which is 21.82% and the minimum is Anyang station, which is 16.36%; the median frequency is 9.09% at Anyang station, and the minimum is 3.64% at Xinxiang station; the frequency of heavy flood at both sites is the same, which is 7.27%.

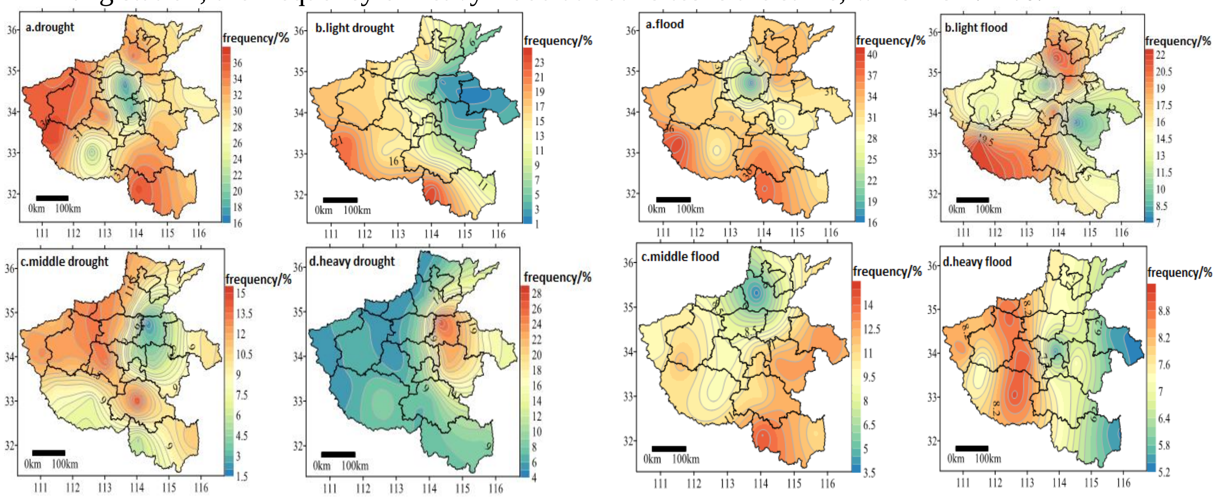


Figure 4(a). Spatial variation of drought frequency in Henan Province during 1961-2015;
4(b). Spatial variation of flood frequency in Henan Province during 1961-2015

4. Conclusions
By analyzing the spatio-temporal variations of drought and flood at different time scales and spatial ranges from 1961 to 2015 in northern Henan Province, we can draw the following conclusions:
(1) The fluctuation amplitude of SPEI value is inversely proportional to the time scale and the fluctuation period of SPEI value is proportional to the time scale. In the distribution trend of average SPEI over different time scales, SPEI-12 fluctuates the most, SPEI-6 follows by SPEI-3, and SPEI-1 fluctuates the least.
(2) The average number of consecutive drought occurrences in the north of Henan Province is 3.5 times, which Xinxiang is higher than this average from 1961 to 2015. The average number of flood occurs in northern Henan Province is 3.7 times, which Anyang is lower than this mean value. The number of consecutive droughts, floods and cumulative durations of all stations in the northern part of Henan Province tends to decrease with time.
(3) The frequency of light and middle drought is higher than heavy drought in northern Henan Province over 55 years; the frequency of light and middle flood is higher than heavy flood. From the perspective of time evolution, the frequency of middle drought in the north of Henan Province in the recent decade (2010s) is higher than that in 1960s, and the frequency of middle flood in 1960s and 1990s is higher than that in 1960s. Our findings reflect drought and flood disasters in northern Henan Province, which show an increasing trend under the background of global warming.
(4) The drought frequency at Anyang station is higher than that at Xinxiang station, the flood frequency at Xinxiang station is higher than that at Anyang. The specific geographic location and climatic conditions in the north of Henan Province have developed their obvious characteristics of spatio-temporal change of drought and flood disasters. It is different from other areas of Henan Province in term of seasonal, regional and inter-annual variations.
(5) The frequency of drought in northern Henan Province gradually decreases to the east, and the minimum value of drought occurs at Anyang station(29.09%). The frequency of flooding in the northern part of Henan Province remained unchanged at 32.73%. For northern Henan Province, the maximum frequency is Xinxiang station, which is 21.82% and the minimum is Anyang station, which is 16.36%.

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