Temporal-spatial evolution characteristics of meteorological drought in Guanzhong Basin based on SPEI drought index

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Abstract: As the main agricultural area of Shaanxi Province, the Guanzhong Basin has a fragile ecology and frequent droughts. This study focuses on the intensity, duration, and frequency of meteorological droughts in Guanzhong Basin, from 1955 to 2015, and the temporal-spatial characteristics of meteorological drought were evaluated based on the standardized precipitation evapotranspiration index (SPEI). Our results show that the four SPEI values all show a decreasing trend with time, which indicates that the frequency of droughts is gradually increasing. Moreover, the frequency of meteorological droughts does not exceed 40%, with a decreasing order of light drought > moderate drought > heavy drought > extreme drought. The mild drought, moderate drought, severe drought, and extreme drought mainly occur in the eastern, west, south, and north parts of the Guanzhong Basin, respectively.

1. Introduction
Drought is one of the many critical meteorological disasters that threaten human survival [1]. With the population increase and economic development, the losses caused by drought are getting more and more serious [2]. Although the drought is developing slowly, it has a wide range of impact and a long duration. It has a serious impact on the environment, society, economy, and especially agricultural production [3]. According to statistics, nearly half of the 70% meteorological disasters in China are drought disasters [4]. Furthermore, the expansion rate of the arid regions in China increased by 3.72% per 10 years, which severely restricted the development of agriculture [5]. The Guanzhong Basin, as the most important and typical agricultural area in Shaanxi Province, includes multiple irrigation areas, such as Jiaokou Irrigation Area [6]. Therefore, it is important to study the temporal-spatial evolution characteristics of meteorological drought in Guanzhong Basin.

There are many methods for the analysis of drought characteristics, including the Palmer drought severity index (PDSI) [7], the standardized precipitation index (SPI) [8], and the standardized precipitation evapotranspiration index (SPEI) [9]. Considering that the PDSI index is highly subjective in the definition of drought levels, and SPI only considers precipitation factors, thus ignores the influence of temperature and other factors on itself, the SPEI combines the advantages of PDSI and SPI and is widely used in drought research. Therefore, this paper uses the SPEI, which is calculated by the meteorological data from 5 meteorological stations over a period of 61 years, to describe the interannual characteristics at different timescales in Guanzhong Basin. The attributes of drought, such
as the scope, intensity, and frequency were also analyzed. This article has an important theoretical basis for drought prevention and relief in the Guanzhong Basin.

2. Study area
Guanzhong Basin is located in the center of Shaanxi province, China, at latitudes from 107°30’ to 110°30’ E, and longitudes from 34°00’ to 35°40’ N [10]. It covers an area of 2 × 104 km2 and is surrounded by Qinling Mountains to the south and Baishan Mountain to the north (Figure 1). Their elevation is around 500-2500 m above sea level [11]. The study area is characterized by warm temperate semi-humid continental monsoon climate, with the average annual temperature, precipitation, and evaporation of 13.7 °C, 569.6 mm, and 1000-1200 mm/yr [10, 11]. As a primary tributary of the Yellow River, Wei River traverses the Guanzhong Basin and is the main surface irrigation water source in this study area.

3. Methods
3.1. Data
The precipitation data in this article comes from the China Meteorological Science Data Sharing Service Network. The monthly observation data, such as precipitation, temperature, and humidity, were select from 5 meteorological observation stations (Baoji, Wugong, Xi’an, Tongchuan, and Huashan) in Guanzhong Basin, from 1955 to 2015 (Figure 1).

3.2. Assessment methods
The standardized precipitation evapotranspiration index (SPEI) was proposed based on the standardized precipitation index (SPI) [9], that is, SPEI refers to the normalization of the cumulative probability value of the difference series between precipitation and crop evapotranspiration, which is obtained by introducing crop evapotranspiration based on the SPI. The SPEI calculates evapotranspiration based on precipitation, temperature, humidity and other data, and uses the difference between precipitation and evapotranspiration to deviate from its average state to reveal regional drought characteristics [4]. For more information on the computation of the SPEI values, the reader is referred to [2]. The criteria for dividing drought degree based on the SPEI are shown in Table 1.

![Figure 1. Map showing the location of Guanzhong Basin and the distribution of meteorological stations.](image)

Table 1. Drought degrees based on the standardized precipitation evapotranspiration index (SPEI).

| Drought degree   | No drought | Mild drought | Moderate drought | Severe drought | Extreme drought |
|------------------|------------|--------------|-----------------|----------------|-----------------|
| SPEI value       | SPEI > -1.0 < SPEI | -1.5 < SPEI ≤ -2.0 | SPEI ≤ -2.0 | | }
To better understand the extent and intensity of drought, the drought frequency \( (P_i) \) was used. The \( P_i \) was calculated using the follow equation:

\[
P_i = \frac{n}{N} \times 100\%
\]

where, \( n \) is the number of drought years at the station, \( N \) is the total number of years of precipitation data, and \( i \) represents the meteorological station.

4. Results and discussion

4.1. Temporal characteristics of droughts in Guanzhong Basin

The average SPEI at various timescales of all of the stations in Guanzhong Basin were calculated from 1955 to 2015, which reflected the change of the drought and wet occurrence in the regions. Figure 2 show the temporal characteristics of the SPEI at four timescales (i.e., SPEI 1, SPEI 3, SPEI 6, and SPEI 12). Because of the short timescales, the SPEI 1, and SPEI 3 values fluctuated frequently, which were greatly affected by the short-term precipitation. As time scales increase, the precipitation accumulation was becoming more and more important and the separations between the dryness and wetness became clearer. The four SPEI values all show a decreasing trend with time. It shows that the frequency of droughts is gradually increasing, which may be closely related to climate warming. The SPEI1 and SPEI3 showed that the extreme drought occurred in September and October 1997, respectively. The SPEI 12 values show that there was basically a drought throughout the 2003-2008 year, while there was basically no drought around 2008-2013. From the value of SPEI12, it can also be seen that the dry and wet distribution characteristics of the study area have a certain periodicity. The similar results were obtained by Guo et al. [4], Fang et al. [1], and Li [3].

4.2. Spatial characteristics of droughts in Guanzhong Basin

4.2.1. Drought frequency at various meteorological stations

The drought frequency of 5 meteorological stations in the Guanzhong Basin is plotted in Figure 3. From Figure 3, the total frequency of different degrees of drought at each meteorological station does not exceed 40%, and the drought frequency in the Guanzhong Basin in the past 61 years is, in decreasing order, light drought > moderate drought > heavy drought > extreme drought. It can be seen that the Guanzhong Basin has frequent droughts due to scarce precipitation and relatively large evapotranspiration. The frequency value of light drought is the largest in Huashan station, while the frequency of extreme drought is the largest in Tongchuan station. Wugong and Xi’an have basically similar climate drought characteristics. The difference in drought frequency at different stations may be related to topographical features and landform types.
4.2.2. The spatial distribution characteristics of drought frequencies

Figure 4 shows the spatial distribution characteristics of different degrees of drought in the Guanzhong Basin. From Figure 4, the mild drought mainly occurs in the eastern part of the Guanzhong Basin, while moderate drought may occur in the west of the Guanzhong Basin. Severe drought is likely to occur near the Qinling Mountains in the central Guanzhong Basin to the south of the Wei River. Extreme drought generally occurs in the Loess Plateau north of the Wei River (Figure 1 and Figure 4).
Figure 3. Drought frequency of different degrees in various meteorological stations in Guanzhong Basin.

Figure 4. Spatial distribution of drought frequency of different grades in Guanzhong Basin.

5. Conclusions
This study was undertaken to evaluate the temporal-spatial characteristics of meteorological drought in Guanzhong Basin based on SPEI drought index. The data of precipitation, temperature, and humidity from 1955 to 2015 were collected from 5 meteorological observation stations (Baoji, Wugong, Xi’an, Tongchuan, and Huashan). The following conclusions can be drawn.

In time, the SPEI 1, and SPEI 3 values fluctuated frequently, which were greatly affected by the short-term precipitation. The four SPEI (SPEI 1, SPEI 3, SPEI 6, and SPEI 12) values all show a decreasing trend with time, which indicates that the frequency of droughts is gradually increasing. Moreover, the dry and wet distribution characteristics have a certain periodicity.

In space, the total frequency of different degrees of drought at each meteorological station does not exceed 40%, and the drought frequency is light drought > moderate drought > heavy drought > extreme drought. Furthermore, the mild drought, moderate drought, severe drought, and extreme drought mainly occur in the eastern, west, south, and north parts of the Guanzhong Basin, respectively.

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References

[1] Fang, Y., Qian, H., Chen, J., Xu, H. (2018) Characteristics of Spatial-Temporal Evolution of Meteorological Drought in the Ningxia Hui Autonomous Region of Northwest China. *Water*. **10**: 992.

[2] Xu, H. (2018) Analysis of spatial and temporal characteristics of drought in Shaanxi Province and evaluation of vulnerability. Xi’an, Chang’an University.

[3] Li, X.Y. (2019) Regional Study on meteorological drought and drought vulnerability: a case study in Xinjiang. Xi’an, Chang’an University.

[4] Guo, M., Zhang, Q.Y., Qian, H., Xu, P.P., Chen, Y. (2019) Analysis on the drought temporal-spatial distribution characteristics of Shaanxi Province based on SPEI. *Journal of Water Resources and Water Engineering*. **30 (3)**: 127-138.

[5] Yu, M., Li, Q., Hayes, M.J., Svoboda, M.D., Heim, R.R. (2014) Are droughts becoming more frequent or severe in China based on the standardized precipitation evapotranspiration index: 1951-2010? *Int. J. Climatol*. **34**, 545-558.

[6] Zhang, Q.Y., Xu, P.P., Qian, H., Yang, F.X. (2020) Hydrogeochemistry and fluoride contamination in Jiaokou Irrigation District, Central China: Assessment based on multivariate statistical approach and human health risk. *Sci Total Environ*. **741**, 140460.

[7] Palmer, W.C. (1965) Meteorology Drought; *US Department of CommerceWeather Bureau: Washington, DC, USA*, 45-58.

[8] McKee, T.B., Doesken, N.J., Kleist, J. (1993) The Relationship of Drought Frequency and Duration to Time Scales. In *Proceedings of the Eight Conference on Applied Climatology, Anaheim, CA, USA*, 17-22, 179-183.

[9] Vicente-Serrano, S.M., Beguería, S., López-Moreno, J.I. (2010) A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. *Journal of Climate*, **23(7)**: 1696-1718.

[10] Xu, P.P., Zhang, Q.Y., Qian, H., Li, M.N., Hou, K. (2019) Characterization of geothermal water in the piedmont region of Qinling Mountains and Lantian-Bahe Group in Guanzhong Basin, China. *Environ Earth Sci.* **78**: 442.

[11] Zhang, Q.Y., Xu, P.P., Qian, H. (2019) Assessment of groundwater quality and human health risk (HHR) evaluation of nitrate in the Central-Western Guanzhong Basin, China. *Int. J. Environ. Res. Public Health*. **16**: 4246.