THE EVOLUTION CHARACTERISTICS OF DROUGHT AND THE ANALYSIS OF RAINFALL INTENSITY PROBABILITY DURING ALTERNATING DRY-WET CHANGE IN THE HAIHE RIVER BASIN

ZHANG, X.[1*] – HUA, Y.[1] – FENG, J.[1*] – YAN, D.[2] – LIU, J.[2] – LI, C.[2] – CHENG, Y.[1] – REN, Q.[3]

[1]*Institute of Environmental Economics, Tianjin Polytechnic University, Tianjin 300387, China*
(e-mail: yonsionh@163.com – Y. Hua; fanxing07@126.com – Y. Cheng)

[2]*State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, 100038 Beijing, China*
(e-mail: yandh@iwhr.com – D. Yan; hettyliu@126.com – J. Liu; azhe051@163.com – C. Li)

[3]*State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A&F University, 712100 Yangling Shaanxi, China*
(e-mail: wxws.2008@163.com)

**Corresponding authors*
e-mail: xuehua671231@163.com – X. Zhang; jingfengwater@126.com – J. Feng

(Received 31st May 2018; accepted 13th Sep 2018)

Abstract. Under the impact of climate change, extreme events occur frequently and the speed of alternation of drought and flood gets faster. Based on the daily rainfall data of 42 meteorological stations for the years 1963-2013, Haihe River basin in China was divided into four sub-regions (region A, region B, region C, region D) by means of cluster analysis of the meteorological stations using the self-organizing map (SOM) neural network method. The drought index of the number of consecutive days without rainfall was used to identify the drought magnitudes and the first rainfall intensity and the maximum daily rainfall after a drought period was analyzed with the Pearson-III frequency curve, then the relationship between rainfall intensity and different drought magnitudes was observed. The results indicated that: (1) Annual rainfall reduced significantly and the drought number increased in the Haihe River basin, meanwhile the occurrence frequency of different drought level showed an overall increasing trend. This region was dominated by light drought, with the probability as 76%, while the probability of moderate drought was about 20%. The spatial difference was significant. The occurrence frequencies of moderate drought and severe drought were higher in region A. The frequency of extraordinary drought was the most in region B as 0.35%. (2) As the drought level increased, the probability of the first effective rainfall reaching heavy rain decreased in region A, region B and region C, while the probability increased in region D. With the increase of the drought number, rainfall frequency decreased and rainfall intensity enhanced obviously.
Keywords: *frequency analysis, evolution characteristics, drought, rainfall, climatic change, Haihe River basin, semi-arid area*

Introduction

Under the impact of climate change, the occurrence frequency and strength of extreme climate events, such as heavy rain, flood and drought has shown an increasing trend as a result of atmospheric circulation anomaly (Burke et al., 2001). Meanwhile, extreme drought and flood events have occurred frequently and widely in the Haihe River basin in China in recent years (Yan et al., 2013). These disasters can create the huge economic loss and the society affects, creating a new challenge for disaster risk management. Rain is a key factor in the occurrence of droughts and floods, as the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1605_63956407

variation of rainfall intensity determines the intensity and range of droughts and floods (Zavareh, 1997). With the speeding alternating drought and flood (Feng et al., 2012), there is an intensive and concentrated rainfall after a long duration of drought (Yan et al., 2013; Feng, 2014). The change of rainfall intensity after drought is the most important for water resources management.

A large number of scholars have studied the temporal and spatial evolution characteristic and driving mechanism of drought events and higher rainfall, such as the drought evaluation method based on the long series of observational rainfall data (Cancelliere et al., 2007; Łabędzki, 2010; Palmer, 1965) and hydrological frequency analysis method based on Pearson-III frequency curve (Narasimhan and Srinivasan, 2005) used to scale the drought severity. Based on the components of water cycle, drought is characterized by meteorological drought, soil moisture drought, hydrological drought, socio-economic drought and ecological drought (Tallaksen, 2009; Huijgevoort, 2012). As such a complex phenomenon, it requires multiple climatological and hydrological parameters to calculate (Mishra and Singh, 2010). Moreover, due to the arid conditions and low precipitation patterns, Haihe River basin is susceptible to drought in crop growing season. Therefore, this paper used consecutive rain-less days as the standard to identify the start and end day of drought released by the Ministry of Water Resources of the People's Republic of China. In a wide range of frequency analysis method, the Pearson-III frequency curve is the most used curve, which is widely applied in hydrological frequency analysis in China. Most studies focused on the analysis of the spatial-temporal distribution of floods and droughts, while little analysis regarding the rainfall intensity change patterns following the drought exists. Thus, this article selected the daily rainfall data of 42 representative meteorological sites in Haihe River from 1963 to 2013, and the basin was divided into four sub-regions by SOM neural network method. The drought index of continuous rain-less day was used to determine the drought degree. The first effective daily rainfall and the maximum daily rainfall following the drought were analyzed with the Pearson-III frequency curve, and then the relationship between rainfall and drought magnitudes was shown.

Materials and methods

Description of the study area

The Haihe River basin includes Beijing, Tianjin, Hebei, Shanxi, Shandong, Henan, Inner Mongolia, Liaoning provinces and is located within the geographic coordinates of 112°-120°E and 35°-43°N. The total area of the basin is 318,000 km^2, including the mountainous area of 189,000 km^2 and the plain area of 129,000 km^2. This basin belongs to the temperate zone and semi-humid continental climate. Annual rainfall is 536 mm and it shows a negative trend. It suffers from drought risk frequently in China. Annual rain is mainly concentrated in the summer monsoon season and average monthly rainfall between June and August accounts for 50-75% of annual rainfall. In particular, heavy rain mostly occurs in July and August, leading to flood as one of the most water logging areas. The flood frequency between 1970 and 1994 is more than 45 times in the basin. The frequent drought and flood disasters are attributed to uneven seasonal distribution of rainfall and its inter-annual variability, which directly affects the sustainable development and property safety.

In this paper, the rainfall data for 42 meteorological stations with continuous observation series in and around the Haihe River basin for the years 1963 to 2013

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1605_63956407

provided by China National Climate Center were selected to analyze the drought and higher rainfall. The numbers of consecutive days without rainfall for both inter-annual and inter-decadal periods were determined.

Clustering methods of SOM and division

Due to the geographical position of the meteorological stations, the altitude and rainy features differ throughout the basin. Thus, meteorological stations within the basin with similar features require the clustering analysis. In this paper, the longitude and latitude of each meteorological station, as well as their respective altitudes and annual mean rainfall were selected for the cluster analysis by the SOM (self-organizing map) neural network algorithm.

A homogeneous area refers to the rainy characteristics of various meteorological sites in the area that are similar and their spatial distribution is even (Gwo-Fong and Lu-Hsien, 2006). The result of regional frequency analysis is representative and credible if the stations in the region belong to a homogeneous area. Using rainfall data for meteorological stations in the homogenous area is more accurate than using rainfall data at single station to analyze regional frequency. Therefore, the SOM neural network algorithm was selected to process the rainy data of 42 meteorological sites and Haihe River basin was divided according to the clustering results.

This article selected the longitude (m), latitude (m), the average annual rainfall (mm), 5-9 monthly rainfall (mm) as eight variables on behalf of regional rainy characteristics, and carried on the normalized processing. Training steps directly influence the performance of the SOM neural network clustering. The greater the training steps are, the more precise classifications are. This article carried on the classification of 42 meteorological sites in the basin and the basin was divided into four regions based on the cluster result with training steps as 2. The results of spatial classification were shown in *Table 1* and the locations of these stations were shown in *Figure 1*.

Drought magnitude standards

Less rain or no rain for a long time lead to drought and no effective continuous rainfall days are used to characterize the drought magnitude in crop growing season. Consecutive rainless days refer to the number of consecutive days without rainfall. Based on the standard of the classification for drought severity released by the Ministry of Water Resources of the People's Republic of China, the drought evaluation criteria are shown in *Table 2* as follows: If consecutive rain-less days last for 15 to 30 days, it belongs to the light drought; If consecutive rain-less days last for 31 to 50 days in a row, it belongs to the moderate drought; If consecutive rain-less days last for 51 to 75 days, it belongs to severe drought; If consecutive rain-less days exceed 75 days, it belongs to the extraordinary drought.

Table 1. *Cluster results of meteorological stations in and around Haihe River Basin*

Subarea	Meteorological stations
Region A	53399, 53478, 53487, 53593, 53663, 53673, 54208, 54308, 54311, 54401, 54405, 54423, 54511, 54518, 54527, 54602, 54606, 54618
Region B	53588, 53698, 53782, 53787, 53798, 53898, 53986, 54705, 54808, 54823, 54906, 57083
Region C	54416, 54429, 54436, 54449, 54534, 54539, 54616, 54623, 54624
Region D	54714, 54715, 54725

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1605_63956407

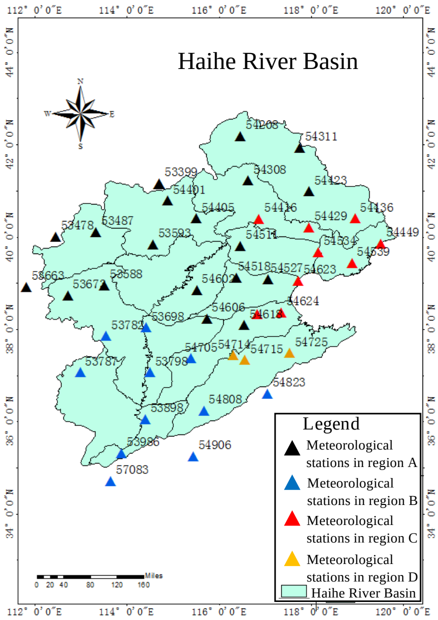

Figure 1. *Locations of meteorological stations in and around Haihe River Basin*

Table 2. *Drought classifications derived from continuous non-effective rainy days*

Drought classification	Continuous non-effective rainy days (d)
No drought	<15
Mild drought	15~30
Moderate drought	31~50
Severe drought	51~75
Extreme drought	>75

Pearson-III frequency curve

Pearson-III frequency distribution model has been widely applied in the field of hydrology and meteorology. This distribution is the third of 13 types of distribution curves which is put forward by the British biologist Pearson. Pearson-III frequency curve is asymmetric unmoral and skew normal distribution curve which one end is limited and the other end is unlimited. It refers to gamma distribution and the probability density function is as follows (*Eq. 1*):

$$f(x)=\frac{\beta^{\alpha}}{\Gamma(\alpha)}(x-b)^{\alpha-1}e^{-\beta(x-b)}(b\le x<\infty) \qquad \text{(Eq.1)}$$

Where $\Gamma(\alpha)$ is gamma function, $\Gamma(\alpha)=\int_0^{\infty}x^{\alpha-1}e^{-x}dx;\alpha,\beta>0$. Three original parameters *α, β, b* can be converted appropriately, and can be shown as three statistical parameters $\bar{x}$, C_v, C_s (*Eqs. 2, 3* and *4*):

$$\alpha=\frac{4}{C_S^2} \qquad \text{(Eq.2)}$$

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1605_63956407

$$\beta = \frac{2}{\bar{x} C_V C_S} \quad \text{(Eq.3)}$$

$$b = \bar{x}(1 - \frac{2C_v}{C_S}) \quad \text{(Eq.4)}$$

where C_v is dispersion coefficient; C_S is deviation factor; $\bar{x}$ is the average. The three statistical parameters can be determined primarily by the moment's method. Moment method is used to calculate the three statistical parameters of the formula which is as follows (*Eqs. 5, 6* and *7*):

$$\bar{x} = 1/n \sum x_i \quad \text{(Eq.5)}$$

$$C_V = \sqrt{\frac{\sum (k_i - 1)^2}{n-1}} \quad \text{(Eq.6)}$$

$$C_s = \frac{\sum (k_i - 1)^3}{(n-3) C_v^3} \quad \text{(Eq.7)}$$

Adding these undetermined parameters into the equations of Pearson-III type curve, the equation is written as (*Eq. 8*):

$$y = f(\bar{x}, C_v, C_s, x) \quad \text{(Eq.8)}$$

The division of rainy intensity

According to the national 24-h rainfall standard, rainfall is divided into light rain, moderate rain, heavy rain, rainstorm, heavy rainstorm and extraordinary rainstorm. If total rainfall during 24 h is less than 10.0 mm, it is light rain; if between 10.0 and 24.9 mm, it is moderate rain; if between 25.0 and 49.9 mm, it is heavy rain; if between 50.0 and 99.9 mm, it is rainstorm; if between 100.0 and 249.0 mm, it is heavy rainstorm; if more than 250.0 mm, it is extraordinary rainstorm. Considering water availability, light rain and heavy rainstorm are not effectively used for crops and sometimes cause natural disasters. Thus, in the paper, only effective rainfall (including moderate rain, heavy rain, rainstorm) was use to analyze its relationship between drought.

Results and discussion

The analysis of drought in the Haihe River basin

Time evolution characteristic of droughts

According to no effective rainy days in a row, the sum of the drought frequency in different regions in the Haihe River basin was calculated. The results indicated that drought frequency showed an increasing trend in the Haihe River basin from 1963 to 2013. The total drought frequency increased at a rate of 2.23% per year in 18 meteorological stations of region A, the total drought frequency increased at a rate of

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1605_63956407

about 7.8% per year in 12 meteorological stations, 8.9% per year in 9 meteorological stations, 2.5% per year in 3 meteorological stations, respectively in region B, region C and region D. Drought frequency increased notably in region A, while it increased more slowly in region D. Region A was the economic society center of the basin, and the increase of no-rainfall day seriously affected the crop growth and the social and economic development.

Space evolution characteristic of droughts

According to no effective rainy days, the drought frequency in four areas under different drought degree was calculated between 1963 and 2013 as shown in *Table 3*. It could be seen that region A, region B, region C and region D were all given priority to light drought which accounted for about 75% of the total number of drought, the second was moderate drought, and the probability of extraordinary drought occurred least. The probability of moderate drought and severe drought in region A was higher than that of region B, C and D, and the probability of extraordinary drought was the largest in region B with 0.35%.

Table 3. *The proportion of different drought numbers of regional total numbers during 1963 to 2013*

Drought degree	**Region A**		**Region B**		**Region C**		**Region D**	
	Frequency	**Proportion (%)**	**Frequency**	**Proportion (%)**	**Frequency**	**Proportion (%)**	**Frequency**	**Proportion (%)**
Light drought	2468	74.70%	1748	76.23%	1277	78.15%	464	76.07%
Moderate drought	692	20.94%	452	19.71%	300	18.36%	125	20.49%
Severe drought	133	4.03%	85	3.71%	55	3.37%	21	3.44%
Extraordinary drought	11	0.33%	8	0.35%	2	0.12%	0	0

The analysis of rainfall frequency after drought in Haihe River basin

The frequency of multi-yearly mean effective rainfall

Only effective rainfall is available for crops. Thus, the paper used the Pearson-III curve to only analyze the frequency of multi-yearly mean effective rainfall in each subarea of the Haihe River basin, and the probability of the moderate rain to heavy rain was calculated but probably sum of rainfall percentage within a region was less than 100%. According to Pearson-III frequency curve, the probability of the multi-yearly mean effective rainfall was different and the results were illustrated in *Table 4*.

Table 4. *The frequency of multi-yearly mean effective rainfall in different areas*

Subarea	**Moderate rain (%)**	**Heavy rain (%)**	**Rainstorm (%)**	**Heavy rainstorm (%)**
Region A	9.65	2.24	0.2	0
Region B	12.57	3.78	0.54	0.02
Region C	15.3	5.54	1.1	0.06
Region D	13.99	4.82	0.88	0.04

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1605_63956407

The probability of moderate rain, heavy rain, rainstorm and heavy rainstorm was 9.65%, 2.24%, 0.2% and 0 for region A, 12.57%, 3.78%, 0.54% and 0.02% for region B, 15.3%, 5.54%, 1.1% and 0.06 for region C, 13.99%, 4.82%, 0.88% and 0.04% for region D, respectively.

The frequency of the first effective rainfall after different drought degrees

This paper used consecutive rain-less days as drought standard and the first effective rainfall after drought period to represent the rainfall intensity at the end of the drought. The crop growing season in Haihe River basin was from May to September and in the periods the droughts and floods occurred frequently, causing disasters for the most important cash crop of summer corn growing. Thus, the first effective rainfall after different drought degrees during the growing season of crops was calculated. For further analysis, Pearson-III was used to analyze the frequency of the first effective rainfall after drought with different magnitudes in each subarea.

This paper only took region A as an example to analyze the first effective rain frequency after different drought degrees. *Figure 2* listed the Pearson-III curve after different droughts for region A. The results were as follows: The probability of moderate rain, heavy rain, rainstorm and heavy rainstorm after light drought were 39.02%, 9.65%, 1.26% and 0.33%, respectively shown in *Figure 2a*. From the Pearson-III curve for moderate drought in *Figure 2b*, it illustrated that the respective probabilities of moderate rain, heavy rain, rainstorm and heavy rainstorm were 40.85%, 8.28%, 0.7% and 0.13%. As shown in *Figure 2c* of the Pearson-III curve for severe drought, the respective probabilities of moderate rain, heavy rain, rainstorm and heavy rainstorm were 38.06%, 9.28%, 1.17% and 0.3%. From the Pearson-III curve of extraordinary drought in *Figure 2d,* the respective probabilities of moderate rain, heavy rain, rainstorm and heavy rainstorm were 50.25%, 7.97%, 0.12% and 0.

The rainfall frequencies after drought with different magnitudes in the other subareas for the years 1963-2013 were shown in *Table 3*. We presented the frequency of first effective rainfall after a drought period in sub-areas in *Table 5*. The effective rainfall did not include light rain (total rainfall during 24 h is less than 10.0 mm) and extraordinary rainstorm (total rainfall during 24 h is more than 250.0 mm), which could not been used and managed effectively for crops in growing seasons. Thus, the sum of frequency in different clusters was less than 100% within one region in case of all drought degrees.

From *Table 3* it was concluded that in region A, for the light and moderate drought, the occurrence frequency of moderate rain increased, then reduced and finally increased. The probability of moderate rain was the maximum after extraordinary drought at 50.25%, while the frequency for heavy rain first reduced, then increased and finally reduced, and the frequency for heavy rain was the least after extraordinary drought. In region B, for the light and moderate drought, the frequency for moderate rain decreased continuously, while the probability of rainfall after drought was higher than region A. In region C, for the the light and moderate drought, the occurrence frequency for moderate rain increased, while for the extraordinary drought, the occurrence frequency for moderate rain increased obviously. In region D, for the light and moderate drought, occurrence frequency of moderate rain increased significantly and the occurrence frequency for heavy rain first reduced, then increased and finally reduced. The probability of flood disaster of the first effective rainfall after severe drought was the most in region D.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1605_63956407

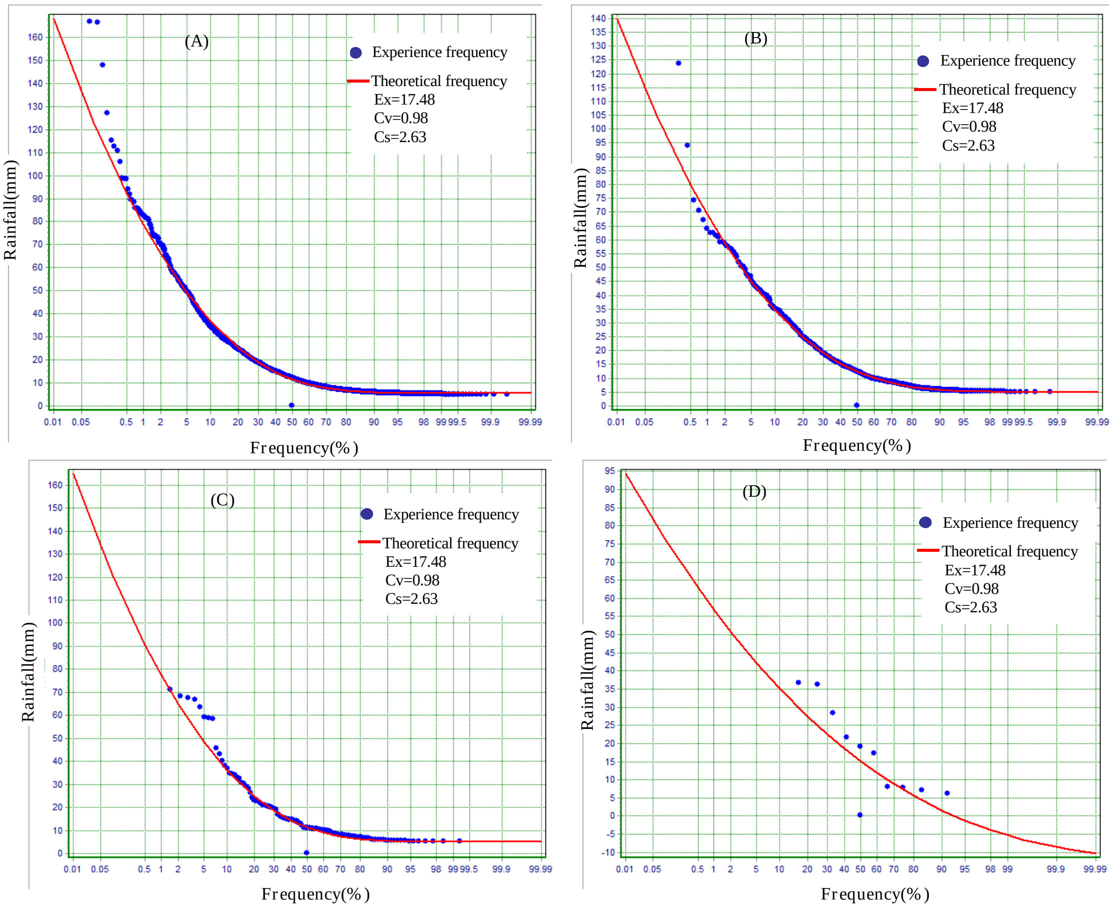

Figure 2. *Frequency of the first effective rainfall after different droughts in region A (a: light drought; b: moderate drought; c: severe drought; d: extraordinary drought)*

Table 5. *The frequency of the first effective rainfall after drought in subareas*

Subarea	Drought degree	Moderate rain (%)	Heavy rain (%)	Rainstorm (%)	Heavy rainstorm (%)
Region A	Light drought	39.02	9.65	1.26	0.33
	Moderate drought	40.85	8.28	0.7	0.13
	Heavy drought	38.06	9.28	1.17	0.3
	Extraordinary drought	50.25	7.97	0.12	0
Region B	Light drought	49.44	19	3.6	1.29
	Moderate drought	49.11	15.27	2.62	0.8
	Heavy drought	43.63	8.33	0.53	0.08
	Extraordinary drought	35.09	0.5	0	0
Region C	Light drought	46.91	15.1	2.94	1
	Moderate drought	39.38	9.32	1.1	0.27
	Heavy drought	60.69	17.24	1.4	0.22
Region D	Light drought	52.09	17.33	3.27	1.07
	Moderate drought	54.24	12.99	1.17	0.22
	Heavy drought	66.01	28.47	5.32	1.51

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1605_63956407

In summary, from the analysis of the probability of the first effective rainfall after the different degrees of drought, it was concluded that with the increase in drought magnitude, the probability of extraordinary rainstorm, in the Haihe River basin became lower in region A, region B and region C, however, the probability of extraordinary rainstorm increased in region D. With the increase in drought magnitude, the probability of different degrees of rainfall in different areas showed different trends. In region A, for the light and moderate drought, the occurrence frequency for moderate rain first reduced, then increased and finally reduced. In contrary, for region B, it showed a continuously decreasing trend. In region C and D, for the light drought and moderate drought, the occurrence frequency for moderate rain first reduced and then increased.

Compared with the probability of multi-yearly mean effective rainfall, it presented that the probabilities of moderate rain, heavy rain, rainstorm, heavy rainstorm were 9.65%, 2.24%, 0.2% and 0, respectively in region A. However, the respective probabilities of moderate rain, heavy rain, rainstorm, heavy rainstorm of the first effective rainy after light drought were 39.02%, 9.65%, 1.26% and 0.33%, the respective probabilities of moderate rain, heavy rain, rainstorm, heavy rainstorm of the first effective rainfall after moderate drought were 40.85%, 8.28%, 0.7% and 0.13%, those of the first effective rainfall after severe drought were 38.06%, 9.28%, 1.17% and 0.3% and after extraordinary drought were 50.25%, 7.97%, 0.12% and 0. The probability of the first effective rainy after drought was relatively higher than that of multi-yearly mean effective rainfall in region B, region C and region D. The results showed that the probability of heavy rain for the first effective rainfall after drought was strongly higher and it was easy to suffer flood disaster after droughts.

The frequency of maximum daily rainfall after different drought degrees

Pearson-III curve was used to analyze the frequency of the maximum daily rainfall after droughts with different magnitudes in each subarea of the Haihe River basin. The results of the frequency of maximum daily rainfall after droughts in region A were presented in *Figure 3*. Based on the Pearson-III curve of light drought, the probability of moderate rain was 62.47%, that of heavy rain was 23.96%, that of rainstorm was 5.19% and that of heavy rainstorm was 1.83%, respectively. For the moderate drought, the respective probabilities of moderate rain, heavy rain, rainstorm and heavy rainstorm reached 58.2%, 23.73%, 6.48% and 2.76%. For the Pearson-III curve of severe drought, the respective probabilities of moderate rain, heavy rain, rainstorm and heavy rainstorm were 72.02%, 35.61%, 10.17% and 4.17%. Moreover, for the Pearson-III curve of extraordinary drought, the respective probabilities of moderate rain, heavy rain, rainstorm and heavy rainstorm were 81.75%, 60.46%, 23.64% and 8.81%, respectively.

The rainfall frequencies after drought with different magnitudes in the other subareas for the years 1963-2013 were listed in *Table 6*. In this table, it was concluded that in region A, for the light drought and moderate drought, the occurrence frequency for moderate rain first reduced then increased and the frequency for rainstorm increased continuously. In region B, for the light drought, moderate drought and severe drought, the occurrence frequency for moderate rain decreased continuously. On the contrary, the occurrence frequency for rainstorm increased obviously after moderate drought. With the increase of drought degree, the occurrence frequency for heavy rain increased significantly. In region C, for the light drought magnitude, the occurrence frequency for heavy rain decreased continuously. With the increase of drought degree, the occurrence frequency for moderate rain increased significantly. Region D showed the same trend as region C.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1605_63956407

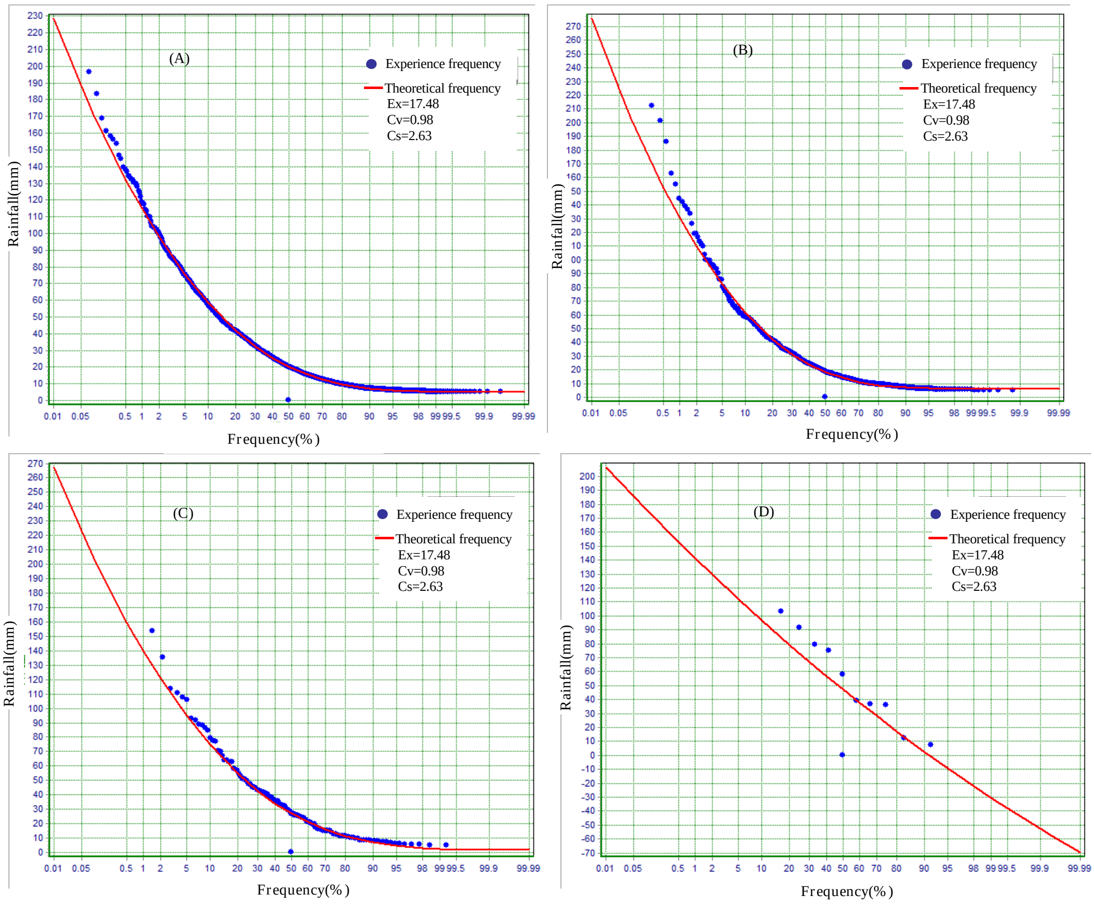

Figure 3. *Frequency of maximum daily rainfall after different droughts in region A (a: light drought; b: moderate drought; c: severe drought; d: extraordinary drought)*

Table 6. *The frequency of the maximum daily rainfall after different drought magnitude in subareas*

Subarea	Drought degree	Moderate rain (%)	Heavy rain (%)	Rainstorm (%)	Heavy rainstorm (%)
Region A	Light drought	62.47	23.96	5.19	1.83
	Moderate drought	58.2	23.73	6.48	2.76
	Heavy drought	72.02	35.61	10.17	4.17
	Extraordinary drought	81.75	60.46	23.64	8.81
Region B	Light drought	71.66	35.43	11.13	5.01
	Moderate drought	67.56	34.29	12.49	6.4
	Heavy drought	66.47	31.94	8.77	3.5
	Extraordinary drought	77.01	47.16	17.39	8.15
Region C	Light drought	70.52	38.91	15.78	8.64
	Moderate drought	60.66	30.61	12.08	6.67
	Heavy drought	77.02	46.26	17.84	8.91
Region D	Light drought	72.08	37.39	12.31	5.67
	Moderate drought	66.1	31.21	10.15	4.81
	Heavy drought	81.45	54.03	22.39	11.25

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1605_63956407

Generally, from the analysis of the probability of the maximum daily rainfall after different droughts, it was concluded that with the increase in drought magnitude, the probability of heavy rainstorm after drought increased. However, with the increase in drought magnitude, the probability of different degrees of rainfall in different areas showed different characteristics. The whole trend showed that for the light and moderate drought magnitude, the occurrence frequency for moderate rain first reduced and then increased in the four subareas for region A, region B, region C and region D generally. The probability of rainfall after moderate drought was lower than other degree of drought in region A, region C and region D, while the probability of rainfall after severe drought was notably lower than other degree of drought in region B.

Compared with the probability of multi-yearly mean effective rainfall in *Table 2*, the results indicated that the respective probabilities of moderate rain, heavy rain, rainstorm, heavy rainstorm were 9.65%, 2.24%, 0.2% and 0 in region A for the multi-yearly average. However, the respective probabilities of moderate rain, heavy rain, rainstorm, heavy rainstorm of the maximum daily rainfall after light drought could reach up to 62.47%, 23.96%, 5.19% and 1.83%, those after moderate drought 58.2%, 23.73%, 6.48% and 2.76%, those after severe drought 72.02%, 35.61%, 10.17% and 4.17% and those after extraordinary drought 81.75%, 60.46%, 23.64% and 8.81%, respectively, in *Table 4*. Furthermore, in the same way, the probability of the maximum daily rainfall after drought was significantly higher than multi-yearly mean effective rainfall in region B, region C and region D. The results showed that the probability of heavy rain for the maximum daily rainfall after drought was higher and the region there was more vulnerable to suffer flood disaster after drought.

Conclusions

In recent years, extreme climatic events such as alternating droughts and floods, sharp transitions between droughts and floods, and floods following extreme droughts, have been a research hotspot. This paper analyzed the relationship between drought and rainfall intensity through the rainfall frequency after different drought magnitudes based on the daily rainfall data from 42 stations for the years 1963-2013 in the Haihe River basin in northern China. The conclusions were as follows:

(1) Annual rainfall showed a dramatical reduction trend in the Haihe River basin and drought frequency increased. The result was consistent with the finding that the mean values of daily precipitation declined, and its fluctuation became weak with years by Sang (2014). Drought numbers for region A increased the most at a rate of about 0.223 times per year. The region was dominated by light drought. The probability of light drought and moderate drought were 76% and 20%, while that of extraordinary drought was the least.

(2) With the increase in drought magnitude, the probability of extraordinary rainstorm of the first effective rainfall became lower in region A, region B and region C, however, the probability of extraordinary rainstorm increased in region D. And with the increase of drought degree, the probability of extraordinary rainstorm of the maximum rainfall in A, B, C, D four regions increased significantly. Compared with the probability of multi-yearly mean effective rainfall, the probability of heavy rain to heavy rainstorm of the first effective rainfall was 4 to 5 times than the multi-yearly mean effective rainfall and the probability of heavy rain to heavy rainstorm of the maximum rainfall was 9 to 10 times than the multi-yearly mean effective rainfall.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1605_63956407

Based on the frequency levels of different rainfall after different droughts in the region, we evaluated that more rainfall happened after higher drought and a dry-wet alternation happened frequently. With the increase of the drought numbers, rainfall frequency decreased and the rainfall intensity enhanced obviously. This result was consistent with the findings of Zhang (2014) that the frequency of extreme precipitation was decreasing, but the intensity of extreme precipitation was increasing in the Huang-Huai-Hai River basin, and moreover, the probability distribution functions of simple daily intensity index and consecutive dry days were positively shifted while the rest of the indices were negatively shifted. Because the flood in the basin was primarily caused by the intensive heavy rainstorm, the Haihe River basin was in higher frequency of simultaneous flood and drought disasters and more vulnerable to the impact of climatic change.

Acknowledgments. The authors acknowledge the National Social Science Fund of China (18BJY079) and the Training Plan for Innovation Teams in Tianjin Colleges and Universities (TD13-5038).

REFERENCES

[1] Burke, E. J., Brown, S. J., Christidis, N. (2001): Modeling the recent evolution of global drought and projections for the twenty-first century with the Hadley centre climate model. – J. Hydrometeorol. 7(5): 1113.

[2] Cancelliere, A., Mauro, G. D., Bonaccorso, B. G. et al. (2007): Drought forecasting using the 15 standardized precipitation index. – Water Resour. Manage. 21: 801-819.

[3] Feng, J., Yan, D., Li, C. (2012): General framework and key issues concerning integrated strategies for coping with drought and flood in China in a changing environment. – Natural Hazards 64(1): 577-592.

[4] Feng, J., Yan, D., Li, C., Gao, Y., Liu, J. (2014): Regional frequency analysis of extreme precipitation after drought events in the Haihe River basin, Northwest China. – J. Hydrol. Eng. 19(6): 1101-1112.

[5] Gwo-Fong, L., Lu-Hsien, C. (2006): Identification of homogeneous regions for regional frequency analysis using the self-organizing map. – J. Hydrol. 324: 1-9.

[6] Huijgevoort, M. H. J. V., Hazenberg, P., Lanen, H. A. J. V. et al. (2012): A generic method for hydrological drought identification across different climate regions. – Hydrol. Earth Syst. Sci. 16(8): 2437-2451.

[7] Łabędzki, L. (2010): Estimation of local drought frequency in central Poland using the standardized precipitation index SPI. – Irrigat. Drain. 56(1): 67-77.

[8] Mishra, A. K., Singh, V. P. (2010): A review of drought concepts. – J. Hydrol. 391: 202-216.

[9] Narasimhan, B., Srinivasan, R. (2005): Development and evaluation of soil moisture deficit index (SMDI) and evapotranspiration deficit index (ETDI) for agricultural drought monitoring. – Agric. Forest Meteorol. 133(1): 69-88.

[10] Palmer, W. C. (1965): Meteorological Drought. – Research Paper No. 45. U. S. Weather Bureau, Washington, DC, pp. 45-58.

[11] Sang, Y. F., Wang, Z., Liu, C. (2014): Spatial and temporal variability of precipitation extrema in the Haihe River basin, China. – Hydrol. Processes 28(3): 926-932.

[12] Tallaksen, L. M., Hisdal, H., van Lanen, H. A. J. (2009): Space-time modelling of catchment scale drought characteristics. – J. Hydrol. 375: 363-372.

[13] Yan, D. H., Wu, D., Huang, R., Wang, L. N. (2013): Drought evolution characteristics and precipitation intensity changes during alternating dry-wet

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1605_63956407

changes in the Huang-Huai-Hai River basin. – Hydrol. Earth Syst. Sci. Discuss. 17(7): 2859-2871.
[14] Zavareh, K. (1997): Extreme precipitation events and the applicability of global climate models to the study of floods and droughts. – Mathematics and Computers in Simulation (43): 261-268.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1605_63956407