Postprint of Copula-Based Drought Hazard Assessment in the Beijing-Tianjin-Hebei Region over the Past 60 Years

Authors: Li Qian, Wang Ying, Xu Yingjun, Yu Haiyang, Long Shuang, Huang Jingling, Yingjun Xu

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Abstract

Drought disaster constitutes one of the primary meteorological hazards in the Beijing-Tianjin-Hebei region, profoundly impacting socioeconomic development and food security. Assessing drought disaster risk in this region and identifying high-risk zones aims to provide scientific references for disaster prevention and emergency management. Utilizing daily precipitation data from 37 meteorological stations spanning 1958–2017, the Standardized Precipitation Index (SPI6) was computed, and run theory was employed to define drought duration and drought intensity. The Kolmogorov-Smirnov (K-S) test and Akaike Information Criterion (AIC) method were respectively applied to determine the optimal marginal distribution functions and Copula function for these indicators, thereby calculating return periods of drought intensity and drought duration at the 5-year, 10-year, 30-year, and 50-year return levels. The results demonstrate that SPI6 in the Beijing-Tianjin-Hebei region has exhibited a declining trend since the mid-1960s; the exponential distribution and generalized extreme value distribution represent the optimal marginal distributions for drought duration and drought intensity, respectively, while Frank Copula demonstrates the best fit for modeling the joint probability distribution; regarding joint return periods of drought duration and intensity, areas including Beijing, Cangzhou, Hengshui, and northern Chengde exhibit longer return periods and thus lower risk at the 30-year and 50-year levels, whereas other regions demonstrate higher risk; and theoretical values of joint return periods for station-based drought disasters align well with actual observations, effectively reflecting real-world disaster conditions.

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Full Text

Preamble

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Authors: LI Qian[1,3], WANG Ying[1,2,3], XU Ying-jun[1,2,3], YU Hai-yang , LONG Shuang[1,3], HUANG Jing-ling[1,3]

Affiliations:
[1] Key Laboratory of Environment Change and Natural Disaster, Ministry of Education, Beijing Normal University, Beijing 100875, China
[2] State Key Laboratory of Earth Surface Processes and Resources Ecology, Beijing Normal University, Beijing 100875, China
[3] Faculty of Geographical Science, Beijing Normal University, Beijing 100875, China
Hebei Meteorological Disaster Prevention Center, Shijiazhuang 050021, China

Corresponding Author: E-mail: liqian@mail.bnu.edu.cn

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1. Introduction and Methods

1.1 Study Area and Data

The Beijing-Tianjin-Hebei region is located between 113°04 –119°53 E and 36°01 –42°37 N, covering an area of approximately 93,825 km^2 with a population of 1.11×10 and GDP of 8.2559×10^{12} yuan (2017 data). The region faces serious drought risks that threaten economic development and food security.

Based on precipitation data from 37 meteorological stations during 1958–2017, we calculated the 6-month Standardized Precipitation Index (SPI6). Drought duration and severity were identified using run theory, with drought events defined as periods where SPI6 -0.5. The run theory identifies drought characteristics through three key parameters: drought duration (D), severity (S), and intensity (I). Specifically, when SPI6 falls below -1.0, it marks the beginning of a drought event; when SPI6 rises above -0.5, the event ends. The cumulative SPI6 value during the event represents drought severity, while intensity is calculated as severity divided by duration.

1.2 Methodology

Marginal Distribution Fitting: We employed the Kolmogorov-Smirnov (K-S) test to evaluate the goodness-of-fit for marginal distributions. Candidate distributions included exponential, gamma, Weibull, log-normal, and generalized extreme value (GEV) distributions. The Akaike Information Criterion (AIC) was used for optimal distribution selection:

$$AIC = n \log(\sqrt{MSE}) + 2l$$

where n is sample size, MSE is mean squared error, and l is the number of parameters.

Copula Functions: Archimedean Copulas were selected for constructing joint distributions due to their flexibility and computational efficiency. Three bivariate Archimedean Copulas were evaluated: Clayton, Frank, and Gumbel (Table 2). The Frank Copula demonstrated the best performance based on AIC criteria and was used for subsequent analysis.

Joint Return Period: The joint return period of drought duration and severity was calculated using:

$$T(s,d) = \frac{1}{P(S \geq s \cup D \geq d)} = \frac{1}{1 - C(F_S(s), F_D(d))}$$

where C is the Copula function, and $F_S(s)$ and $F_D(d)$ are marginal cumulative distribution functions of severity and duration, respectively.

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2. Results and Analysis

2.1 Temporal Variation of SPI6

During 1958–2017, the SPI6 showed a downward trend from the mid-1960s to present, indicating increasing drought severity. Mann-Kendall test detected significant abrupt changes around 1964–1966 and during the 1990s. The region experienced 166 drought events (SPI6 -0.5), with the most severe droughts occurring in 1965, 1972, 1980–1981, 1997–1998, and 2014–2015.

[Figure 5: see original paper] shows the Mann-Kendall test results for SPI6 abrupt change analysis. The period 1958–1977 was characterized by frequent, short-duration droughts, while 1978–1997 saw moderate drought events. Since 1998, the region has experienced prolonged, severe droughts with higher intensity.

2.2 Copula Function Selection

The K-S test confirmed that drought duration follows an exponential distribution, while drought severity follows a generalized extreme value distribution. Among the three Archimedean Copulas, the Frank Copula yielded the lowest AIC value (FIGURE:7), indicating the best fit for modeling the joint distribution of drought duration and severity.

2.3 Joint Return Period Analysis

Joint return periods were calculated for four scenarios: 5-year (RP5a), 10-year (RP10a), 30-year (RP30a), and 50-year (RP50a) return periods (TABLE:4, TABLE:5). Results show:

- **Short return periods (5a, 10a):** Beijing, Cangzhou, Hengshui, and northern Chengde exhibit relatively long joint return periods (low hazard), with values of 4.78–8.41 years for drought duration and 5.31–7.50 for severity.
- **Long return periods (30a, 50a):** The same regions show joint return periods of 10.82–21.16 years for duration and 14.76–83.24 for severity, indicating lower drought risk compared to other areas.

The joint return period provides a more comprehensive risk assessment than univariate analysis, as it simultaneously considers both drought duration and severity. The theoretical joint return periods closely match historical drought disasters (e.g., the 2015 drought event), validating the model' s reliability.

2.4 Spatial Distribution of Drought Hazard

[Figure 9: see original paper] illustrates the spatial patterns of joint return periods across the region. Areas with shorter joint return periods (higher hazard) are concentrated in Zhangjiakou, Baoding, Shijiazhuang, and Handan, where both drought duration and severity exhibit high values. In contrast, coastal areas (Tangshan, Qinhuangdao) and parts of Beijing show longer return periods, indicating lower hazard.

The 50-year return period map reveals that most of Hebei Province faces moderate to high drought hazard, with joint return periods for severity exceeding 20 years in over 60% of the region. This suggests that extreme drought events pose significant risks to water resources and agricultural production.

References

[?] Zhang Liyang, Yang Dong, Ma Lu. Characteristics of meteorological drought in the Beijing-Tianjin-Hebei area and cause analysis. *Journal of Hydroelectric Engineering*, 2017, 36(12): 28-38.

[?] Liu X, Wang S, Zhou Y, et al. Spatial analysis of meteorological drought return periods in China using Copulas. *Natural Hazards*, 2016, 80(1): 367-388.

[?] Ganguli P, Reddy M J. Risk assessment of droughts in Gujarat using Bivariate Copulas. *Water Resources Management*, 2012, 26(11): 3301-3327.

[?] Liu X, Wang S, Zhou Y, et al. Spatial analysis of meteorological drought return periods in China using Copulas. *Natural Hazards*, 2016, 80(1): 367-388.

[?] Han Haitao, Hu Wenchao, Chen Xuejun, et al. Application and comparison of three meteorological drought indices. *Agricultural Research in the Arid Areas*, 2009, 27(1): 237-241.

[?] Chen L, Singh V P, Guo S, et al. Drought analysis using Copulas. *Journal of Hydrologic Engineering*, 2013, 18(7): 797-808.

[?] Li Ming, Zhang Yongqing, Zhang Lianzhi. Analysis of drought characteristics of Changchun City in 106 years based on Copula function. *Journal of Arid Land Resources and Environment*, 2017, 31(6): 147-153.

[?] Shiau J, Feng S, Nadarajah S. Assessment of hydrological droughts for the Yellow River, China, using Copulas. *Hydrological Processes*, 2007, 21(16): 2157-2163.

[?] Liu C, Zhang Q, Singh V P, et al. Copula-based evaluations of drought variations in Guangdong, south China. *Natural Hazards*, 2011, 59(3): 1533-1546.

[?] Li Tianshui, Wang Shun, Zhuang Wenhua, et al. Application of the theory of run and Copula function to the joint distribution of two-dimension drought variables. *Journal of Arid Land Resources and Environment*, 2016, 30(6): 77-82.

[?] Weng B, Zhang P, Li S. Drought risk assessment in China with Copulas. *Arabian Journal of Geosciences*, 2015, 8(12): 10193-10202.

[?] Wang Hong, Yu Jinhua, Li Zongtao. Spatial-temporal characteristics of drought in Hebei Province in recent 49 years. *Scientia Geographica Sinica*, 2016, 36(1): 149-156.

[?] Liao Yaoming, Zhang Cunjie. Spatio-temporal distribution characteristics and disaster change of drought in China based on meteorological drought composite index. *Meteorological Monthly*, 2017, 43(11): 1402-1409.

[?] Li Shuangshuang, Yang Saini, Liu Yanxu, et al. Spatio-temporal clustering characteristics of drought, heavy rain and hot waves in the Beijing-Tianjin-Hebei Region during 1960-2013. *Scientia Geographica Sinica*, 2016, 36(1): 149-156.

[?] Zhang Jinlong, Liu Xuefeng, Yu Changwen. Analysis on distribution and variation of drought in Hebei Province. *Arid Zone Research*, 2012, 29(1): 41-46.

[?] Zhang Jing, Liang Shubo, Xu Xiaoguang, et al. Temporal and spatial distribution characteristics of droughts for recent 50 years in Hebei Province based on meteorological drought composite index. *Resources Science*, 2012, 34(6): 1089-1094.

[?] Li Ying, Feng Yu, Tang Weinan, et al. Analysis of agricultural meteorological drought disaster around western Liaoning Province based on Copula function. *Agricultural Research in the Arid Areas*, 2018, 36(2): 279-287.

[?] Yan Feng, Wang Yanjiao, Wu Bo. Spatial and temporal distributions of drought in Hebei Province over the past 50 years. *Geographical Research*, 2010, 29(3): 423-430.

Abstract

Drought disaster is one of the major meteorological disasters in the Beijing-Tianjin-Hebei region, China, with serious economic and food security impacts. The hazard of drought disasters is evaluated to identify the high hazard areas, and provide references for disaster prevention and emergency control. Based on the precipitation data of 37 meteorological stations from 1958 to 2017, the standardized precipitation index at 6-month scale (SPI6) is calculated. Drought duration and severity are defined using run theory. We use the Kolmogorov-Smirnov method and AIC method to confirm the most fitted marginal distributions and the Copula function. The return periods of drought duration and severity are calculated under different return periods (RP5a, 10a, 30a, 50a). The results show that SPI6 is in a downward trend from the mid-1960s to current times. The exponential distribution and the generalized extreme value distribution are the optimal marginal distributions of drought duration and intensity, respectively. Frank Copula has the best fitting in the calculation of joint probability distribution. As far as the joint return periods of drought duration and severity show, Beijing, Cangzhou, Hengshui and north Chengde of Hebei Province have a long joint return period with low hazard, and the rest of the region has a short joint return period with high hazard (RP30a, 50a). The theoretical joint return period of the drought disaster is close to the actual situation, which indicates that the joint return period can better reflect the situations of drought disasters.

Keywords: drought; standardized precipitation index; Copula; joint distribution; Beijing-Tianjin-Hebei region